Computational Tools for Creating a 4-D North American Continent and Mantle

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Hierarchy of Geophysical Scales: Connecting Global, Regional and Local Data

Elements of the Global Model

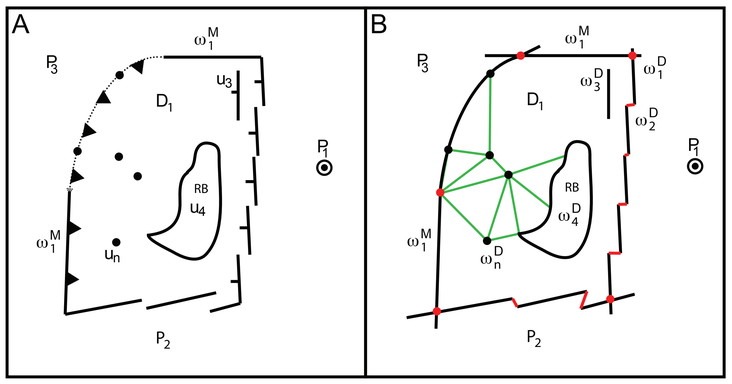
• Plate Polygons: about 1373 logical plate polygons, global coverage from Present Day to 240Ma

• Deforming Zones: 5 regional networks (active period): North America (0-36Ma), Andes (0-45Ma), South East Asia (0-51Ma), South Atlantic (110-150Ma), African Interior (84-132Ma)

• Micro-Blocks: 10 blocks in North America, and 15 South East Asia, a few in the South Atlantic

• Features: tens of thousands of points, lines, and polygons

• Data Management: the model is separated into 5 rotation sets, and about 8 feature sets, which become about 20 distinct layers



Reconstructing Topologies

A. Geological data and concepts used in the reconstruction and B. The computer representation. In A we have a deforming region (D1) that is part of plate 1 (P1). D1 is bounded by a subducting margin on the left and an extending region on the right. The normal faults denote the defuse boundary between D1 and P1. The top and bottom boundaries have a mostlty transform sense of motion. Within D1 there are a few deformation points (black dots), normal faults, and a rigid block (RB). The displacements u3, u4, un… are with respect to fixed plate P1, where P1 is with respect to a global set of plate rotations. In B we show the implementation of the deforming region that is consistent with the concepts of a continuously closely plate (CCP, Gurnis et al. [2012]). The outer boundary of D1 is a topological closed polygon, with the intersection points, and 'rubber banding' computed at each moment of time (red dots and lines). Within D1 the continuous deformation is represented by a triangular mesh, formed via Delaney triangulation algorithms (we show a few of the many triangles in green). Linear interpolation is used to find the velocity and displacements for features found within the mesh, and reconctuct them in the deforming area.

Global system of plate polygons

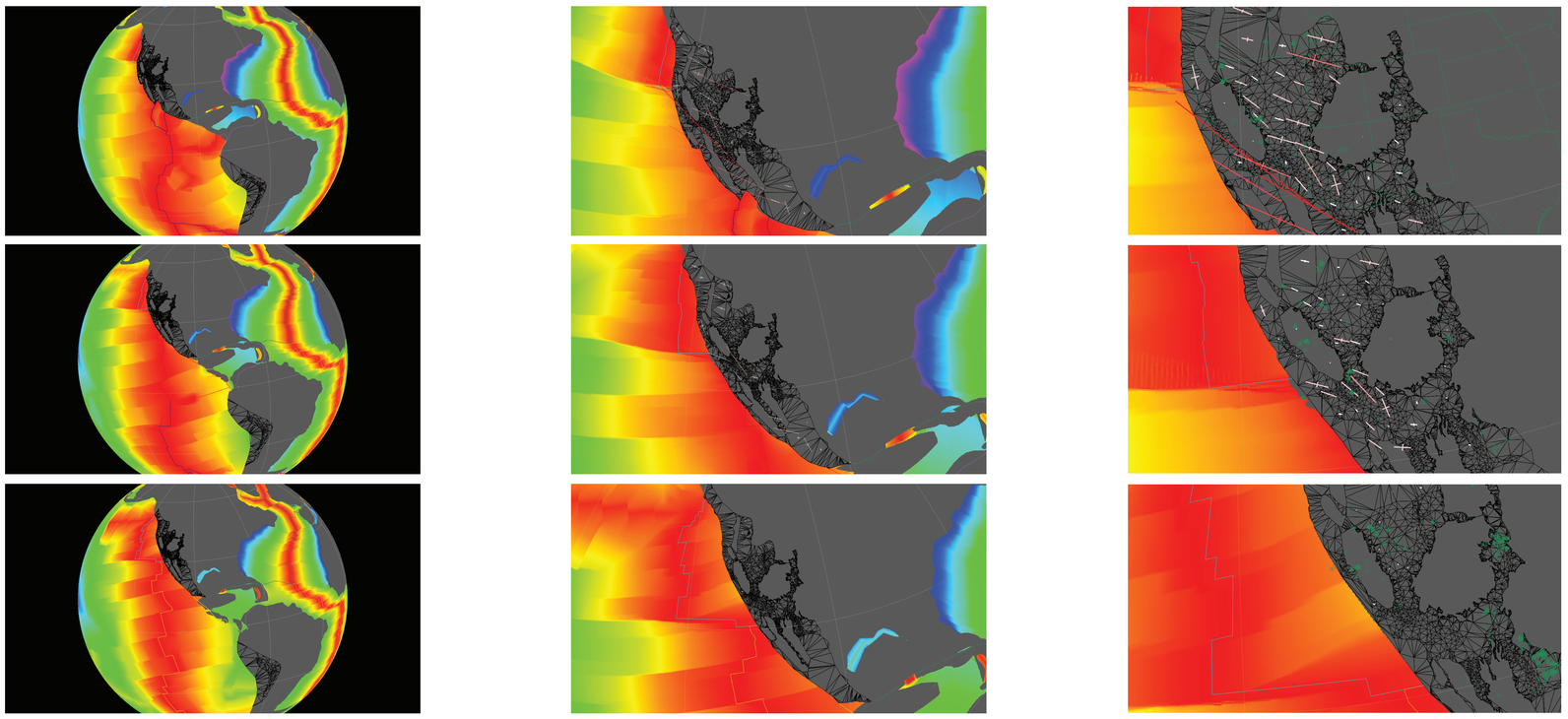
Regional zones of deformation

Local areas with detailed data

Present Day

17 Ma

35 Ma



Feature elements at the Global Scale include the world wide system of trenches and subduction zones, mid ocean ridges and spreading centers, and transforms. This line data is combined into the major and minor plates.

Feature elements at the Regional Scale include a Deformation Zone modeled as a topological network, with a Delaunay triangulation for interpolation.

Features at the Local Scale include basin a nd range polygons & 1000's of measured displacement points. NAVDAT samples in green triangles. Accumulated strain (36 to 0Ma) in red-to-white crosses.

Reconstruction and Deformation within Topological Networks (Deforming Plates)

t_{n+2} t_{n+1} t_n

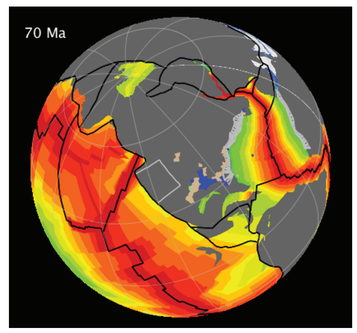
Instantaneous velocity field and strain rate on mesh

Reconstruct Individual samples (boreholes) backward in time

IC, location

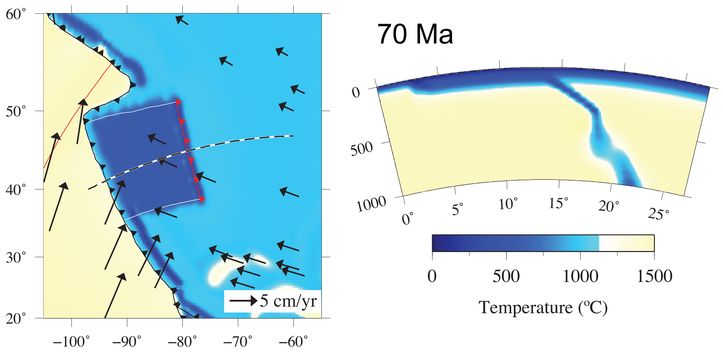
Follow (track) deformation (strain,…) of sample forward in time

Connecting Surface Plate Velocity to Global Mantle Convection



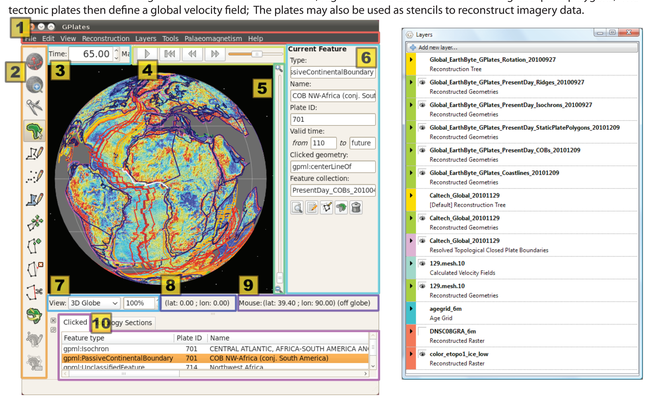
GPlates view at 70 Ma showing the age of the oceanic lithosphere with outlines of continuously closing plates needed to link time-dependent kinematics to geodynamic flow models. Note the outline of the topological feature associated with the Laramide flat slab in white and lithologies from the MacroStrat database (accessed by GPlates directly as a Web Service in an EarthCube demonstration project, see below).

(left) Map at 110 km depth showing the temperature field of the assimilated Laramide flat slab from the CitcomS finite element model at 70 Ma, along with a few velocity vectors. The indentation in the trench north of the flat slab is the pre-Siletzia configuration. (right) Cross section through the flat slab (orientation of profile shown on left).



Interactive Plate Tectonic Reconstructions

GPlates has a variety of traditional tools for tectonic reconstructions, as well as advanced functionality for research. The fundamental data elements of GPlates are Total Reconstruction Poles (arranged in plate circuit like dependencies) and Geophysical Features (specified with geometry, reconstruction ages, and other properties). Other data elements include derived types, like topological closed plate polygons, deformation zones and velocity fields; and coverage types, like age grids and raster images. We organize all the data into conceptual layers, and the connections between the layers help define the reconstruction model. For example: rotation data determines how regular feature data is reconstructed; regular feature data defines the set of global plate polygons; The tectonic plates then define a global velocity field; The plates may also be used as stencils to reconstruct imagery data.

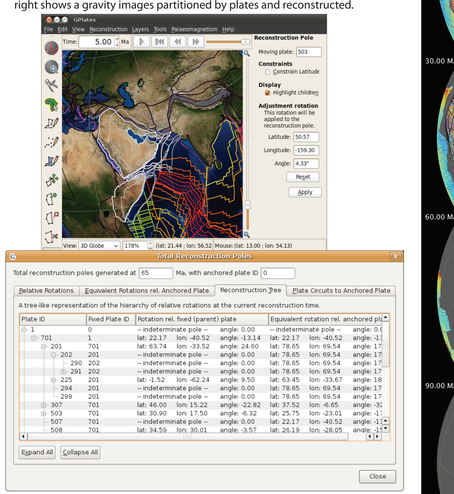


1 Menu Bar - The GPlates menu items allow access to basic functionality and advanced workflows for specific analysis tasks.
2 Tool Palette - Most of these tools are used to interact with the geometry and geography of geophysical features.
3 Time Controls - A collection of user-interface controls for precise control over the reconstruction time.
4 Animation Controls - Tools to manipulate the animation of reconstructions; Other dialogs exist to export data during animations.
5 Zoom Slider - A mouse-controlled slider which controls the zoom level of the Globe View camera.
6 Task Panel - Workflow and task-specific information and controls which correspond to the currently-activated tool.
7 View Control - A variety of 3D globe and 2D map projections are available in the main window.
8 Camera Coordinate - An information field which indicates the current globe position of the Globe View.
9 Mouse Coordinate - An information field which indicates the current globe position of the mouse.
10 Clicked Geometry Table - Displays a summary of features (and their basic properties) under the mouse during selection.

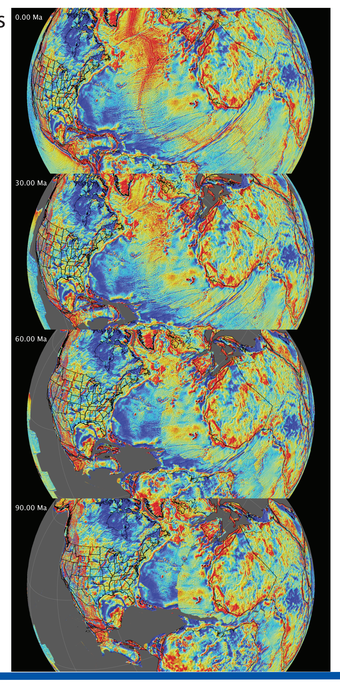
Rotation Tools for Reconstructing Rasters

One of the foundations of a plate tectonic reconstruction model is the rotation data defining the relative motion between plates. GPlates has tools to create and edit Euler Pole data, both graphically and in tabular form.

The combination of rotation data and the global plate polygon set allows for reconstruction of image rasters back in time. The sequence of images to the right shows a gravity images partitioned by plates and reconstructed.



GPlates offers many different views into the rotation system. The plate circuits and relative rotations can be evaluated at any reconstruction time, or for any pair of fixed and moving pairs.



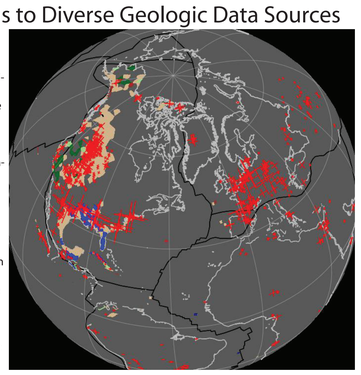
Web Feature Server Connections to Diverse Geologic Data Sources

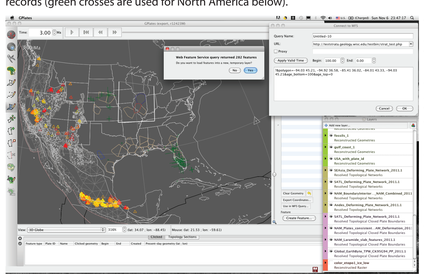
With the Macrostrat project at the University of Wisconsin (*Peters, S.E. 2006*) we have created Web Feature Services (WFS). Macrostrat is a comprehensive relational database currently containing 31625 stratigraphic units and more than 90,000 attributes (radioisotopic ages, lithology, economic uses, etc.) This data facilitates the rigorous testing of hypotheses related to the spatial and temporal distribution of sedimentary, igneous, and metamorphic rocks and proxy data extracted from them.

GPlates is used to define a search with a bounding box and temporal range, and send a WFS query. Features found from the query are returned via XML and then processed into our native GPML, translating locations and preserving feature properties contained in the databases.

Lithostratigraphic unit features are categorized with nine rock unit types: carbonate in blue, siliciclastic in tan; metamorphic in red; etc. Feature properties include thickness data of rock records. These are shown as patches in the global image to the right, and as polygon outlines in North America below.

Paleobiology Database (PaleoDB) features are categorized by fossil density. The the global image to the right, the sizes of the red crosses are proportional to number of species in fossil records (green crosses are used for North America below).



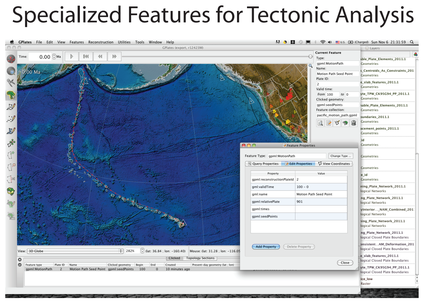


The image at left combines Macrostrat data as above (fossil collections in green), with samples from The North American Volcanic and Intrusive Rock Database (NAVDAT). This data was accessed via public shapefiles and contain over 200 attributes. Samples are shown as colored triangles: mafic in red, intermediate in orange; felsic in yellow).

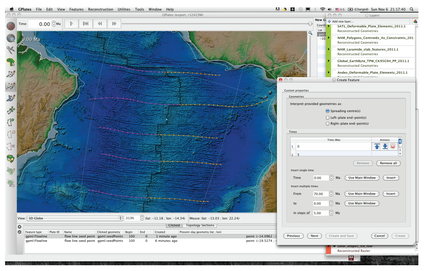
Also shown above are a few general data sets imported via shapefiles: Coastal outlines and Political boundaries in white; Present day hot spots in white triangles.

All imported data has been assigned to appropriate rotation data using our set of global plate polygons: Each feature is located within a polygon and given the same rotation id as that plate.

Specialized Features for Tectonic Analysis



Motion Paths illustrate the movement of plates over time, either with respect to the anchor plate, or with respect to some other specified plate.



Flowlines represent the movement of material away from a spreading centre, and are calculated based on half stage-poles between two plates at specified time-intervals.