

# Cartometric Analysis of Vogt's Map

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## Abstract

Old maps of Czech Lands deposited at the Map Collection of Charles University in Prague belonging among the most important collections in the Czech Republic. This article shortly describes the most interesting maps from the period 1518 (Claudianus's map) to 1720 (Müller's map). It is focused more detailed on the Vogt's map, that represents an important cartographic work dated in the first quarter of the 18th century. It deals with an assessment of the cartometric accuracy of Vogt's map, the methodology is based on geometric analyses of sets of identical points in the old map and of a reference map. Some techniques of multiquadratic interpolation are used. The results of the analysis including scale isolines, rotation, displacement vectors of identical points were visualized using the MapAnalyst software and the extension software ArcGIS, 3D Analyst.

**Keywords:** cartometric analysis, isolines, distortion, MapAnalyst, old maps of Bohemia

## 1 Introduction

Maps of Czech Lands, i.e. Bohemia, Moravia and Silesia, created by individuals in the period of 1518 - 1720 are part of our history and represent important cultural heritage of immense value. They give evidence about the period in which they originated. Old maps reflect the society and culture, and they become important historical sources. This article presents an short overview of the most significant cartographic works from the given period deposited in the Map Collection of Charles University in Prague, which is one of the most important map collection in the Czech Republic. The research was conducted within the project "Cartometric and semiotic analysis and visualization of the old Czech Lands maps in the period 1518 – 1720".

The Map Collection of Charles University in Prague was founded by professor Václav Švambera in 1920 as the State Collection of Maps of the Czechoslovak Republic. The basic elements of this collection were represented by the funds from the Department of Geography of the Faculty of Science, some map sheets from the Vienna War Archives after the collapse of the Austro-Hungarian Empire, and cartographic archive materials from various libraries. After the World War II the State Collection of Maps acquired map funds from the German University in Prague. Later, the fund was enriched by cartographic archive materials from the National Museum. Since 1994 the Map Collection of the Charles University has served as a workplace of the Faculty of Science. Professor Bedřich Šalamon and professor Karel Kuchař belong among its prominent representatives. The collection funds contain originals and facsimiles of cartographic works from the 8th century up to now. Maps from atlases from the 16th, 17th and 18th centuries can probably be declared as the most beautiful cartographic works.

## 2 Analysis and assessment of old maps

During the 1st half of 2008 the map fund of the Charles University was researched thoroughly, with particular emphasis on map works of Bohemia, Moravia and Silesia from the period 1518 - 1720. During the analysis and assessment of these old maps a number of questions and problems arouse. The works' dating details served to determine the author, year of publication and name of publisher. In case only some data were stated on the map or they were completely absent, the

map's date of origin was determined following the characteristic features for particular phases of cartographic production, for individual authors or publishers. The representation of map content, typeface, material used, reproduction technique and artistic elaboration are among such features. Authors of the maps were mostly cartographers, land surveyors, draftsmen, engravers, publishers, printers, clerks or artists. The information whether the work is an original, facsimile, copy or derivative was also important. In our selection Comenius's map of Moravia is a facsimile, other maps are originals.

**Cartographic analysis.** The analysis of map content can provide us with answers to other relevant questions related to analysis and assessment of maps. Similarly to modern maps, old maps also include some map elements which were becoming more and more precise with the development of cartography and geodesy.

The basic elements of map content are: settlements, paths and roads, granges, castles, monasteries, baths, vineyards, waters and various natural-history curiosities. Political and territorial self-governing divisions of depicted areas are represented by various types of boundary lines and surfaces of different colors.

Another assessed element of map content is the relief. Till the end of the 18th century relief used to be represented by a stylized drawing of elevations using pictures of hills and mountains, so called hill method. The position of the legend is also important.

The legend contains a group of symbols for elements used in the maps, together with verbal explanation of their meaning. Usually they are arranged according to a determined hierarchy.

**Cartometric analysis.** Cartometric analyses of the map are also important, they verify cartographic parameters of the map. The following cartometric analysis are carried out: positional accuracy of the map, calculation of the map scale, calculation of the rotation of the map. They can be expressed using different cartographic techniques (vectors of displacement, isolines or distortion grid).

Cartographic analysis of the selected elements will follow.

## 2.1 Analysis of the content of selected maps

Maps from the period 1518 - 1720 representing the area of Bohemia, Moravia and Silesia were chosen from the Map Collection of Charles University in Prague. After assessment of the extent of damage and degree of legibility their suitability for further processing was decided. Selected maps were scanned by large-format scanner Contex Crystal XL 42 Plus with the resolution of 200 dpi and in the format .tif. After scanning them the paper originals were no longer used and all further analyses will be performed using the scans in electronic format.

For analyses the following maps were chosen: Criginger's map by Gerhard de Jode, Mercator and Kaerius, Aretin's map of Bohemia, Vogt's map of Bohemia, map of Moravia by Abraham Ortelius based on Pavel Fabricius, Comenius's map of Moravia and Müller's map of Moravia, see Tab. 1.

Cartometric analyses are currently completed only for Vogt's map, other maps are in progress.

## 3 Vogt's map of Bohemia

Vogt's map is an important cartographic work dated in the first quarter of the 18th century. Because it is not known to the wider public as other maps from this period are, let us characterize it briefly, basing our description on works of prof. Kuchar (Kuchar 1958, 1960, 1961). The map was part of the book "Das jetz-lebende Königreich Böhmen in seiner historisch und geographischen Beschreibung vorgestellt" published in 1712 whose author was the abbot of the Plasy Monastery Johann Gregor Vogt. The map's size is 853 x 656 cm, its scale along the central meridian is quoted to be 396 800. The map represents the area of Bohemia between the parallels 48° - 51°30'. The map does not directly include geographic grid, around the map frame there is a scale with the division of 2' in the direction of longitude and latitude. The map is not created following a particular map projection.

Vogt's map represents altogether 3110 objects; it differentiates walled towns, small towns, villages, churches, castles, ruins, and includes perspective views of some castles (Bezděz). The map contains geographic names in two languages but it conforms to German custom. The map is richly illustrated, thus being not only an important cartographic, but also

Table 1: *List of old maps used for analysis.*

Map	Author	Year of the publication	Author of engravings	Approx. scale
Chorographia insignis regni Bohemiae	Johann Criginger	1584	Gerhard de Jode	1 : 683 500
Regni Bohemiae nova et exacta descriptio	Petr Aretin of Ehrenfeld	1619	Paulus Bayard	1 : 504 000
Vogt's map of Bohemia	Johann Georg Vogt	1712	-	1 : 396 800
Map of Moravia by Abraham Ortelius	Pavel Fabricius	1573	-	1 : 455 000
Comenius's map of Moravia	Jan Amos Komenský	1627	Abraham Goose	1 : 530 000
Tabula generalit Marchionatus Moraviae in sex circulos divisae	Jan Kryštof Müller	1716	Jan Kryštof Leidig	1 : 630 000

a significant artistic work. Vogt's map can be labeled the last independent work created by one cartographer. For the purpose of cartometric analyses we used the original of Vogt's map deposited in the Map Collection of Charles University in Prague.

### 3.1 Digitization of Vogt's map

Digitization of the original of Vogt's map by scanning was our first step. Further progress was influenced by the mechanical characteristics of the original. The material used for manufacturing Vogt's map is paper pasted on canvas. The map had been folded several times; at these places there is mechanical damage of the paper and uneven stretching of the canvas. The map is compiled of 18 map fields, see Figure 1. Digitization of the map with subsequent creation of continuous raster image presents a relatively difficult problem because of the above stated reasons.

The original of Vogt's map was scanned using the large-format scanner Contex CRYSTAL XL 42 with the resolution 200 dpi in the format TIFF. Pixel size was 0.127 mm. Then retouching of raster was performed removing impurities with software. This step was performed with the help of the tool Remove Speckles in the program MicroStation Descartes XM.

#### 3.1.1 Creation of continuous map image

Because of repeated folding of Vogt's map and its long-term storage in folded position a slight shift and rotation of individual map fields occurred. Therefore, the creation of continuous map image of Vogt's map was performed in three stages. The operations were completed using the software MicroStation Descartes XM.

**Cutting scanned raster along map fields.** The scanned raster was cut by software along the boundaries of map fields into the total of 18 raster images (3 rows, 6 columns). These images were not always rectangle-shaped, in some cases they were shaped like trapezoids. On several places the mechanical wear of the original caused spontaneous removal of small parts of the map drawing, especially along the folds. Therefore, the reconstruction did not result in an entirely continuous image of Vogt's map.

**Projective transformation of map fields.** Map fields are shifted in relation to each other and partly rotated. Because of using sheet-feed scanner with a material with higher basis weight some map fields were distorted towards a trapezoid shape. These places are unambiguously identifiable on the raster image. For removing this trapezoid distortion we used projective transformation representing the relationship between two planes in central projection. Identical points represented the corners of the reconstructed map fields. The size of the reconstructed field was derived from four adjoining fields.

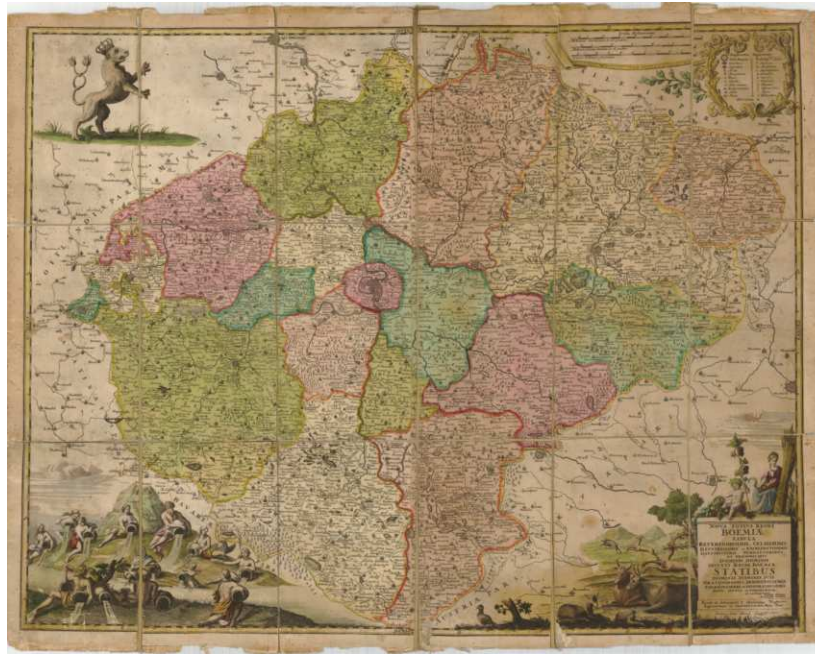


Figure 1: Illustration of Vogt's map from the Map Collection of the Faculty of Science, Charles University in Prague.

**Linking boundary contacts of adjoining fields.** At the contact places of map fields' edges there still were reciprocal shifts in the image, even after projective transformation. For linking boundary contacts of the neighboring fields, non-residual Jung's transformation was used with the aim of decreasing the extent of image transformation inside the map field to a maximum. Identical points in the local coordinate system were selected at contact places of neighboring raster images in the areas of linking line elements (waters, roads). The corresponding identical point in the global coordinate system represented middle position of both identical points, its coordinates can be determined as the arithmetic mean of the coordinates of these points.

For each raster we used approx. 20 identical points selected according to the above stated principles. We do not enclose the overview of the coefficients of Jung's transformation because of the extent of this article.

**Merging raster images.** Individual raster images were then trimmed along vectorized boundaries of neighboring map fields. In the program Descartes, using the function Merge, all 18 raster images were put together creating a final raster image which represented a continuous variant of Vogt's map. Existing jointing at contacting map sheets were filled with a mask in the color of the maps background due to aesthetic reasons.

### 3.1.2 Transformation of Vogt's map

The next step was the transformation of raster Vogt's map into the JTSK coordinate system. Here, selection of a set of identical points used for the calculation of transformation key played an important role. We will discuss this step in detail because it considerably influences the analysis results. Because of the fact the Vogt's map represents the area of all Bohemia we used the database ZABAGED as our reference map. However, the map represents also the area of Kladzko which had been part of the Czech Lands in the period of the origin of the map. Because the database ZABAGED does not offer any map materials for this area we did not include it into the cartometric analysis.

**Selection of identical points.** The selection of identical points used for the calculation of a transformation key is a relatively complicated matter. When a map contains a geographical grid it seems best to use nodal points of meridians and parallels supplemented by significant and easy-to-identify points in the map. With such points we suppose that their position does not change significantly with time. Identical points should be distributed around the whole area,

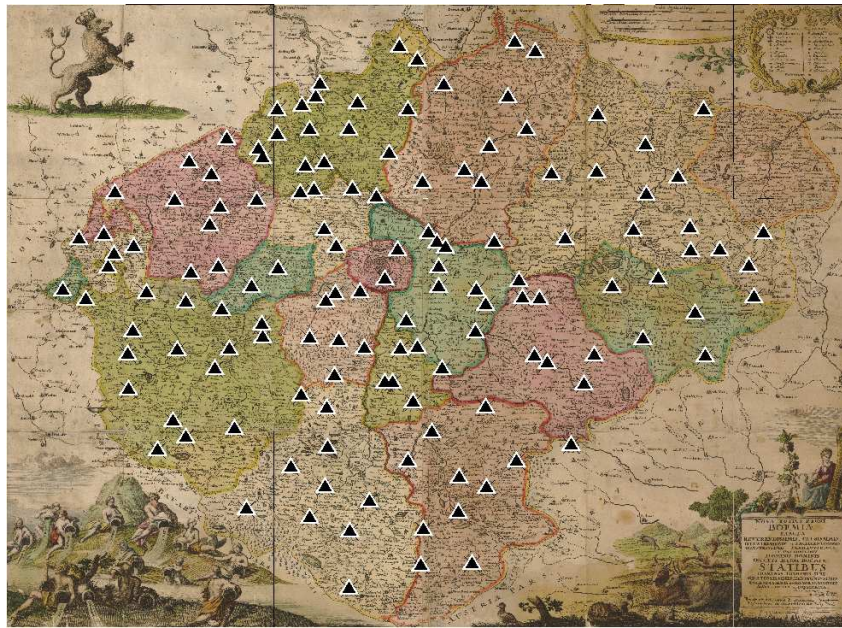


Figure 2: Distribution of 137 identical points for the calculation of a transformation key.

ideally in an even manner, so that the resulting transformation key has a global character, i.e. takes into account the geometrical-cartographic characteristics of the whole cartographic work.

Because the Vogt's map does not contain a geographical grid it is not possible to use nodal points. To calculate the transformation key we selected 137 identical points out of the total of 3110 elements found in the map (4.5%). This number can seem relatively small at first sight. However, the points were chosen carefully, taking into account the above stated principles, and they apparently constitute a relatively representative sample, see Figure 2. A similar result is presented in Vejrová (2008) using a set of 447 identical points. A complex cartometric analysis of Vogt's map would be possible only after its complete vectorization, which was not done due to time reasons. The set of identical points is "almost" convex, with the exception of the south-east and north-east parts.

**Type of identical points.** Identical points represented towns, castles and chateaus evenly distributed around the area of the Czech Lands. A number of smaller towns depicted in the area of Sudetenland do not exist anymore these days, and most of the towns expanded considerably due to social or industrial reasons. When looking for corresponding points in the database ZABAGED we respected the historical development of particular towns and tried to select the position of each identical point in the area of the original center of the town: square, church, fort, castle, chateau, ruin. In some cases these points are not situated in the center of the currently built-up area and are noticeably oriented towards the periphery. This is the case in towns whose expansion is influenced by the shape of the surrounding relief, typical for hilly areas or foothills. Among other identical points there could be e.g. river confluences, ponds or other easily identifiable elements. However, it was not possible to perform further work on this topic due to time reasons.

The idea of cartometric analysis in the context of individual map topics could also be interesting, e.g. analyses of the accuracy of depicting municipalities, rivers or ponds. The map was not assessed as a whole but according to particular content elements.

**Affine transformation.** To prevent distortion of the geometrical and positional relationship between the points we used affine transformation of first order. Higher-degree transformations were not used for the analyses because they cause unnatural distortions of the map image. Because of the redundancy of identical points the transformation coefficients were adjusted according to the method of the least squares  $v^T v = \min$ . The parameters determined from the set of 137 identical points using the program MapAnalyst and supplemented with the characteristics of accuracies of their determination represented by the standard deviation  $\sigma$ .

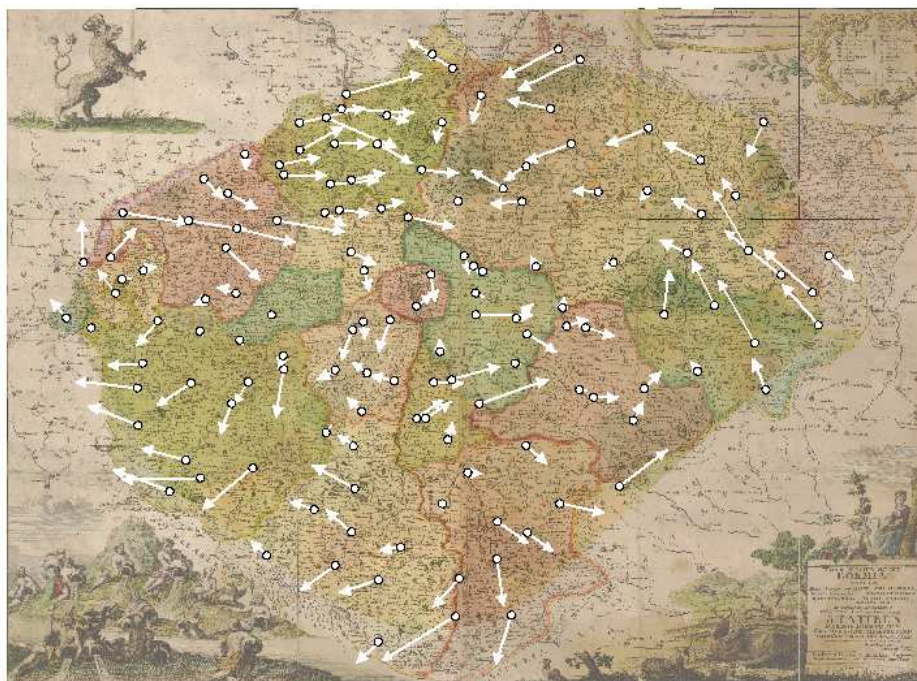


Figure 3: Positional displacement of 137 identical points represented in the scale 2:1.

### 3.1.3 Cartometric analyses

Because of the fact that cartographic work is a relatively extensive set of point, line and areal cartographic signs, it is not usually possible to perform an analysis of the map as a whole, due to time reasons. Therefore, it is necessary to choose only a subset of such elements which represent a sample set in which we can suppose a higher degree of positional accuracy.

The basic set of points which was used for cartometric analyses contain 137 identical points. After completing affine transformation we could perform the cartometric analyses of Vogt's map. The results of the analyses serve as an approximate assessment criterion illustrating the accuracy of the map's construction. The results are presented in the form of tables or graphical outputs.

It is necessary to emphasize that the below stated results of cartometric analyses are dependent on the choice of the set of identical points serving for the calculation of the transformation key. If the number or distribution of identical points changed the results would be slightly different.

Corrections on identical points affine transformation belongs to the group of residual transformations; identical points in both coordinate systems are not fully identified. The values of corrections  $v_{xy}$  of identical points can be used to assess the accuracy of depiction of elements on the map, see Figure 3. Table 2 contains a list of 5 most and 5 least accurately depicted towns. It is interesting that using the stated transformation key the depiction of the town of Plasy (West Bohemia) was assessed as the most accurate. The town was the author's birthplace. The ruin of the castle Žampach in East Bohemia (identical point 133) was depicted very inaccurately; here the value of correction is three times bigger than standard deviation.

Table 2: Five settlements with smallest residual (to left) and greatest residuals (to right).

Settlement	Residuals [m]	Settlement	Residuals [m]
Plasy	72	Žampach	18 630
Čelákovice	310	Hejnice	16 019
Čistá	329	Vlašim	15 977
Nečtiny	806	Domažlice	15 134
Rakovník	951	Frydlant	14 975

**Positional accuracy of Vogt's map.** Based on selected identical points, a standard deviation describing positional accuracy of Vogt's map reviled 8256m. This value is rather remarkable considering the fact that Vogt's map was not created on solid geometric and geodetic basis. Moreover, the stated value is highly influenced by errors that originate in the incorrect placig of some objects into the map. After eliminating an identical point no. 133, the standard deviation in position decreases to 8068m.

**Calculation of the map's scale.** When we know the resolution of the scanned raster image defined by the pixel size  $d$  and the scale coefficients  $m_x, m_y$  of the affine transformation we can determine the scale numbers of the map  $M_x, M_y$  in the direction of the  $x, y$ :  $M_x = 418865$ ,  $M_y = 431865$ . The calculated data deviate by approx. 6% from the scale number 396 800 stated in available literature and are in accord with the results presented in Vejrová (2008).

### 3.1.4 Calculation of scale and rotation

Analyses of scale and rotation are an important factor illustrating the accuracy of the construction of a cartographic work. We used the program MapAnalyst which is specialized for cartometric analyses of old and historical maps (Jenny 2006, Jenny et al. 2007). For this purpose the program contains a complex geometrical-analytical apparatus using multiquadratic interpolation of a set of identical points. Detailed information about the methodology of analyses using multiquadratic interpolation can be found in Beineke (2000, 2007). The process of cartometric analysis is fully automated, with the exception of collection of identical points. This fact contributes to speediness and overall reliability of the analytic process.

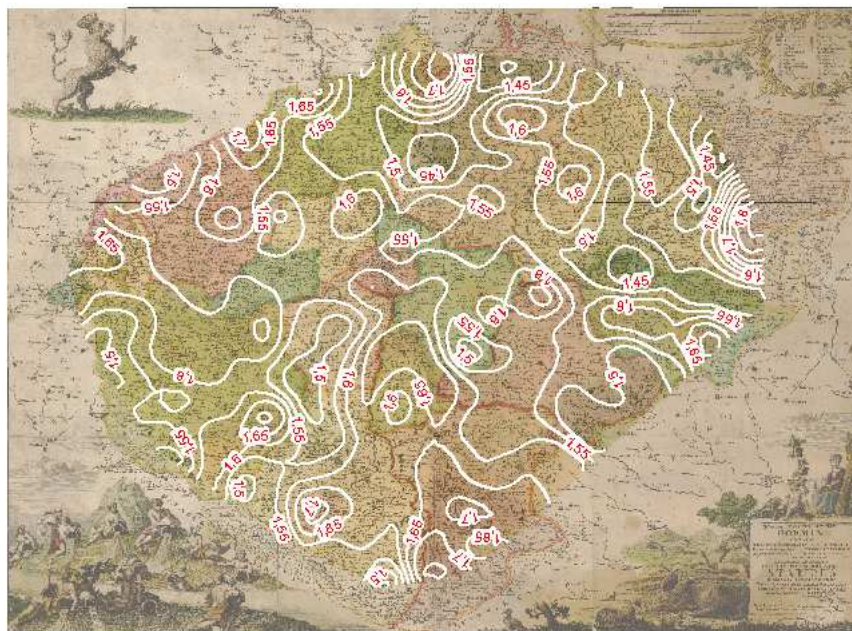


Figure 4: Scale isolines of the longitudes of Vogt's map generated with the step 0.05.

Using the set of 137 of identical points and parameters of the affine transformation the program MapAnalyst generated isolines of scale and rotation. Because of the fact the isolines generated by the program were not straight (but curved) and it is not possible to work out their description, the visualization was performed in the program ArcGIS. For this purpose we used the extensions SpatialAnalyst and 3D Analyst. The function TopoToRaster was used to generate a 5m raster model from these data. This process lead to the creation of two 3D models showing the dependence of the scale and rotation on the geographical position of the point. Using the extension 3D Analyst isolines of scale and rotation were generated for these two models.

Scale isolines, see Figure 4, show that the positional accuracy of Vogt's map changes depending on geographical position. Taking into account this criterion the best results in the map are reached in the area of Central and West Bohemia, the

worst ones in the area of North and East Bohemia. This is the consequence of some objects (Žampach, Frýdlant) being incorrectly depicted, in the order of approx. 15km. Distortion values come under interval  $\langle 1.4, 1.8 \rangle$ .

Rotation isolines, see Figure 5, indicate that the biggest rotation appears in the areas of East, South and West Bohemia. On the other hand, the centre of Bohemia demonstrates relatively small rotation values. Rotation values for Vogt's map come under interval  $\langle -5^\circ, 50^\circ \rangle$ . If we assess Vogt's map taking into account both viewpoints, the following conclusions will be drawn. Vogt's map demonstrates the smallest accuracy in the area of East Bohemia where there are considerable positional and angular distortions. The highest accuracy has been detected in the area of Central and partly West Bohemia where there are minimum positional and angular distortions.

### 3.2 Result evaluation

The results arising from cartometric analyses are influenced by a number of various factors. The following three important factors can be considered as crucial in our case:

- *The original's quality*

The quality of the scanned original plays an important role in the process of cartometric analysis. In this case only the original was available. It had to be transformed into a continuous raster map using several heterogeneous geometrical procedures. It is probable that non-linear changes in the reciprocal position of some identical points of both sets appeared, thus influencing the achieved results.

- *Selection of identical points*

It is best to perform cartometric analysis in a completely digitized cartographic work. If it is not possible due to financial or time reasons, it is possible to perform the analysis only for a subset of the map's content. In such case testing points have to be selected so that they are evenly distributed around the whole surface of the map, and their position has not significantly changed with time. Interpolation techniques based on multiquadratic interpolation are suitable for processing a set with approximately the same density of points. Unevenly distributed clusters of points or places containing no points negatively influence the achieved results. The used set of 137 identical points can be considered as sufficient; however, it was not always possible to maintain the same density of points. In mountain areas, especially in the Krkonoše or Šumava Mountains, the necessary number of identical points was not available. Often these points are situated on the edge of the area; this is the reason we can suppose they will have higher weight when calculating some parameters of the transformation key (rotation).

- *Interpolation technique*

The technique of multiquadratic interpolation also played an important role. It was performed in the program MapAnalyst to reconstruct the continuous surface from discrete data. It is necessary to take into account the fact that the results represent only one of other possible mathematical models constructed for the input data.

Even in spite of the above stated facts the achieved results can be considered valid. None of the factors probably played such a significant role that would considerably influence the results of the cartometric analyses. However, to verify this it would be necessary to perform further tests of statistical character.

## 4 Conclusion

This article deals with the process of digitization and cartometric analysis of old maps, in particular the analysis of the original of Vogt's map, using the technique of comparing sets of identical points on an old and a modern map. The methodology used during the work enables to analyse inaccuracies in old maps, making use of modern mathematical-geometrical procedures, thus contributing to the speediness and reliability of the analysis. The calculated parameters were visualized using the software MapAnalyst and ArcGIS, giving us interesting information about the accuracy in the construction of Vogt's map depending on the position of points. The results were influenced especially by the selection of identical points which served as a basis for determining a transformation key, and by the method of multiquadratic interpolation which was used.

Cartographic analysis of the selected old maps will follow.





Figure 5: Rotation isolines of Vogt's map generated with the step  $10^\circ$ .

## 5 Acknowledgments

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