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DIGITAL CARTOGRAPHY AND HISTORICAL MAPS: TECHNIQUES, APPLICATIONS AND PECULIARITIES

Cartografia Digital e Mapas Históricos: Técnicas, Aplicações e Peculiaridades

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ABSTRACT

Through specific examples, some support that digital cartography provides to historical cartography is presented. This paper highlights the differences in treatment between present and historical maps, through some typical cases, with their difficulties and possible solutions. Typical tasks are: determination of the scale, type of map projection, coordinates used, prime meridian, evaluation of errors and precision. Major difficulties are the identification of the projection in which the map was produced and the correct analysis and interpretation of statistical indicators. Some applications are also presented, such as the precise location of monuments, buildings, streets and old ways, often no longer existing or modified. Finally, suggestions are made as to graphically present the results. These tasks lead to a dialogue between the historical element and the revelations of the cartographic analysis; the quantitative aspects illustrate the qualitative ones, in the use of a technique for the benefit of history.

Keywords: Historical Cartography; Digital Cartography; Brazilian Historical Maps.

RESUMO

Através de exemplos concretos, apresentam-se alguns auxílios que a Cartografia digital presta à Cartografia histórica. Destacam-se as diferenças de tratamento entre os mapas históricos e os atuais, através de alguns casos típicos, com suas dificuldades e possíveis soluções. Tarefas típicas são: determinação da escala, tipo de projeção cartográfica, coordenadas utilizadas, meridiano de origem, avaliar erros e precisões. As maiores dificuldades são a identificação da projeção na qual o mapa foi produzido, a análise e correta interpretação dos indicadores estatísticos. São apresentadas também algumas aplicações como a localização exata de monumentos, edifícios, ruas e caminhos antigos, muitas vezes não mais existentes ou modificados. Finalmente, são feitas sugestões de como apresentar graficamente os resultados. Nessas tarefas, provoca-se um diálogo entre o elemento histórico e as revelações da análise cartográfica; o quantitativo ilustra o qualitativo, numa utilização da técnica em benefício da história.

Palavras chaves: Cartografia histórica; Cartografia digital; Mapas Históricos Brasileiros.

1. INTRODUCTION

A map can be viewed from different angles and viewpoints, with different emphasis and looks: historical, sociological, political, artistic or geographic. Options are not mutually exclusive, but complementary. This paper seeks to show that the cartographic vision, in a broad sense, can bring large contributions to the discussions. Harley (1968) presented a methodology for cartographic assessment of old maps, and, at the same time, advocated that the computer could provide great help in the task of overlaying ancient and modern maps, so quantifying distortions. Gradually, the dream is becoming a reality: computing resources have evolved a lot, and with them, the digital cartography; but there are still many challenges when it comes to historical maps, for which the digital mapping programs present only a few facilities, since they were not designed for that.

Especially considered is the application of these new methods to old maps, particularly those prior to the last quarter of the eighteenth century, in which even the mathematical cartography (projections and other technical elements) was not yet consolidated. At the same time consider the help that digital cartography provides to the cartography of historical maps: working in digital media, in addition, to facilitate visual analysis of a cartographic document and its comparison with modern maps, presents a series of benefits and new possibilities, which will be illustrated through study cases, which can be adapted to each situation and user needs.

The exhibition of cases presents the steps to be followed to get the greatest benefit from the digital tools and to make studies, for example, for the determination of the prime meridian, assessment of the accuracy of the map, location of roads and buildings, studies of changes and expansion of cities among others.

2. PRELIMINARY TASKS

The first step in the study of a map consists in obtaining a copy of it in digital media with good resolution. This is a technical requirement for the reading of images that needs to develop the look, to calibrate the details, to divide the image by spatial or subject cuts and then to make the synthesis. In order to obtain a copy with good resolution (300 dpi, for example), one should resorts to museums, reference centers of historical cartography, public or private collections. Noteworthy, in Brazil, is the Collection of digital maps recently made available by the National Library (BIBLIOTECA NACIONAL, 2011), through the Project *Cartografia Histórica dos séculos XVI ao XVIII* (Cartographic History from the sixteenth to the eighteenth century), in medium resolution. Higher-resolution copies can be requested at this Institution by the researchers.

Before starting the analysis, it is interesting to raise some preliminary data to serve as references to the subsequent steps and surveys: author, date, size, format or medium in which it is drawn, approximate scale, type of projection used, prime meridian, graduation of coordinates and others. In some cases, there is a catalog entry to the map; this author collaborated in the implementation and reviewing of these records available online by the National Library of Brazil. In other cases, especially in historical maps prior to the last quarter of the eighteenth century, these data do not appear explicitly, although one can try to determine them, as will be shown below.

3. SCALE

Old maps can bring the so-called ‘trunk of leagues’ (*tronco de léguas*, in Portuguese maps), which is a kind of a graphic scale. There can be more than one (and the map can have more than one) depending on the scale variation with latitude (CORTESÃO, 1960). Such scale has the advantage of proportionally varying with the entire cartographic document, extensions, reductions or digital media file. To get a rough idea of the scale, there is a simple way: to measure in hard copy at the equator the distance between two consecutive meridians that cut it; a mathematical example illustrates what needs to be done: if to 10 degrees at the equator corresponds to a distance of approximately D = 1,100km, and if the measured distance is d = 2.2 cm, then the scale is the relationship of these values (d / D) or 1: 50,000,000, which is a scale proper of a world map. It is then possible to check if the scale is the same along the meridians and, if necessary, how it varies along parallels. In the case of a digital map on a computer screen, it is not possible to determine the scale, but, instead, a graphic scale can be build and superimposed on the map in the proper position.

4. PRIME MERIDIAN

In ancient maps (until 1750) the prime meridian does not commonly appear explicitly in cards or in notes; some did not even have longitude degrees. Those who have it may or may not have represented the origin on the map, and in this case it suffices see the places through which the prime meridian passes: Canary Islands, Cape Verde, the Azores, the extreme west of Africa or any other. When the source is not listed or not declared, the challenge is to determine it.

The first step of such determination is to check the counting direction of the longitude and its amplitude of variation. For example, there are old maps of Brazil with origin in the meridian of the Isle of Ferro, in Rio de Janeiro (*Morro do Castelo*, Castle Hill), Praia (Cabo Verde archipelago) and others. The longitudes from these three meridians are usually counted from the point of origin to the west, and from 0 to 360 °.

To determine the origin of the meridians of a map it would be sufficient theoretically to compare the longitude (λa) of any point (a) with the longitude of same point, obtained from a current map, with origin in Greenwich (λg). The mathematical equation is:

$$\lambda_{ori} = \lambda_g - (360 - \lambda_a) \quad (1)$$

Where:

λori - Longitude of central meridian, with respect to Greenwich; to be determined

λg - Longitude of the point in respect to Greenwich, obtained from a current map

λa - Longitude of the point measured on the ancient map

If the longitude is reckoned eastward, the term in brackets should be simply replaced by λa. One must also interpret the sign of the result, making a sketch to verify if the origin is east or west of Greenwich.

Not to depend on only one measure, the same calculation can be performed for several points and then calculate the mean and standard deviation of the sample. As an example, the determination of the prime meridian of the Father Fritz's Amazon River Map of 1707 is shown in Figure 1. As can be seen, it is graduated in latitude and longitude, with a growing range of latitude, in an orthogonal grid.

Table 1 was devised to show it. With a digital mapping program (MapInfo ®) the longitudes of 26 places were extracted from the map and transferred to a spreadsheet (column λa); the operation was repeated on a current map, leading to column λg data.

Applying Equation (1), one obtains the last column (λori), the longitude of the prime meridian of this map. The spreadsheet allows the calculation of the mean and standard deviation, which defines the interval 15.25 ± 0.97 °. These two extreme values can be interpreted as follows: the first one corresponds to a systematic difference between the map coordinates of the old and the current map; which corresponds to the mismatch between the meridians of origin, also including the error in transporting the longitude from an observatory (e.g. Paris) to the point of origin of measurement in the old map (e.g. Quito).

The magnitude of the error depends on the technology of the time: until the eighteenth century, the transportation of longitude was made by estimating distances, directions and latitudes; on land (ground survey) over distances through ways and directions, to project on north-south and east-west directions; in the ocean the account was made by the leagues navigated and as a function of the strength of the wind, combined with the direction (estimated by the compass or needle) and corrected by latitudes measured at constant intervals. A simple explanation of this methodology can be found in REIS (1994). From the second half of the eighteenth century astronomical methods started to be applied, especially the occultation or eclipse of Jupiter's satellites method that applies well on land, but not on the high seas while crossing the ocean.

Only after the last quarter of the eighteenth century the use of the chronometer (invented shortly before) was generalized, with great impact on the improvement of the quality of the maps and of the longitudes in relation to European meridians. Thus, it is common to find large systematic errors in longitude on maps prior to this. For example, the the Count of Pagan map's (1655), which adopts the island of Sao Miguel in the Azores as the origin of longitudes presents an error of 7º for the longitude of Quito, which was the starting point in America for the transport of longitudes (CINTRA, 2011). This systematic error can be compensated and to some extent even eliminated by subtracting from

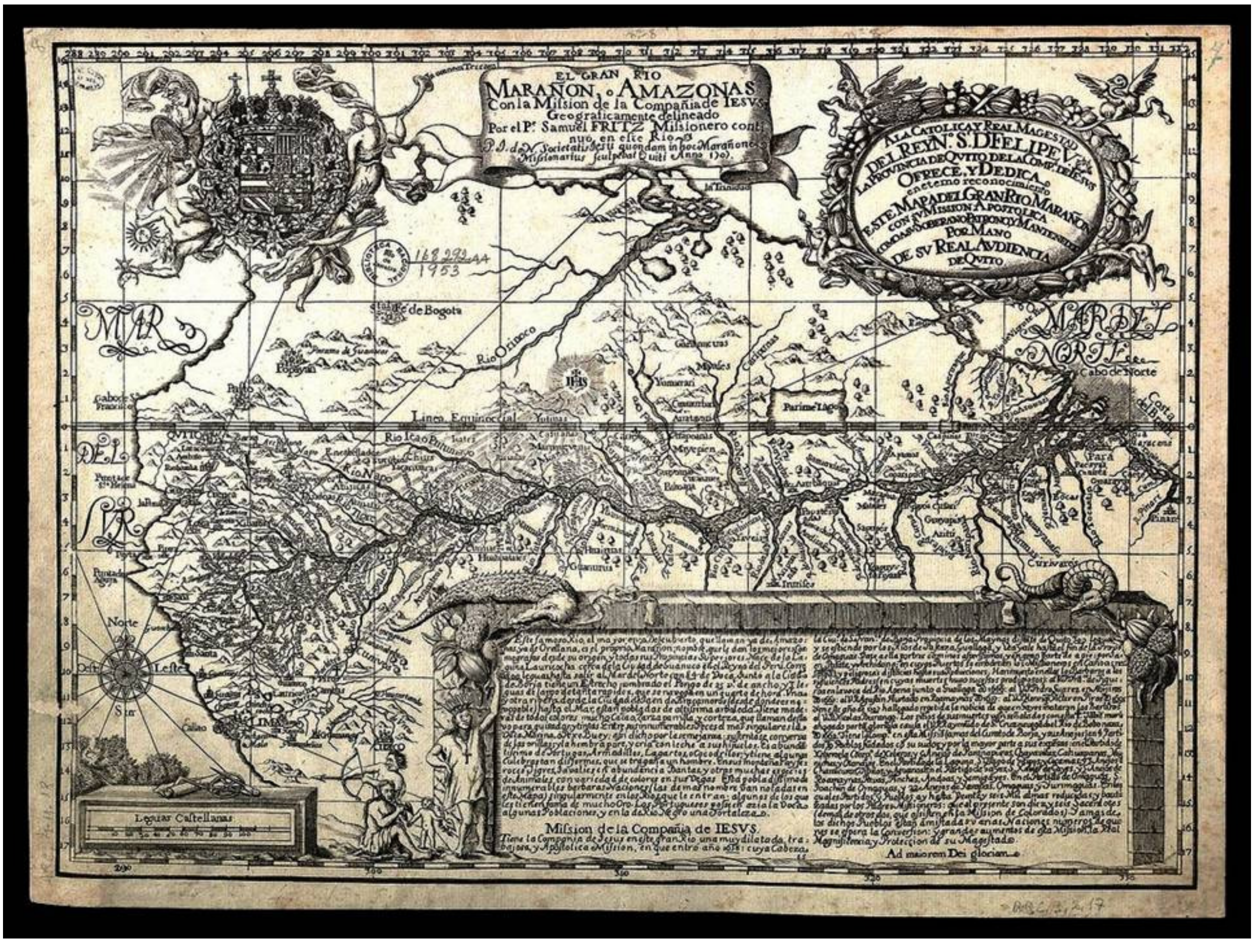

Fig.1: Father Fritz 's map of the Amazon River. Available at the National Library: http://bndigital.bn.br/cartografia/.

each value of longitude, the average of all measurements. This corresponds to introducing a translation across the map without changing their relative positions.

The second parameter, the standard deviation, measures the internal consistency or discrepancy of the different measurements of a set of longitudes. That is, the longitude errors of transportation from one point to another. In this case, the value of 0.97 indicates the precision with which Father Fritz made his survey of longitudes. The standard deviation and the mean define a range that is associated to the 68% probability of an outcome to be within it.

In this case and relying on these two parameters, the main town or place located in the range 15.25 ± 0.97 can be searched on a current map. This search indicates that the prime meridian is located in the Canary Islands and most likely in Las Palmas de Gran Canaria (longitude 15.4). But do not rule out other possibilities such as Santa Cruz de Tenerife (16.2 °) and the Ferro Island (18.0º), the most western of these islands, because there may have been an error in transporting the coordinates of the point of origin to a point in the map in question, which can be the coordinates from Quito, from which Father Fritz calculated the others. The help of historical data was then sought, by conducting a research in the Jesuit's journal and in other of his writings to find clues about how the measurements were taken and what was the prime meridian adopted.

5. CARTOGRAPHIC PROJECTION

Modern maps usually indicate the projection used; this is not the case with most of the old ones (1500-1775). This information, however, is necessary to analyze the accuracy, extract coordinates and make comparisons and overlays with maps. KEUNING (1955), SNYDER (1997) and GASPAR (2005) are good references to start these studies. Annex D of the latter book, named *Table for the identification of projections*, shows binary identification keys. Having the map in question in view, answers are given to questions

Table 1 - determination of the prime meridian of amazonia Father Fritz's Map

n	Place	λa	360-λa	λg	λori
1	Borja	297.12	62.88	-77.54	14.66
2	Pastaça	298.24	61.76	-76.41	14.65
3	Guallaga	298.92	61.08	-75.62	14.54
4	Chambira	299.63	60.37	-74.84	14.47
5	Tigre	300.56	59.44	-74.11	14.67
6	Ucaiale	301.01	58.99	-73.51	14.52
7	Nanay (Iquitos)	301.59	58.41	-73.22	14.81
8	Napo	301.88	58.12	-72.70	14.58
9	Javari	303.97	56.03	-69.97	13.94
10	Iça	306.54	53.46	-67.94	14.48
11	Jutai	307.63	52.37	-66.77	14.40
12	Juruá	308.62	51.38	-65.73	14.35
13	Tefé	310.74	49.26	-64.67	15.41
14	Purus	313.34	46.66	-61.48	14.82
15	Negro (Manaus)	314.67	45.33	-59.94	14.61
16	Madeira	315.89	44.11	-58.78	14.67
17	Jamundá	318.85	41.15	-56.14	14.99
18	Trombetas	319.58	40.42	-55.63	15.21
19	Topajós	321.03	38.97	-54.94	15.97
20	Curupatuba	322.38	37.62	-54.06	16.44
21	Urubuquara	323.09	36.91	-53.34	16.43
22	Paru	323.93	36.07	-52.67	16.60
23	Xingu	324.15	35.85	-52.25	16.40
24	Curupá	325.31	34.69	-51.62	16.93
25	Macapá	325.89	34.11	-51.09	16.98
26	Pará	328.58	31.42	-48.47	17.05
			average		15.25
			standard deviation		0.97

about the geometric properties of the parallels and meridians. Each question generates two paths (answer yes or no) and so on faced with new issues, until the name or type of projection is attained.

The diagram in Figure 2, built from Annex D illustrates a portion of the decision tree. To understand it, one can follow its application to the map in Figure 3.

The answer to question (1) is yes (Y) and going to numbers (2), (3) and (40), always answering yes, until one reach the shaded box with the name of the projection: Cylindrical equidistant meridian. Same analysis is applied to the map of Figure 4; to distinguish one from another it is necessary to add one more question to the scheme proposed by Gaspar (2005): is the graticule square or not? The affirmative answer leads to the projection, which is called Flat Square Projection, *Plate Carrée* in French and *Carta Plana Quadrada* in Portuguese. The negative answer leads to the Projection called Equirectangular or Flat Rectangular Chart projection.

The last example, in Figure 5, completes the explanation. Examining it, the answer is yes to questions (1), (2), (3), no to question (4), yes to (41), no to the (42) and finally to decide between (44a) and (44b), one must examine how the spacing of the parallels grows, if proportionally to the formula α or to tan ϕ. For this, measurements of distances between consecutive parallels should be made and the growth law checked. For this map, printed in a certain scale, the distance between the parallels was measured, resulting in: 9 / 10 / 11 / 15 and 24 mm,

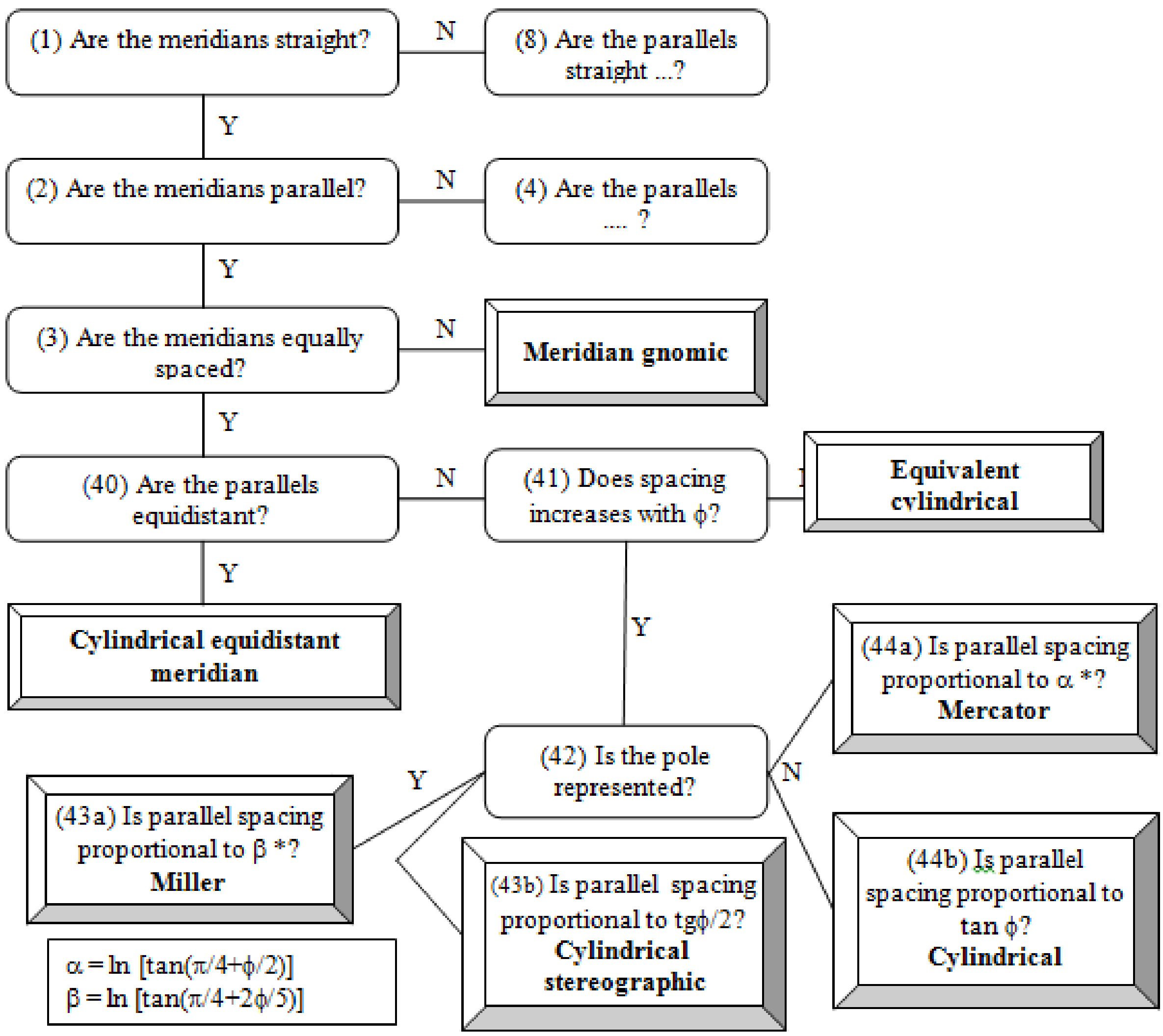

Fig. 2: Decision tree for equatorial cylindrical projections, adapted from Gaspar (2005).

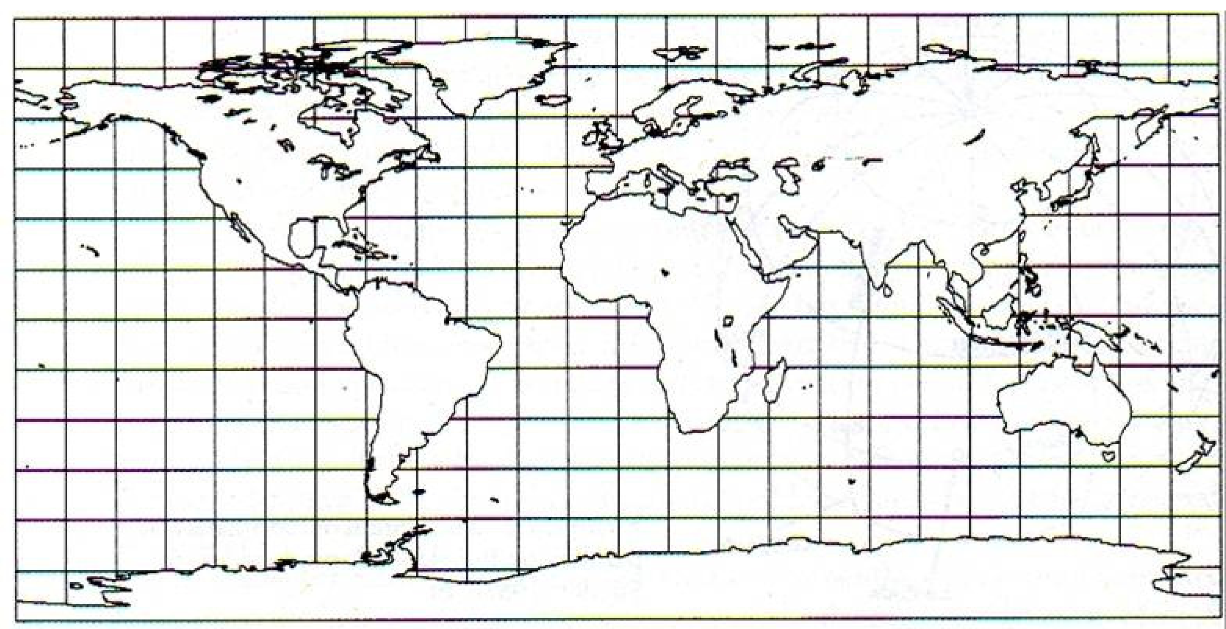

Fig. 3: World Map in the Flat Square projection (*Plate Carrée* in French or *Carta Plana Quadrada* in Portuguese).

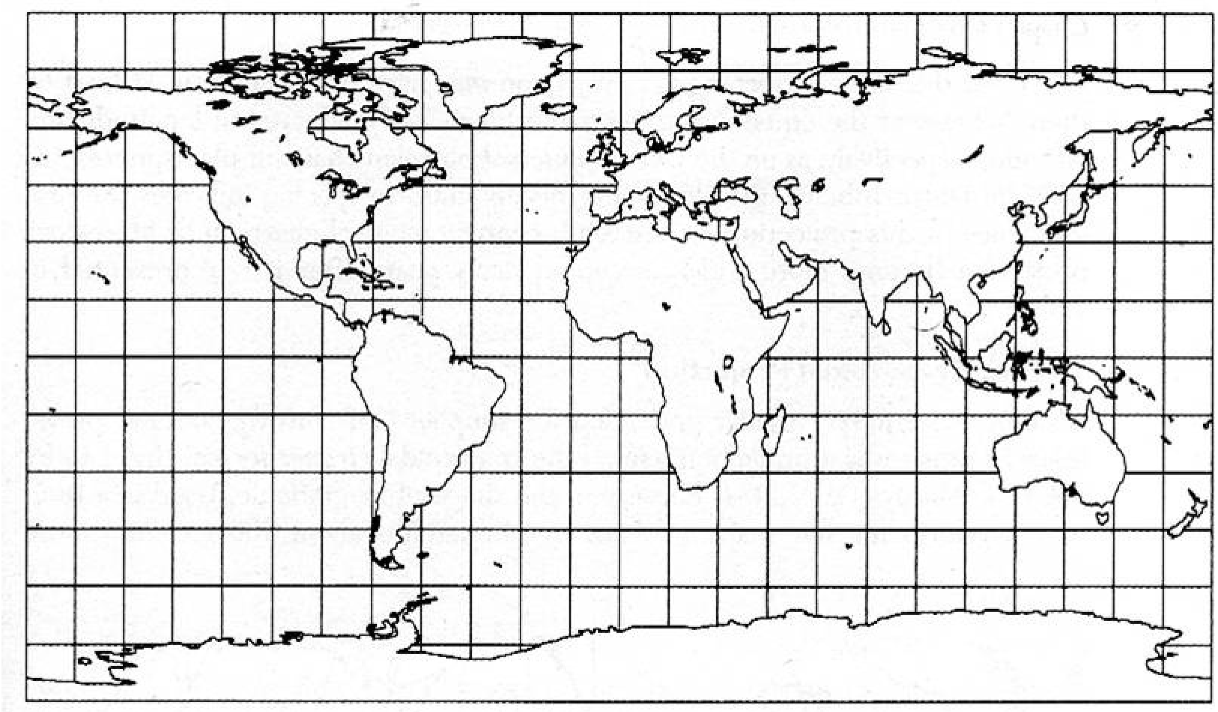

Fig. 4: World map in Equirectangular or Flat Rectangular Chart projection.

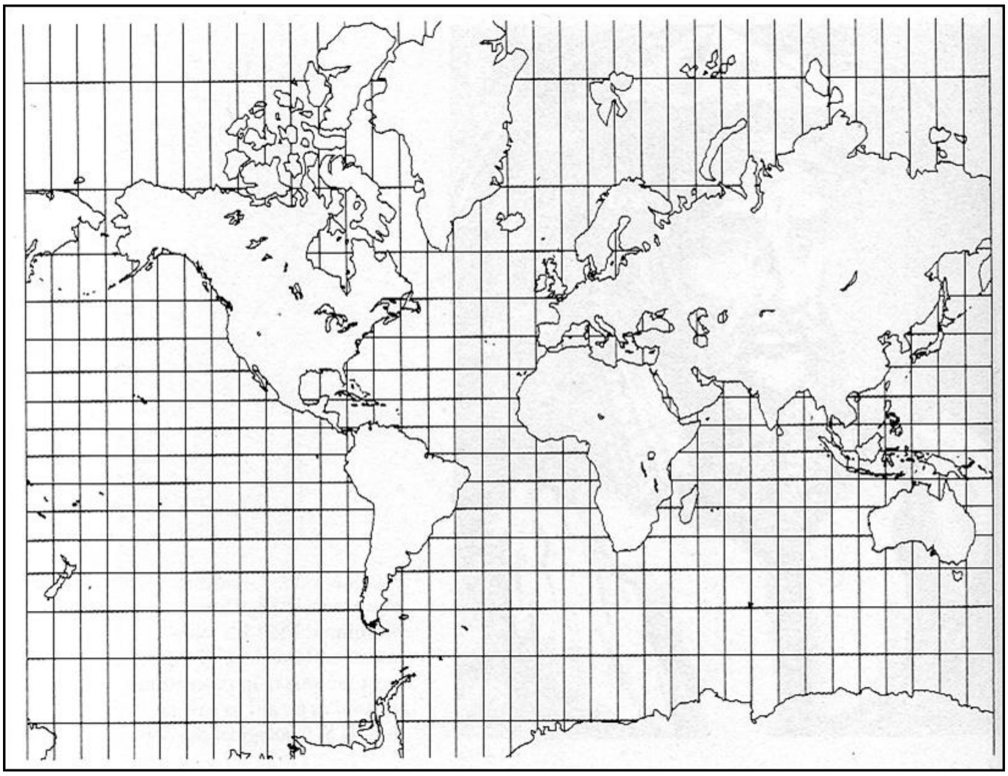

Fig. 5: Classic Mercator Projection with a cylinder of vertical axis.

corresponding to the range of latitudes: 0 / 15 / 30 / 45 / 60 and 75, respectively. The cumulative summation is: 9 / 19 / 30 / 45 and 69 mm; the ratios to the first value (9 mm) are: / 2.1 / 3.3 / 5.0 and 7.7; this series exactly matches the values provided by the formula $\alpha = \ln [\tan (p / 4 + \phi / 2)]$, indicating that the projection is the Mercator one, the most famous of all and the one that maintains forms and directions, useful in navigation. The ratios to tan ϕ leads to the following sequence: 1 / 2.2 / 3.7 / 6.5

and 13.9, which leads to rule out the possibility of being a Cylindrical centrographic projection.

The latter example also shows that for maps in the equatorial region, as are the Amazon River (from 0 to 10º), it is not easy to discern which the projection is, because the distance between parallels is very similar (indistinguishable on this scale map) and also very similar to the spacing of the meridians at the equator. For practical purposes of calculation and extraction of coordinates, any of these projections and even the Flat Square can be adopted. An example is Father Fritz's map or the Count of Pagan's of the same region.

As to other projections, the answer to questions (1) and (2) leads to questions (8) and (4), which will lead to others, generating families of projection: Azimuthal polar and Polar Conic, through the ramifications of decision similar to those presented. The foregoing exemplifies the help that such a tree provides to the identification of the projections, and shows the difficulties that are much greater than indicated, when the meridians and parallels are curved.

6. PROGRAM FOR DIGITAL CARTOGRAPHY

The choice of a digital mapping program complies with the purpose of use. For the study of historical maps, many functions are not necessary; however, some specific facilities would be desirable, for example:

a) Options that consider those projections that were used in the first maps of modern times, that is, as from the Great Navigations, as in the examples pointed out above;

b) The possibility of creating and exporting tables to spreadsheets in order to carry out calculations and studies, for example, the determination of the meridian of origin or an assessment of accuracy. Normally programs provide options for such export and the user can do the rest in the spreadsheet;

c) Some graphic and cartographic resources such as: map overlay capabilities through transparency of images; overlaying of vector files extracted from an ancient map on a new map; insertion of symbols, line drawings, ability to write on the maps, and other products for the generation and presentation of cartographic results. These resources do exist, but with different implementations: there are good programs for GIS that present more limited resources or are harder to use than others specifically focused on the cartographic production and presentation.

Some aspects are discussed of these facilities, focused on working with historical maps of the time frame indicated are discussed as follows.

7. OPTIONS OF CARTOGRAPHIC PROJECTION

Figure 6 shows the first steps in the registration or georeferencing process, associated with the definition of projection, illustrating the options with MapInfo ®, a program for digital cartography. For the first operation, in the figure example, the coordinates of the four corners of the map are defined, and the latitude and longitude can be seen on *Image Registration* window, which also shows the lower left corner of the map and the Pt4 point. Even before providing these coordinates, some parameters must be defined; the work unit firstly: clicking on the *Units* button, the dialog box opens and the unities in which the data will be provided are chosen, in this case, degrees. In other cases it could be meters, kilometers, miles or some other. Then the process of defining the projection begins; in this case, when the *Projection* button is clicked on, the *Choose Projection* dialog box opens; it has two fields: *Category*, and its associated, the *Category Members*. In the example, the category chosen was *Longitude / Latitude*, and in the next field, the option with the same name: *Longitude / Latitude*: this for a map in a Flat Square projection. In the same figure another registration operation is shown, used for a current map of the Amazon region: Category: *Brazil - Polyconic system* and option *Brazil - Amazon Region (South American 1969)*.

At this moment a new question emerges to be examined: what *Category* and what *Category Member* is to be used; in short, what projection we should be used in a specific case. This problem seemed to be already solved in section 5 above. But the first stumbling block is to correlate the name of old projections with the names of current projections in the program; for example, the option *Latitude / Longitude*, with the sub-option of the same name corresponds to a projection in which meridians and parallels are straight and perpendicular, which occurs with basically all the projections shown in the diagram of Figure 2 and (nominally) represented by the maps of Figures 3, 4 and 5. Can a single option be used for more than one projection? To answer the question it is necessary to know the mathematics implicit in this and in other similar programs: in this case, the transformation used by the program (affine transformation) allows the absorption of two translations, one rotation and two scaling factors. Hence, in practice, this option can be applied to cylindrical equidistant meridian projections, that is, both the Flat Square (same scale in both directions) and the Equirectangular (one scale in each direction, with greater spacing between the parallels than between the meridians, though constant).

But it can not be applied to those projections in which the spacing increases or decreases with latitude (see question 41 in Figure 2), because this option of the program does not implement a variable (increasing) scale with latitude. However, the program implements the Mercator projection, in the category *World Projections*, and Category Member *Mercator NAD27* or *Mercator WGS 84*.

Based on this information, it is seen that these two *Categories Members* have been developed for modern world maps, since NAD27 or WGS 84 refer to two ellipsoids as models of the earth, when in the early projection (old maps) the earth was considered spherical. This difference of models does not cause significant difference in the world maps, but there is nothing like performing a test. The latter recommendation indicates the existence of a control system for the good or bad record of a map: the column Error (pixel) that appears in the Registration window (Figure 6): the error is of the order of a pixel, which represents a good fit. The program requires at least 4 points, so that there is redundancy and the least squares method can be applied and the residue at each point can be calculated. Experience shows (NERO, 2000) that greatly increasing the number of points does not necessarily lead to a better fit; on the contrary, it is harmful in many cases. An error can occur precisely because of poor location or bad definition of a set of points. Four to six well-defined points with integer coordinates are suggested, for example, at the intersection of meridians and parallels and control is made by calculating (or verifying) the coordinates of the mesh elsewhere. Figure 7 shows a good option for this: at the bottom and left corner there are three options: one of them, the *Cursor Location* is very helpful in this task and all of those that involve quantitative studies. This figure also shows the cartographic symbol option chosen to represent a village or locality: a small red cross, to highlight and define the point accurately without polluting the representation.

The existence of some options does not mean, however, that all problems are solved: there are over 200 types of projections and digital mapping programs provide many options, in general to modern maps (from the nineteenth century to the present day), but in spite of solving one case or another, they are not prepared for old maps which we are dealing with.

In the absence of other options, there is the possibility, with its risks, to use a modern projection for old maps, making local registrations (adjusts), controlling the region of validity and extracting coordinates of points by an interpolation that imitates the manual process of calculating coordinates in a printed atlas.

As can seen, the subject is complex and each old map, which also did not specify the projection, requires a specific study. To date, there are no reports of an application program that deals with digital cartography and provides specific options for old maps, even though the MapAnalyst ® is an interesting option for many tasks (JENNY, 2006 and 2010).

8. EXTRACTION OF COORDINATES FOR QUANTITATIVE STUDIES

Another important function for quantitative and qualitative studies on historical maps refers to the creation of tables, as shown in Figures 8 and 9. The fields of the Table (corresponding to the columns) can be defined with the characteristics of each one: its identification ID (integer), its name (in the case with 10 characters), longitude and latitude (with 7 digits, 4 of them after the comma). These last two fields are collected automatically by the program, at the x and y centroid of the point where the symbol was placed. Figure 8 presents an example for the city of Goias in the Map of the Corts: in one of the windows the coordinates of a point are shown, being recorded in a table, as shown in Figure 9, which shows the process under construction. Exporting to a spreadsheet is fairly simple as well as importation, when necessary.

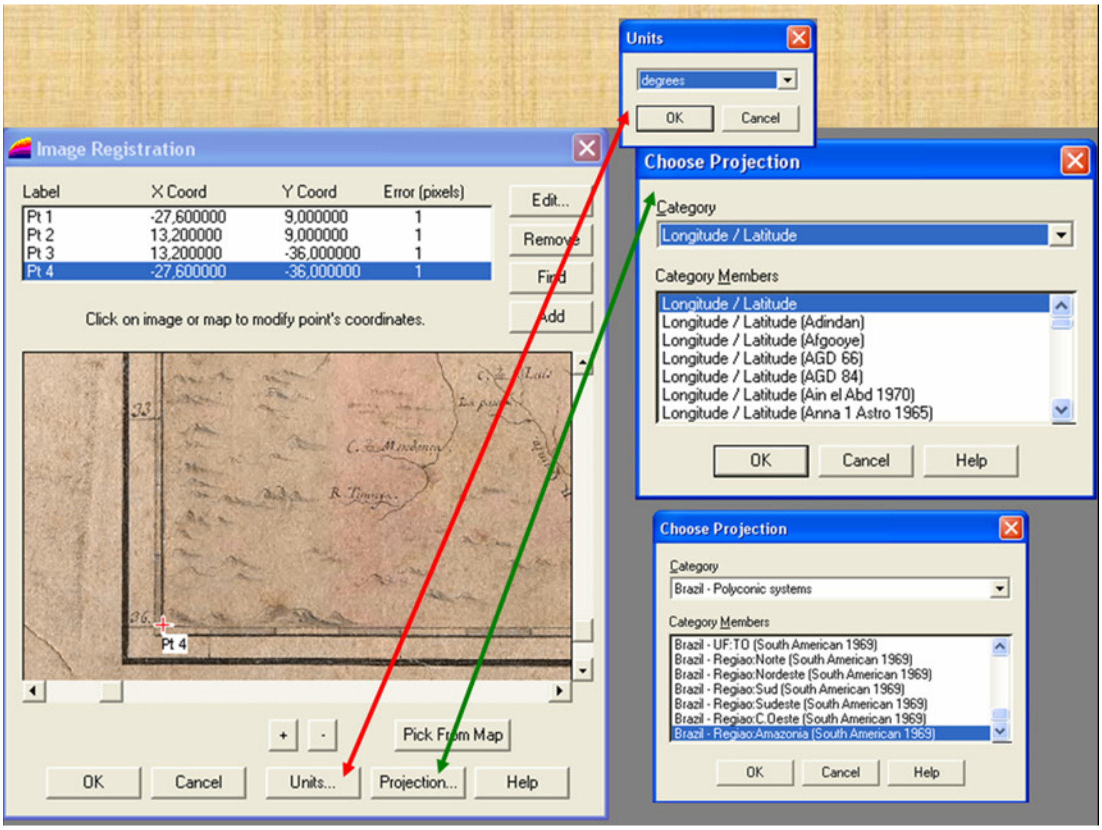

Fig. 6: Registration and selection of a map projection process.

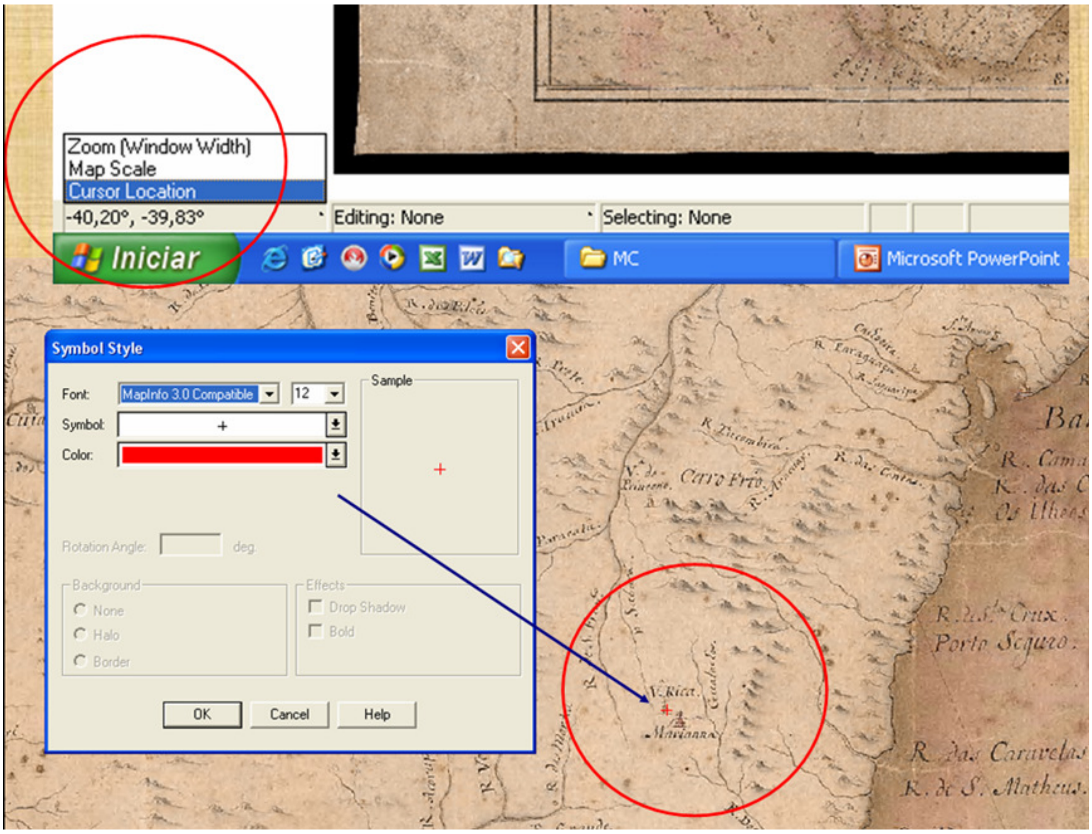

Fig. 7: Illustration of options: show the coordinates of the cursor and the style of the symbol to represent a location.

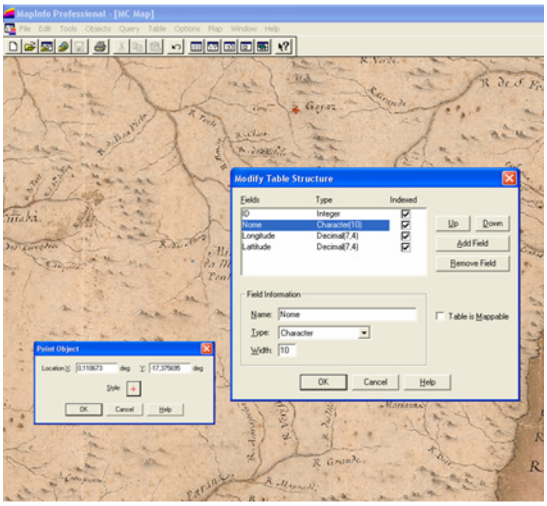

Fig. 8: Creating Tables, with its structure and an example of a point.

MapInfo Professional - [Tabela_1 Browser:1]

File Edit Tools Objects Query Table Options Browse Windo

ID	Local	Longitude	Latitude
339	Lavras do Funil	339,281	-21,3799
338	Lavras do Funil	338,321	-21,4199
339	São José del Rei	339,35	-21,3307
338	Tamanduá	338,412	-20,3002
340	Barbacena	339,924	-21,5548
340	Queluz	339,958	-20,9032
338	Campanha da Princes	337,712	-22,0096
339	Baependi	338,579	-22,2804
339	Iuruoca	338,788	-22,4233
337	Ouro Fino	336,614	-22,3733
339	Carrancas	338,768	-21,7923
336	Paracatu	336,484	-16,1526
340	Caeté	339,89	-19,9603
339	Foz Velhas	339,314	-16,3436
339	Foz Paracatu	339,248	-15,5081
340	Foz Carinhanha	339,707	-13,3126
341	Vila do Príncipe	340,899	-18,6092
342	Rio Pardo	342,282	-15,054
341	Tejuco	340,772	-18,2156
341	Rio Vermelho	341,27	-18,3606
340	Santo Antonio	339,687	-20,197
338	Santana do Bambia	337,978	-19,7447

Fig. 9: Table of coordinates.

From the tables, already in a spreadsheet, for example, the Excel ®, one can perform various studies and analysis. In conjunction with the determination of the prime meridian, the analysis of its accuracy can be made in comparison with current maps. To do this the steps are: a) Choosing well-defined points in the historical map, which have remained unchanged until today; b) Taking their coordinates (longitude and latitude), filling up the columns of the spreadsheet; c) Using Equation (1) determine the meridian of origin, if this is not yet defined; d) Referring all longitudes to Greenwich, by adding or subtracting the coordinate of the prime meridian of the old map; e) Extracting the coordinates of these points on a modern and more precise map, for instance, using Brazilian maps provided by the IBGE, creating two more columns; f) Calculating the differences between the coordinates (Äλ and Äφ), obtaining two columns that will be the object of analysis; g) Calculating the basic statistical parameters: mean (μ), which indicates the value of a systematic error that can be corrected; the standard deviation (σ) that measures the accuracy with which it was built; the symmetry and kurtosis measures, which are indicators of normal statistical data. The frequency histogram can also be built, as seen in the example of Figure 10.

These histograms, supplementing the mathematical analysis, allows to detect the existence of gross errors, with frequencies of values far from the average , for example a distance of over 3σ (and their elimination if justified), the excessive concentration of errors around the average, fictitiously indicating a high accuracy and further analyses.

Another possibility is to study the variation of errors. An example of this possibility is the analysis

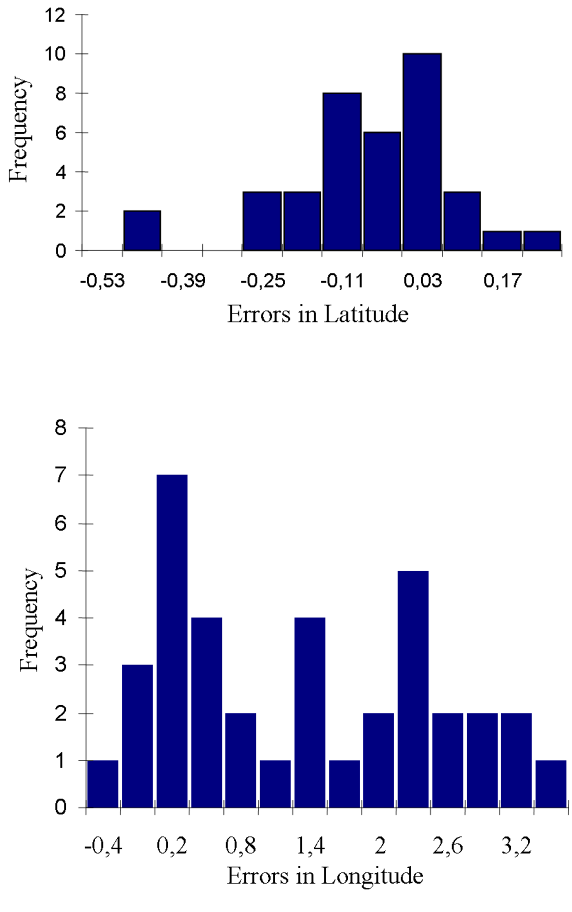

Fig. 10: Histogram for errors or deviations in the two coordinates.

of the growth of errors in longitude with their transportation point by point from one origin. Figure 11 illustrates this by showing the growth of the error in longitude along the Amazon River, in the maps of the three authors: La Condamine, Fritz and D'Anville. An analysis of errors allows to reach interesting conclusions: the profile of errors of La Condamine shows a mistake of 3° in the longitude measurement in the mouth of the Napo River, which contaminated with error all longitudes; the analysis of variation of errors (comparative morphology) shows that D 'Anville uses the Father Fritz's map from Jaén to Napo and the one of La Condamine's from that point to the Tapajós.

9. CARTOGRAPHIC SYNTHESIS PRODUCTS

For the presentation of results and visual comparisons, it is interesting to use certain features provided by the programs. Particularly, the concept and the use of information layers, drawings and measurements on the map, the insertion of symbols and others that permit the construction of good graphical products, as exemplified below.

a) The deconstruction of maps. It is customary to employ this term for a map that is drawn from an old map by copying the features (cities, rivers, mountain ranges, borders and other features) in accordance with the principles and techniques of modern cartography, aiming at greater clarity, readability and information transmission. A reconstruction is conducted, maintaining the essence and renewing the form: a translation of the ancient map to the modern terms is effected, freeing it from features proper of its time, now considered superfluous: iconography, artistic expressions of representation of elements such as compass, graphic scales and others.

No equivalence should be intended to the old map, which has an irreplaceable value as a document of an era and a wealth of information that the rebuilt map does not have. This can serve other purposes, such as the creation of new products and didactic and illustrative synthesis. An example is presented in Figure 12, showing, in a simplified way, the route of three explorers of the Amazon River at different times. It includes borders, cities and place names at an ancient time in a simplified manner, in accordance with what is meant to be displayed. One question rises when it comes to old maps is whether this deconstruction must correct / amend or not the prime meridian and the (erroneous) position of points. Of course, if this is done, the characteristics of the ancient map will be destroyed.

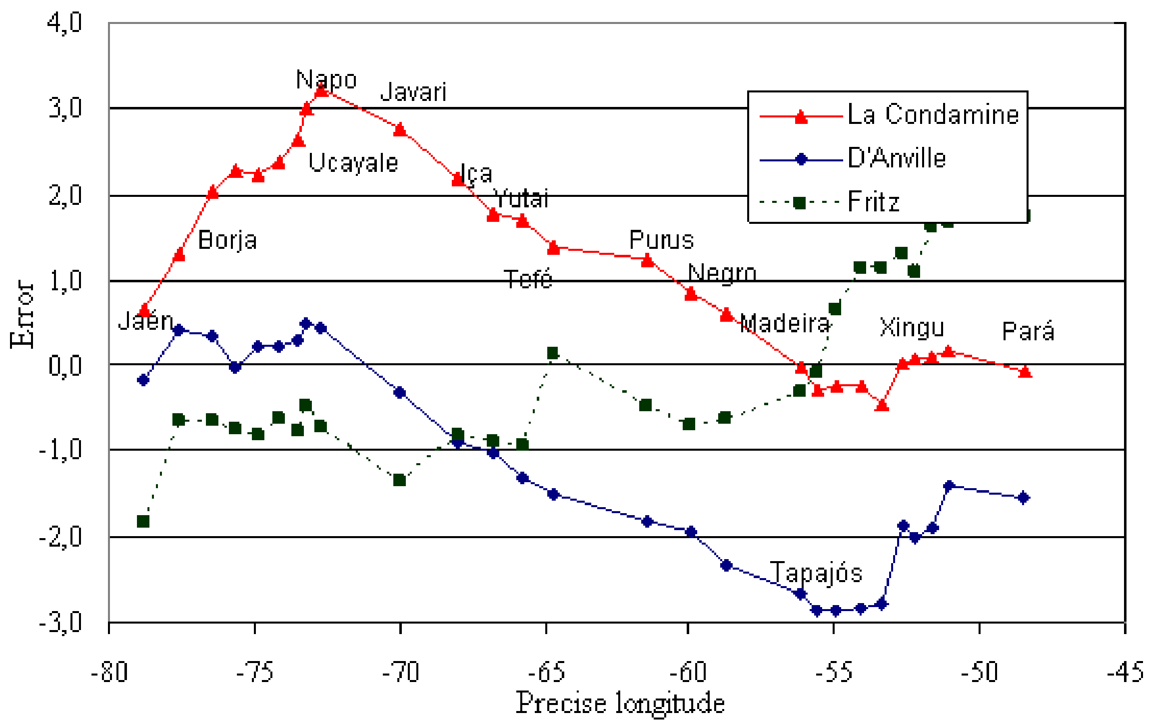

Fig. 11: Propagation of error in longitude of the Amazon for three maps: La Condamine, D'Anville and Fritz.

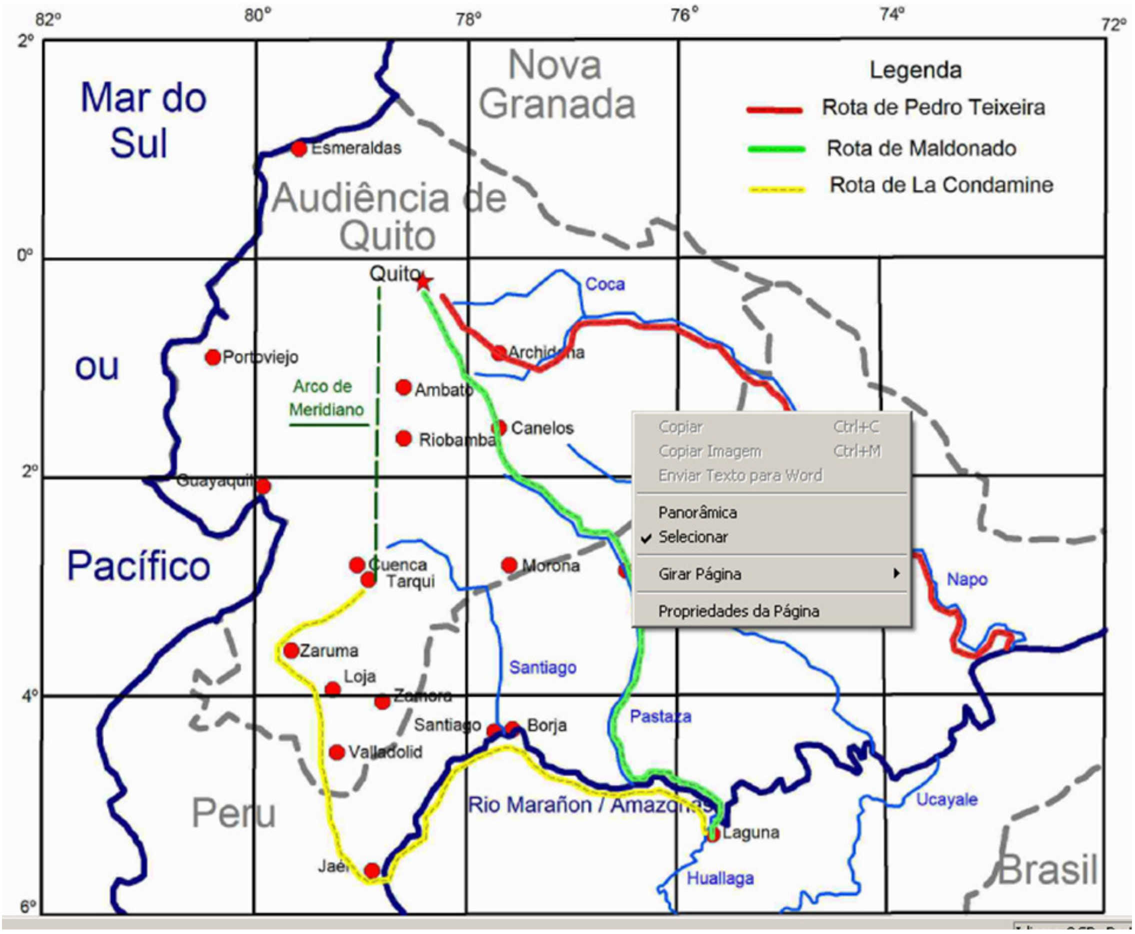

Fig. 12: Simplified map of the Ecuador region reflecting the situation of the seventeenth and eighteenth centuries and including the Teixeira, Maldonado and La Condamine routes.

b) Superposition of maps and transparency features. MARGARY (1977) presented the very natural proposal of comparison by the superposition of maps of the same region: the old and the current ones. Figure 13 illustrates the result of his method: thin lines represent the true boundary line compared with the stronger one of the old map; symbols in the form of a small cross in the modern map are counterposed to the symbol of a small circle in the old one. With the advent of the resources of transparency, visibility and overlapping layers, this can be done in digital media.

Figure 14 illustrates the potential of the resource to work with layers, each of which can be controlled: the visibility, the possibility to draw on it, to point to elements and to show attributes. This allows, for example, to show only the points extracted and measured; to superimpose the points with a current map, as in Figure 15 and make a qualitative analysis, as well a quantitative one. As for Figure 16, the process of turn out transparent and in gray-scale a color image, by choosing *Table, Raster, Adjust Image Styles* is applied. This, applied to a map of the city may have applications such as the location of old buildings (Figure 17) and an overview map of the city's growth (Figure 18). In the first case, the 1972 EMPLASA map was taken as a cartographic base and some old buildings taken from the City Plan of 1810, prepared by Colonel Rufino, were placed on it by applying a transparency to them, so plan used as base can be seen; in this way the buildings of the *Teatro São José* (Saint Joseph Theater) and the *Casa da Câmara e da Cadeia* (Town Hall and Jail) of the City of São Paulo were accurately located. In the second case, the same base map was used, in light gray (dimmed) and over them there were placed, with the property of transparency, the polygons that

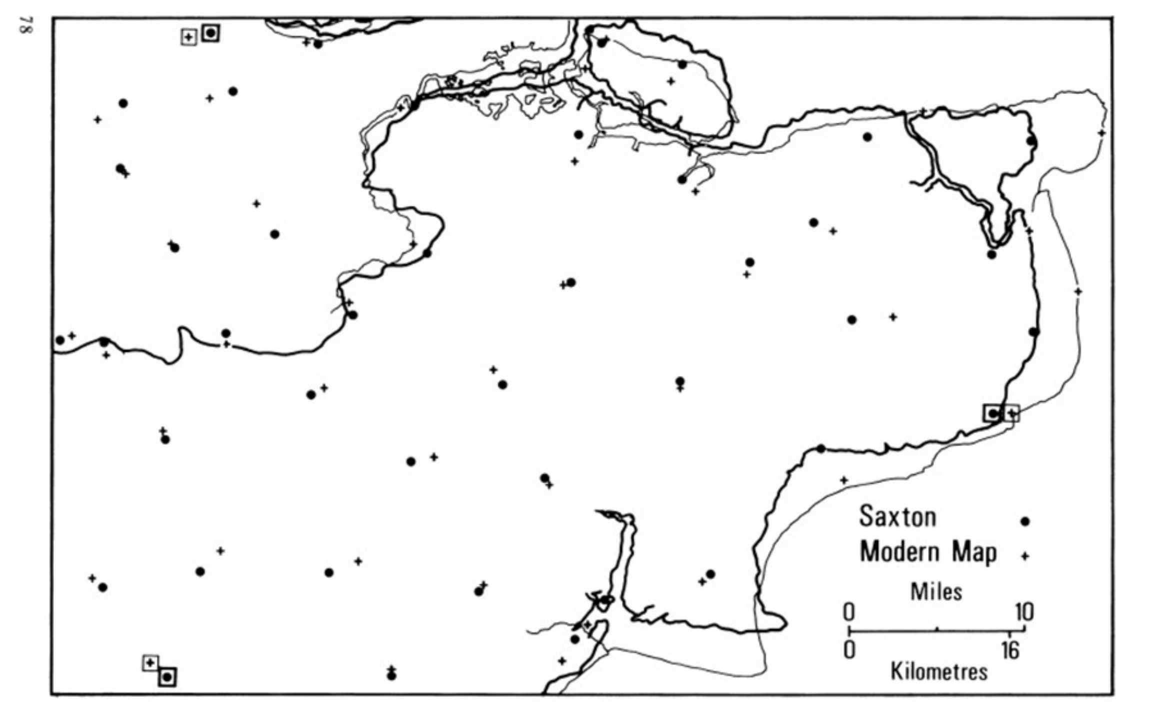

Fig. 13: Comparison by superimposition of an ancient map (bold lines and circular symbol) over a more accurate one (thinner line and cross-head symbol). Source: MARGARY (1977).

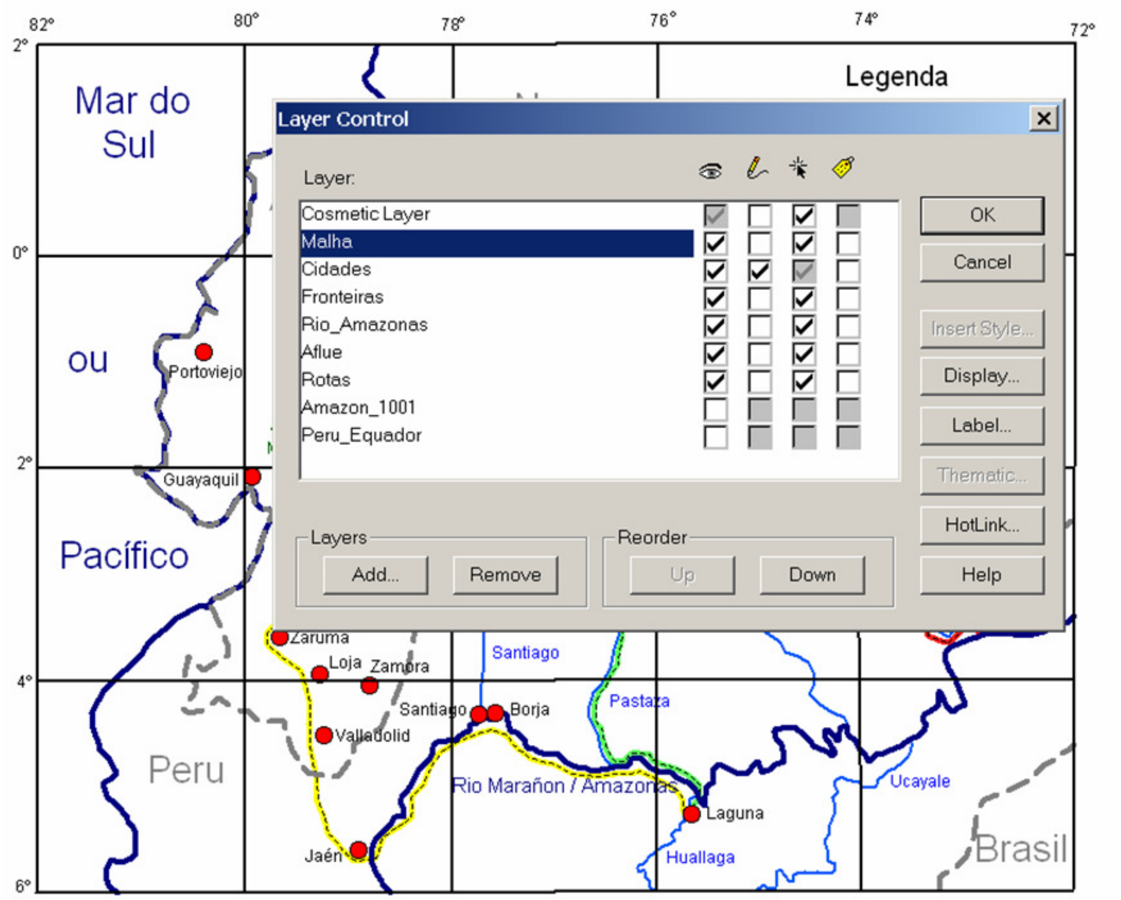

Fig. 14: Control of layers: visibility, editing, pointing and labelling.

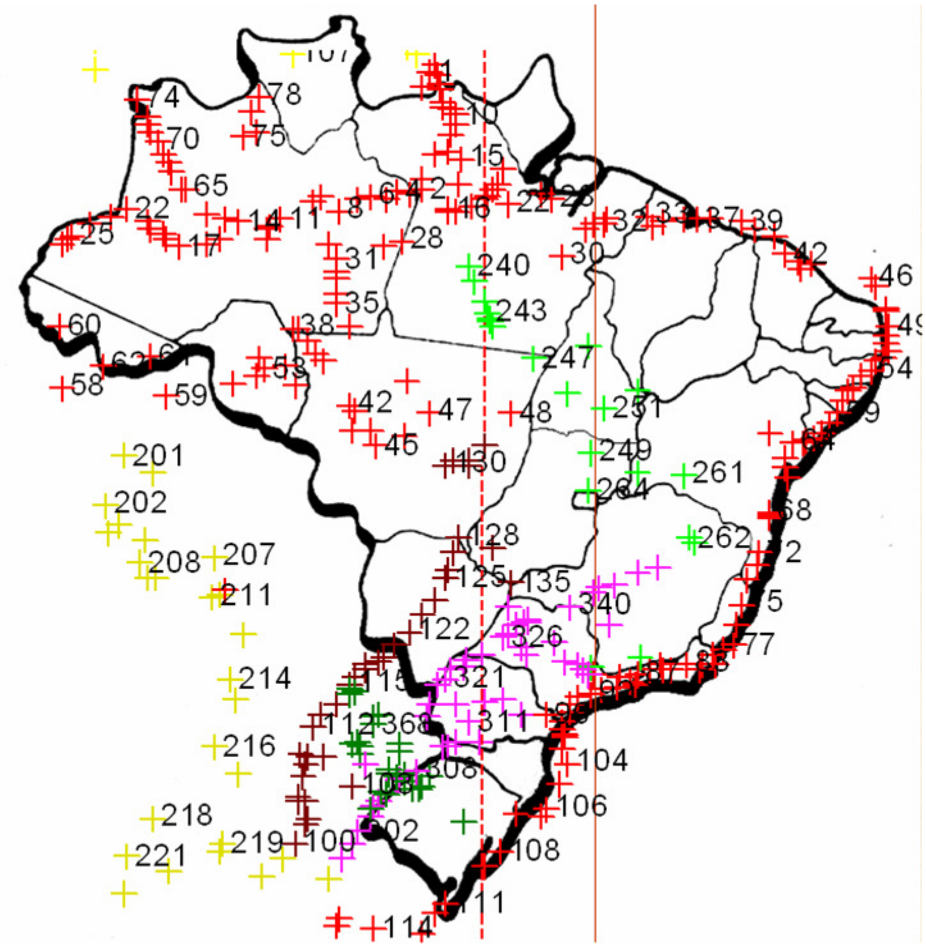

Fig. 15: Overlay of points (and features) of old maps in current maps.

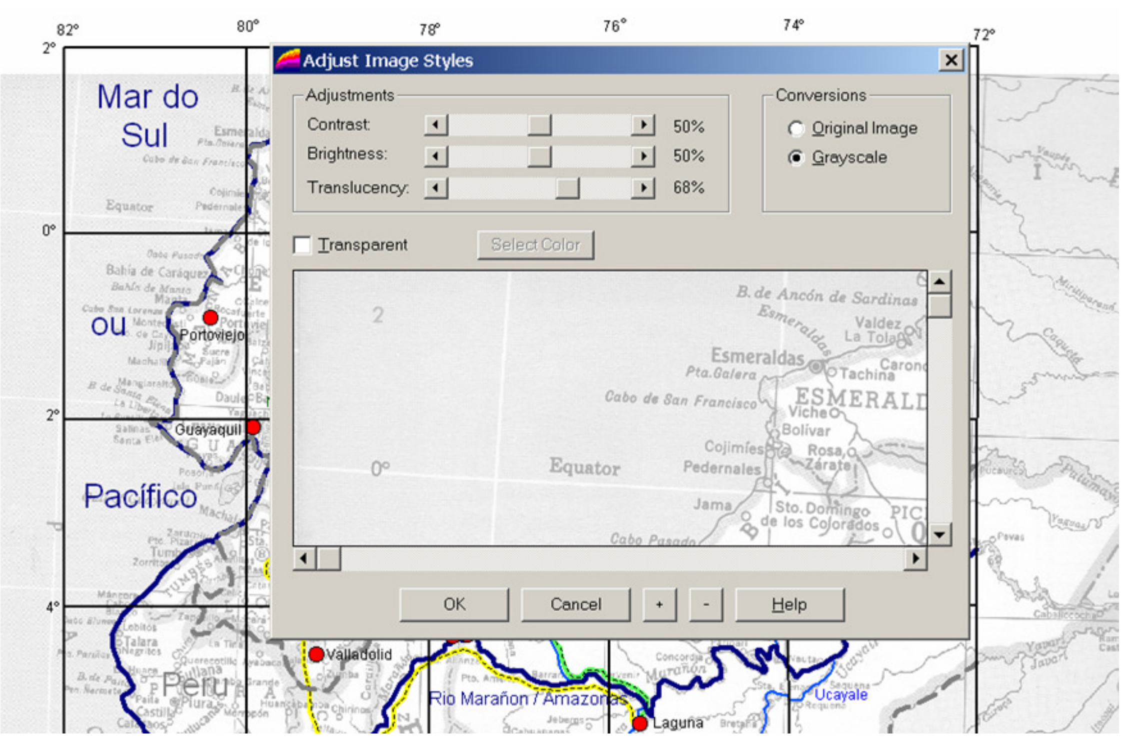

Fig. 16: Option to set the style of a raster image controlling contrast, brightness, transparency and grayscale.

Fig. 17: Spotting ancient buildings on current maps.

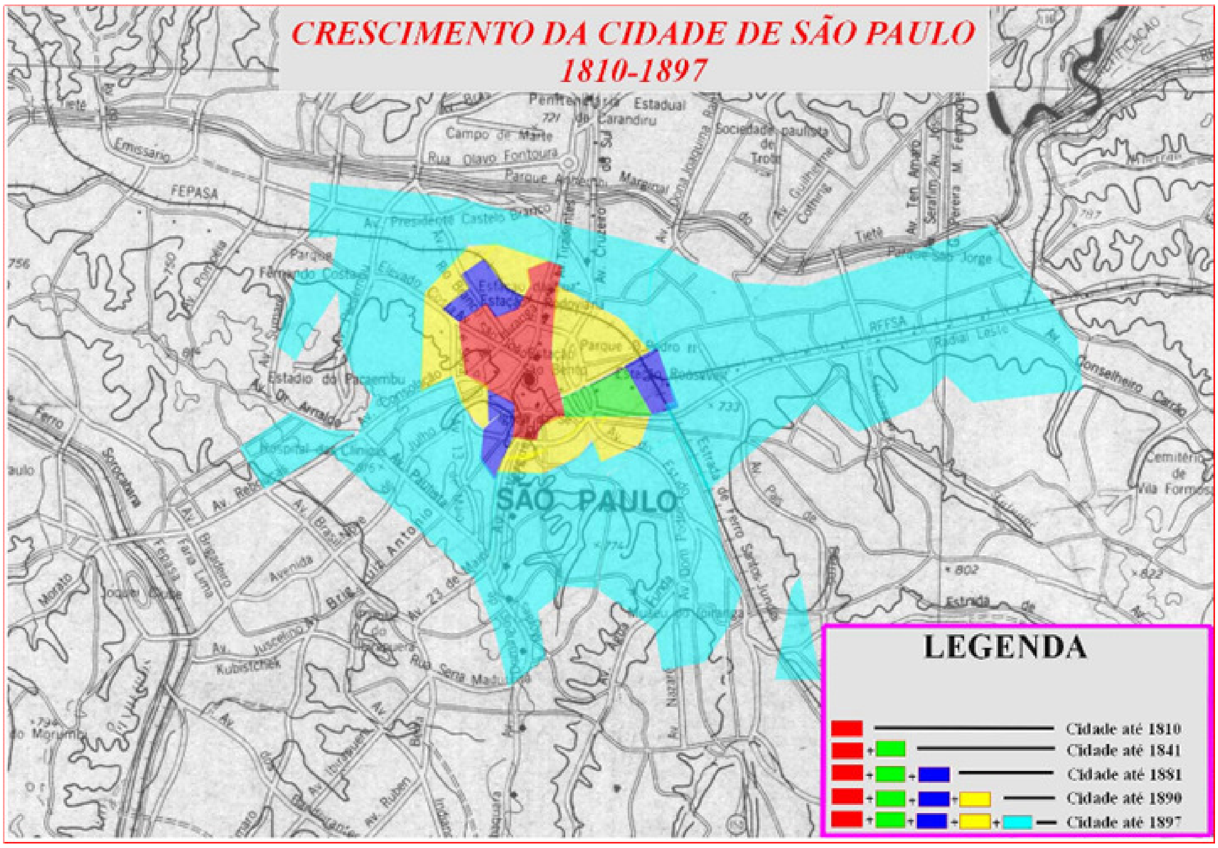

Fig. 18: Resources of transparency and overlay to graphically display the growth of cities.

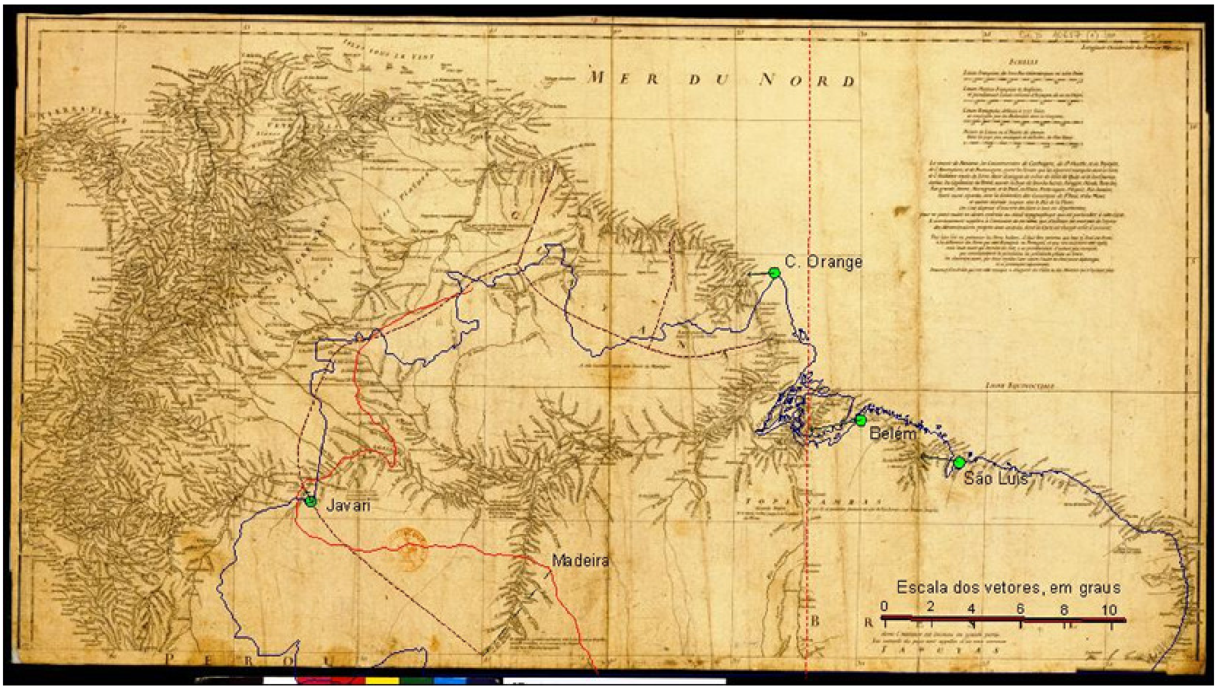

Fig. 19: Map of D'Anville with several overlapping boundary lines.

Fig. 20: Map of the Courts, with its distortions indicated by green arrows, distorted borders in red and real borders in blue.

represent the urban area of São Paulo at different times.

c) Creation of other products

Figure 19 shows an old map (D'Anville), which was built thinking of the negotiations of the Madrid Treaty, even though it has not been used. On it were overlapped: Brazil's current borders in blue; the border proposed by this map in dashed line; and the border effectively proposed in that Treaty, taken from the Map of the Courts, which was the base document for the agreement that defined the borders of Brazil in 1750. For comparison purposes, a graphic scale was added, in degrees.

In addition error vectors can be added to maps of this style, which are represented by arrows joining the position of a locality in the old map with the real position, as exemplified in Figure 20 through the Map of the Courtes. The components of this vector are the errors in latitude and longitude, and its magnitude is the total error. In this case the actual border of Brazil (in blue), the red line proposed by this Treaty and the meridian of Tordesillas were added. Figures like this, increasing the number of vectors, if necessary, graphically show the distortions of a map, and allow seeing the good adherence along the east coast and the great errors at some important points.

10. CONCLUSION

The examples of studies and applications could be multiplied indefinitely. With the foregoing and with varied examples, the contribution that Digital Cartography can provide to Historical Cartography is expected to have been shown.

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