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Altimetry on the second military survey maps in the territories of Bohemia, Moravia and Silesia

Keywords: Altimetry; Second Military Survey; Bohemia; Moravia; Silesia.

Summary: The Second Military Survey in the territories of the former Austrian-Hungarian Monarchy was done between 1806 and 1869. Its purpose was to remove the defects of the First Military Survey including gross position errors and cartographic representation defects of objects in maps, and to contribute to a well-arranged map for the entire monarchy. In the territories where the cadastral survey was completed (Bohemia, Moravia, Silesia, etc.) the outcomes were exploited for the military survey. Reduced and generalised planimetric content from the cadastral maps and cadastral triangulation was used to outline the planimetric content of the Second Military Survey. This assured an improved positional accuracy and better work economy. The territory of Bohemia was surveyed between 1842 and 1853 (267 handwritten colour sections 1:28 800), Moravia and Silesia between 1836 and 1840 (146 handwritten colour sections 1:28 800). Currently, the map originals are stored in the Vienna Military archive department of the Austrian State Archives.

The aim of this contribution is to describe the methodology of altimetry and determination of heights displayed on the Second Military Survey maps of Bohemia, Moravia and Silesia. The accuracy of the elevations has been analysed. Attention is paid to the portrayal of altimetry on the maps.

The Second Military Survey (Franzische Landesaufnahme) 1806 – 1869

The original concept of the Second Military Survey

The Second Military Survey was launched on 2nd April 1806 by a decree of Emperor Francis II¹ (Hofstätter 1989: 61). In the same year the Emperor also authorized a proposal by general A. Mayer von Heldensfeld², head of general quartermaster staff (Generalquartiermeisterstab), to establish the military triangulation (Boguszak and Cisar 1961: 14), called the astronomical-geodetical network, for the whole territory of the Austrian monarchy as a reference coordinate frame of the Second Military Survey. The Topographic Institute in Vienna initiated the first measurements in 1806 and triangulation works proceeded in difficult conditions with a small number of officers.

The military triangulation was completed for Bohemia, Moravia, and Silesia by 1811 (Fig. 1). The coordinates of the trigonometric points were probably used for the revision of the topographic survey in Bohemia between 1812 and 1819.

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¹ Emperor Francis (*1768 – †1835) was the first Roman (Francis the I.) and thus the second Austrian emperor (Francis the II.). He dominated in years 1792 – 1835.

² Anton Freiherr Mayer von Heldensfeld (*1765 – †1842) Field-Marshal of Austrian army (Nischer 1925: 108).

The complete network of the military triangulation was originally intended as a uniform coordinate reference system (St. Stephen), in order to create a continuous display of the whole monarchy in the uniform layout of map sheets. Marshal Fallon, Marshal Maurich, Marshal Mertz, Lieutenant Kielmann and Lieutenant Schweiger took part in the majority of measurements.

The original plan was to display the whole monarchy in the Cassini-Soldner transversal cylindrical projection with the central meridian passing through the St. Stephen trigonometric station. The map sheets in the so-called older section division formed a plane network of rectangles in scale 1:28 800 with sizes of 24 x 16 Viennese inches (63 x 42 cm), parallel with coordinate axes, displaying an area of 2,4 x 1,6 Austrian mile (18 x 12 km) (Kuchar 1967: 82). The sections were indicated from west to east by capital letters R, Q,A, then by roman numerals I, II, ...LXIV. The rows were indicated from north to south by 16, 17, ...102. Selected map sheets around large cities, strategically important objects, military objects and exercising grounds were represented in scale 1:14 400.



Figure 1: Military triangulation built in the former territory of Bohemia, Moravia and Silesia between 1806 and 1811. The territory triangulated in 1806 – pink, 1807 – yellow, 1808 – blue, 1810 – dark green, 1811 – red, (*Arbeiten des k. k. Generalquartiermeisterstabs... 1850*).

The plane table method was used for the detailed topographic survey. The planimetric objects were included in the military triangulation network by graphical intersections, pacing or distance estimation.

The modified concept of the Second Military Survey

In some territories (e.g. Bohemia, Moravia, Silesia, Dalmatia, Carinthia) the cadastre survey was already finished or in progress. This allowed a modified approach for the Military Survey by using actual results of the cadastre survey. This combination was also used for the general topographic and administrative maps of individual territories of the monarchy. The modification applied to both horizontal control and cartographical foundations. It also affected the process of surveying.

The trigonometric network was established by the triangulation office of i.r. (imperial royal) General Staff (k.k. Generalstab). Between 1807 and 1840 the triangulation network was established exclusively by military officers. Later, civil topographers cooperated as well. The network was constructed in distinct steps, beginning with first order points, subsequently densified later until the fourth order. The detailed surveying works began when the triangulation had been completed. The first order network (*Grosses Netz*) was established in Bohemia between 1824 and 1825, and 1827 and 1840, and in Moravia between 1821 and 1826 (Cada 2005: 36). The densification to second and third order (*Kleines Netz*) depended on the progress of the surveying. The second and the third order networks were established in Bohemia between 1825 and 1840, and in Moravia between 1822 and 1829 (Cada 2005: 36). All the networks were completed in 1858.

According to Boguszak and Cisar (1961: 16) and Cada (2005: 37) the coordinates for Bohemia were given in a plane coordinate system with the origin at the trigonometric station Gusterberg. For Moravia and Silesia the origin was at the trigonometric station St. Stephen in Vienna. The networks from the first to the third order in Bohemia (51 953 km²) contained 2 623 trigonometric points. Permanent marking was made between 1845 and 1850, when only 2 234 points were located and monumented. In Moravia and Silesia (27 375 km²) there were 1 069 points between 1850 and 1852, but only 833 were monumented. The height above sea level (Adriatic system) of the trigonometric points was determined in Viennese fathoms with two decimal positions. More information about the geodetic control and its use for the Second Military Survey can be found in Cada and Vichrova (2009).

The Cassini-Soldner projection was also used for the cadastre survey. The central meridian was chosen in the centre of a territory and passed through a significant station of the trigonometric network (Gusterberg, St. Stephen). The reasons for using more than one reference point was the practical task of producing maps for several administrative regions and the need to cover the whole monarchy with cadastral maps. Also, an unfavourable longitudinal distortion in parallels existed in the border regions.

The usage of geodetic and cartographic controls for cadastre survey and generalized cadastral planimetry is the major feature of the modified concept of the Second Military Survey. In consequence these changes invoked another layout of the map. The new map sheets of the Second Military Survey were derived from the map sheets of stable cadastre, i.e. a division of a plane coordinate system with parallels to the coordinate axes. The new map sections (2 x 2 Austrian miles = 800 x 800 fathoms) were scaled 1:28 800 to 20 x 20 Viennese inches, i.e. 52,7 x 52,7 cm (Boguszak and Cisar 1961: 16; Kuchar 1967: 85). One map section of the Second Military Survey displayed an area of four fundamental sheets of the stable cadastre. The columns (*Colonne*) parallel to the X axis were numbered with Roman numerals in the direction from east (*O – ostliche Colonne*) to west (*W – westliche Colonne*). The rows (*Schichte*) parallel to the Y axis were numbered with Arabic numerals from north to south (Boguszak and Cisar 1961: 16; Kuchar 1967: 84 – 85).

In territories where the cadastral survey was already finished or in progress, the planimetric contents of cadastral maps in scale 1:2 880 were used. They were pantographically reduced and simplified to the scale 1:28 800. The short time between the cadastral and topographic surveys allowed the use of most of the planimetry. The topographer adjusted only the planimetry according to the military legend and surveyed the terrain relief and some new objects that were not displayed in cadastral maps.

Using the cadastral planimetry significantly accelerated and rationalised the topographic works. In such territories, one topographer and an assistant completed 3 sections of the new map sheets each year. This is equal to 12 square Austrian miles each year or 690 km². The original concept (without using the planimetry of cadastral maps) planned for only 4 – 6 square Austrian miles each year (230 – 345 km²). The acquisition costs of mapping of one square Austrian mile decreased from 250 to 120 Gulden (Kuchar 1967: 84). The main differences between the original and the modified concepts are shown in Table 1.

Original map sections in scale 1:28 800 for Bohemia (267 handwritten colour sections 1:28 800), Moravia and Silesia (146 handwritten colour sections 1:28 800) are kept in the map collection of the Austrian State Archives – Military Archive in Vienna (Österreichisches Staatsarchiv – Kriegsarchiv Wien).

Comparative characteristics	Original concept	Modified concept
Triangulation	military	cadastral
System of coordinates	St. Stephen	St. Stephen, Gusterberg
Section indexing	original	modified
Size of one map section	24'' x 16'' (63 x 42 cm)	20'' x 20'' (52,7 x 52,7 cm)
Displayed territory	18 x 12 km	15 x 15 km
Area of territory displayed on one map sheet	221,0 km ²	230,2 km ²
Surveying method	Topographic survey with a measuring table	Use of cadastral planimetry
Map drawing	All sections without regard to provincial borders	Only territory within provincial borders

Table.1 Major differences between original and modified concepts for Bohemia, Moravia and Silesia.

Portrayal of altimetry on maps

The altimetry on the maps of the Second Military Survey is portrayed according to the legend shown in *Muster-Blätter...* (1831 – 1840) by Lehmann hachures and spot heights. The hachures portray not only the direction of the maximum gradient but also the slope of the terrain. The slope is portrayed by functionally dependent length and thickness of the hachures and distances between them according to the precise scale (Fig. 2). The map legend includes type models of the elementary landforms. Each of these model landforms is displayed by contours with inclined cuts in important profiles (Fig. 3). From all the cartographic map symbols shown in *Muster-Blätter...* (1831 – 1840) the Feature Catalogue of the Second Military Survey was produced. The whole catalogue is present and described in detail in Vichrova (2005). A digital version of the catalogue can be found at: http://home.zcu.cz/~vichrova/clanky/Katalog_objektu_VII.pdf.

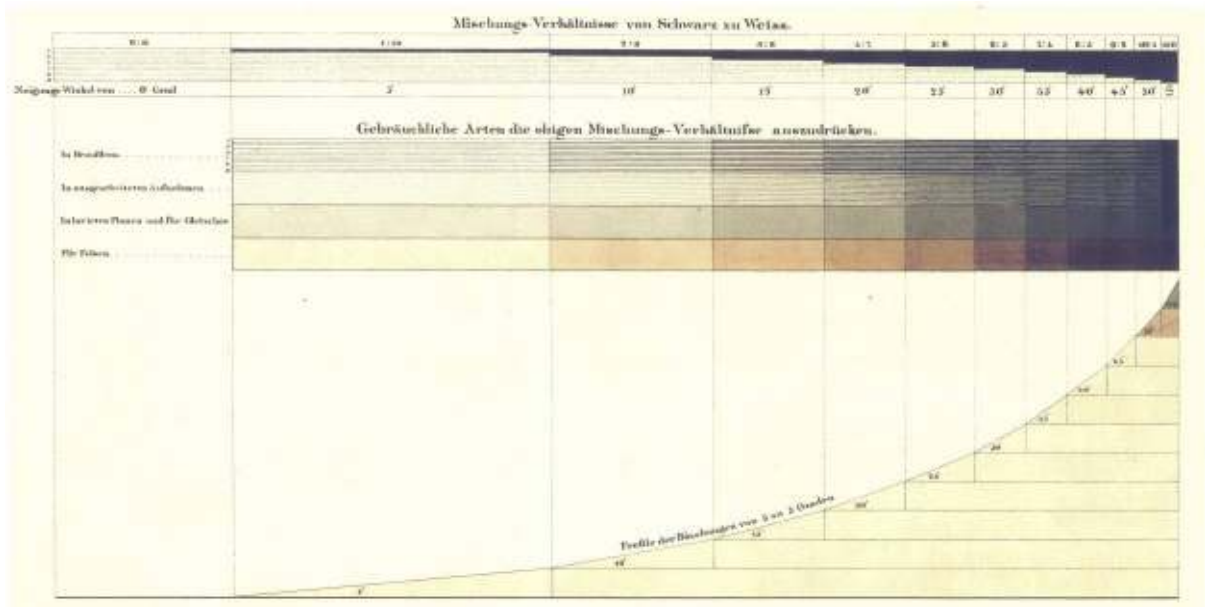


Figure 2: Scale for portrayal of the slope of the terrain. (*Muster-Blätter... 1831 – 1840*).

Figure 3 depicts a model example of one of the landforms present in the feature catalogue. This includes mountains, rocks and mountain glaciers, plains, highlands, Alpine-type mountains, mountains with permanent snow cover and karst mountains. The example depicts a gully. The description of the landform and geographical names are not present but these are included in the final map sheets of the Second Military Survey. The cuts depicting the character of the terrain are shown on the model example.



Figure 3: Landform – gully: portrayal using hachures and appropriate geometric model with depicted cutting planes and profiles (*Muster-Blätter... 1831 – 1840*).

The representation of the terrain on maps using hachure gives a true plastic image of the terrain, as well as objective and visual information about the permeability of the area. The disadvantage of this method is a high graphical load of the map sheet in comparison with other symbols on the map.

The representation of the landforms on the maps of the Second Military Survey was accomplished by spot heights chosen mostly from geodetic control. The heights on the map sheets of Bohemia, Moravia and Silesia are produced according to the modified technology in units of Viennese fathoms with an accuracy of two decimal points (Fig. 4). No spot heights were found on the map sheets in the area of South Bohemia (Vitorazsko) which were produced according to the original technology.

The following section of the paper is focused mainly on the methods of determination of the spot heights and analysis of their accuracy.



Figure 4: An example of the depiction of the spot height on the map.

Available sources and methodology of height determination

Determination of heights from military triangulation measurements

The building of the military triangulation of the Austrian Monarchy began in 1806. After sample measurements and setting the methodology for processing of the measured data the “*Instruction für die bey der k. k. österreichischen Landes-Vermessung angestellten Herren Officiere*” was published in 1810 (Binnenthal 1810). The methodology should have ensured a unified approach in building the triangulation network and also the processing of measured data. The military triangulation in the former territory of Bohemia, Moravia and Silesia was built between 1806 and 1811 (Fig. 1).

The triangulation record also contains calculation records (Funck 1810 – 1811; Augustin 1811) with determined heights of trigonometric points including their differences in elevation. The calculation records contain measured values including height of the standpoint, height of the target and measured zenithal distance; values taken from other calculation records including logarithm of the length or length, coefficient of refraction; and calculated values including zenithal length reduction, differences in elevation, elevation of trigonometric points and targeted points located on them.

The determination of heights was done by trigonometric measuring of zenithal lengths on targeted points. The distance between the targeted points was several tens of kilometres. The zenithal lengths were reduced to the elevation of the standpoint and also to the targeted point. Differences in elevation between trigonometric points were calculated from the reduced zenithal lengths and the lengths of the sides. Then the height above sea level of the targeted point was calculated from a minimum of two various points with previously determined heights. The final height of the determining point was set by arithmetic mean. If the height of the targeted point was also measured then the height above sea level of the natural terrain at the trigonometric point was calculated.

The calculation network and the heights of the trigonometric points were reconstructed from the calculation records (Funck 1810 – 1811; Augustin 1811) for the territories that according to the administrative division from the years between 1751 and 1842 encompassed the whole territory of the Pilsen, Klatovy and Prachen regions, and for parts of the Locket, Zatec, Beroun, Tabor and Budejovice regions. The location of the territories is shown in Figure 5. The network built between 1810 and 1811 by Hejtmann Funck is blue. The network built in 1811 by Hejtmann Augustin is green. The network shown in red is a part of the trigonometric network that was measured twice by both these surveyors.

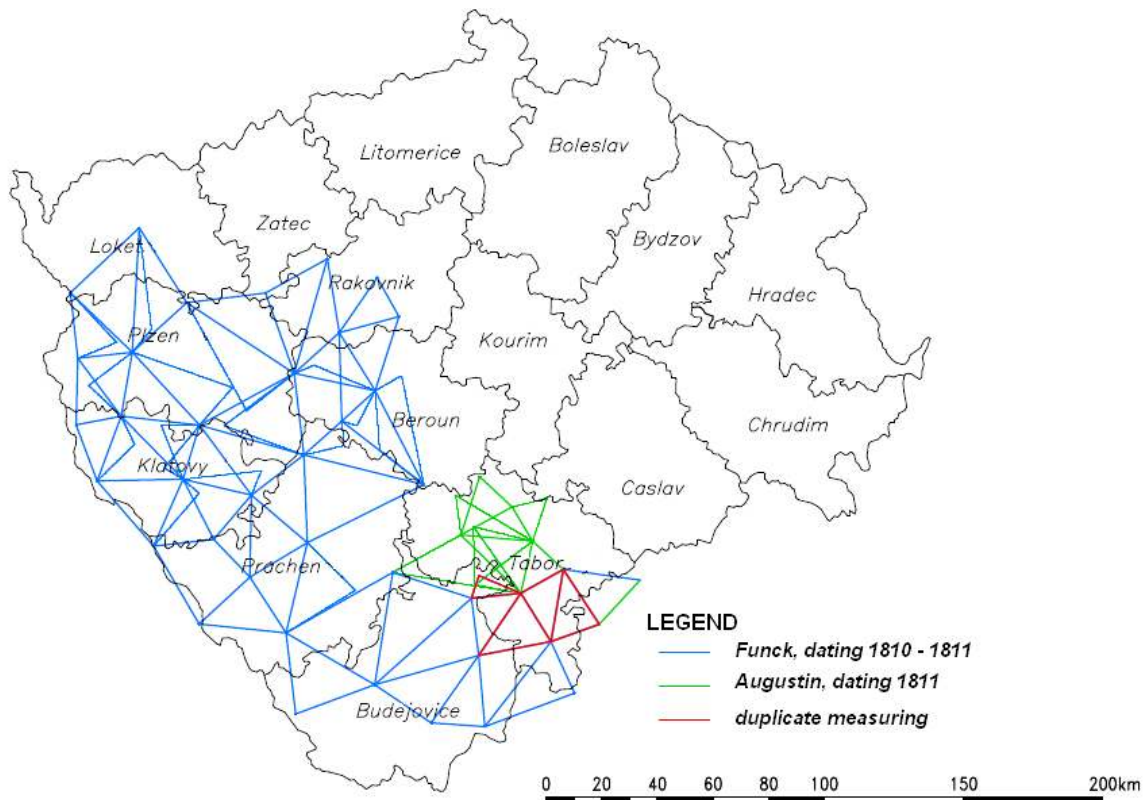


Figure 5: Calculation network for determination of heights of trigonometric points reconstructed according to Funck (1810 – 1811) and Augustin (1811). The background layer represents administrative division from the years between 1751 – 1842.

From the differences in elevation of individual sides the height misclosures were calculated for triangles of the calculation network: $u = \Delta h_1 + \Delta h_2 + \Delta h_3$, where Δh_1 , Δh_2 and Δh_3 are differences in elevation between the vertices of the triangle. Then the average value of the height misclosure was set \bar{u} :

$$\bar{u} = \frac{\sum_{i=1}^n u_i}{n}$$

In this calculation n is the number of triangles. In a given calculation record the average value of the height misclosure was set for major triangles, minor triangles and for all the train mentioned in the calculation protocol (Table 2).

	Number of triangles	Calculation record from the years between 1810 – 1811 surveyor: Hptm. Funck	Calculation record from 1811 surveyor: Hptm. Augustin	Number of triangles
		Average value of the height misclosure [Viennese fathoms]		
major triangles	45	- 0.02	0.00	6
minor triangles	18	0.37	3.09	10
locality as a whole	63	0.09	1.93	16

Table 2: Average values of the height misclosures.

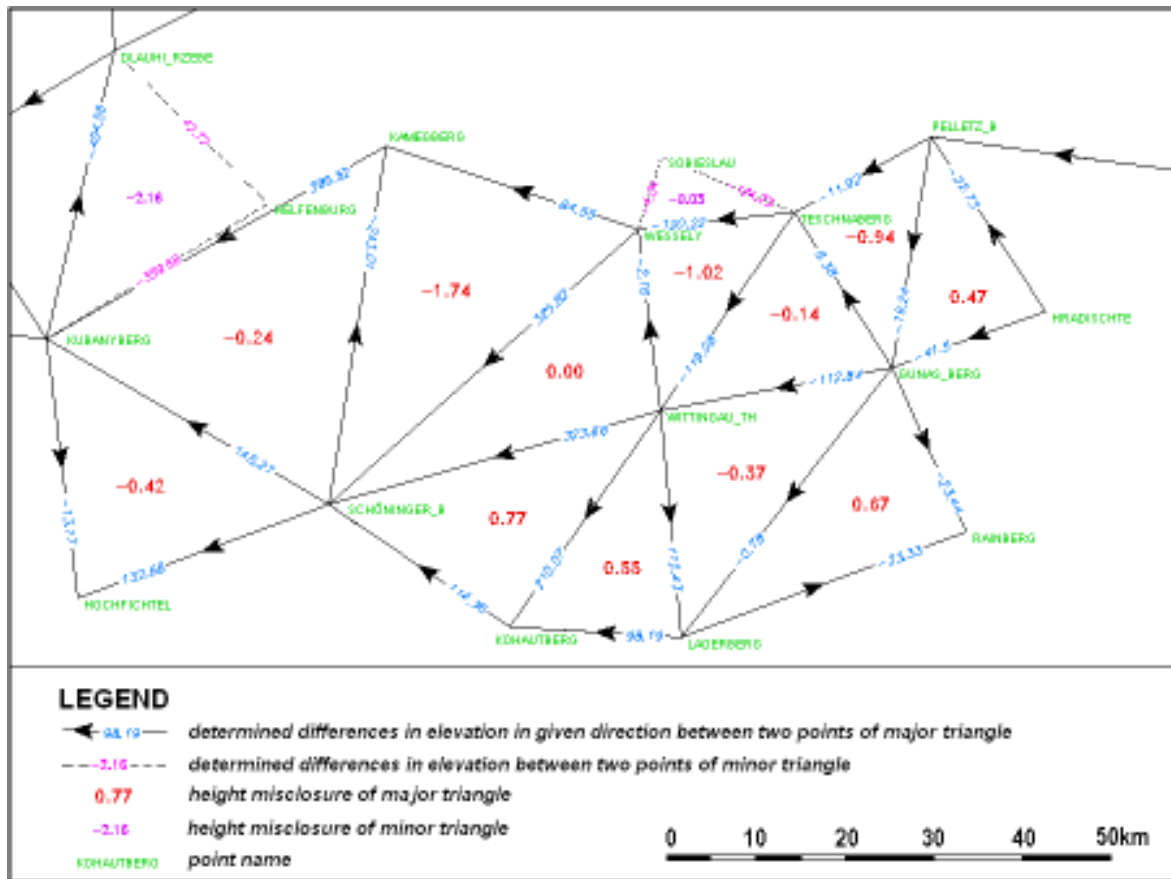


Figure 6: Reconstruction of the part of the calculation network for height determination and differences in elevation of trigonometric points. The network was built and measured by Funck between 1810 and 1811.

All the zenithal lengths in the major triangles were measured from both ends (points accessible with measuring equipment). The zenithal lengths in the minor triangles were not measured from both ends. One of the minor triangle vertices was usually a permanently targeted point e.g. a church tower, castle tower. The example of the reconstructed calculation network of the record (Funck 1801 – 1811) is given in Figure 6.

From the values shown in Table 2 it is evident that the set of the analysed height misclosures from Funck (1810 – 1811) is not influenced by systematic errors because average errors of the height misclosures are close to zero. Systematic errors were proved for the set of the analysed values from Augustin (1811), where the average value of the height misclosure is 3.09 Viennese fathoms, i particularly in the case of minor triangles. It was discovered by studying Augustin (1811) that a correction for refraction was not included in the calculations. Taking into account the lengths of the trigonometric sides, the overall reliability of the data decreases when omitting the corrections.

A part of the reconstructed network from the calculation records from Funck (1810 – 1811) and Augustin (1811) was determined twice (Fig. 5). The values corresponding to independently determined differences in elevation and their differences are shown in Table 3.

Differences in elevation between points	Determined difference in elevation between two points [Vienn. fathoms]		Difference between (1) and (2) [Vienn. fathoms]
	(1) surveyor Hptm. Funck	(2) surveyor Hptm. Augustin	
Pelletz Berg – Hradische	22.73	22.90	-0.17
Hradische – Gunas Berg	-41.50	-41.12	-0.38
Gunas Berg – Pelletz Berg	19.24	19.261	-0.021
Pelletz Berg – Gunas Berg	-19.24	-19.261	0.021
Gunas Berg - Teschnaberg	6.38	6.115	0.265
Teschnaberg – Pelletz Berg	11.92	12.19	-0.27
Teschnaberg – Gunas Berg	-6.38	-6.115	-0.265
Gunas Berg – Wittingau Thurm	-112.84	-114.5	1.66
Wittingau Thurm – Teschnaberg	119.08	121.33	-2.25
Sobieschau – Teschnaberg	124.23	123.89	0.34
Teschnaberg – Wessely Thurm	-120.22	-122.88	2.66
Wessely Thurm – Sobieschau	-4.04	3.146	-0.894

Table 3: Twice determined differences in elevation in the calculation records (Funck 1810 – 1811 and Augustin 1811) for trigonometric points (part of the reconstructed network from the years between 1810 and 1811).

The mean error of the twice determined difference in elevation was determined from the difference between differences in elevation:

$$m_h = \sqrt{\frac{\sum_{i=1}^n \delta_i \delta_i}{n-1}} = 1.21 \text{ Vienn. fath.} = 2.30 \text{ m}$$

In this equation, n is the number of twice determined differences in elevation and $\delta_i = h_i^F - h_i^A$ is the difference between twice determined difference in elevation from Funck (1810 – 1811) and Augustin (1811).

In total 71 points with determined heights were tested from the calculation records of Funck (1810 – 1811) and Augustin (1811). 38 points out of 71 points are displayed on the map sheets of the Second Military Survey (see Table 4). From the values of differences dz shown in Table 4 it is obvious that the heights taken from the calculation records of Funck (1810 – 1811) and Augustin (1811) from the years between 1810 – 1811 do not match the heights depicted on the map sheets of the Second Military Survey.

Point name	dz [Vienn. fathoms]	Point name	dz [Vienn. fathoms]	Point name	dz [Vienn. fathoms]
Tabor Stadthurm	-24.980	Osserberg	-10.720	Makowa	-8.720
Drachow Thurm	-19.854	Sbanberg	-10.349	Pelletz	-8.505
Studený Wrch	-15.480	Sedlitz	-10.150	Dolickenanhöhe	-8.282
Rodnberg	-13.778	Wolfsberg	-10.090	Bernklauerhöhe	-8.153
Spitzberg	-14.000	Heiligerberg	-9.910	Gunasberg	-7.515
Gistebnitz Kapelle	-13.206	Dobrowaberg	-9.830	Kamek Berg	-6.702
Trzemschinberg	-12.080	Brnberg	-9.740	Straschitz Berg	-5.132
Swidnikberg	-12.043	Boreckberg	-9.720	Tillenberg	1.506
Miltschin Kapelle	-11.906	Schöningerberg	-9.600	Rattina	4.330
Hochfichtelberg	-11.370	Stricky berg	-9.560	Wessely	11.663
Gr. Czerkovberg	-11.090	Kubanyberg	-9.530	Klattau	14.160
Zbirow	-10.860	Hradistie	-9.000	Pilsen	25.610
Kohautberg	-10.790	Trzemoschnaberg	-9.220	---	---

dz – difference in height between identical points taken from calculation records (Funcnk 1810 – 1811 or Augustin 1811) and spot heights taken from the map sheets of the Second Military Survey

Table 4: Names of the trigonometric points and differences in heights taken from Funcnk (1810-1811) or Augustin (1811) with regard to the spot heights taken from the map sheets of the Second Military Survey.

Calculation records of the triangulation of the stable cadastre

Triangulation of the stable cadastre was built in Bohemia, Moravia and Silesia between 1821 and 1840. It was finished in 1858 (Cada 2005: 36). Part of the triangulation documentation archived in the Central Archive of Survey and Cadastre in Prague (*Ustředni archiv Zememěřického úřadu*) is the calculation records with differences in elevation and heights of the trigonometric points of the cadastral triangulation (*Zenithdistanzen... 1830* and *Zenithdistanzen... 1837*). From the calculation methods presented in the records it is evident that the methodology for calculation of differences of elevation and heights of trigonometric points was preserved.

Determination of heights was done by trigonometric measurements of zenithal lengths on targeted points. From the reduced zenithal lengths and lengths of the sides reduced by coefficient of refraction the difference in elevation between the trigonometric points was calculated. Then the calculation of the height above sea level of the top of the targeted trigonometric point followed. This was done from at a minimum of two different places. The result was an arithmetic mean. If the height of the targeted point was also measured then the height above sea level of the natural terrain at the trigonometric point was calculated. The example of the calculation of the difference in elevation between the points Homolka and Chlum is shown in Figure 7. Chlum and Homolka are located near Pilsen.

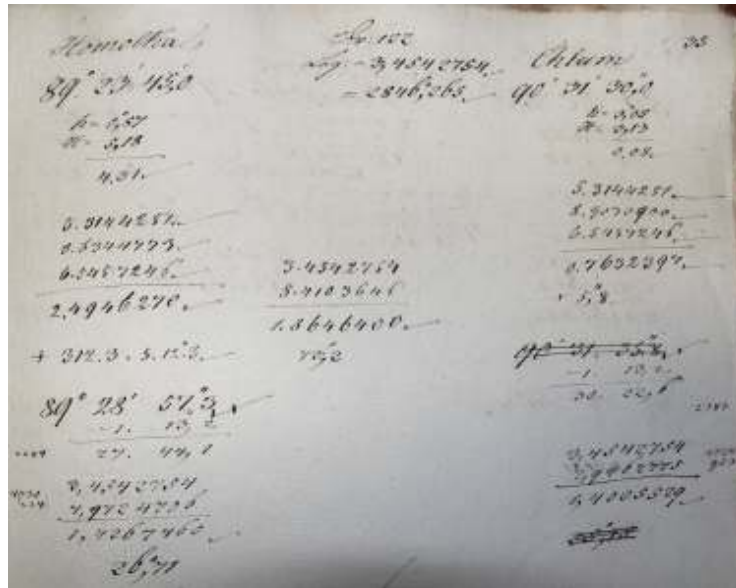


Figure 7: Example of the calculation: the difference in elevation between the points Homolka and Chlum (*Zenithdistanzen...* 1830).

Part of the calculation network with differences in elevation and heights of trigonometric points was reconstructed from data taken from the record of *Zusammenstellung...*(1825 – 1840). According to the administrative division from the years between 1751 and 1842 this part covers the south of the Pilsen region (Fig. 8). It is evident from there that this calculation network (23 points/400 km²) was denser than the network reconstructed according to the calculation records of the military triangulation (1 point /400km²).

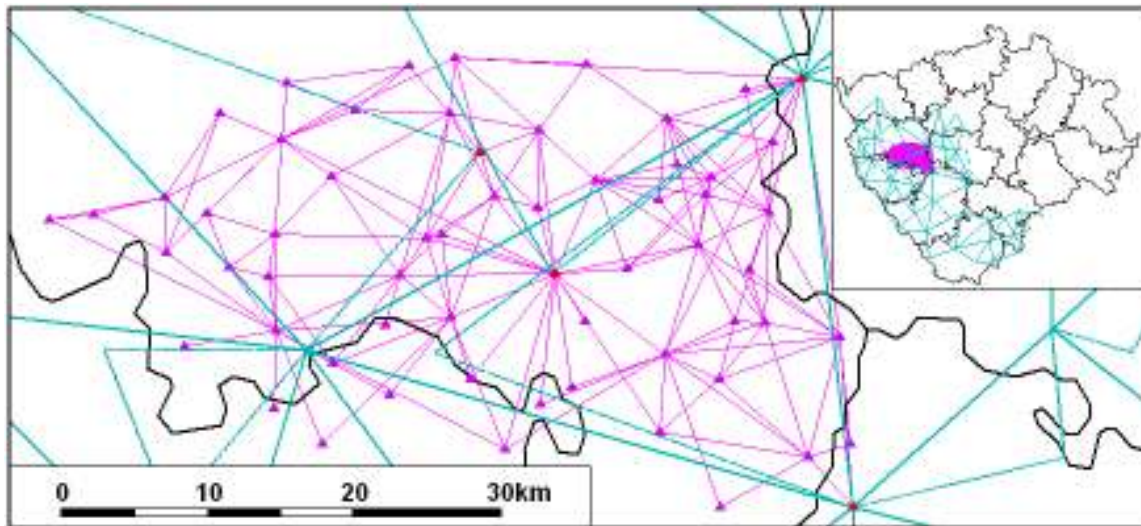


Figure 8: Calculation network for determination of heights of trigonometric points reconstructed according to *Zusammenstellung...* (1825 – 1840) – pink and Funck (1810 – 1811) – blue with identical points – red. The background layer represents administrative division from the years between 1751 – 1842.

Height misclosures (u) were calculated from the differences in elevation of single sides for triangles of the calculation network according to the formula mentioned in the previous section. An average value of the height misclosure for the whole locality was also calculated: $\bar{u} = -0.02$ Viennese fathoms. It is evident that the set of analysed variables is not influenced by any systematic error.

On the map sheets of the Second Military Survey points were found that were identical to the trigonometric points from part of the reconstructed calculation network shown in *Zusammenstellung...* (1825 – 1840). 61 identical points were found in total. 8 points were excluded from the analysis. 7 of these were excluded due to missing spot heights or non-readable heights on the map, particularly in the case of permanently targeted points in built-up areas. 1 of them was excluded due to uncertainty in the point of reference of the targeted point; church tower or terrain. The number of analysed identical points was reduced to 53. The mean error (m_H) was calculated for these identical points:

$$m_H = \sqrt{\frac{\sum_{i=1}^n \delta_i \delta_i}{n-1}} = 0.14 \text{ Vienn. fath.} = 0.26 \text{ m}$$

In this calculation, n is the number of identical points and $\delta_i = h_i^S - h_i^{IVM}$ is the difference of heights taken from *Zusammenstellung...* (1825 – 1840) and from the maps of the Second Military Survey. It is evident from the mean error that spot heights of the trigonometric points on the maps of the Second Military Survey for Bohemia, Moravia and Silesia are equal to trigonometrically determined heights of trigonometric points of the stable cadastre.

List of heights and topographic descriptions to trigonometric points of the triangulation of stable cadastre for Bohemia, Moravia and Silesia

A part of the triangulation documentation of the cadastral triangulation, archive fund: *Cassini-Soldnerova zobrazovací soustava (1821 – 1900)*, archived in the Central Archive of Survey and Cadastre in Prague is a list of trigonometric points for Bohemia, Moravia and Silesia with determined heights and topographic description of points – *Abstände, Höhen und Topogr. Beschreibungen der Katasterpunkte Böhmen, Mähren u. Schlesien (Abstände, Höhen... 1873)*. In the first part of the document there are mentioned points for the former territory of Bohemia. In the second part there are points for the former territory of Moravia and Silesia with a year of processing of the points. It enabled the construction of a time series of the processing of data of the trigonometric points (Fig. 9).

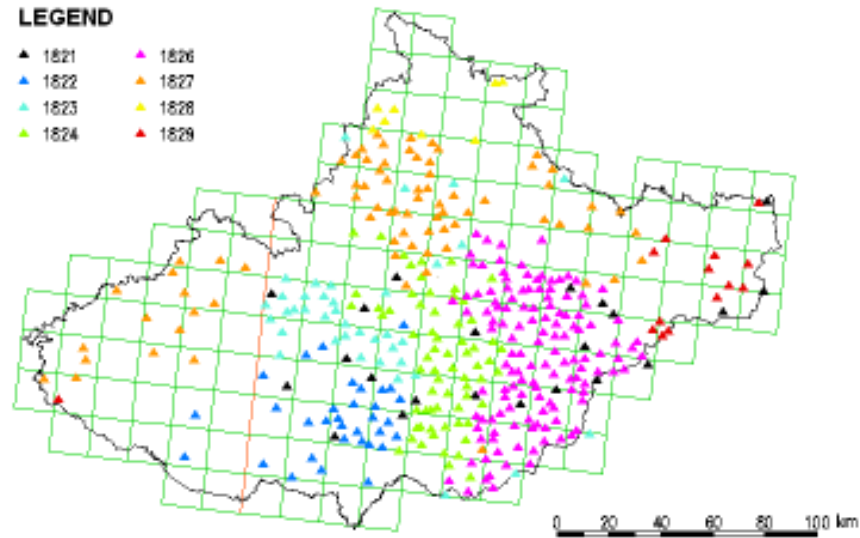


Figure 9: Time serie of the processing of data of the trigonometric points on the former territory of Moravia and Silesia according to *Abstände, Höhen...* (1873).

The values of spot heights on map sheets of the Second Military Survey were compared with heights listed in *Abstände, Höhen...* (1873). In total 2 493 trigonometrically determined heights of the points were found on the map sheets of the Second Military Survey for Bohemia. 2 240 points were labelled with height and 253 were not labelled with height. The conformity between the heights from the maps of the Second Military Survey and from *Abstände, Höhen...* (1873) was tested. 17 points were excluded due to missing identical points in *Abstände, Höhen...* (1873) and another 247 were excluded too, due to missing height values on maps or in *Abstände, Höhen...* (1873). The number of analysed points was therefore reduced from 2493 to 2229 points. On map sheets for Moravia and Silesia only 906 trigonometrical points were found. 493 points were labelled with height on the maps and 413 points were not labelled with heights. The conformity between the heights from the maps of the Second Military Survey and from *Abstände, Höhen...* (1873) was tested. 33 points were excluded due to missing identical points in *Abstände, Höhen...* (1873) and another 389 were excluded too, due to missing height values on maps or in *Abstände, Höhen...* (1873) (Fig. 10). The number of analysed points was therefore reduced from 906 to 484 points.

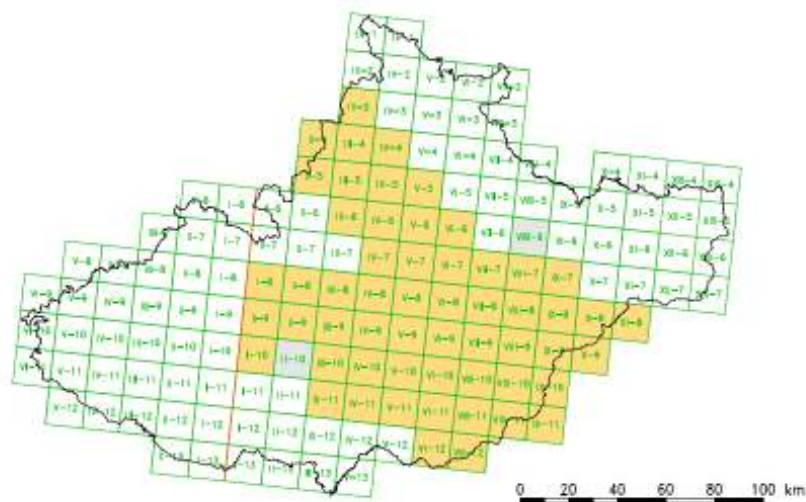


Figure 10: Set of map sheets for Moravia and Silesia with orange highlighted sections where spot height values of trigonometrical points are missing.

A testing parameter Δ_{dz} was set to test the conformity of spot heights notations on map sheets of the Second Military Survey and in *Abstände, Höhen...* (1873):

$$\Delta_{dz} = \sqrt{\frac{\sum_{i=1}^n dz_i^2}{n}}$$

In this equation, n is the number of pairs of trigonometrically determined points with heights displayed both on the map and also in *Abstände, Höhen...* (1873), dz_i is the difference (in meters) of height from *Abstände, Höhen...* (1873) and spot height values on the map.

From the set of points for **Bohemia** (2 229 identical points) 43 outlying values were excluded (points where dz_i exceeded treble of the testing parameter Δ_{dz}). The testing parameter has changed for the final 2 186 identical points: $\Delta_{dz} = 0.39$ m.

From the set of points for Moravia and Silesia (486 identical points) 9 outlying values were excluded. The testing parameter has changed for the final 475 identical points: $\Delta_{dz} = 0.30$ m.

Testing of the set of dz_i variables for Bohemia and for Moravia and Silesia using Dt2 programme did not prove the normality of any of these sets of tested variables. Histograms of rel. frequency after exclusion of outlying values are shown in Fig. 11.

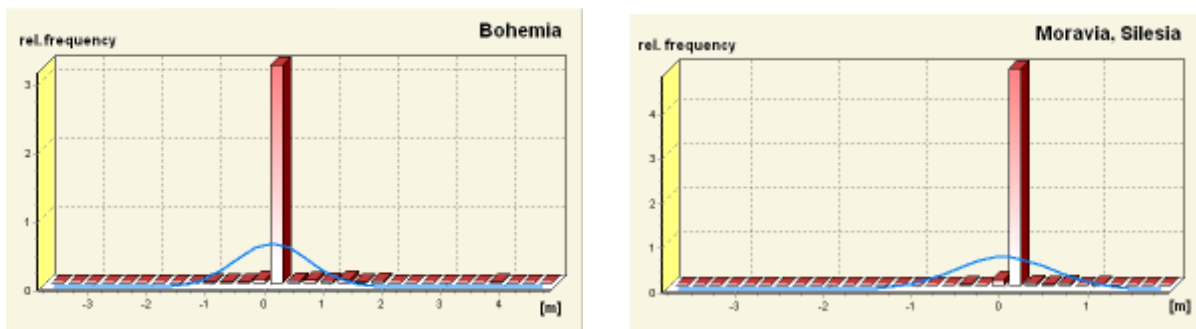


Figure 11: Histograms of rel. frequency after exclusion of outlying values: Bohemia (left) and Moravia and Silesia (right).

The values of the testing parameters for both analysed sets of variables are mutually comparable and close to zero. From this statement we can assume that heights of trigonometric points displayed on the maps of the Second Military Survey are identical to corresponding heights shown in *Abstände, Höhen...* (1873).

Conclusion

On the maps of the Second Military Survey, altimetry plays an integral role in the content. The chosen method for the depiction of topographic surfaces using Lehmann hachures displays the terrain plastically to the detriment of other content; it decreases the overall readability in the areas with fragmented terrain. Conversely, such distinctive depiction clearly indicates the permeability of the given area. Spot heights are part of the altimetry on the maps.

This study found that there was an areal network of geodetic points determined horizontally and vertically in the territory of Bohemia between 1810 and 1811. In the territory of West and South Bohemia the spot heights of trigonometrical points on the map sheets of the Second Military Survey were missing. This military triangulation network was sparser than the geodetic control for mapping stable cadastre. This explains the difference in point monumentation in the terrain compared with that used for geodetic control for stable cadastre. The monumentation for military surveys was based on high quality and digital triangulation of the first to third order performed by the triangulation office. Therefore it is evident that many points were used for triangulation for the stable cadastre, for example points *Rattina*, *Trzemschin Berg* and *Brdo Berg*, (Cada 1999 and Cada 2003). The experience of the surveyors building the geodetic control for the Second Military Survey in the territory of Bohemia, Moravia and Silesia was used for building the digital triangulation for the stable cadastre. Therefore the building of the digital triangulation for the stable cadastre was done in a short time period but with high quality.

Calculation records have been studied and trigonometric points of the cadastral triangulation reviewed. This shows that the methodology of calculation of differences of elevation and heights of trigonometric points was preserved. It is also proved that map sheets of the Second Military Survey contain spot heights adopted from triangulation documentation of the stable cadastre. Through the process of mapping the topographer worked with generalised planimetric content of the stable cadastre. Together with points of digital triangulation the topographer determined heights trigonometrically. These were shown on maps in the form of spot heights.

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