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J. P. Cogné

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PaleoMac: A Macintosh™ application for treating paleomagnetic data and making plate reconstructions

J. P. Cogné

*Institut de Physique du Globe de Paris, Laboratoire de Paléomagnétisme, 4 place Jussieu, 75252, Paris cedex 05, France
(cogne@ipgp.jussieu.fr)*

[1] This brief note provides an overview of a new Macintosh™ application, PaleoMac, (MacOS 8.0 or later, 15Mb RAM required) which permits rapid processing of paleomagnetic data, from the demagnetization data acquired in the laboratory, to the treatment of paleomagnetic poles, plate reconstructions, finite rotation computations on a sphere, and characterization of relative plate motions. Capabilities of PaleoMac include (1) high interactivity between the user and data displayed on screen which provides a fast and easy way to handle, add and remove data or contours, perform computations on subsets of points, change projections, sizes, etc.; (2) performance of all standard principal component analysis and statistical processing on a sphere [Fisher, 1953] etc.); (3) output of high quality plots, compatible with graphic programs such as Adobe Illustrator, and output of numerical results as ASCII files. Beyond its usefulness in treating paleomagnetic data, its ability to handle plate motion computations should be of large interest to the Earth science community.

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Index Terms: 1525 Geomagnetism and Paleomagnetism: Paleomagnetism applied to tectonics (regional, global); 8155 Tectonophysics: Evolution of the Earth: Plate motions—general; 0910 Exploration Geophysics: Data processing; 1594 Geomagnetism and Paleomagnetism: Instruments and techniques.

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1. Introduction

[2] The PaleoMac application for Macintosh™ computers was originally designed as a laboratory tool, able to handle paleomagnetic data files, perform component analysis and interpretations, and produce high-quality plots. It has, however, evolved with time, and it is now able to handle the entire process from paleomagnetic data treatment through final interpretation in terms of paleogeographic reconstructions of plates on the Earth. So, although it has been conceived in, and has been strongly

influenced by, a paleomagnetic environment, its completeness and high flexibility surpass paleomagnetic interests alone. Its capabilities in computation and graphic representation of “objects” on the Earth (poles, locations, plate contours..) should generate interest to a broader geological community.

2. So, What Does Paleomac Do?

[3] PaleoMac generates and handles two kinds of binary files of specific format containing (1) demagnetization data, which are typically sets of

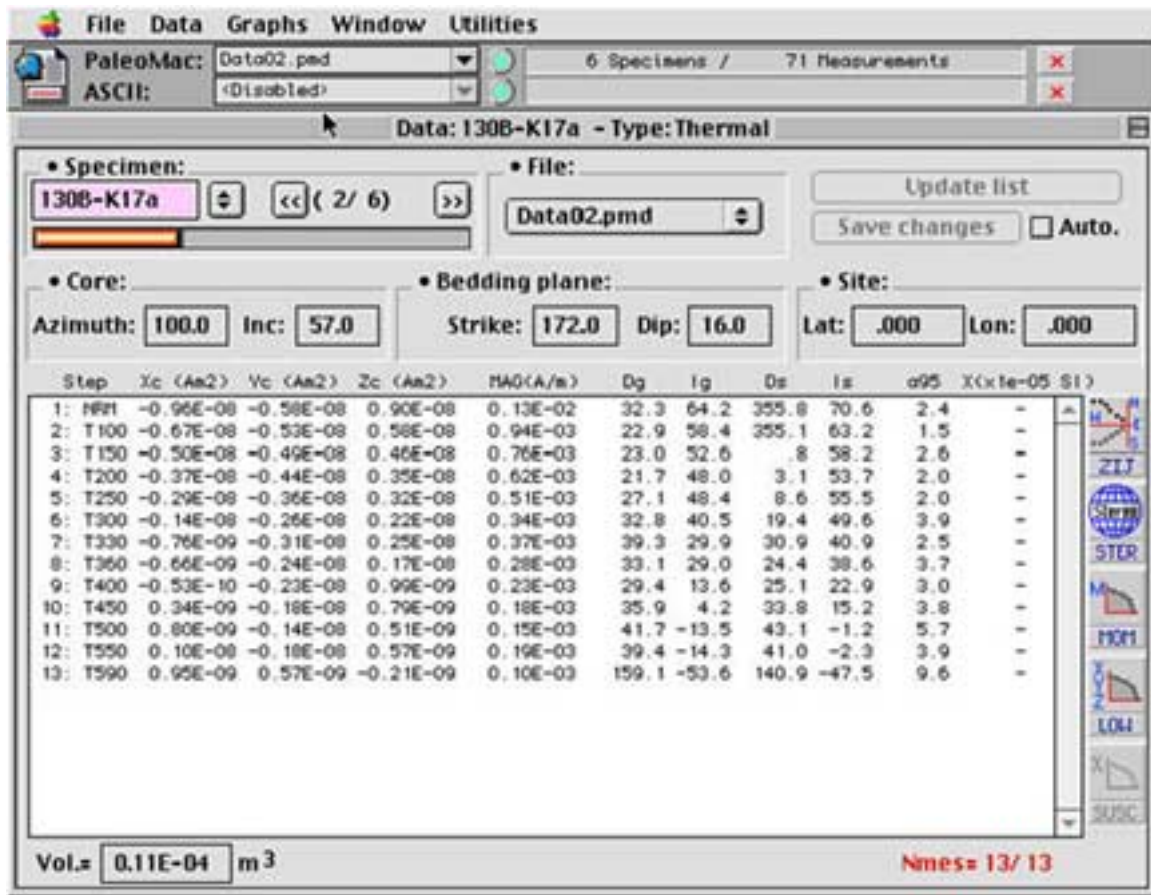


Figure 1. Interface of demagnetization PMD data list. When a PMD file is opened, the first specimen appears with its measurements. The parameters (core azimuth and dip, bedding strike and dip etc.) may be edited directly in this window. Various buttons allow quick access to other samples, previously opened files and graphs.

{X, Y, Z} magnetization components as a function of demagnetization step, and (2) results of component adjustments and computations, which are lists of {Declination, Inclination} data with various parameters (intensity, circles of confidence, site location on the Earth, etc.). It is moreover able to handle almost any type of ASCII file containing such data (i.e. Declination/Inclination of directional data in local coordinates, or Latitude/Longitude of points in Geocentric coordinates). Finally, PaleoMac handles various kind of data on the Earth sphere (paleopoles, Apparent Polar Wander Paths, plate contours, etc.), which provides a powerful tool to compute and produce paleogeographic reconstructions.

[4] PaleoMac makes computations (components, statistics, rotations...) and generates graphic outputs in either PICT, or PostScript format, which can

then be opened and reworked by most Adobe Illustrator applications (tested versions: 3.2, 5.5, 6.0, 8.0 and 9.0). It is thus extremely easy to go from the demagnetization data as obtained in the laboratory to the final figure of a scientific paper. The operation of PaleoMac can be divided into three categories which are summarized in the following subsections.

2.1. Demagnetization Data Processing (PMD Type Data)

[5] Data are contained in binary files with extension .PMD (for PaleoMagnetic Data) generated by the application (capacity: 200 specimens with a maximum of 70 demagnetization measurements per specimen). The first step is to import data from the laboratory measurement files into the PaleoMac .PMD binary files. Nowadays, PaleoMac can import

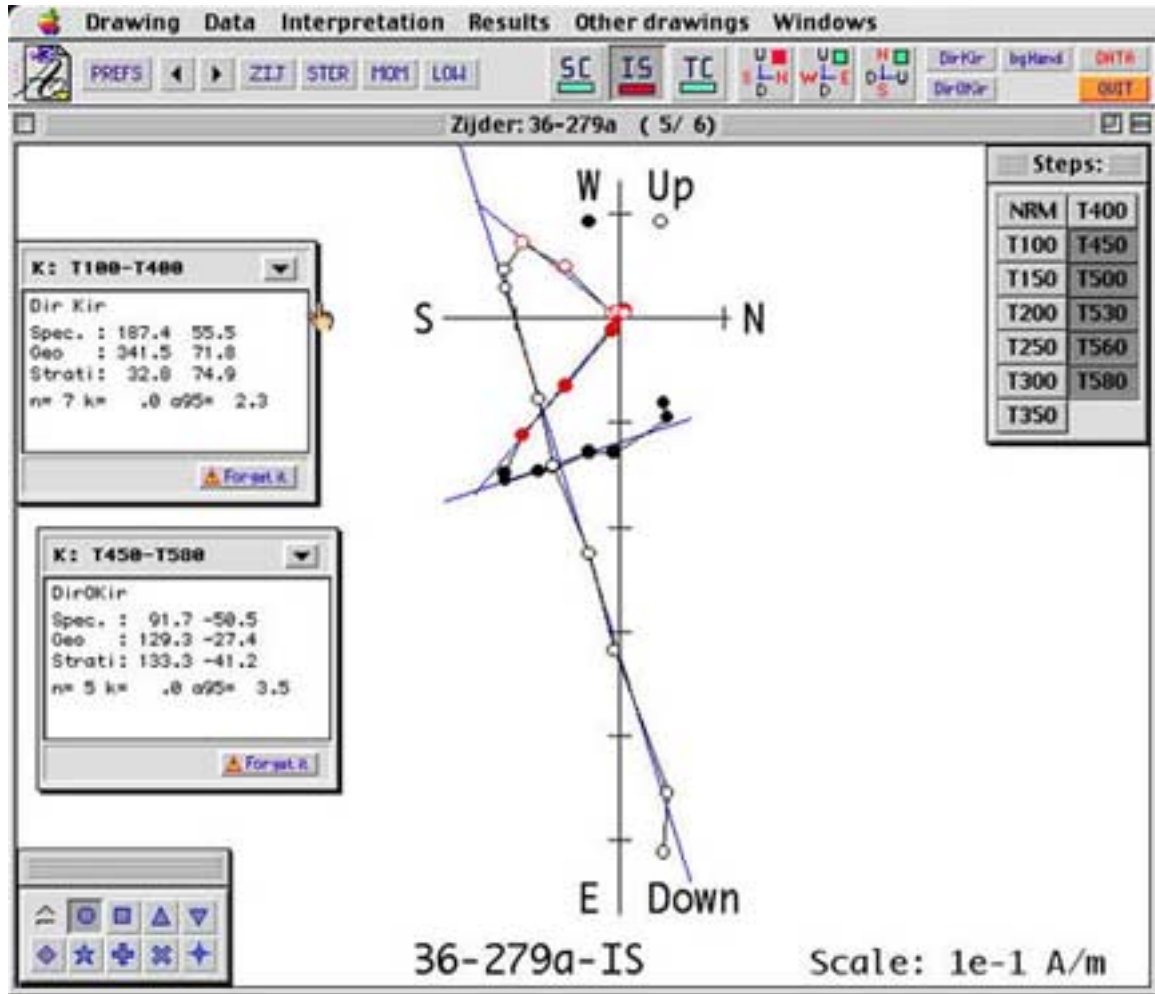


Figure 2. *Zijderveld* [1967] plot as it appears on the screen. On this example, two magnetic components (in blue) have been fitted to different temperature steps (points in red are selected data, on which a least-square line fitting has been done); the corresponding results are displayed in the small windows to the left (these windows may be displaced anywhere on the screen). The selection of demagnetization steps is made either by clicking them on the screen, or by clicking the relevant steps in the “Steps” window to the right.

data of specific format from 6 paleomagnetic laboratories around the world: IPGP, UC Santa Cruz, Caltech, University of Rennes, Berkeley Geochronological Center and UC Davis.

[6] After opening a PMD file (Figure 1), the paleomagnetic data can be displayed in one of three standard coordinates systems: Sample (or core), In-Situ, and Tilt-Corrected in the following graphs: (1) orthogonal vector end-points projection [*Zijderveld*, 1967] (Figure 2); (2) equal-area and stereographic projections; (3) magnetization decay curve, $M = f(\text{step})$; (4) susceptibility curve, $\chi = f(\text{step})$; (5) components decay curve, $\{X, Y, Z\} =$

$f(\text{step})$, allowing to perform the Lowrie test [*Lowrie*, 1990].

[7] The available computational capabilities on these data are: (1) Least squares fitting of magnetization components (with or without constraint to the origin of *Zijderveld* plots, see Figure 2); (2) Eye-ball fitting of components, by interactive component tracing and modifications directly with the mouse on the screen; (3) Fisher statistics [*Fisher*, 1953]; (4) Great circle fitting [*Halls*, 1978].

[8] The results of these computations, which show as Declination/Inclination of components, together

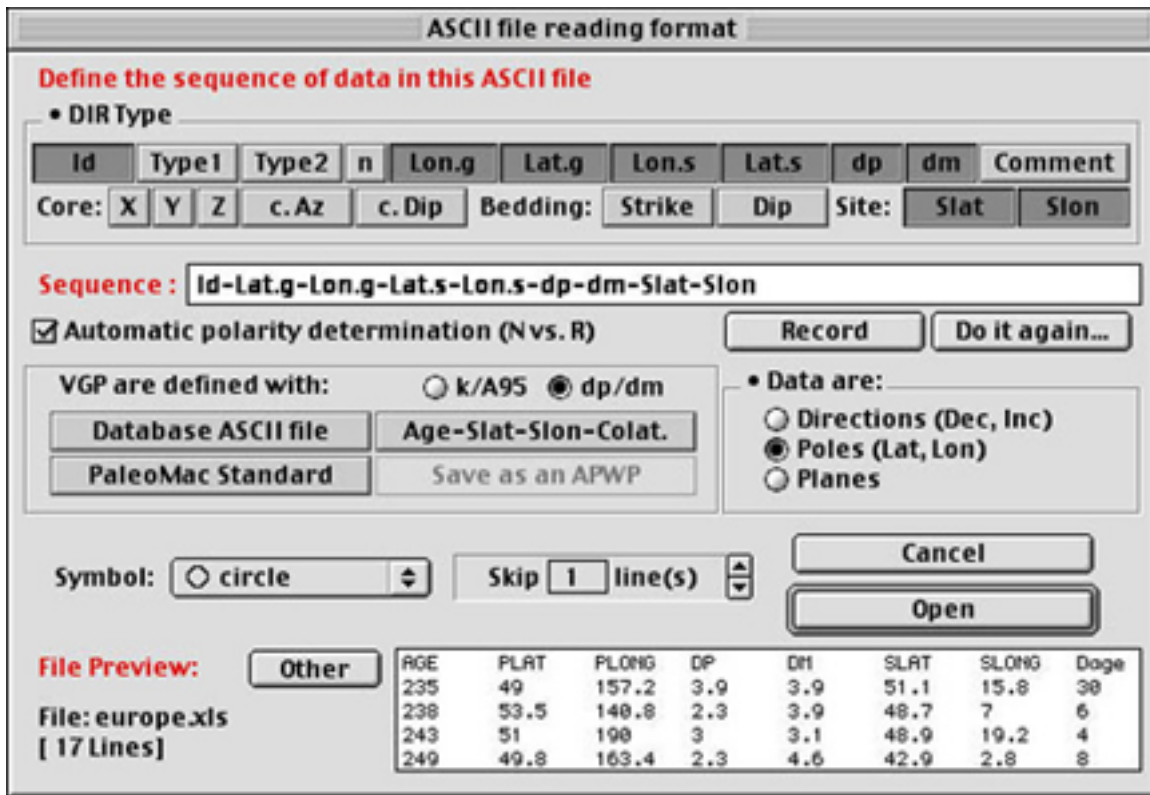


Figure 3. This interface allows the user to define the sequence of data contained in any kind of ASCII file. In this example, data come from the Global Paleomagnetic database of *McElhinny and Lock* [1996].

with a number of parameters such as the *Fisher* [1953] parameters k , α_{95} , R etc., for a given demagnetization range, may be saved and recorded in .DIR type files.

2.2. Directional Data (Dec/Inc) Processing in the Local Coordinate System (DIR Type Data)

[9] PaleoMac generates its own binary file format (with .DIR extension, for DIRection). These .DIR files contain, for example, the results of demagnetization interpretations, but also any kind of directional data distributions. Moreover, the application is able to open any kind of ASCII file containing similar data sets {Dec, Inc} with or without other parameters (k , α_{95} , bedding strike and dip, site latitude and longitude, magnetization intensity, susceptibility..), in any order within the file. A “formatting box” (Figure 3) allows to define this order before reading the file. The application jointly handles two data lists: in both geographic

(in-situ, IS) and stratigraphic (tilt-corrected, TC) coordinates and may be represented in either equal-area or stereographic projections (Figure 4).

[10] The computational capabilities on these data are: (1) Fisher statistics [*Fisher*, 1953]; (2) averages of vectors and planes [*McFadden and McElhinny*, 1988]; (3) bivariate statistics [*LeGoff*, 1990]; (4) mean inclination [*McFadden and Reid*, 1982]; (5) great circle fitting and great circles intersections [*Halls*, 1978]; (6) small-circle fitting [*Mardia and Gadsden*, 1977] and small-circle intersections; (7) mixed average of vectors and small-circle (which is a derivation of the mixed average of vectors and plane of *McFadden and McElhinny* [1988]); (8) rotations, either interactive with the mouse on the screen, with numerical output, or by numerical input of parameters; (9) density diagrams; (10) stepwise unfolding.

[11] Because PaleoMac handles IS and TC data lists, some statistical tests may be performed on these populations such as: (1) *McElhinny* [1964]

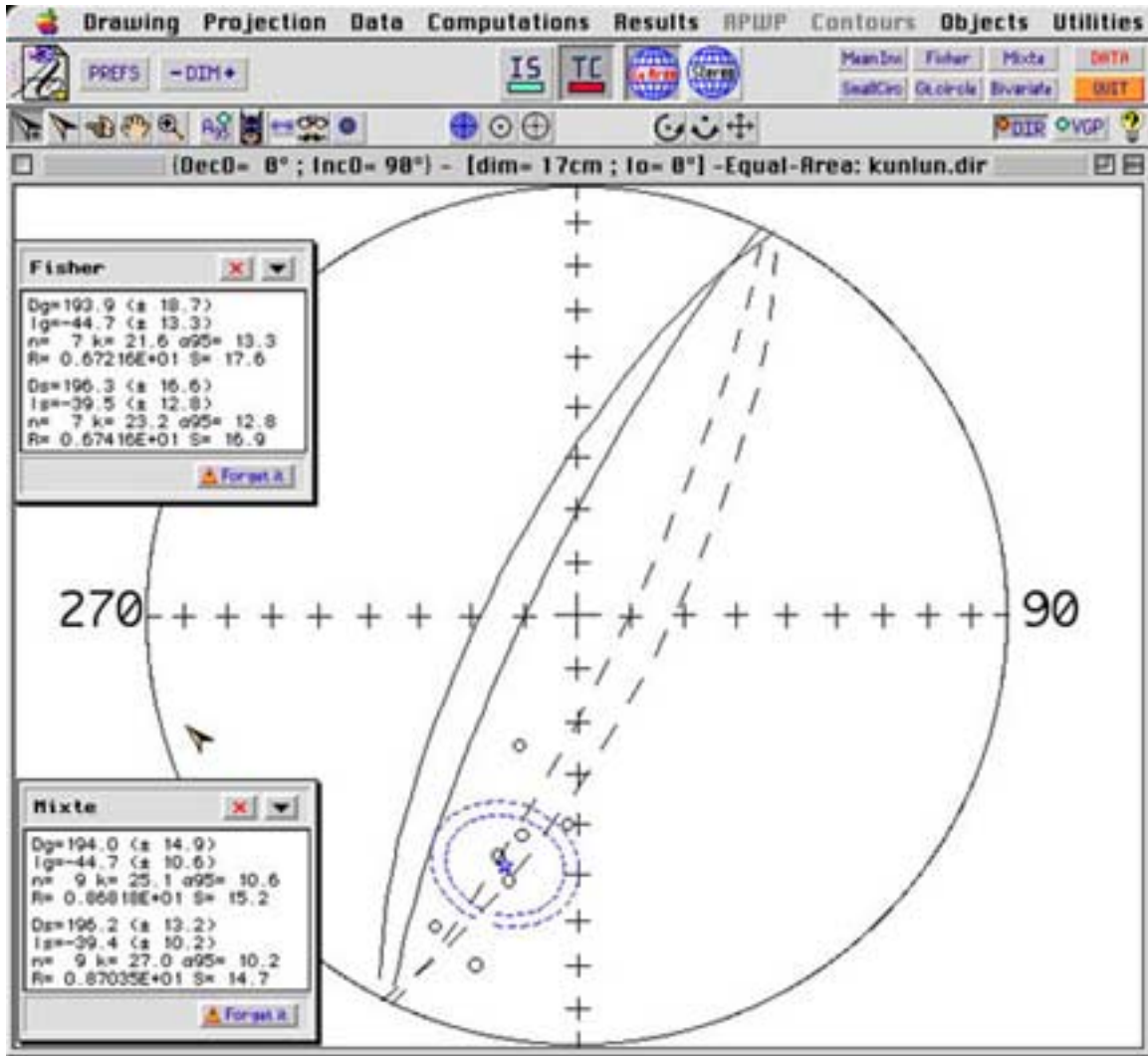


Figure 4. Stereonet window, showing the appearance of Paleomac interface. The various buttons provide shortcuts to several graphic and computation functions. In this example, two computations (Fisher and Mixed averages, in blue) have been done, and the results are displayed in the small windows to the left of the screen (these windows may be displaced anywhere on the screen). One or both mean directions may be saved in a DIR file.

fold test; (2) *McFadden* [1990] fold test; (3) reversals test [*McFadden and Lowes*, 1981; *McFadden and McElhinny*, 1990]; (4) Jackknife test [*Tauxe et al.*, 1991]. The results of these computations may be saved and recorded in .DIR files.

[12] The latest versions of Paleomac include the use of a stratigraphic position parameter (i.e. stratigraphic height or depth), allowing to generate classical magnetostratigraphic plots, e.g. declination, inclination, VGP latitude, magnetic moment and/or susceptibility as a function of stratigraphic

position. Finally, Paleomac computes the Paleopoles positions, or Virtual Geomagnetic Poles (VGP), with their {dp/dm} or A95 areas of confidence, from these data lists (see below).

2.3. Data Processing in the Geocentric Coordinates System (VGP Type Data)

[13] The paleopoles (Latitude/Longitude) are recorded in .DIR files noting again that it is possible to open any kind of ASCII files containing this kind of data (Lat, Lon, k, a95, dp, dm, site lat, site lon etc.), providing their order in the file has

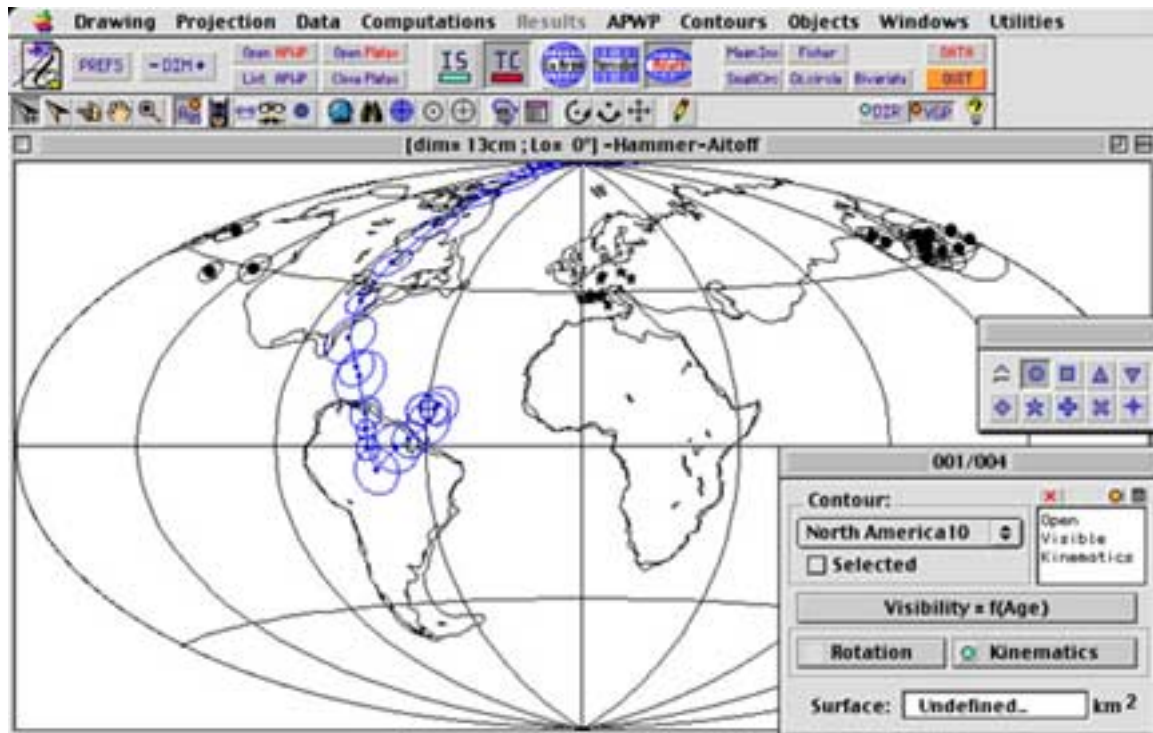


Figure 5. Hammer-Aitoff Earth projection showing various objects manipulated by PaleoMac: paleopoles (black dots with areas of 95% confidence) and their corresponding sites (stars), APWP (blue curve) and plate contours. The small window to the lower right corner allows access to various settings on each contour (selection, kinematics link, rotations, etc). Any of these objects can be selected, either on clicking them in the graph, or in the data lists. This provides an easy way to select objects, either visually, or accounting for their characteristics (location, age, polarity etc). Any kind of rotation, visually, numerically or driven by kinematics parameters, may then be applied.

been specified on opening (Figure 3). Furthermore, PaleoMac has some pre-defined formats which allows one to open specific ASCII files such the ones which can be extracted from the Global Paleomagnetic Database of *McElhinny and Lock* [1996].

[14] The computations available are the same as for DIR type data, except for the mixed average of vectors and planes of *McFadden and McElhinny* [1988], which is of no use here. Finally, if ages are assigned to the data, PaleoMac can compute an Apparent Polar Wander Path (APWP). A set of synthetic APWPs of *Besse and Courtillot* [1991, 2002] for the main continents is provided with the application. It is then straightforward to compare any paleopole computed by the user with these reference APWPs, or with any other paleopole, and translate the differences in terms of tectonic movements of the studied area.

[15] The graphic representation of data can be made in seven projections (Figure 5) centered on any area of interest: Equal-Area, Stereographic, Orthographic (“view from space”), Mollweide, Hammer-Aitoff, Cylindrical Equivalent and Rectangular. To these global projections, PaleoMac adds the possibility to “zoom” on detailed maps in 4 projections systems: Equal-Area, Stereographic, Mercator, and Lambert conical conformal.

2.4. Plate Contours and Paleogeographic Reconstructions

[16] It is probably the paleogeographic reconstructions capabilities of PaleoMac that makes it a useful and powerful tool. The application can open and handle plate contour files which typically contain sets of {Lat., Long.} points on the Earth. A set of such files for the main continent and block

contours is provided with the application. These contours, as well as the data points, the site locations, or the APWPs, can then be rotated within the Earth reference frame in three ways:

1. Rotations can be made completely manually and interactively, by selecting the objects with the mouse on the screen, and then dragging them in the desired way. The resulting rotation parameters on the sphere are then displayed.

2. A second way is to enter the rotation parameters to be applied to the selected objects.

3. Finally, it is possible to “drive” the rotation of objects (poles, sites, contours. . .) by linking them to kinematic parameter files. These files contain a list of finite rotation parameters for various geological ages, allowing to build and test paleogeographic reconstructions.

[17] The PaleoMac folder contains three sets of pre-defined reconstructions schemes for the major continental blocks (North and South America, Africa, Eurasia, Australia, Antarctica, India, Groenland, Madagascar, Spain), for which kinematics parameters are found in the literature: (1) a set of blocks in the paleomagnetic reference frame where the parameters are derived from the synthetic APWP of *Besse and Courtillot* [2002]; (2) a set of blocks in the hot spot reference frame down to 130 Ma, following the parameters of *Müller et al.* [1993]; (3) a set of blocks in the hot spot reference frame down to 200 Ma, following the parameters of *Müller et al.* [1993] for the 0–130 Ma period, and the older and less well constrained parameters of *Morgan* [1983] for the 130–200 Ma period.

[18] The kinematics parameters of the Global Isochron Chart of *Royer et al.* [1992] are also provided, allowing the user to link these files to any relevant object on the Earth, and then reconstruct the paleoposition of the objects at a given age.

[19] Beyond these pre-defined sets, PaleoMac allows the user to construct his own databases of contours and kinematics files, either using the files contained in the downloadable folder, or following the templates provided with the application. Finally, PaleoMac can generate a series of pictures with age increments computed by interpolation,

which allows one to construct cartoons of plate tectonics.

3. Availability: System Requirements

[20] PaleoMac is a freeware, and can be downloaded from the following address: <http://www.ipgp.jussieu.fr/~cogne>. The downloadable archive (PaleoMac_5.2.sea.hqx, 7Mb of size) produces a folder containing the application itself and various files (statistical tables, IGRF parameters files, plate contours, kinematic parameters files, language interfaces, etc.). The latest versions need MacOS 8.0 or later systems, and minimum 15 megabytes of free memory to run. Regarding the interface language, PaleoMac now runs in French and in English. It is however possible to translate the interface resources to make it running under other languages.

[21] The above site also contains several help pages which can be consulted online. These html pages are also grouped into a downloadable folder (PaleoMac_Help.sea.hqx, 13Mb), and can be run locally on each computer.

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