Developing PAMS—A Paleolocation Web Service

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Abstract. We describe the development of a web mapping service called PAMS – A Paleolocation Mapping Service. PAMS generates and maps the paleographic location of any given point on the earth's surface, given location and a geologic age. PAMS is freely available at paleolocation.org. PAMS represents an advance on previous paleographic mapping software for two reasons: the use of a previously unavailable, high-quality plate reconstruction database, and the presentation of the mapping service as a web service, with greater ease of use for both end users and web developers.

Understanding how PAMS was developed, and why it takes the form it does requires an understanding of issues that are particular to paleolocation, as well as more general web mapping concerns. Particular to paleolocation, we describe previous efforts in the area of paleographic mapping, the particular paleographic plate data we are using, and the coordinate rotation methods that are necessary. More generally, we describe our software implementation including the database schema, what kinds of scientific and educational applications are foreseen for this service, and suggestions for future work. We hope that PAMS can serve as an example of how geospatial mapping services should be developed in the service of scientific research and education in the geosciences.

Keywords: Web services, web mapping, paleolocation

1.   Introduction

The genesis for this paleogeographic mapping service came from discussions with the Non-vertebrate Paleontology Laboratory (NPL) of the Texas Natural Science Center at the University of Texas at Austin. While NPL was

already plotting the location of their fossil finds through their web site paleocentral.org, they also sought to automate the process of plotting those same points in their deep geologic context. Thus, for example, a marine fossil that had been discovered in Cretaceous age rock could be mapped in its current terrestrial locality, but could not easily be mapped in its original marine context during the Cretaceous.

The Texas Advanced Computing Center[1] which was already hosting NPL databases began to implement a service that would be able to accomplish this, not only for paleocentral.org, but for any client that wished to translate space-time coordinates from the present day into the geologic past.

The process of plotting an arbitrary point on the modern globe in an arbitrary geological age requires two elements: 1) the appropriate base map for the age in question and 2) a function able to compute the rotated location of the modern point for that age. It is thus insufficient to simply map the coordinates of the modern point on a base map of the desired age due to the plate tectonic shifts that will have occurred during the intervening time as shown in Figure 1.
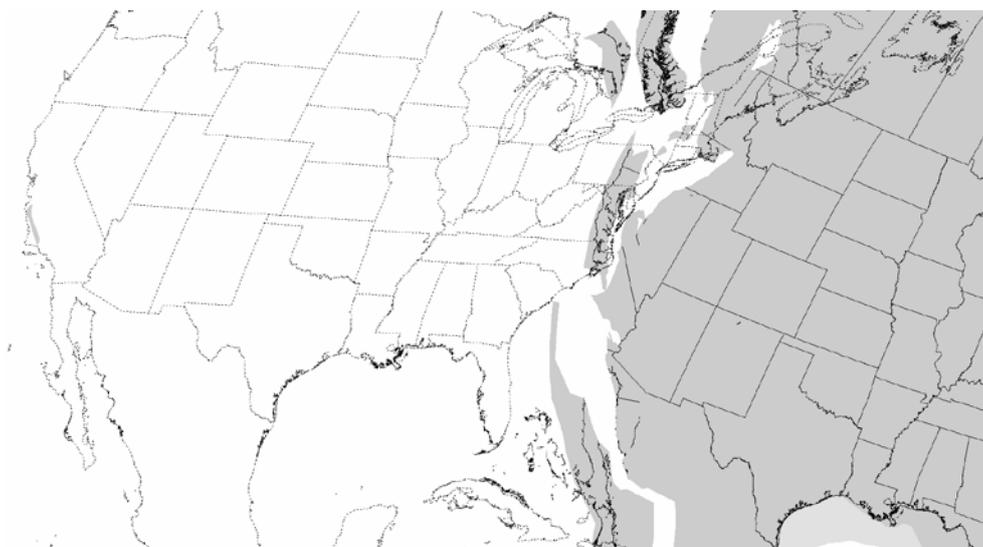

Figure 1- Image showing continental drift over time. The map shows the approximate location of the Western United States during the Albian age some 118 million years ago as compared to its present position today (shown in dotted lines).

The first necessary element, a set of global base map reconstructions for each geologic age, was obtained from the PLATES project at the University of Texas Institute for Geophysics (UTIG). The second, an algorithm to perform the correct rotation of the coordinates for the age in question is briefly described below. The remainder of the paper describes our implementation, and concludes with possible extensions and future work

Providing PAMS as a web service is both directly useful and serves as an example of the next logical step in paleolocation spatial data provisioning. First, PAMS has an interface that leverages web browsers in a standards-compliant way, and is therefore accessible on a wide variety of devices. This helps PAMS serve its clients (see the Applications section below for details) in the easiest way possible: they need to provide only the bare minimum of information (Lat, Long, and Age in Millions of Years Ago, abbreviated Ma), and they receive an interface that shows them both where they are and where they would have been, with no software installation needed. We also provide our service as a REST-oriented web call, whereby users need only make an HTTP GET request to access PAMS. This follows best practices as a scalable, idempotent HTTP-based web service (Richardson & Ruby).

2. Data

The geologic time scale is divided into hierarchical divisions from eon through era, period, epoch and age. PLATES provided 43 reconstructions based from the 2007 edition of their atlas, each mapping to a geologic *age*.

The data obtained from the PLATES project took form of a base map and reconstruction for each of the ages provided. The base maps were flattened from vector maps with polygons representing each of the plates extant during that age into simple jpegs such that oceanic crust was indicated as blue while continental crust was indicated with brown.

Each reconstruction also contained axes used to rotate the coordinates for a point on a given plate from the present to its corresponding location during the age in question

2.1. Coordinate Rotation

Coordinate rotation is the key to the translation of points on the surface of the modern globe into points on the appropriate ancient landscape. These rotations are called Euler rotations, as Greiner states, "The motions of rigid lithospheric plates on the Earth's surface can be described by Euler rotations. These rotations are performed around a rotation axis through the
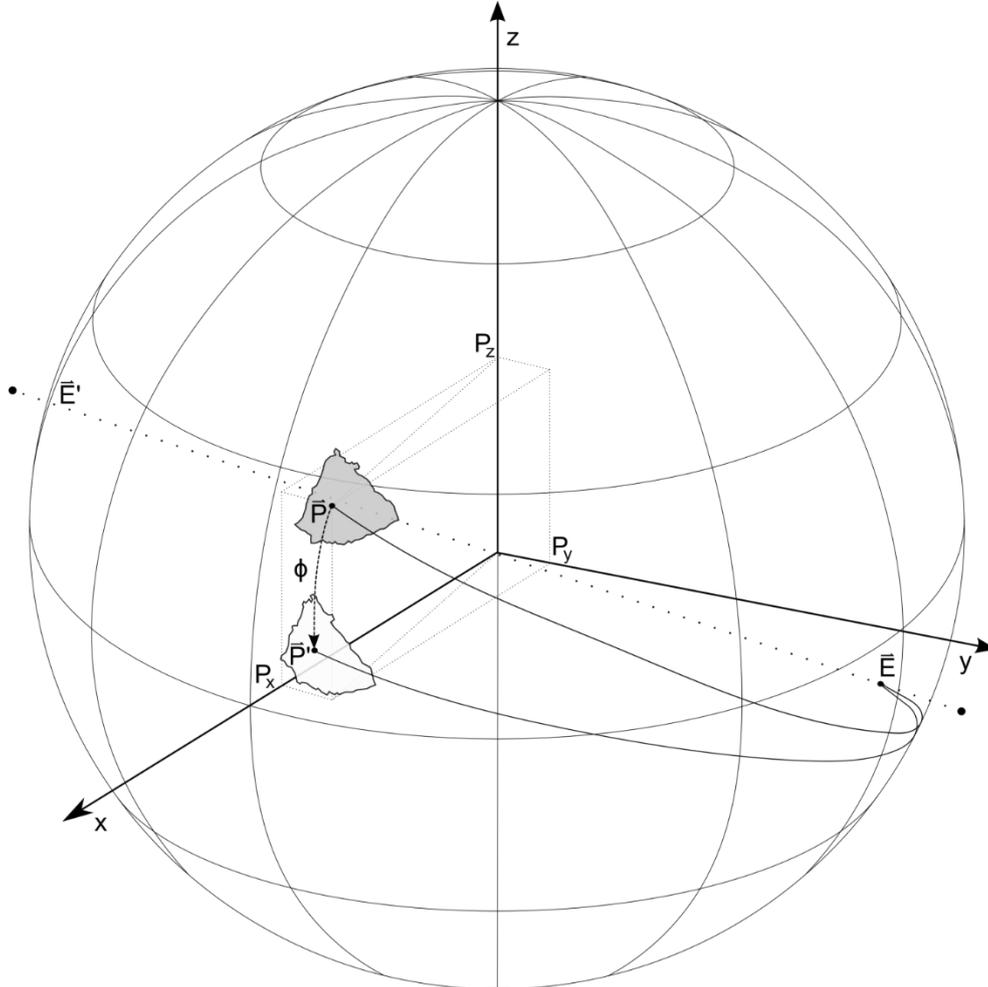
Figure 2-Euler Rotation of the Modern Iberian Plate into the Albian Age some 100 Million Years Ago (Adapted from Greiner).

center of the Earth. The intersection of the rotation axis with the Earth's surface is called [a] Euler pole" (Greiner).

Figure 2 shows the rotation of a modern point on the Iberian plate into its analogous position during the Albian age some 100 million years ago.

The rotation function (described in Dutch n.d.) takes the Euler pole and the point being rotated expressed in Cartesian coordinates and the rotation angle in radians and produces the resulting rotated point which can then be converted back into geographic coordinates.

3. Implementation

The software stack for the database is PostgreSQL running on a Linux (CentOS) server with PostGIS installed on top of PostgreSQL supporting spatial functionality. The service is exposed both as a standalone web application (http://paleolocation.org, see Figure 3) enabling users to query a point for a given age and retrieve a map of that point for the nearest available reconstruction; and as a web service that may be integrated into other applications such as the NPL's paleocentral.org fossil catalog.
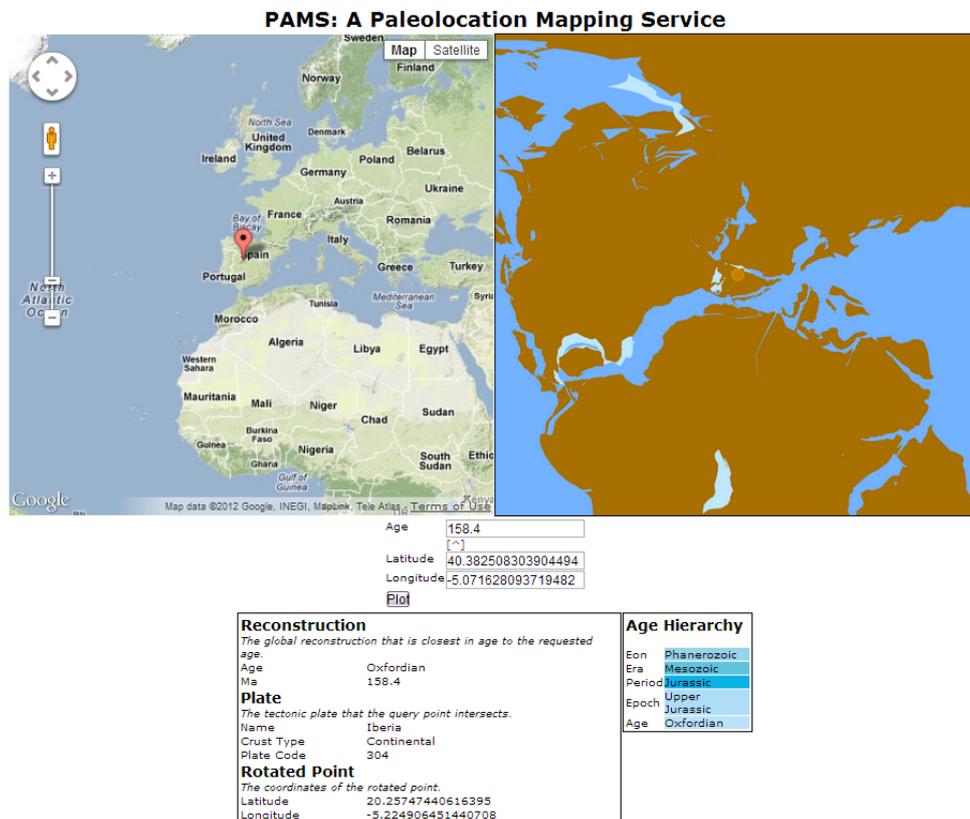
Figure 3-A screen capture of the PAMS reference implementation.

Regardless of the interface, queries are submitted as a latitude and longitude provided in decimal degrees and as an age, provided in millions of years ago.

Once the most appropriate reconstruction has been identified, a spatial query is performed in order to locate the plate on the modern globe that contains the query point and thus the appropriate Euler pole and rotation angle. The latitude and longitude of the resulting rotated point along with the URL of the relevant base map are the output parameters of the service.

While most continental plates are ancient and will have appeared prior to the age being queried, deep oceanic plates can be relatively young due to their constant subduction beneath the lighter and higher continental plates. Thus the oldest oceanic crust is in the Western Pacific and does not exceed 180 million years in age, roughly coincident with the mid Jurassic time period (Müller, figure 1). If the query point intersects a plate that possesses an

appearance date prior to the age being requested, no meaningful results may be returned and an error message will be issued instead.

3.1. Web Service

Integration of PAMS into a site via its web service can be achieve via its REST interface. Requests take the form of an HTTP GET request with the desired input parameters as follows:

```
http://paleolocation.org/rotation/plot?lat=30.5&lng=-98.2&age=233
```

This results in a JSON response taking the following form:

```
{"baseMap":{"url":"http://paleolocation.org/.../Anisian.png"},
  "error" : { "code" : 0,
      "message" : "None"
    },
  "nearestAge" : { "age" : "Anisian",
      "eon" : "Phanerozoic",
      "epoch" : "Middle Triassic",
      "era" : "Mesozoic",
      "period" : "Triassic",
    },
  "reconstruction" : { "age" : "Anisian",
      "ma" : 241.45
    },
  "rotatedCoordinates" : { "latitude" : -4.50207,
      "longitude" : -53.49050
    },
  "techtonicPlate" : { "appearance" : 750,
      "crustType" : "Continental",
      "name" : "Laurentia (Paleozoic North America)",
      "plateCode" : 101
    }
}
```

Once the query has been made, and the rotated coordinates have been determined along with the appropriate base map, displaying the point on the base map in the client application is up to the developer. We have developed a reference PAMS implementation that employs the OpenLayers Javascript API for use in the display of the mapping.

```
0 var point = data.rotatedCoordinates;
1 map = new OpenLayers.Map('pMap', {});
2 var base = new OpenLayers.Layer.Image(
        'Base Map',
        data.baseMap.url,
```

```
                new OpenLayers.Bounds(-180.0, -90, 180, 90),
                new OpenLayers.Size(4725, 2361),
                {numZoomLevels:7, maxResolution:1.0});
3 var points = new OpenLayers.Layer.Vector('Point Map')
4 map.addLayers([base, points]);
5 map.setCenter(new OpenLayers.LonLat(point.longitude,
                point.latitude));
6 map.zoomTo(2);
7 var point = new OpenLayers.Geometry.Point(point.longitude,
                point.latitude);
8 var paleoLocation = new OpenLayers.Feature.Vector(point);
9 map.layers[1].addFeatures([paleoLocation]);
```

In this client, line 1 creates the OpenLayers map object into a pMap div. Line 2 uses the OpenLayers image layer type to create the base map layer. This layer points to the appropriate PNG image as returned from the service located in the data.r.age variable. The bounds of the map are them set to represent the entire globe and the size of the image in pixels is also provided. Here we also set a couple of map options, these will naturally vary based on the API being used. Line 3 constructs a new vector layer that will be used to contain the rotated point being mapped. The base and point layers are then added to the map object in line 4. Following some default centering and zooming, the point itself is added to the map at the coordinates provided by the service (in the variables point.longitude, point.latitude respectively) in lines 7 through 9.

OpenLayers is just one of many client-side libraries that can be used to display and integrate the results of PAMS into an application. The client is also responsible for collecting the user's query data. In the case of a site like paleocentral.org, the query data (i.e. geographic coordinates and rock age) is all provided through the specimen metadata. However, in a scenario in which users are required to enter their own query data the client site should aid in this. For example, the reference implementation uses a Google Maps window in order to provide coordinate selection in the modern world. Additionally, stratigraphic layers could be used on the query interface in order to suggest rock age for a given point. The USGS provides such layers for coverage of the United States, and other sources can be obtained for global coverage (USGS, n.d.). While such assistance can be helpful, users must be cautioned that such stratigraphic layers, necessarily of limited resolution, will only offer a first order approximation of rock age. That age will always be subject to local anomalies, the accuracy and precision with which the coordinates have been located and any number of other factors.

4. Conclusions and Further Work

There are some logical extensions to PAMS which would increase its impact. PAMS is in effect a spatiotemporal framework for the Earth which could serve as a digital environment within which to integrate any number of paleolocation data points. This might include professionally curated paleontological collections such as those represented by the NPL, but also crowd-sourced "citizen science" collections that are contributed to a possible future database as well. PAMS could be expanded to allow for automated collection donation and serve as a sort of metacollection space for paleographic data.

At present, PAMS only provides a single layer in its base map. This layer is strictly a tectonic plate reconstruction. While it broadly distinguishes between continental and oceanic plate, for example, it explicitly makes no attempt to provide realistic coastlines, mountain ranges, bathymetry or other paleogeographic elements. While these sorts of structures are necessarily speculative when applied to deep geological time, they could provide a level of graphic interest that could serve to elevate the attractiveness of the service in educational and popularization settings. A good number of additional layers could also be introduced to cover various aspects of paleographic data such as climate, paleobiogeography and faunal zones (Biology Colloquium, Clarkson, Geological Society of London 1990, 1973, Hallam).

We believe that PAMS will provide a useful new web-based approach to the mapping of deep geologic time that will be easily leveraged by a number of potential clients.

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