Terra Antiqua: a paleogeographic reconstruction plugin for QGIS

This presentation contains hyperlinks to help navigate through the tool description. You need to open it with Microsoft PowerPoint to use these funtions.

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Diego Ruiz, Jovid Aminov, Guillaume Dupont-Nivet, Fernando Poblete, Thomas van der Linden, Douwe van Hinsbergen

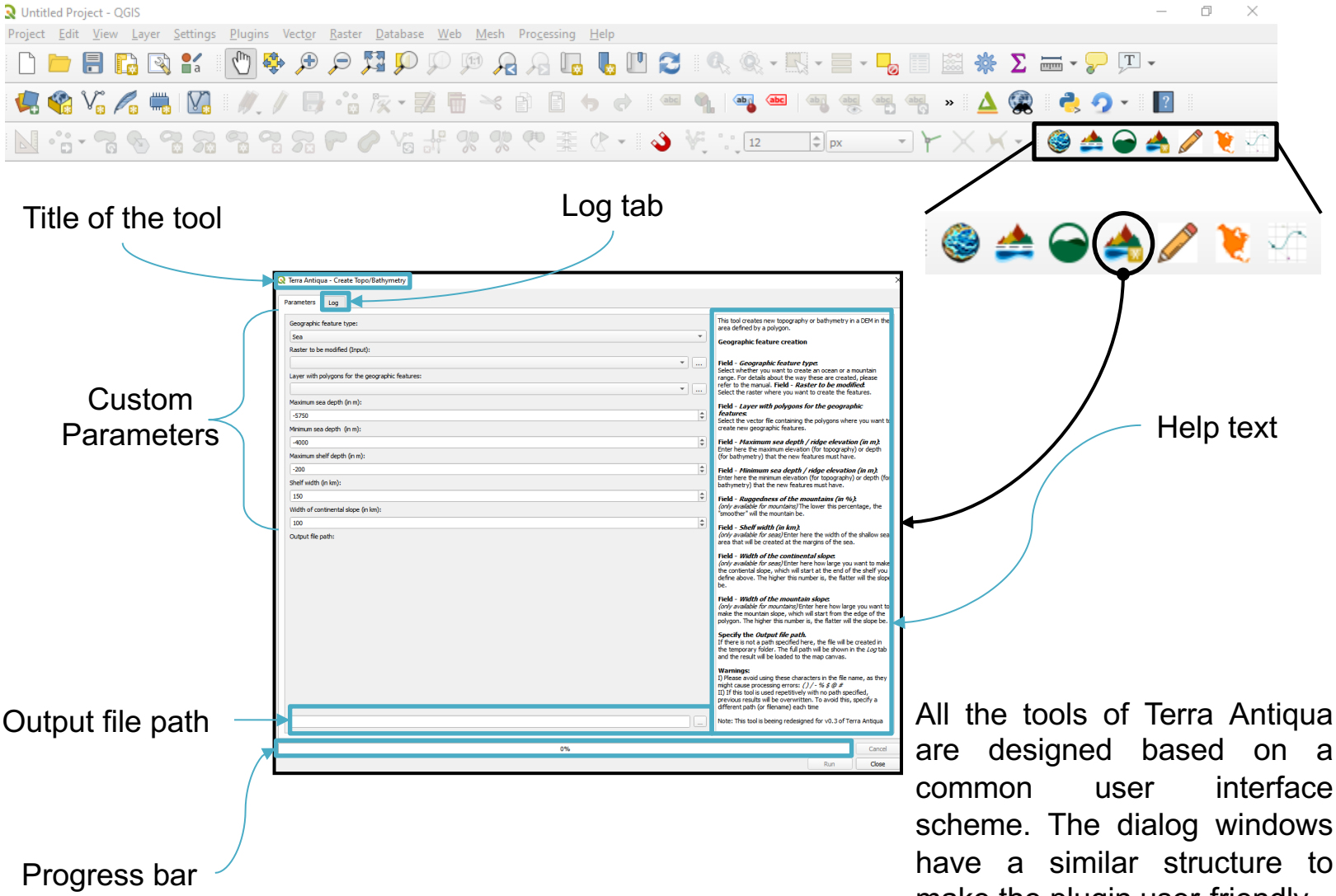
Introduction

In recent years, interest in assessing how the climate may change under anthropogenic forcing is increasing. The climate models are getting better and better thanks to the improved understanding of climate in geological past as well as increasing computing power.
Paleogeographic maps, alongside with the atmospheric composition, solar insolation and land surface properties play a central role in climate models. They are also important in all fields of geological studies, allowing to visualize results of these studies in their paleocoordinates.

Although programs like Gplates provide precise tools and algorithms to reconstruct the past position of continents and oceanic plateaus, they do not allow to reconstruct a complete paleogeographic map, because such software deals only with present day rotated topography and Bathymetry.
Current algorithms that allow creating paleotopography / paleobathymetry by modifying present day topography and bathymetry are sophisticated and lack user-friendly graphical interfaces.
Such algorithms are mostly developed using scripting languages in Matlab and GMT (Generic mapping tools) environments, and require coupling these scripts with other Geographic Information Systems (GIS) to finally produce a Digital Elevation Model (DEM) for the time of reconstruction.

Here we introduce Terra Antiqua, a plugin for QGIS that provides a **user-friendly GUI** (graphical user interface) and robust algorithms to reconstruct paleogeographic maps for different times. QGIS is a **cross-platform and free** GIS that is widely used in earth and environmental sciences.
The plugin is written in python programming language and utilizes QGIS, GDAL and Qt Python APIs. The workflow is **intuitive** and the user is provided with **guiding tips** for each algorithm and tool. Terra Antiqua takes as an **input rotated** (e.g. in Gplates) **present day topography and bathymetry**, alongside with rotated vector masks that are used to modify this data. The final paleogeographic map, in the form of a DEM or symbolized raster, can be saved in any raster format that is supported by modern GIS software.

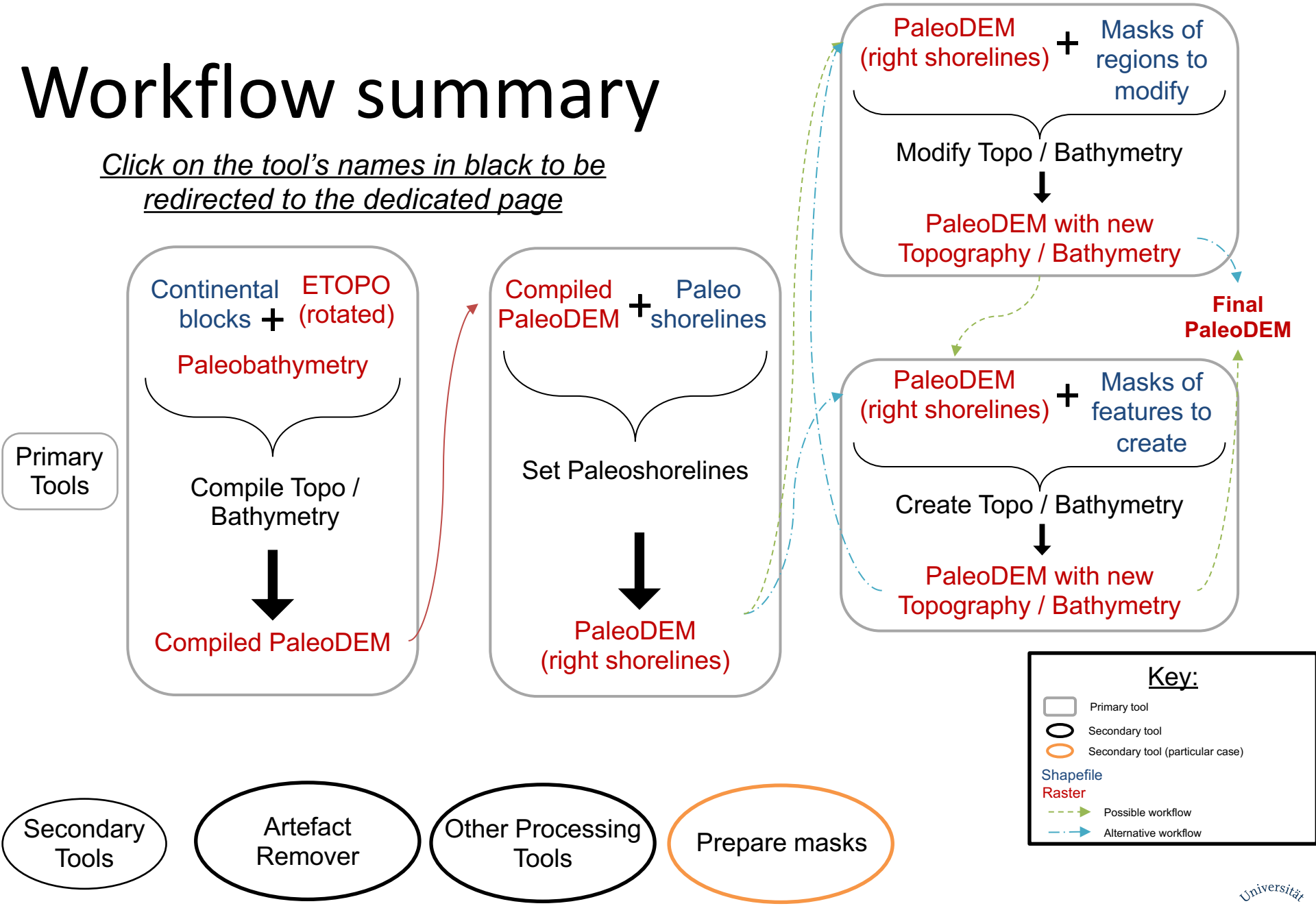
Dialog Interface



All the tools of Terra Antiqua are designed based on a common user interface scheme. The dialog windows have a similar structure to make the plugin user-friendly.

Workflow summary

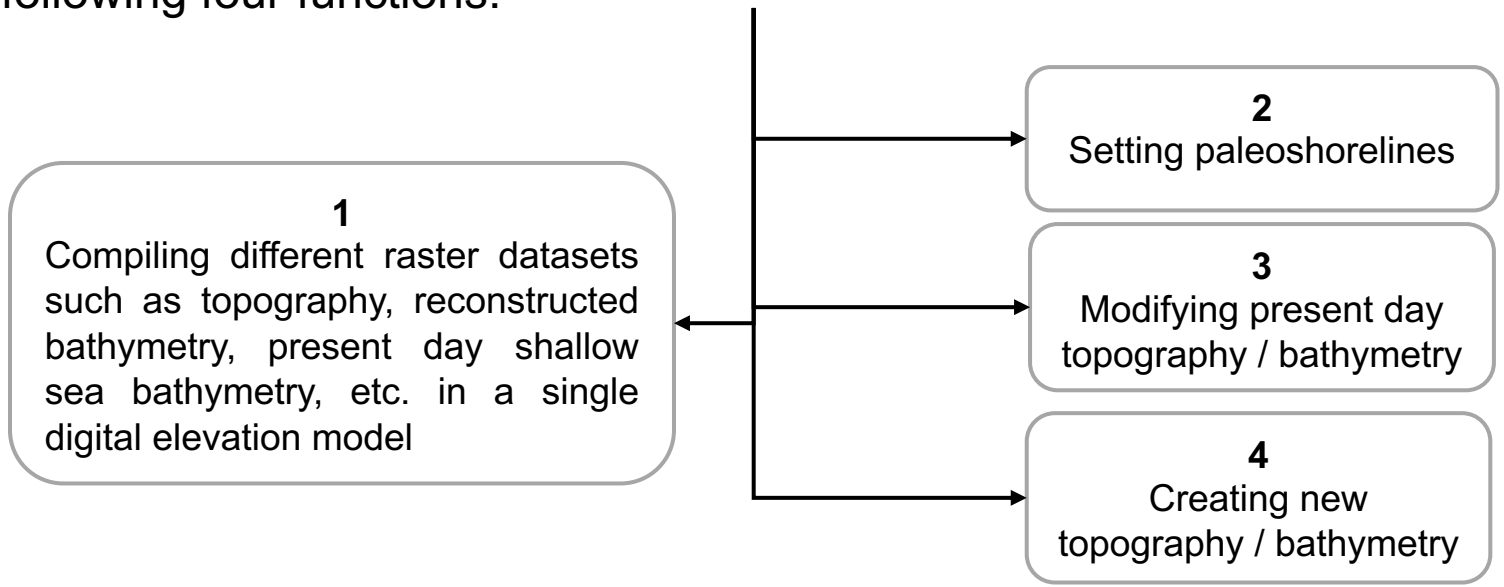
Click on the tool's names in black to be redirected to the dedicated page



Final slide: The team

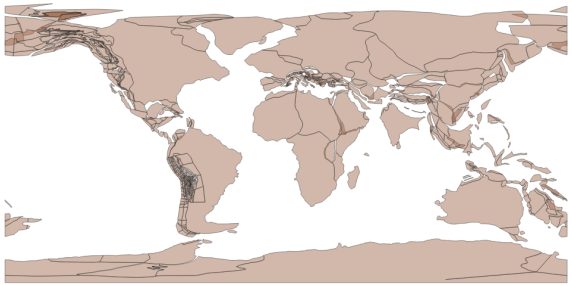
Primary tools: reconstruction

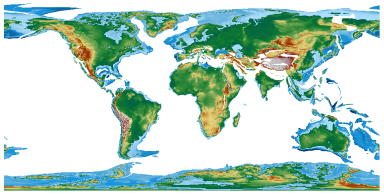
The primary tools comprise the core of the plugin and are designed for the very reconstruction of the past geography. These tools modify pixel values (i.e. elevation values) of a raster, and distinguish the pixels to be modified with the help of vector masks that are drawn by the user. The paleotopography and paleobathymetry are reconstructed using the geological constraints (e.g. fossil records, thermochronology) compiled by reviewing the appropriate literature for each region.
They should be used in order and the output of the previous tool can be used as an input for the next tool. The primary tools include the following four functions.

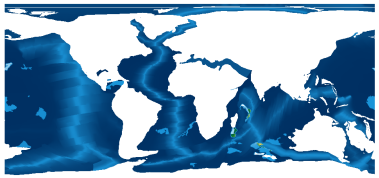


Compile Topo / Bathymetry

Input:







Workflow:

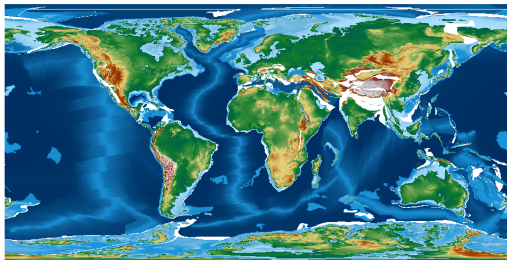
This tool is designed to be the first step. The purpose is to create a raster that combines the topography and the bathymetry at a given time of reconstruction. Polygons representing the continental blocks are used to help the tool to differentiate between the topography and the bathymetry.

Operating mode:

The algorithm distinguishes between the different type of data being compiled with the help of vector masks. In the simplest scenario, in which only two raster datasets are compiled: topography and bathymetry, the vector masks covering continental blocks are used.

Yet, the user may compile more than two datasets. For example, if the rotated present day shallow sea bathymetry is supplied separately, an appropriate vector file comprising masks that cover shallow sea area should also be supplied. The bathymetry can also be calculated from the rotated present day ocean age grid. The compilation is performed in an overlapping order: first putting bathymetry, then shallow sea bathymetry (if supplied) and only after the continental blocks. Overlapping pixels remove existing ones.

Output:



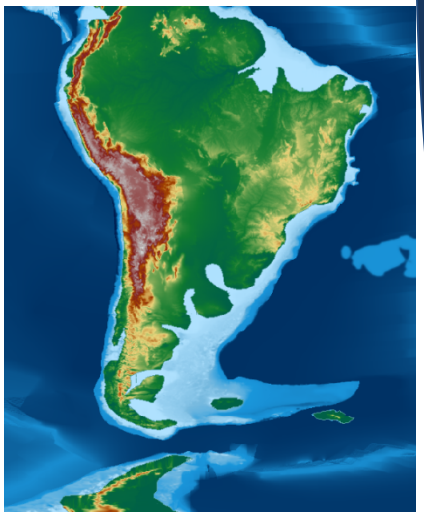
Set Paleoshorelines

Input:

Workflow:

Used after Compile Topo/Bathymetry. This tool will redefine the shorelines in the whole map based on the polygons provided. It will emerge the areas that should be emerged but appear underwater and vice versa. The result will be a PaleoDEM with the right paleoshorelines.

Output:

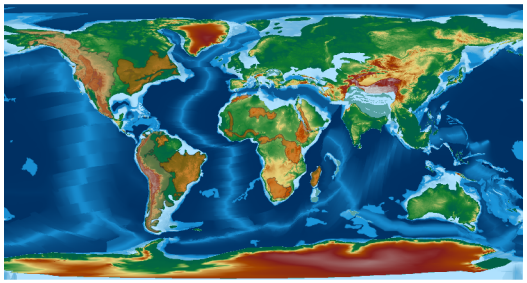


Operating mode:

Setting paleoshorelines is a simple reassignment of pixel values based on their position relative to the shorelines of the time of reconstruction. If a pixel with positive elevation value is outside the paleoshoreline polygon its value will be modified (1) to submerge it below the sea level and (2) to emmerge if it is inside the polygon but has a negative value. Pixel value reassignment is performed using two alternative approaches: interpolation and rescaling. In the case of interpolation all positive elevation values outside the paleoshoreline polygons are removed and then interpolated from adjacent pixels. The same is done for the negative values inside the polygons. In case of rescaling, the values of the pixels to be modified are linearly rescaled between 0.1 (-0.1 in case of submerging) and the maximum (or minimum) value that is provided by the user.

Modify Topo / Bathymetry

Input:



Workflow:

This tool should be used on the paleoDEM with the set paleoshorelines. It allows to modify the elevation values of a topography / bathymetry raster in a given area. That area must be defined by a mask contained in a vector file *(Shapefile; .shp)*. The topography modification must be performed in one of the two following ways:

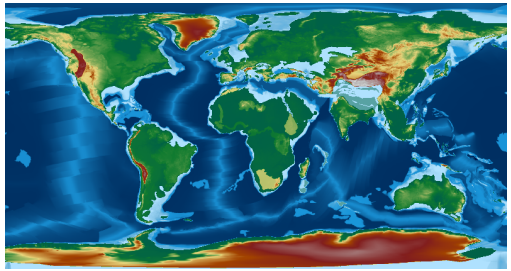
- Linearly rescaling the elevation between a given maximum and minimum
- Applying a mathematical formula of your own

These parameters are to be defined in the interface dialog.

Operating mode:

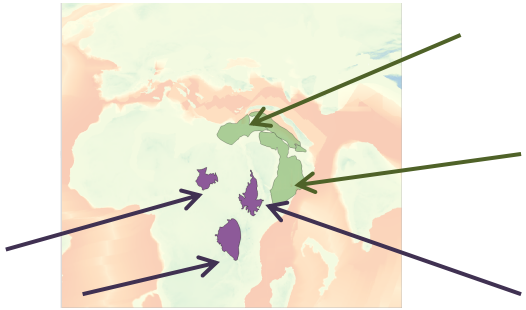
The vector masks are first rasterized using GDAL library. The resulting raster contains 1s inside polygons and 0s outside them. These raster masks are then used to filter out the pixel values that need to be modified. The elevation value of each pixel is then modified either by linear rescaling or any other formula that is provided by the user. Formula, elevation ranges to be modified and other parameters can be entered either directly in the dialog or retrieved from the attribute table of the input vector file. The modified raster is then saved as a new raster and added to the current QGIS project as a new layer, automatically simbolized with an intuitive colour palette.

Output:



Create Topo / Bathymetry

Input:



Workflow:

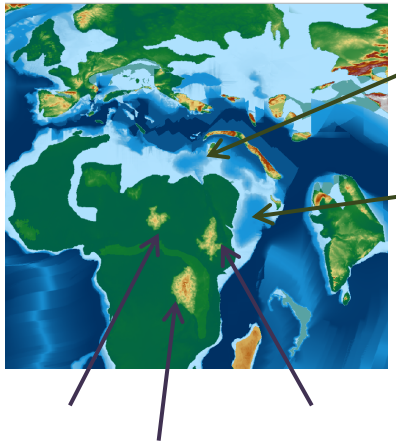
This tool creates new topography or bathymetry (mountain or sea) in the DEM in the area defined by a polygon. The original data in the extent of the new geographic feature will be erased. Several parameters that control the geometry and topo/bathymetry of the features can be entered. For sea, we can enter the maximum depth, minimum depth, shelf depth, shelf width and slope width. For the mountains, we can enter the maximum height, the minimum height, the ruggedness and the mountain slope width.

Operating mode:

This tool follows five steps:

1. creating random points within the polygon
2. assigning elevation values to the pixels, which lie beneath the created random points. The maximum depth (maximum elevation for mountains) is assigned to pixels, which are furthest from the edge of the polygon; the minimum to closest pixels to the edge.
3. the width of a continental slope for sea or mountain slope for mountain is used to create these elements. The minimum depth (sea) or elevation (mountain) is assigned to the pixels at the inner edge of the slope. The slope width defines the elevation / depth gradient of the slope.
4. For the sea, the shelf zone is created using maximum shelf depth and shelf width parameters. The depth values of the shelf are interpolated between maximum shelf depth provided by the user and the elevation of surrounding pixels.
5. Finally the whole area of the feature is interpolated to create a continuous pattern of elevation / depth values.

Output:



Secondary tools: enhancement

After the reconstruction is finished using the primary tools, one may need to enhance the produced DEM. For example, some areas may end up missing elevation values. This is common for paleogeographic maps because after rotating present day topography and bathymetry, gaps can appear between the blocks. These gaps represent areas with the topography and bathymetry destroyed by deformation or subduction of an oceanic crust beneath a continental or another oceanic crust. These missing values can be filled by interpolation.

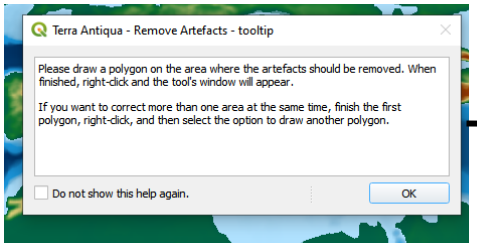
Artefacts can also be introduced to the map during the raster processing within the framework of Terra Antiqua. For example, filling gaps by interpolation can cause some abnormally high or low values that need to be removed.

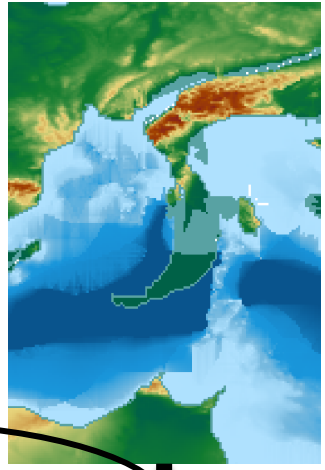
In addition, one may want to copy a regional reconstructed paleogeography into a global one, or to isostatically compensate for the ice loss on Greenland and Antarctica. To avoid sharp boundaries between the modified and created geographic features one may also want to smooth the raster. The secondary tools are designed to enhance DEMs after the reconstruction is done.

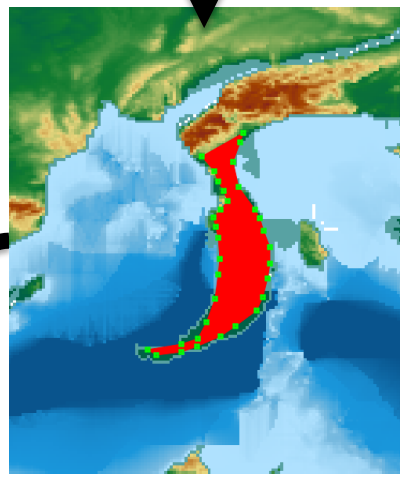
Artefact Remover

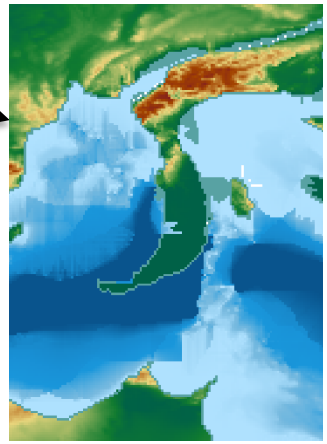
Workflow:

Artefact remover is designed to remove the artefacts that are present in the data or introduced during different processing steps from the DEM raster. Polygons (in red on the figure) are used to specify the area where artefacts will be removed and artefact values are defined by a mathematical expression entered in the corresponding field from the dialog interface.









Operating mode:

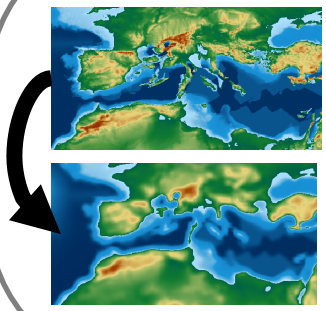
Similar to the primary tools, the drawn polygon is rasterized and the raster mask is used to filter out the pixels which contain artefacts. After the artefacts are removed the pixels may be kept empty to be filled later by interpolation of the whole raster or interpolated immediately. In the latter case the interpolation is performed only for the gaps inside the drawn polygon. The latter option also provides the possibility to just fill the gaps in certain areas of the raster that are covered by polygon masks. In this case, instead of a mathematical expression to distinguish artefacts, the user needs to type “NoData” in the appropriate field. If needed, more than one polygon can be drawn. In higher versions this tool will also allow selecting a shapefile that contains previously drawn polygons.

More processing tools

This module contains four small enhancement tools (*Smoothing, Isostatic compensation, Fill gaps* and *Copy/paste raster*). All of them are intended to be used at the end of the processing to ensure a good-looking result.

Please keep in mind that, since Terra Antiqua is still in developpment, feedback and comments about its structure are most welcome.

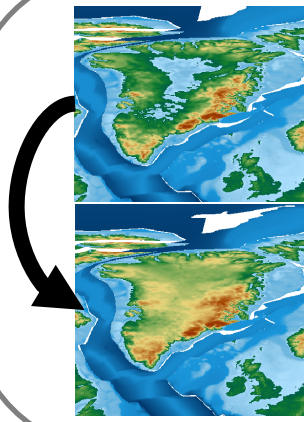
Smoothing



This tool is designed to reduce abrupt elevation changes in a DEM by averaging the values around it.
The only customization parameter is the smoothing factor, which represents the radius around a given pixel that will be taken into consideration. The greater the factor the smoother will the resulting raster be.

The smoothing utilizes the filtering technique that is widely used in digital image processing. In this case, mean and Gaussian low-pass filters are used alternatively. A kernel window defined by the smoothing factor is placed on the raster and the value for the central pixel is calculated by (1) multiplying the values of the kernel and the raster, and (2) summing all the resulting values. Then the kernel window is moved by one pixel to calculate the value of the next pixel.

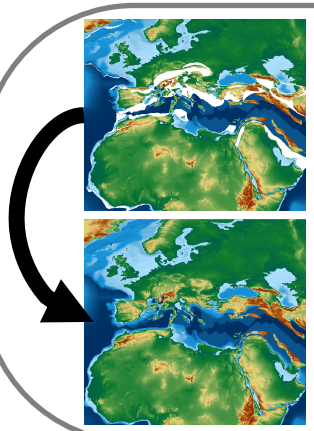
Isostatic compensation



This tool compensates for the absence of ice mass in the poles. The values of the DEM will be modified in the areas where there is a noticeable difference between ice and bedrock topography. The percentage of ice to be removed from the polar regions must be defined. The higher it is, the higher the resulting topography will be.

This tool uses present day ice and bedrock topography to calculate the thickness of present day ice covering Antarctic and Greenland. The thickness is determined by subtracting the bedrock topography from ice topography. Then that topography is raised by ⅓ of the current ice thickness, if all the ice is removed. If it is removed partially, the amount of removed ice is taken into account as follow:
$Hn = H + (0.3*It*Ra)$
Where Hn is new elevation value, H – old value, It – ice thickness, Ra – removed amount of ice.

More processing tools



Fill gaps

This tool is intended to interpolate values for gaps between rotated tectonic blocks. It generates elevation data in each empty pixel by averaging pixel values around it, using inverse distance weighting.
There is the option to use it in the whole map or constrain it to a region.

Inverse distance weighting (IDW) in the interpolation method implemented in the GDAL library, and it provides a fast algorithm to fill the pixels with NoData values (empty pixels). In Terra Antiqua we use a python binding to GDAL's IDW interpolation. This tool requires the NoData values and the valid elevation values to be mapped. The *Fill gaps* tool gets NoData values from the raster's metadata and maps the values, which need to be interpolated from the mapped valid values.

Copy/paste raster

This tool allows you to copy values from a raster into another one. The values of the pixels covered by a mask will be copied into the second raster.
The area you copy from the original raster will be in the same position in the target raster.

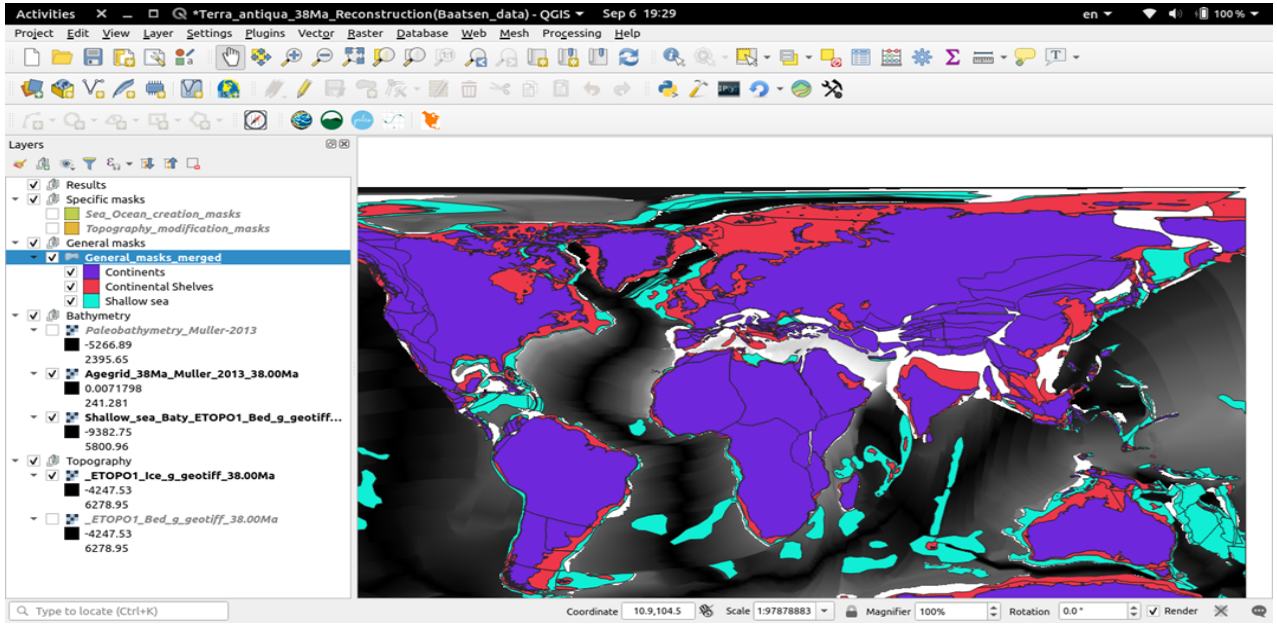
This is tool uses a simple technique of copying a value from one raster and pasting it into another one. The position to copy it from a raster and paste it to another one is determined by the polygon mask provided. For now, the *copy-from* and the *paste-to* rasters should have the same resolution and size. For example, if the raster to *paste-to* is a global DEM with the resolution of 0.1 degree (size of 1800x3600), the *copy-from* raster should also have the same size and resolution.

Prepare Masks*

Vector polygon masks that are stored in shapefiles play a central role in Terra Antiqua, since they control the area, where topography and bathymetry is modified/created. The same shapefiles can also contain attributive information for each polygon that can be used to modify/create topography and bathymetry.

Often, masks can be drawn in the form of polylines and polygons in Gplates and are stored in different shapefiles. To make it easy to work with them, this tool allows polygonization of masks to combine them into a single shapefile. Like the *Compile Topo/Bathymetry* tool, the masks are combined in order, and overlapping masks clip underlying masks.

Masks can also contain error-prone invalid geometries that need to be fixed before they can be used in Terra Antiqua. These invalid geometries are fixed by the *Prepare masks* tool.



* This tool is the only secondary tool that is also a processing tool. Since it doesn't process the rasters but the shapefiles and its use at the moment being quite limited, we classify it as secondary.

Universität Potsdam

Team

This plugin being actively developped, the icons for the different modules are in the process of being designed. All comments and / or critics are welcome. We are looking forward to your impressions!

The team:


Plugin development and programming: Diego Ruiz[1], Jovid Aminov[2]

Project supervision: Guillaume Dupont-Nivet[1]

Method development: Fernando Poblete[3]

Icon design: Corinna Kallich[1]

Other contributions: Thomas van der Linden[4], Dowe van Hinsbergen[4]

[1]Institute for Geosciences, University of Potsdam, Germany

[2]Institute of geology, earthquake engineering and seismology, Academy of Sciences of the Republic of Tajikistan

[3]Departamento de Geología, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Santiago, Chile

[4]Department of Earth Sciences, Utrecht University, The Netherlands

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