Müller's maps of the Czech lands and their analysis

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Abstract
Müller's maps of Moravia and Bohemia are important parts of the cartographic and art history. They are not just beautifully and well made, but also part of the living heritage, which have been attracting the attention of people for centuries. Apart from that, they have significantly contributed to the development of cartography. Processing and cartometric analysis of these maps can open access to them and show their quality. Georeferencing significantly improves the possibilities of comparing the map with the present situation. They show the evolution of the landscape as well as that of human settlements. Moreover, publication of the map on the Internet makes it accessible to academics and to the general public. Thus they make a valuable contribution to the popularization of cartography and increase interest in maps.

Keywords: old maps, Müller's map of Bohemia, Müller's map of Moravia, cartometric analysis

Introduction: Johann Christopher Müller

J. Ch. Müller was an important Austrian military engineer and above all an exceptional cartographer (cf. Kretschmer et al., 2004). He was born in 1673 near Nuremberg, where studied maths and engineering drawing. He was on duty of count Marsigli and he was concerned in the mapping of Hungary after the Austrian-Turkish war. The Emperor of the Austrian empire charged him to construct a map of Hungary, which was published under the title „Mappa Regni Hungarie" at the scale of 1 : 550,000 in the year 1709. Müller planned to make up the unified atlas of the whole Austrian empire, „Atlas Austriacus". He worked out the maps of the Czech lands: the map of Moravia in 1712 and the map of Bohemia in 1723. He had died in 1721, before the Map of Bohemia was published. The map of Silesia, which he was working on, was completed later by Johann Wolfgang Wieland later.

During his works, Müller used instruments which he named „instrumenta matematica". Distances were measured by a viatorium (measuring wheel) behind a chariot, directions by compass, and astronomical measuring was made by a big astronomical quadrant. He mapped the Czech lands county to county and processed the measured data in winter times.

In this work, we analyze two maps of J. Ch. Müller: the Map of Moravia (1716) and the Map of Bohemia (PLEASE INSERT DATE). For both maps, we provide data on their compilation history, cartometric analysis and the method of making seamless sheet mosaic and the map rectification. The legend of these map products are also discussed, as well as the Internet publication of them.

Map of Moravia

Müller was charged by Emperor Charles VI to create the map of Moravia. He started to map Znojmo county in 1708 and in four years he mapped all former eight Moravian counties. The manuscript of the map at 1 : 115,000 was dedicated to the Emperor. Copper printing tablets were engraved by Johann Christopher Leidig. The map was set out on four sheets in 1716.

The title of the map is „Tabula generalis Marchionatus Moraviae in sex circulos divisea“. The scale of the map is approx. 1 : 180,000. The entire size of map is 974 x 1,374 mm and the size of a map section is 487 x 687 mm. The map was later completed by a geographical grid. The map has two graphic scale bars (Moravian miles and hours of march). Müller's map of Moravia was many times reprinted and was used as a pattern for the maps of the eight Moravian counties.

Cartometric analysis of the Müller's map of Moravia

As written above, Müller's map of Moravia was created on four map sheets. We scanned prints from Central Archives of Surveying, Mapping and Cadastre and we disposed of them during all project. The aim of the analysis was to find out his cartographic projection (if there was any) and get the value of scale of this map. Analyzing the known information about the map (Kuchař, 1959, Semotanová, 2006), the authors found that the coordinate grid was added to the map later (after 1720). The grid shows that Müller could use normal cylindrical projection with two undistorted parallels, but there is no proof that this grid corresponds to the original map drawing. It is more probable that he did not use any projection and the grid was added only as additional information without any geometric base.

Calculating the value of the scale can be done in several ways. The graphic scale bar in the map is depicted in Moravian miles (approx. 9.2 km). Unfortunately, we do not have any reliable information about the length of this mile. The value 9.2 km is not very precise. After measuring the graphic scale bar, we got 50.74 mm for one Moravian mile. From this, the scale of the map can be very easily computed: approx. 1 : 181,000.

As we know that the coordinate grid was added later, it cannot be used for computing the scale. Another method is measuring the map drawing (distances between towns in the map). All four map sheets were measured by using this method. A few representative distances were chosen in the two main directions on every map sheet. These distances were also measured on a current digital map. From these results, the scale of every map sheet was computed. During this computation, some of the distances had to be dropped due to their evident error. Finally, we obtained four values. The mean value for the whole map is approximately 1 : 173,800. The problem of this method is in choosing the distances that are used in the computation.

The supplemental method of determining the scale of Müller's map of Moravia is the measurement of the map frame. We tried to compare the known dimensions of the frame with the measured dimensions of our raster. For comparison we used the value given by Kuchař (1959). The measured dimensions are 1,376.11 mm and 972.17 mm, the known dimensions are 1,374 mm and 974 mm. As it can be seen, the differences are very small, which can be caused by the shrinkage of the paper during almost 300 years. What is more, we do not know if the dimensions measured by Kuchař are correct.

Fig. 1. Isolines of the scale on Müller's map of Moravia

There are two main methods of determining the scale of old maps. The usage of the graphic scale bar depends on the perfect knowledge of old measurement units. The measurement of distances is highly dependant on the identified places in the map. From these methods we got the information that the scale of Müller's map of Moravia is somewhere between 1 : 173,000 and 1 : 181,000. Till today the most cited value is 1 : 180,000 computed and published by Kuchař in 1959. A more complex method of determining the scale of old maps is the usage of global transformations with many identical points. As the scale of old maps is usually not constant (maps are locally distorted), the best method of showing the scale of an old map is visualizing the isolines of the scale on the map. For this solution, we used the Map Analyst free software. When Helmert's transformation was used, the mean scale was computed by MapAnalyst as 1 : 179,000. In Fig. 1., you can see isolines of the scale on the map. The scale varies between 1 : 160,000 and 1 : 200,000. The centre of the map has the scale of about 1 : 180,000.

The seamless sheet mosaic of the Müller's map of Moravia

Müller's map of Moravia was created on four map sheets. For later visualization, merging all these sheets together is needed to create a seamless map. The authors studied this problem thoroughly. The simplest method of merging four sheets together was their transformation on the known dimensions of the map frame (Kuchař 1959). From these dimensions we can get the coordinates in a local system for the corners of every map sheet. Every map sheet can be then transformed using corner (identical) points. As we need the seamless map without any blank spaces, the transformation should be non-residual. We chose projective transformation that needs exactly four identical points. After four transformations we got the seamless map with right dimensions. Although the corner points fit precisely, other points on the edges of map sheets were somehow distorted. The edges of two adjacent map sheets were shifted or bended. These problems are caused by the imprecision of Müller's drawing and also by the shrinkage of the map paper. The detail of these problems can be seen in Fig. 2.

Fig. 2. Problems of adjacent map sheets after projective transformation

We tried to improve the situation on the edges with more complicated transformation. Our first attempt was based on the identical points on the edges (continued paths, rivers). Using non-residual transformation, these points were shifted into the mean position. Line segments became continuous after this step. IDW (inverse distance weighted) transformation was used. The problem of this transformation is the deformation of other points in the map (far from the edges). The map frame was significantly distorted after this transformation.

In our second attempt we added the grid of fixed points in the map that should stay at their positions. Then only a narrow zone along the edges was transformed. After all four transformations we got the continuous map drawing of the Müller's map of Moravia. Fig. 3 shows one of the edges before and after the transformation.

Fig. 3. Non-residual transformation of the edges of map sheets

After the transformation we obtained the seamless map, where the lines on the edges fit precisely. There are still some problems on the edges, but they cannot be removed. They are caused by the missing or redundant drawing or by different style of drawing on the adjacent map sheets. These problems can be seen in Fig. 4. Despite these problems we were satisfied with the result.

Fig. 4. Problems on the edge of map sheets

Rectification of Müller's map of Moravia

After we had the seamless map, we wanted to compare it with some current digital map. The first step should be georeferencing of the map into some well-defined coordinate system. The clear choice was the Czech national coordinate system S-JTSK. We found identical points in the map and their current position in S-JTSK. It is very important to choose representative points on the map. They should be spread on the map. We found out that the only symbols that can be used properly are towns. Especially towns with outer walls on the map can be identified very easily. We had to keep in mind the fact that bigger towns are probably depicted more precisely as well as towns on the emperor's roads. Small settlements in mountains and near the borders of Moravia are depicted with less precision. It is caused by the method of Müller's mapping.

After choosing the right set of 65 identical points, we transformed them into S-JTSK. As the map could be distorted in both main dimensions, we used affine transformation. The standard error of position from this transformation is 2.10 km. We tried to use another transformations, especially polynomial ones. Using the same identical points, we got a standard error of position 1.85 km for second-order polynomial transformation and 1.70 km for third-order polynomial transformation. The higher order of transformation means the bigger distortion of the map. It is a question which type of transformation is the best for old maps. At the end, we tested the spline transformation that is non-residual.

Another solution of georeferencing the map was to georeference the four original map sheets and after georeferencing merge them together. During this we discovered that it is not the right way. After the georeferencing of separate map sheets there appeared many errors and it was impossible to merge the map sheets correctly.

Map of Bohemia

Emperor Charles VI charged Müller to create an „authentic and complete" map of the Czech kingdom, together with various military information. Müller mapped former 12 Czech counties and the districts of Cheb and Glatz. He also made a detailed map of the Czech-Saxon border (1 : 40,000) and some military marching maps. Müller made out the map of whole Bohemia on 25 sheets and one sheet with a general map. The manuscript was dedicated to the Emperor. The copper printing tablets were engraved by Michael Kauffer and Jan Daniel Herz, and the allegorical views were designed by Vaclav Vavrinec Reiner.

The title of the map is „Mappa geographica regni Bohemiae". The scale of the general map is 1 : 649,180 and the scale of whole map is approx. 1 : 132,000. The size of one map section is 473

x 557 mm and the entire size is 2,403 x 2,822 mm. The scales of geographical grid are displayed on the map frame. The map has two graphic scale bars (Czech miles and hours of march). It is decorated with allegorical scenes in the corners

Almost 11,000 points of settlement reflect the extension and quality of this map. Müller's map of Bohemia was many times reprinted, revised, copied, and was used as a pattern for other maps. The map was also a part of big atlases in various forms. The map was remade for the first time by Johann Wolfgang Wieland, yet in 1726. These things reflect the quality and popularity of this map.

Cartometric analysis of Müller's map of Bohemia

We used scans of Müller's map of Bohemia published by the Institute of History of Academy of Sciences of the Czech Republic for whole research. Our research lightly took up earlier project on Müller's map of Bohemia at our department (Mikšovský, Zimová, 2006). The first task was to specify the used map projection. Just like the map of Moravia, this map of Bohemia has a geographic grid scale on the map frame. The measurement of the grid scale concluded to define the map projection as a normal aspect of cylindrical projection equidistant in meridian with two standard parallels. Using the projection equations, the latitude of the standard parallel was identified as 50° 04‘. This value is close to the value of Prague's parallel as well as to the rounded value of 50°. It is questionable which of them was in the author's plans. Nevertheless, the coordinate grid of the map of Bohemia is more accurate than those of the Moravian map, which is just roughly estimative.

It was unsuccessful to find out in which towns, if in any, Müller did his astronomical measurement. That is noted by Kuchař (1959), but it is impossible to look up older notations. This fact has led to the opinion that no measurements were done (Čada, 2006). On the other hand it is hard to believe it should be possible make so accurate map without any geodetic measurements. So the fact of astronomical measurement is uncertified.

We determined the map scale by several methods (Cajthaml, Krejčí, 2007) as well as by the previous map. The graphic scale bar on the map of Bohemia displays two Czech miles. We know that one Czech mile is 300 strands and one strand is 52 Prague ells. The most probable value of one ell is 0.5914 m. We determined the distance of 1 Czech mile as 68.8 mm in the map and the map scale as approx. 1 : 134,000 by careful measurement of scale bar.

Another method, the measuring of distances between towns in the map was done just for a few couples of towns in a test area, which resulted in a map scale of 1: 132,000.

In the next step, we again used MapAnalyst software for the map scale determination by global transformation (Helmert) with many identical points. The scale varies between 1 : 130,000 and 1 : 136,000. The resulted mean scale was computed as 1 : 133,000. The depiction of the local scale distortions was made as well. The isolines of scale are shown by Fig. 5.

Fig. 5. Isolines of the scale on Müller's map of Bohemia

It can be stated that the theory of our scale determination results verified the ordinarily used value of 1 : 132,000 defined by Kuchař.

The seamless sheet mosaic of Müller's map of Bohemia

We have prints of the map which had been quartered and a cloth had been used for mounting. The gaps between the quarters were irregular. For a seamless map creation, 100 images had to be merged into one resulting image. There are different methods of doing it. Knowing the size of a map section (557 x 473 mm) allowed us to construct a regular grid defining the map-section corners. Further, it was necessary to measure each map section in 16 points (corners of quarters) and interpolate their coordinates. The next step was the projective transformation of every quarter. The result is one raster image merging every quarter without gaps. The difference of map section 13 between before and after merging can be seen in Fig. 6. By this way, 25 sheets of Müller's map of Bohemia were merged into one raster image. The edges of two adjacent map sheets were not adjusted. Notice that the non-comprimed data volume of this image has exceeded 2 GB.

Fig. 6. Depiction of map section 13 before and after merging

Rectification of Müller's map of Bohemia

It seemed suitable to use the known map frame corners coordinates or the drawings of the grid for georeferencing. The geographical grid in Müller's map of Bohemia does not correspond to the values common in the Czech lands. The prime meridian would be almost 2 degrees to the west of Ferro. It is questionable how it is possible.

Therefore, other method of georeferencing was chosen. Namely, georeferencing was done by using the network of identical points, which represented major towns and river confluences. Both variants and their combination were tested. The use of the towns with walls as identical points seemed to be most suitable. The medieval pattern of a town with walls is well noticeable in up-to-date maps and orthophoto maps (see Fig. 7). It was found that towns without walls have a generally bigger position deviation. They were less important and probably lower importance was given to their field mapping and drawing.

Fig. 7. Comparison of the situation on Müller's map with a present orthophoto

Coordinates of more than 100 points were taken. Misplaced points were excluded from transformations. Generally the problematic points were outside the Czech lands, further away and in hilly terrain. This is related with the used methods of measurement. Points in some areas have a similar position deviation. A set of 83 identical points was used for the transformation of the map into the S-JTSK. We used affine transformation with a standard error of position of 1.23 km. Other transformations were tested as well.

Legends of Müller's maps

Legends of both maps are well made. The author used many symbols for different types of municipalities, settlements, important institutions, and places of extraction and processing of natural resources. Legends are in Latin and in case of the map of Bohemia in German also. The map also displays rivers, main roads and relief described by „method of hills“. The map of Moravia has 19 kinds of symbols. The map of Bohemia, due to its bigger scale and better elaboration contains 39 symbols. We can find more kinds of towns (royal town, town with castle) more symbols of mining and processing of raw materials. Examples of sketching of some symbols and their differences between the map of Moravia and Bohemia can be seen in Fig. 8.

Fig. 8. Examples of map symbols

Visualization of Müller's maps on the Internet

The best method of making Müller's maps accessible for public is their Internet visualization. There are several methods used on the Internet (Cajthaml, 2007). We prefer two types of applications. For original or merged map sheets some Internet viewer is an ideal solution. This viewer should be able to work with large raster data (hundreds of MB). As we made research on the available products, we recommend Zoomify application. It was successfully used for visualization of old maps for example at http://oldmaps.geolab.cz (Brůna, Křováková, 2006). It is a Flash-based application, which can work very fast with a large amount of data. The data are cut into small tiles in many resolution layers and Flash application can handle these tiles very quickly. Fig. 9 shows the web application. Using this method we published both map of Müller (Bohemia and Moravia). Maps can be found at http://maps.fsv.cvut.cz/muller/index2.html.

Fig. 9. Zoomify application - Müller's map of Bohemia

The second type of application is used for georeferenced data. It is based on UMN MapServer application and its JavaScript interface (msCross library). In map server, data can be very easily compared with other geodata (such as current settlements, borders). Our application allows the displaying of both maps georeferenced by different transformations (affine and spline). For better comparison one layer was created as a combination of both maps. Müller's map of Moravia was clipped along the Czech-Moravian border, and now the combined image of these two maps is available. Map server application can be seen in Fig. 10. This application can be found on the web at http://maps.fsv.cvut.cz/muller/index.html.

Fig. 10. Map server application - Müller's maps of Bohemia and Moravia

Conclusions

It is possible to consider Müller's works as the most extensive and best done, made by only one person. In fact, his work was not overrun until the first military mapping of the Austrian empire. Our research of these nice maps verified and sometimes specified earlier findings. The merging of the 4 sheets of the map of Moravia as well as the 25 sheets of the map of Bohemia provided a more compact view of these maps. We consider the visualization and publishing of these maps to the general public on the Internet as an important result of our work.

Our onwards attention may be turned to the map of Silesia (initiated by Müller and completed by Wieland) to get down research and publication of the maps of the area of the Czech Republic. The map of Hungary could be processed as well and our research of Müller's maps would be finalized.

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Figure captions:

Fig. 1. Isolines of the scale on Müller's map of Moravia