

Analysis of watercourses on Aretin's Map of the Bohemian Kingdom from 1619

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ABSTRACT

Historic maps provide evidence of landscape development, including the shape of watercourses in the past. Aretin's map of the Bohemian Kingdom (contemporary Czechia) from 1619 is Bohemia's third-oldest map. In this analysis of Aretin's map, we aimed to create an overview of watercourses at the beginning of the 17th century. We used MapAnalyst software to perform cartometric analyses and plotted watercourses on a contemporary map. Special interest was given to watercourses outside of the Bohemian Kingdom, which have not been included in previous analyses of the map. Content, semiotic, and cartometric analyses focusing on watercourses and on changes in the depiction of rivers over the four editions of Aretin's map were performed to identify and label the previously unnamed rivers.

KEYWORDS

old map; Aretin; watercourses; cartometric analysis; 17th century; Bohemia

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1. Introduction

Cartographic sources, primarily old maps and plans are among the most valuable sources of information about the past. They illustrate development and landscape changes over the defined territory, inform about the geopolitical situation, etc. (Trpáková 2009; Hvizdák 2023). An important part of their content are hydrographic elements, represented by all natural and artificial water areas, watercourses, and surrounding objects.

Watercourses were essential for transport and strategic planning of settlement establishment, but they are skewed and distorted on the old maps (Gregory 2014). The style, completeness, and accuracy of the cartographic representation of watercourses provide evidence of their importance to our ancestors.

The article focuses on analyzing watercourses on Aretin's map of Bohemia, the third oldest cartographic depiction of Bohemia (1619) and its subsequent editions.

It is the first map on which watercourses are comprehensively shown. However, the analyzed map is

not based on precise geodetic measurements, so their locations or shapes are distorted and skewed, which was common at the time.

The analyses focused on finding geometrical discrepancies in the hydrographic elements depiction and unnamed watercourses identification, were performed on four copies of Aretin's map from 1619, 1632, 1665, and before 1747, obtained from the Map Collection of the Faculty of Science of Charles University and the National Archives in Prague.

The analyses of rivers on old maps were presented in several papers. Gatta used old georeferenced maps to compare the historical landscape of Bologna with the current state (Gatta 2020). The possibilities of identification and interpretation of cartographic symbols on old maps were described in Gašperič (2023).

The first study of Aretin's map of Bohemia from 1619, was presented by Kuchař and Roubík (1936). Later on, for example, Roubík (1951), Bayer (2009), Semotanová (2001, 2008), Novotná et al. (2022), were focused on cartometric and semiotic analyses, but watercourses were mentioned marginally. Some topographic inaccuracies, especially regarding water-



Fig. 1 Aretin's map of Bohemia, 2nd edition of 1632. Source: Map Collection of the Faculty of Science, Charles University.

courses in eastern Bohemia and the Erzgebirge (Kuchař 1936; Roubík 1951; Novotná et al. 2022) were found.

We generally assume, that the depiction of the watercourses at this time is very general or inaccurate. This paper concentrates on watercourses and water areas analyses in order to find positional inaccuracies in their depiction and identify unknown river names.

Are there some regions on the map, that were more accurately depicted than the others and why? Does it somehow correlate with Aretin's experience – e.g. are the regions, where he surely lived and work, more detailed than the others? Georeferenced digital copies of maps and vector layers of watercourses were used for the analyses.

2. Aretin's map of Bohemia

Aretin's map of Bohemia from 1619 is the third oldest map of the Bohemia territory, with four known editions (1619, 1632, 1665, and before 1747). The first two editions are assigned to Paulus Aretin of Ehrenfeld (active between the years 1608 and 1632) Between 1600 and 1608, he worked as a junior scribe in Klatovy. In 1609, he became secretary to the aristocrat Peter Wok of Rosenberg (1539–1611). After three years, he moved to Prague and was awarded the title of Prague burgher.

The third edition of Aretin's map (which was issued after Aretin's death) is assigned to Daniel Wussin (1621–1691), and the fourth (and undated) edition is assigned to his son Kaspar Wussin (1664–1747). The famous Aretin family of engravers, publishers, and booksellers was established in the 17th century by Daniel Wussin, who came from Graz and moved to Prague (Kuchař 1936). The first analysis of Aretin's map of Bohemia (see Fig. 1) entitled "Regni Bohemiae Nova et Exacta Descriptio" (New and Exact Description of the Bohemian Kingdom) presented Kuchař (1959).

The rectangular map frame oriented to the north has dimensions of 574 × 766 mm, its approximate scale is 1 : 504,000 (Kuchař 1936). A detailed



Fig. 2 An example of the representation of the royal town of Hradec Králové, settlements and relief on the 2nd edition of Aretin's map of Bohemia. Source: Map Collection of the Faculty of Science, Charles University.

explanation of the map symbols was also presented. The settlements depicted by a circle with a dot, emphasized by a silhouetted mask, containing 1157 items (Kuchař 1936), are differentiated into the following categories: free royal towns, towns of the Bohemian king, manorial towns, and villages. Moreover, different map symbols were used to depict fortresses, castles, chateaux, and monasteries. The map also shows relief, vegetation, and water supplies, as well as map labels. The terrain is represented by the hill method with shading; see Fig. 2.

Compared to the previous maps of Bohemia (Klauďán's, 1518, and Criginger's, 1568), watercourses are depicted in more detail. Although many rivers are drawn, they remain unnamed. Rivers in Bohemia are connected to foreign streams, but there are many inaccuracies and errors (Novotná et al. 2022). The most visible changes between the fourth editions of Aretin's map refer to the depiction of rivers in eastern Bohemia.

Only two roads are depicted: The Golden Trail, leading through Prachatice, and the New Trail, leading through Český Krumlov. Aretin's map of Bohemia is the first map showing the borders of the 15 regions in Bohemia. The graphic decoration consists of two columns placed next to the left and right frames of the map; they show six male and female figures wearing historical clothing.

The map was engraved and published using the copperplate technique. Kuchař (1958) supposed that all editions were printed from two identical printing plates; differences in topographical content are evident.

The original edition of Aretin's map of Bohemia from 1619 is owned by the National Archives of the Czech Republic, located in Prague, under the inventory number NAD 0324/1256. The other three editions of Aretin's map are part of the Map Collection of the Faculty of Science, Charles University.

3. Methods

The article aimed to perform complex content-based and fundamental cartometric analyses of watercourses on Aretin's map of Bohemia from 1619 and its subsequent editions. Descriptive, comparative, and analytical methods were used to analyze the map content and evaluate the correctness of the watercourses depiction. More specifically, we can determine how watercourses are drawn and described on the map, compare their depiction with the current state, and determine their positional accuracy.

3.1 Content analysis

The map content includes all the objects, phenomena, and their relationships. Contemporary cartography classifies map elements according to their origin,

character, and meaning into four categories: mathematical, physical-geographical, socio-economic, complementary, and semiotic elements (Voženílek 2004).

3.1.1 Mathematical elements

Mathematical elements represent the structural foundation of the map. They include geodetic bases, cartographic representation, map scale, coordinate system, map frame, sheet layout, and map composition (Voženílek 2004).

3.1.2 Socio-economic elements

Settlements are essential elements, often used to localize and identify rivers on the map. According to the map scale, they can be represented in two ways – by point or area cartographic symbols. For the oldest maps of Bohemia territory, the most common representation of settlements uses point symbols (Semotanová 2001); see Fig. 2. Roads joining different locations are represented by linear symbols (Voženílek 2004).

3.1.3 Physical-geographical elements

Physical-geographical elements are objects of living and non-living nature: relief, watersheds, and vegetation cover. Watercourses involve all standing and flowing waters on and under the Earth's surface (oceans and seas, lakes, artificial reservoirs, watercourses, and springs). Flowing watercourses are represented by continuous lines from their confluences to the sources; their thicknesses correspond to the widths. On some old maps, it is possible to see watercourses drawn with the same wide line. For example, Klaudyán's map of Bohemia from 1518.

As mentioned above, the content-based analyses concerned watercourses, water areas, and bridges. The goal was to find and identify all rivers and water areas on Aretin's map of Bohemia in all four editions. Moreover, the topographic accuracy of the watercourses and water areas was also examined.

A specific feature of watercourses on old maps is their linear character. For content-based analysis, it is necessary to georeference the analyzed map and vectorize the watercourses so that the data can easily be overlaid with the current base map. This helps to identify the location and direction of watercourses and water areas (Farooqi 2023; Tsorlini 2014).

3.2 Semiotic analysis

Subsequently, semiotic analysis, focusing on cartographic symbols and their use forming the map language, was performed.

Cartographic symbols can be divided into three categories according to their geometry (point, line, and areal). They have different properties, such as shape, size, structure, filling or orientation.

Linear and areal cartographic symbols are essential for analyzing the watercourses. Linear symbols are used for objects of linear shapes, especially rivers,

roads, and streets. Single, double, dotted, or dashed lines and their combinations are frequently used for their graphic representation. Areal symbols, consisting of two components (contour and fill), are suitable for water area representation (Medyńska-Gulij 2013). Regarding Aretin's map, the depiction of watercourses, water areas, and bridges is analyzed in all four editions of the map.

3.3 Description analysis

Object labels are an essential part of the map content, clarifying the qualitative and quantitative features of the map objects. Old maps use various font styles, sizes, and languages. The geographical names of watercourses are generally called hydronyms. The analyses of watercourses, water areas, and bridge labels on Aretin's map of Bohemia is involved.

3.4 Cartometric analyses

Using modern tools, cartometric analyses of old maps allow verification and evaluation of their geometric accuracy. They provide helpful information about map construction, geodesic bases, and cartographic processing (Bayer 2009; Jenny 2011; Aguilar-Camacho 2022).

The cartometric analyses are based on a comparison of the old and reference (i.e., current) maps in order to detect and interpret their changes. A fundamental step affecting the results is the proper choice of identical points used for the transformation key calculation. Aretin's map of Bohemia does not contain a geographic grid. Therefore, easily identifiable points assumed not to have changed significantly in space and time are used. Typically, we prefer historical centers of villages, castles, chateaux, religious buildings, and confluences of rivers.

A first-degree affine transformation was applied to prevent geometric distortion of objects. It has several benefits, such as keeping the spatial relationships between map objects, eliminating the sheet shrinking, but it is not conformal. Transformations of higher degrees causing unnatural twisting of the map content, were not used in the analyses (Bayer 2009).

The equations of the affine transformation can be written in the form

$$\begin{aligned} X &= m_x \cos(\alpha)x - m_y \sin(\alpha)y + \Delta x, \\ Y &= m_x \sin(\alpha)x + m_y \cos(\alpha)y + \Delta y, \end{aligned}$$

where x, y represent the coordinates in the local coordinate system (the old map), X, Y the coordinates in the global coordinate system (the reference map), m_x, m_y are scale factors in the x, y directions, α is the rotation angle (Bayer 2009).

Results include estimating the map scale and rotation, displacement vectors and their changes depending on the geographic position. Displacement vectors

with the given size and direction are a simple but efficient graphical technique. Deviations from the median suspected of being outliers caused by positional errors can easily be identified. The results are visualized using various methods of thematic cartography, such as isolines or deformation grid (Jenny 2011). Beineke (2001, 2007) presented a comprehensive mathematical background based on multiquadratic interpolation (Hardy 1972). The proposed technology for evaluating maps was fully automated in MapAnalyst software (Jenny 2006), which was also used in this paper.

4. Results

The results of analyses involving the four editions of Aretin’s map of Bohemia (1619, 1632, 1665, and before 1747) will be presented. Digitized maps in the tiff format (resolution 400 dpi) were provided by the Map Collection of the Faculty of Science of Charles University and the National Archives of the Czech Republic. Initially, the maps were georeferenced in QGIS software, and a complete vector model of the watercourses was created. Subsequently, semiotic analyses of the watercourses (see Sec. 3.2) and map labels (see Sec. 3.3) were performed. Finally, the depicted watercourses, areas, and bridges were compared with the base map, and a content analysis was carried out (see Sec. 3.1).

4.1 Semiotic analysis and description of watercourses

On Aretin’s map of Bohemia, watercourses are depicted using line symbols, the size of which corresponds to the dominance of the river. The space between the riverside lines is longitudinally hatched. The water areas are visualized using the area symbols, with the boundaries (simple contour) and the interior parts (fill combined with hatching and dots); see Tab. 1.

Drawn with the graduated line symbols, the rivers Labe (“Elbe”) and Vltava are dominating. Regarding the ponds, there are two unnamed ponds in South Bohemia near Třeboň and the Jordán pond. At the con-

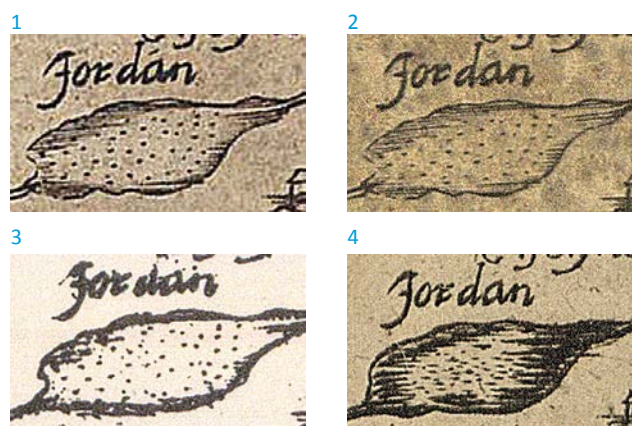


Fig. 3 Change in areal symbol intensity on the Aretin map (1st, 2nd, 3rd and 4th editions). Source: National Archives of the Czech Republic, Map Collection of the Faculty of Science, Charles University.

fluence of rivers, the line symbol thickness is adjusted, so the tributary has a narrower representation.

Aretin’s map was printed on paper using hand-engraved copper plates. Therefore, the saturation of line features does not indicate a particular river attribute (such as its importance). Regarding area symbols depicting ponds, their edges are highlighted. Because the fourth edition of the map has been overprinted, the linear and areal water features are more intense and darker. See Jordan Pond on the fourth edition map in Fig. 3.

The river symbols are filled with longitudinal hatches following the flow direction. It is apparent that the area symbols of the ponds are exaggerated, their edges highlighted by extended hatches, which are either horizontal or have a slight gradient as the river flows into/out of the pond; the center of the pond is filled with dots. The specific edition of the map is also reflected – the newer the map, the more hatching on line and area features. This phenomenon is present in all water areas and is particularly evident at the Jordan Pond (Fig. 3), which has longer lines with lower spacing on the eastern shore.

The watercourse labels are on all editions of Aretin’s map of Bohemia in German, Czech, and Latin languages. For example, the Labe river in Latin is *Albis* or

Tab. 1 Map symbols of Aretin’s map of Bohemia.

Content of the map field	Element	Type of map symbol	Map symbol
watercourses	river	line symbol	
	pond	area symbol	

Source: Map Collection of the Faculty of Science, Charles University.

Tab. 2 Descriptions of watercourses on Aretin’s maps of Bohemia.

Language of description	Map edition	Object name
Latin	First edition, 1619	
Czech	Fourth edition, before 1747	
German	Fourth edition, before 1747	

Source: National Archives of the Czech Republic, Map Collection of the Faculty of Science, Charles University.



Fig. 4 Situation around the spring of the Vltava river in Šumava. The angel with a compass in the 2nd edition (left) was removed on the 4th edition of Aretin's map (right). In the 4th edition, the spring of the Vltava river was redrawn, signs for the forest and the inscription "Passauer Wald" were added. Source: Map Collection of the Faculty of Science, Charles University.

Labe in Czech. The watercourse labels are handwritten (serif, italic font) with calligraphic tendencies; see Tab. 2. Behind the river names, the suffix "fl" or "flu" has been added, identifying the abbreviation from the Latin word "fluvius".

4.2 Content analysis

The location and identification of all rivers and water areas depicted on four editions of Aretin's map, as well as the geometric and topographic accuracy with respect to the present, were analyzed.

4.2.1 Watercourses on Aretin's map

In total, 121 watercourses on the four editions of Aretin's map of Bohemia were identified, of which 41 were described, and 17 water areas, including 2 described ponds (Bethlehem, Jordan) and 2 described springs (Labe, Morava).

The dominant river is Vltava. The fourth edition of Aretin's map omits the sketch of a cherub with a compass near the Vltava spring. Instead, its upper flow is depicted and labeled as Passauer Wald; see Fig. 4. The first right-side tributary of Vltava is the Malše river, but with a reduced flow length. According to Aretin's opinion, the river starts at the village of Dolní Dvořiště (*Dworzissté*). However, forming the Czech-Austrian border, its source is located in Austria near the Viehberg hill. A spring of an unnamed river non-corresponding with the current state of the watercourses, later flowing into Lužnice, is depicted near Dolní Dvořiště. The river flows through the cities of Gmünd and Weitra, which is correct given the course of the river. However, these cities are shifted on Aretin's map, Weitra is depicted north of Gmünd, but in reality, Gmünd is located further north.

The right tributary of Lužnice flowing through the Gmünd is the Braunaubach. Subsequently, the Lužnice river turns incorrectly to the east of Třeboň and flows through the village of Kunžak, where it may be confused with the Nežárka river (or another minor tributary of the Lužnice river).

The Otava river flows into Vltava near the village of Zvíkov (*Zwikow*). Its flow starts at Sušice, while, in reality, the Otava springs southwest of Rejštejn, as a result of the confluence of the Křemelná and Vydra rivers.

The Sázava river is not drawn along the entire length of its course, which is missing in Žďár nad Sázavou (*Zdiar*) and Přebyslav (*Przibislaw*). From Havlíčkův Brod has the same course and direction as at present.

The biggest left-side tributary of Vltava is the Berounka river. It is emerging in Pilsen as the confluence of four rivers: Mže, Radbuza, Úhlava, and Úslava. Compared to present, the course of the Mže river is mirror-reversed; see Fig. 5. It rises south of Bärnau (*Bernaun*), while the Meuse originates in Germany in the Griesbach Forest, which is located north of Bärnau. Then, it flows southeast through Tachov (*Tachow*) and continues through the Stráž (*Straz*) village. At present, the flow direction is somewhat northeast, and it does not pass through Stráž. On Aretin's map, the spring of Radbuza is depicted near the village of Zelena Lhota in Nýrsko (*Zelena Lhota*). However, the right-side tributary of Radbuza, the Úhlava river, originates here; its spring was moved east of the village of Velhartice (*Welhartice*). From its spring, the Radbuza river continues through the villages of Dešenice (*Dessenice*) and Janovice nad Úhlavou (*Janowice*), following the present-day riverbed of Úhlava. The river then turns west towards Domažlice. From Horšovský Týn (*Tejn Horssonoský*), its course is identical to the present.

The Úhlava river flows from the west around the villages of Čachrov (*Czachrow*) and Strážov (*Strazow*). From Klatovy (*Klatowy*), its course is correct. The first tributary of Berounka is the Úslava river; its source is drawn in the Blatno region in the pond area. The river continues through Březnice (*Bréznicé*), then turns west to the village of Blovice (*Hradisste*). Subsequently, it continues northwards through Starý Plzeň (*Plzenecz*), where it flows into the Berounka river; see Fig. 5. The river rises to the southwest at Číhaň and flows around the eastern edge of the town of Plánice.

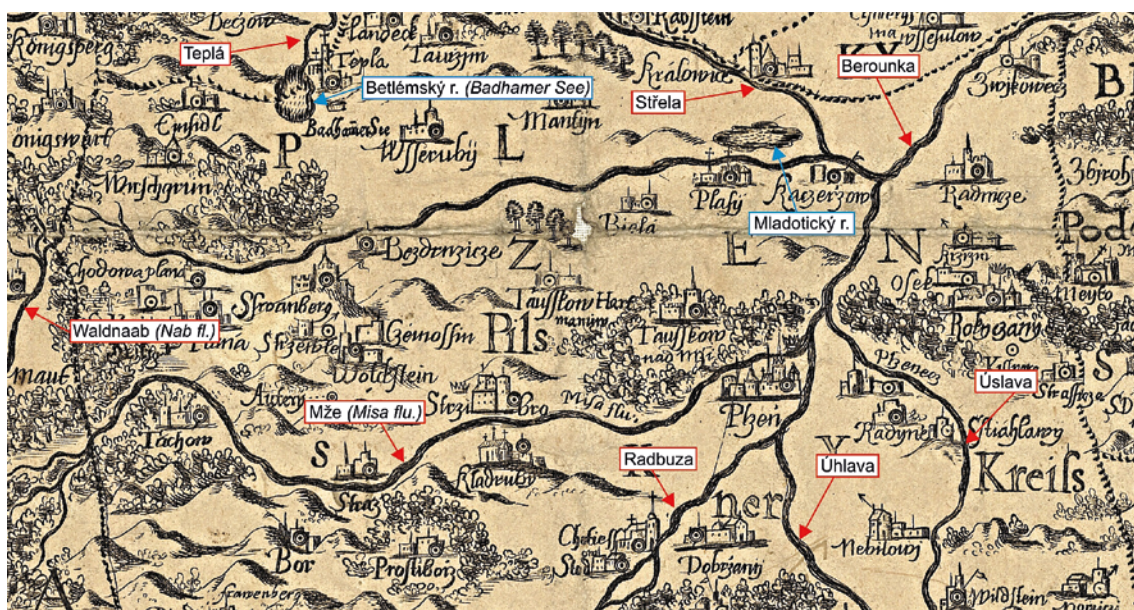


Fig. 5 Watercourses around Pilsen on the 4th edition of Aretin's map. Source: Map Collection of the Faculty of Science, Charles University.

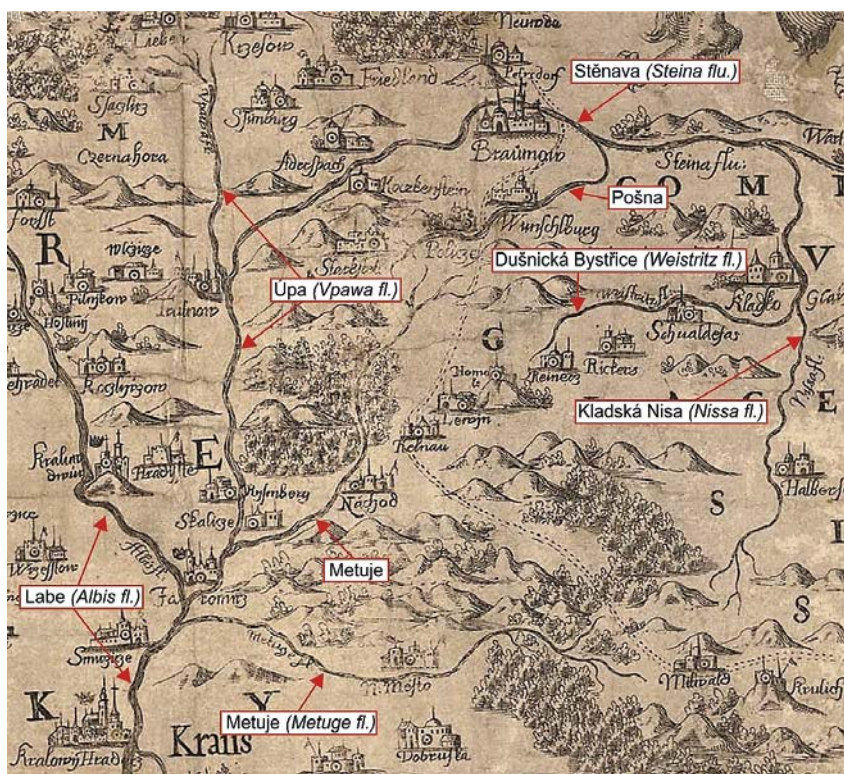


Fig. 6 Twice drawn Metuje river in East Bohemia on the 1st edition of Aretin's map. Source: National Archives of the Czech Republic.

Behind the village of Žinkovy it turns east and continues north through Blovice, Starý Plzenec to Plzeň, where it flows into Berounka.

The rivers in the northeastern part of the map area are, in many cases, incorrectly depicted. At present, the Metuje river rising in Adršpach, flows through Teplice nad Metují, Hronov, Náchod, Nové Město nad Metují and in Jaroměř, it flows into the Labe river. The part of its course from Jaroměř (*Jaromirz*) to Nové

Město nad Metují (*N. Město*) is shown correctly. After that, however, the river continues further east, where it rises at the Polish village of Międzyzlesie (*Mitvald*). In Jaroměř, another stream with an unknown name besides Úpa flows into Labe. It flows through Náchod (*Náchod*) and rises near Police nad Metují (*Policze*). This might be the Metuje river again, as it follows the course of Metuje to some extent. The situation is shown in Fig. 6.

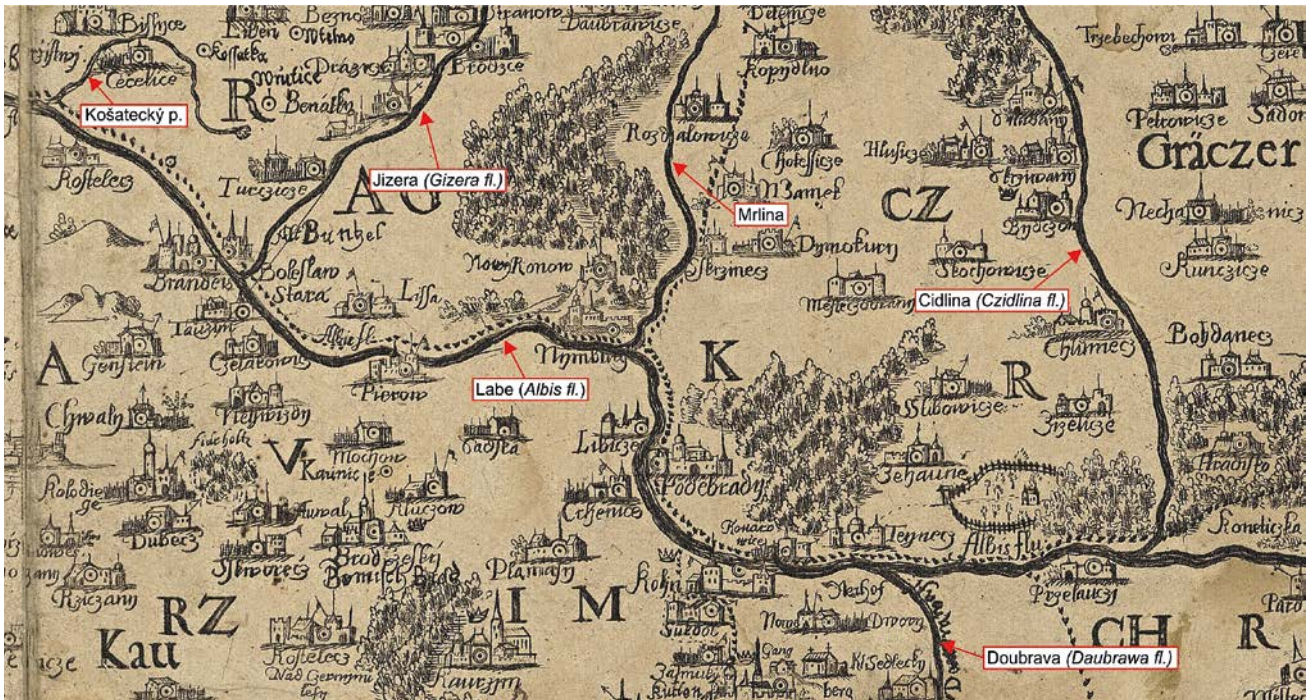


Fig. 7 The Labe river and incorrectly plotted the Cidlina river, 1st edition of Aretin's map. Source: Map Collection of the Faculty of Science, Charles University.

Other tributaries of Labe are Orlice, Loučná and Chrudimka. The course of Chrudimka is depicted from its spring in a northeastern direction, then it turns north and flows into Labe near the village of Stolany. At present, the river flows north-west from its spring to the village of Seč, then turns east, and beyond the village of Nasavrky it continues north

through Slatiňany and Chrudim to Pardubice, where it flows into Labe. Then, near the village of Chrast, the Novohradka river flows into the Loučná river instead of the Chrudimka river in Úhřetice.

The spring of the Cidlina river is depicted near Lomnice nad Popelkou. Then, the river continues south through Jičín (*Giczin*), Nový Bydžov (*Bydczow*),

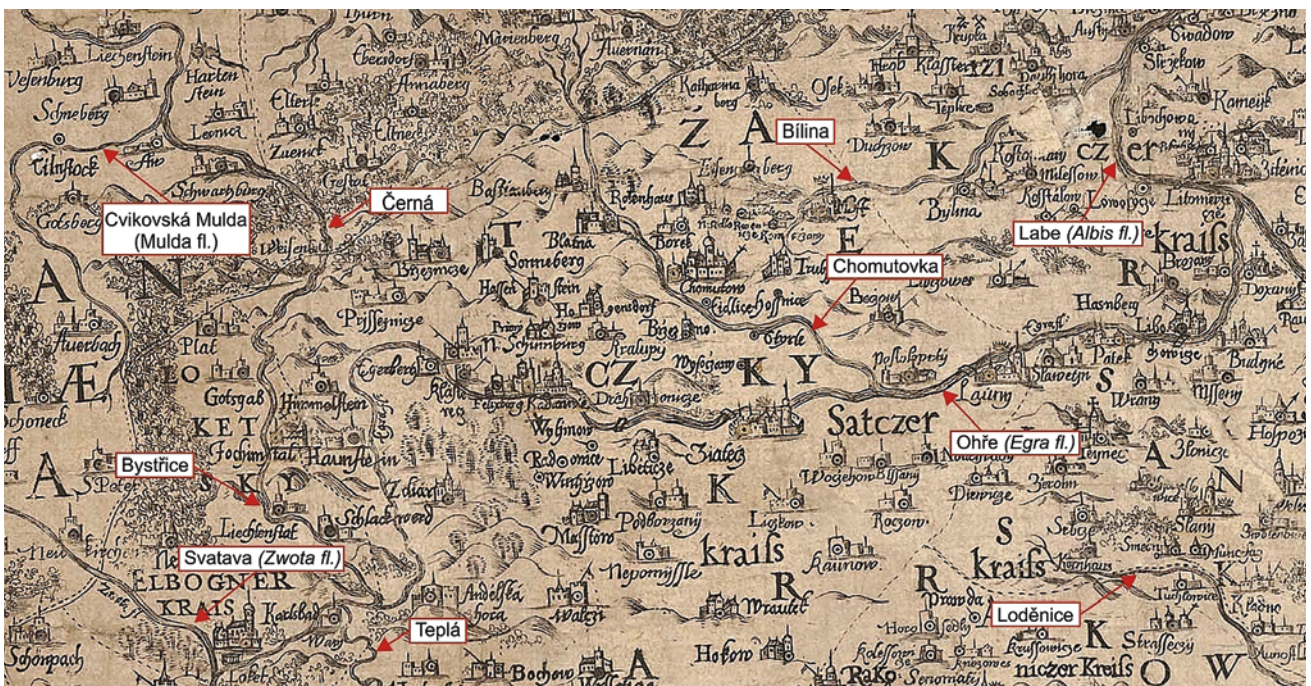


Fig. 8 Connection of the two rivers Černá and Bystřice and the Ohře river on the 1st edition of Aretin's map. Source: National Archives of the Czech Republic.

Chlumec nad Cidlinou (*Chlumecz*) and flows into Labe; see Fig. 7. Today, the river creates a large arc from Chlumec nad Cidlinou through Žiželice, towards the west. At the village of Chotěboř (*Chotěborz*) the spring of the Doubrava river is located. However, it rises near the village of Radostín, which is less than twenty kilometers southeast of Chotěboř, and west of Týnec nad Labem (*Teynecz*), it proceeds to Labe. In Nymburk, the Mrlina river flows into Labe. It runs through Křinec (*Skrzinecz*), continues to Rožďalovice (*Rozdalowice*), and further north. However, it does not turn east to Kopidlno (*Kopydlno*) but flows around Libáň (*Libaně*) from the west, instead of the east. The spring of the Mrlina river is depicted southwest of Staré Hradky, with Mrlina rising in the village of Příklad. The Jizera river and its right-side tributary might be confused, as the river marked as Jizera follows the present course of the Kamenice river closely.

Another right-side tributary of Labe is the Košátky stream. It rises in Mšeno (*Msseno*), where on Aretin's map the stream is shown as far as Kropáčova Vrutice

(*Wrutice*). The Vltava river flows into the Labe river in Mělník.

The confluence of the Labe and Ohře rivers, depicted in Litoměřice, corresponds to the current state; see Fig. 8. In Postoloprty (*Postoloprtyj*) the Chomutovka river flows into the Ohře river. Its spring is located at the southern tip of the Marienberg instead of the Krušné ("Ore") Mountains. Then, the river flows around the village of Blatná (*Blatná*) from the east instead of the west. At Karlovy Vary (*Karlsbad Wary*) the rivers Teplá and Bystřice flow into Ohře. The Bystřice river was probably connected with the Černá river, as this river is also drawn as a right-side tributary of Cvikovská Mulda, which would correspond to Černá. The situation is illustrated in Fig. 8. Another tributary of Ohře is the Svatava river, which was probably joined to Bílý Halštřov. Svatava actually rises south of the town of Schöneck, i.e. north-east of Adorf (*Adorff*), where Bílý Halštřov flows.

The spring of the Jihlava river is depicted in the Pelhřimov region. Then, the river flows through Třebíč

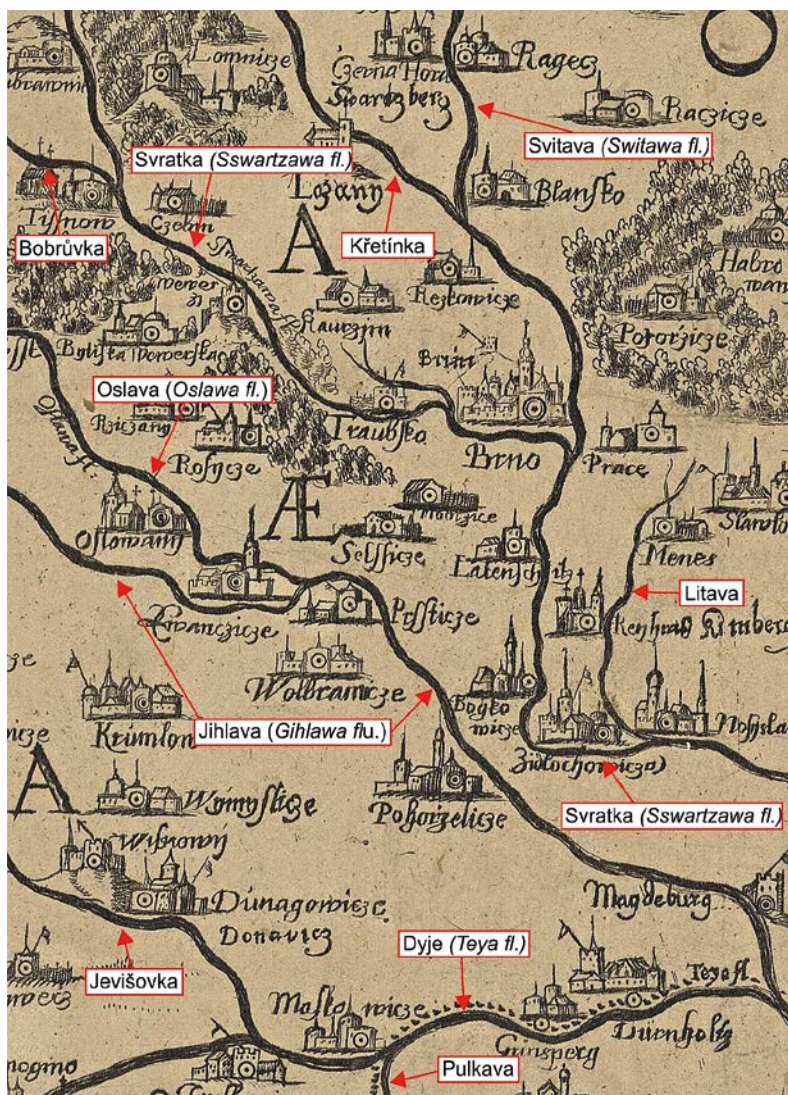


Fig. 9 Watercourses around the Jihlava river, 1st edition of Aretin's map. Source: Map Collection of the Faculty of Science, Charles University.



Fig. 10 Identification of German watercourses on the 4th edition of the Aretin map. Source: Map Collection of the Faculty of Science, Charles University.

(Trzebitz) and Vladislav (*Wladislaw*). At Ivančice (*Iwanczice*) the Oslava river flows into the Jihlava river, which then flows into the Dyje river. Just before the outflow to the Nové Mlýny reservoir on Dyje, Svatka flows into Jihlava; see Fig. 9. It rises northeast of Žďár nad Sázavou in the Žďárské vrchy Hills. In the map, its source is marked at the village of Swoys, south of Svojanov (*Swoganow*). Instead of passing through Nedwedicz, the river flows around it in the west direction. The Bobrůvka river, sometimes marked as the Loučka river, flows into it at Tišnov (*Tissnow*). Then, Svatka continues through the village of Veverská Bítýška (*Bytiska Wewerska*), which is depicted southeast, but the river passed it.

In Brno, the Svitava river flows into the Svatka river, and its source is correctly depicted north of the village of the same name (*Switawy*). The river Svitava bypasses Boskovice (*Bozkowice*) from the west (instead of the east), with an unnamed river inflowing in Blansko. Probably, given the spring in the surroundings of Polička (*Policzka*), it is the Křetínka river. It proceeds through Svojanov (*Swoganow*), while it continues south past Kunštát (*Kunstat*), and then flows around Černá Hora from the west. The confluence of Křetínka and Svitava should be located in Letovice instead of Blansko. Behind Brno, Svatka continues south to Židlochovice (*Zidlochowicze*), where another inflow, probably the river Litava, is depicted. While it rises southeast of Cetechovice, continues west, and

turns southwest to Židlochovice near Slavkov u Brna, its flow is south on the map; see Fig. 9.

The rivers in the south part of the map do not have assigned names. The Pulkava spring is also missing. It rises at the village of Ludweishofen, north of Horn, and its course turns southwest from its outflow to Pulkau (*Pulka*). Three right-hand tributaries join it and further flows south from Eggenburg (*Egenborg*). On the map's boundary, it probably flows into the Kamp river. An unnamed river, entering the map area west of the cartouche, flows through Hollabrunn (*Hollbrunn*) and Gollersdorf (*Gellersdorf*). It is probably the Göllersbach river, which flows through the villages mentioned above. On the map, the river does not aim eastwards, where it should pass through Enzendorf im Thale (*Enczendorf*), but instead it flows around from the west and proceeds north-westwards towards Pulkava.

In the Southwest (above the map scale), the Danube river with its three left-side inflows (Gaißa, Ilz and Erlau from the West) is depicted. An unnamed watercourse flows east of Danube, bypassing the town of Freyung (*Freiung*) from the west; this could be the Erlau river. Towns are depicted inaccurately in this part of the map; for example, Aigen-Schlägl (*Sslegel*) is located southeast of Freyung and Fürholz (*Furholtz*), while the map shows this town northeast. This river probably represents Große Mühl – it flows through Aigen-Schlägl and then continues into Danube. The situation is shown in Fig. 10.

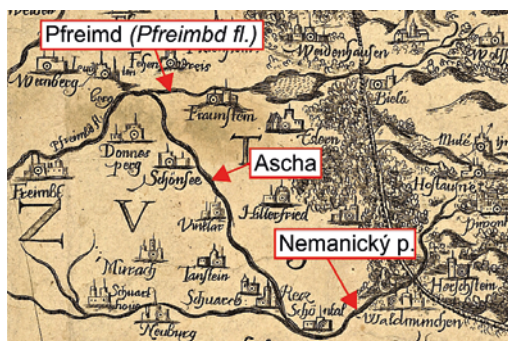


Fig. 11 Incorrect connection of watercourses on the 4th edition of Aretin's map. Source: Map Collection of the Faculty of Science, Charles University.

Above the legend, we can find the Regen river. It rises in the Šumava region as the *Großer Regen* river. At Zwiesel, it continues to the *Kleiner Regen* river and then into the *Schwarzer Regen* river. From the city of Regen, it turns northwest. In *Bad Kötzing* (*Köczing*), the *Weißer Regen* river flows through and continues as the Regen river; see Fig. 10. Behind *Nittenau* (*Nitnau*), it turns south to *Regensburg*, where it flows into Danube. North of Regen in the Bohemian Forest it joins *Nemanice* stream. The *Ascha* river flows into it at *Rötz* (*Recz*), their confluence should be west of *Neunburg vorm Wald* (*Neuburg*). The spring of *Ascha* is missing from the map. Instead, the river continues incorrectly to the *Pfreimd* river, see Fig. 11.

The flow of *Cvikovská Mulda* follows the current watercourse, but the river is interrupted at the village of *Penig* (*Penig*), with a sword held by an imperial eagle in the gap. The confluence of *Cvikovská Mulda* and *Kamenice* is located north of *Wechselburg*, but the correct place is two kilometers to the south. To the east of the *Kamenice* river, the *Sapava* river is drawn, but its shape is skewed. Aretin probably merged two rivers *Flája* and *Sapava*. From *Flöha*, the *Sapava* river continues northwards, and it later flows into the *Freiber Mulde* river.

The *Smědá* and *Lužická Nisa* rivers are depicted north of the spring of the *Ploučnice* river. *Smědá*

follows the border between Germany, Poland, and Czechia, while *Lužická Nisa* actually forms this border. Its course has been shortened, and instead of *Lučany nad Nisou*, its source is drawn at the town of *Zittau* (*Zitawa*).

The *Bobr* river rises northeast of the spring of the *Úpa* river above the village of *Krzeszów* (*Krzesow*). Its source should be located towards the town of *Žacléř*. On the map, the river continues through *Kowary* (*Schmidberg*) and *Miedzianka* (*Kupferberg*) and turns west. Another name for this river is *Kamienna*. However, the *Kamienna* river is a left-hand inflow river of the *Bóbr* river. Aretin joined two different watercourses into one.

As mentioned above, Aretin made a mistake in the northeastern part of the map field. Another inaccurately depicted river is *Stěnavá*, which flows into the *Úpa* river. It should rise south of *Wałbrzych*, where the river continues southeast to *Broumov*, and an unnamed tributary, probably the *Pošna*, flows into *Stěnavá* from the right. The *Kladská Nisa* river is depicted as a left-side tributary of the *Stěnavá* river as well as the left-hand tributary of the *Kladská Nisa* river, the *Dušnická Bystřice* river. Its source is near the village of *Duszniki-Zdrój* (*Reinecz*), but it rises north of *Velká Deštná*, near the *Eagle Mountain*.

The spring of the *Morava* river is west of the springs of the *Divoká* and *Tichá Orlice* rivers, but in reality, it is further north, below the top of *Králický Sněžník*. The river flowing through *Moravská Třebová* (*Trzebowa Morawska*) is probably the *Třebůvka* river. However, it rises to the southwest, not to the north of the town.

An overview of all named watercourses on Aretin's map of Bohemia is shown in the Appendix 1.

4.2.2 Water areas on Aretin's map

A total of 19 water areas are drawn on Aretin's map, while only two are described. The first is the *Jordan pond*, created in 1492 by damming the *Košín* stream, the oldest dam reservoir in Czechia (Krajčíc 2019). The pond is part of the *Tábor* city but is plotted easter.



Fig. 12 The *Betlém pond* (*Badhamer See*) on Aretin's map (2nd and 4th editions). Source: Map Collection of the Faculty of Science, Charles University.



Fig. 13 Water areas in the Třeboň region (4th edition of Aretin's map). Source: Map Collection of the Faculty of Science, Charles University.

The second labeled water area is the Betlém pond (*Badhamer See*), located on the Teplá river near the village of the same name; see Fig. 12.

There are also eight unnamed water areas in the Třeboň region; see Fig. 13. The largest one could be the Rožmberk pond, according to its position to Lomnice nad Lužnicí (*Lomnicze*) and Třeboň as well as due to Lužnice river flowing through it. The history of fish farming in the Třeboň region refers to the 15th century when already 20 ponds in the Třeboň region were established. Unfortunately, the remaining seven water areas have not successfully been identified; see Fig. 13.

Northern the village of Plasy (*Plasij*) the Střela river is shown with a water area (Mladotice pond) founded already in the 14th century (Jánský 2010), but it is now defunct. Its existence was confirmed by the maps of the Second military mapping, where the pond near Mladotice was depicted. Fig. 14 shows the difference in the landscape in the 19th century and today.

The water area near the village of Všeruby (Böhmicsh Weijer) refers to the pond of the same name. The spring of the Úslava river near Blatná, as well as the pond system established in the 15th century, are depicted.



Fig. 14 The Mladotice pond on maps of the 2nd military mapping (top left), at present and on Aretin's map (2nd and 4th edition). Source: Map Collection of the Faculty of Science, Charles University; State Administration of Land Surveying and Cadastre.



Fig. 15 Examples of bridges in Louny, Libochovice and Roudnice on Aretin's map (1st edition). Source: National Archives of the Czech Republic.

Another pond is located north of Eslarn (Eslern) on the Pfreimd river. The larger water area is Železná pond, but instead of being north of Eslarn, it lies western the village of Bělá nad Radbuzou (Bielá). The last unnamed water area is located at the spring of Labe and could represent the Labe meadow in the vicinity of the Labe spring.

4.2.3 Bridges on Aretin's map

All four editions of Aretin's map of Bohemia show the same amount of bridges, eight in total. The bridges are depicted over the Vltava river in Prague, Labe river in Mělník, Roudnice n. Labem and Litoměřice and over the Ohře river in Libochovice, Louny, Žatec and Drahonice. The bridges are drawn simply, using two thicker unfilled lines, either closed at the end, forming a rectangle, or open and stretching across the hatched river; see Fig. 15.

4.3 Cartometric analysis of watercourses on Aretin's map

Cartometric analyses of the first edition of Aretin's map of Bohemia provided in TIFF format with a resolution of 400 DPI, were performed in the MapAnalyst software. While the analyzed map does not have any cartographic projection, the OpenStreetMap layer used as the reference map utilized the Web Mercator coordinate system (EPSG: 3857). Georeferencing was performed using the affine transformation, which is non-conformal but removes the map sheet distortions efficiently. In total, 70 identical points evenly covering the whole map area, respecting the historical and social development of the territory, were collected. The analyses provided the following results. The estimated scale of the Aretin map is 1 : 544,000; the map is rotated by 9° to the east, its standard deviation on the identical points is ±5,322 m, and the average positional error is ±7,526 m. Based on the calculation of displacement vectors, the least accurately drawn towns are Jihlava (18 km), Bad Kötzing (15.0 km), Dobruška

(14.3 km), Domažlice (13.7 km) and Polná (13.0 km). On the contrary, the most accurately depicted are Mšeno (0.9 km), Znojmo (1.5 km), and Petrovice (1.6 km). Fig. 16 shows a deformation grid illustrating the local geometric distortions of the Aretin's map.

The results are in accordance with previous works. Kuchař (1936) estimated the scale as 1 : 504,000, Vejrová (2008) as 1 : 510,000, Bayer (2009) as 1 : 544,766. He also identified the town of Jihlava (18 km) as the most inaccurately depicted and determined the mean positional error of the map as ±7,860 m.

5. Conclusion

The paper is focused on comprehensive content and basic cartometric analyses of watercourses on four known editions of Aretin's map of Bohemia from 1619, 1632, 1665, and before 1747. Several unnamed watercourses and areas were identified using modern computational and geoinformation tools. Furthermore, the graphical representation of hydrographic elements has been analyzed.

In general, we assume that the depiction of watercourses on maps from the 16th and 17th centuries was rather vague or even inaccurate. This reflects the state of knowledge, the quality and quantity of available sources and the limited mobility of people.

While previous maps of the Bohemian Kingdom recorded 9 watercourses on Klaudyán's map of Bohemia (1518) and 61 watercourses on Criginger's map of Bohemia (1568), Aretin's map shows a total of 194 watercourses. Of these, 41 are described on the map and 97 have been newly named in the process of this work.

The results clearly show that the number of watercourses plotted on these maps increases very significantly over time as the map becomes more detailed.

Regarding old maps, no supplementary information about their creation is currently available. For

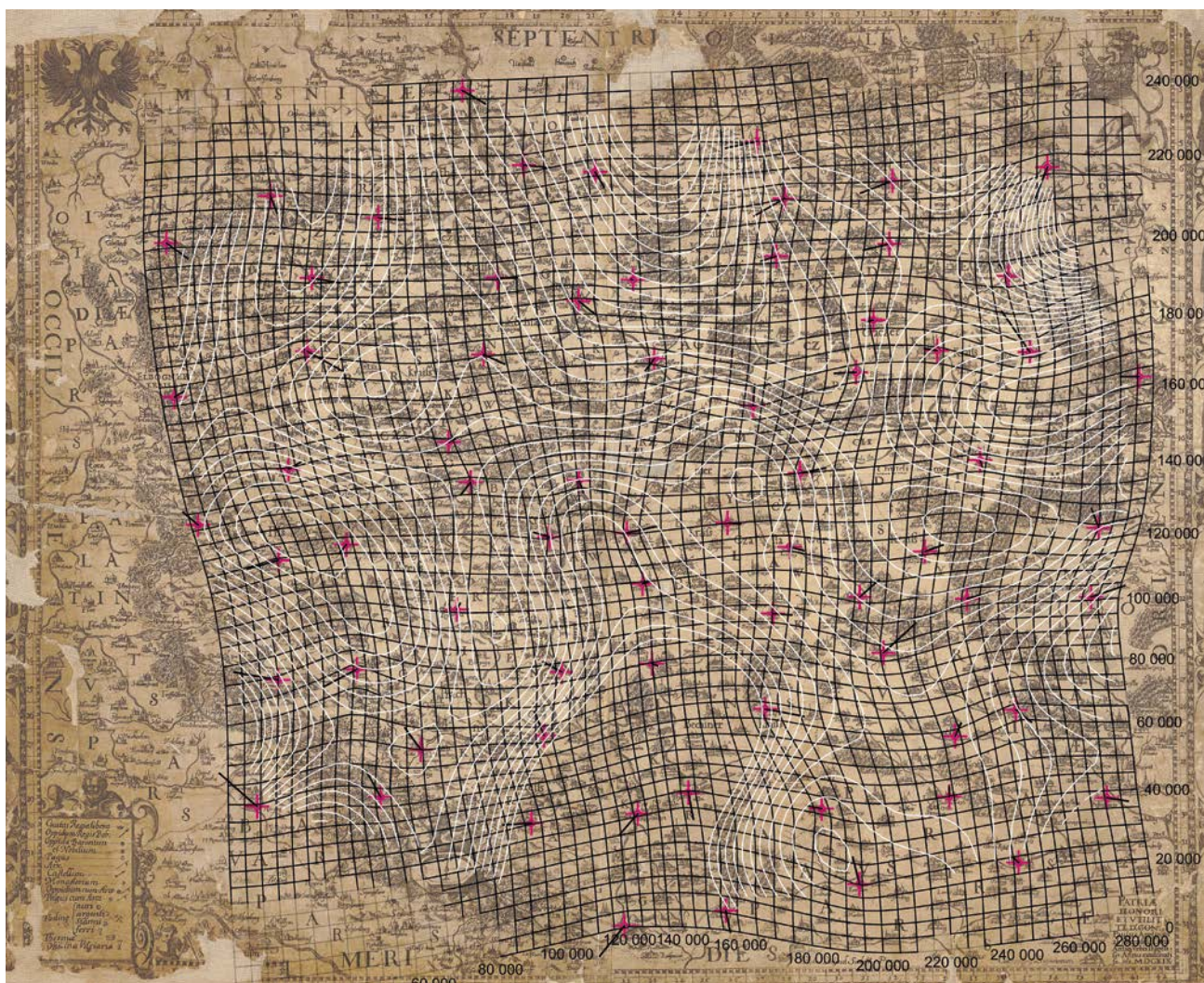


Fig. 16 Deformation grid with identical points and their displacement vectors on the Aretin's map. Source: National Archives of the Czech Republic.

Aretin's map, it cannot be proven whether it is based on the field measurements. Aretin was not a surveyor, but he might, at least partially, use measurements made by the surveyor Simon Podolsky (Kuchař 1936). The lack of map projection may cause graphical errors in drawing watercourses (especially Chrudimka or Saxon rivers).

It has been confirmed that all analyzed editions of Aretin's map of Bohemia contain many graphical errors. In some cases, a watercourse was assigned by two names since its topography corresponded partly to more rivers (Bóbr+Kamienna, Bystrice+Černá, Flöha+Zschopau). Two watercourses were also identified as Metuje. A significant error was found in the depiction of the Labe and Cidlina rivers confluence. Pavel Aretin worked as a tutor of Hynek Březnický from Náchod. It is therefore interesting that in this locality, i.e. in East Bohemia, there are most errors in the drawing of watercourses.

All 138 identified water features (including their names in all map editions) were summarized in a

table; see Appendix. The attached table shows that in terms of the number of watercourses drawn, the individual editions differed only slightly from each other. In particular, there are differences in the drawing of the course of some watercourses; see chapter 4.2.1.

This paper provided new findings about the four editions of Aretin's map. Most watercourses and water areas were identified, their positional inaccuracies were estimated. It is remarkable, that of the 70 longest current Czech rivers, only 11 are not drawn on the map. These rivers are Želivka, Rokytná, Blanice (a tributary of Sázava), Bystrice (a tributary of Cidlina), Lomnice, Stropnice, Dědina, Trnava, Nežárka, Skalice and Klabava. Only two water areas were labeled, four were identified by the authors as Rožmberk, the Všeruby pond, Bílý Halštrov and the Mladotice pond. Of the remaining 13 water areas, 7 are located in the Třeboň region, where the history of fish farming dates back to the middle of the 15th century. In 1609–1611 Aretin worked in the Třeboň region as a secretary of Peter Wok of Rosenberg. It appears very likely that he

knew the locality well and plotted the local pond system on the map. However, adequate sources clearly identifying the depicted water areas in this location have not been found. Based on the results of analyses, comparative methods are suitable for assessing the content of old maps.

Basic cartometric analyses were carried out on the first edition of the map; its scale 1 : 544,000 was determined and compared with the previous results. With an average positional error of $\pm 7,526$ m, the most considerable positional errors were found in southern, south-eastern, and northeastern Bohemia. The least accurately depicted city is Jihlava (18 km). The results of the cartometric analyses illustrate the well-known fact, the lack of solid geodetic bases. Thanks to the application of digital technology (MapAnalyst), the results can easily be visualized.

Summarizing the above-mentioned facts, the main contribution of the paper was the identification, recognition, and description of all the watercourses and water areas. This process was considerably simplified and accelerated by the use of modern software tools.

Table containing a list of watercourses including their labels in the individual editions of Aretin's map of Bohemia can be found in Appendix.

Acknowledgements

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Appendix 1 List of hydronyms on Aretin's map of Bohemia Kingdom.

	Aretin 1st edition, 1619	Aretin 2nd edition, 1632	Aretin 3rd edition, 1665	Aretin 4th edition, before 1747	Current name	State
Rivers						
1	–	–	–	–	Ascha	DE
2	–	–	–	–	Berounka	CZ
3	–	–	–	–	Bílá Řežná / Weißer Regen	DE
5	–	–	–	–	Bílina (CZ)	CZ
6	–	–	–	–	Bílý Halštrov / Weiße Elster	CZ, DE
7	–	–	–	–	Bílý p.	CZ
8	Blánice fl	Blánice fl	Blánice fl	Blánice fl	Blanice	CZ
9	–	–	–	–	Bobruvka	CZ
10	Bober fl	Bober fl	Bober fl	Bober fl	+Bóbr	CZ, PL
11	–	–	–	–	Borecký p.	CZ
12	–	–	–	–	Braunaubach	AT
13	–	–	–	–	+Bystřice	CZ
14	X	–	–	–	Cerhovka	CZ
15	Czidlina fl	Czidlina fl	Czidlina fl	Czidlina fl	Cidlina	CZ
16	–	–	–	–	Cikánský p.	CZ
17	Mulda fl	Mulda fl	Mulda fl	Mulda fl	Cvikovská Mulda / Zwickauer Mulde	DE
18	–	–	–	–	+Černá / Schwarzwasser	CZ, DE
19	–	–	–	–	Černá Řežná / Schwarzer Regen	DE
20	–	–	–	–	Červený p.	CZ
21	X	–	–	–	Divoká Orlice	CZ
22	X	Daubrawa fl	Daubrawa fl	Daubrawa fl	Doubrava	CZ
23	Danub fl	Danub fl	Danub fl	Danub fl	Dunaj / Donau	DE
24	Weistritz fl	Weistritz fl	Weistritz fl	Weistritz fl	Dušnická Bystřice / Bystrzyca Dusznicka	PL
26	Teya fl	Teya fl	Teya fl	Teya fl	Dyje / Thaya	AT, CZ
27	–	–	–	–	Erlau	DE
28	Ssopa fl	Ssopa fl	Ssopa fl	Ssopa fl	+Flöha / Fláje	CZ, DE
29	–	Mulda fl	Mulda fl	Mulda fl	Freiberská Mulda / Freiburger Mulde	CZ, DE
30	–	–	–	–	Frombach	DE
31	–	–	–	–	Gaißa	DE
32	–	–	–	–	Gmoosbach	AT
33	–	–	–	–	Göllersbach	AT
34	–	–	–	–	Große Mühl	DE
35	–	–	–	–	Große Taffa	AT
36	–	–	–	–	Großer Kamp	AT
37	–	–	–	–	Großer Regen	DE
38	Kempnitz fl	Kempnitz fl	Kempnitz fl	Kempnitz fl	Chemnitz	DE
39	–	–	–	–	Chomutovka	CZ
40	Chrudimka	X	X	–	Chrudimka	CZ
41	–	–	–	–	Ilz	DE
42	–	–	–	–	Jevišovka	CZ
43	Gihlawa fl	Gihlawa fl	Gihlawa fl	Gihlawa fl	Jihlava	CZ
44	Gizera fl	Gizera fl	Gizera fl	Gizera fl	Jizera	CZ
45	–	–	–	–	Kamenice	CZ
46	Zak fl	Zak fl	Zak fl	Zak fl	+Kamienna / Zacken	PL
47	–	–	–	–	Chuba / Kamp	AT

	Aretin 1st edition, 1619	Aretin 2nd edition, 1632	Aretin 3rd edition, 1665	Aretin 4th edition, before 1747	Current name	State
48	–	–	–	–	Katzbach	DE
49	Nissa fl	Nissa fl	Nissa fl	Nissa fl	Kladská Nisa / Nysa Kłodzka	CZ, PL
50	–	–	–	–	Košatecký p.	CZ
51	–	–	–	–	Kouba / Chamb	DE
52	X	X	X	–	Krounka	CZ
53	–	–	–	–	Křemenný p.	CZ
54	–	–	–	–	Křemžský p.	CZ
55	–	–	–	–	Křetínka	CZ
56	Albis, Labe fl	Albis, Labe fl	Albis, Labe fl	Albis, Labe fl	Labe	CZ, DE
57	Albis, fons	Albis, fons	Albis, fons	Albis, fons	Labe – pramen	CZ
58	–	–	–	–	Litava	CZ
59	–	–	–	–	Litavka	CZ
60	–	–	–	–	Loděnice	CZ
61	X	–	–	–	Loučná	CZ
62	Neise fl	Neise fl	Neise fl	Neise fl	Lužická Nisa	CZ
63	Lusnicze fl	Lusnicze fl	Lusnicze fl	Lusnicze fl	Lužnice	AT, CZ
65	Kl[einer] Regen fl	Kl[einer] Regen fl	Kl[einer] Regen fl	Kl[einer] Regen fl	Malá Řezná / Kleiner Regen	CZ, DE
67	Maltz fl	Maltz fl	Maltz fl	Maltz fl	Malše / Maltsch	AT, CZ
68	Metuge fl	Metuge fl	Metuge fl	Metuge fl	Metuje	CZ
69	–	–	–	–	Mezný p.	CZ, DE
70	–	–	–	–	Mödringbach	AT
71	–	–	–	–	Morava	CZ
72	Moraviae, fons	Moraviae, fons	Moraviae, fons	Moraviae, fons	Morava – pramen	CZ
73	–	–	–	–	Moravská Dyje / Mährische Thaya	AT, CZ
74	–	–	–	–	Mrlina	CZ
75	Misa fl	Misa fl	Misa fl	Misa fl	Mže / Mies	CZ, DE
76	X	X	X	–	Novohradka	CZ
77	–	–	–	–	Odrava	CZ, DE
78	Egra fl	Egra fl	Egra fl	Egra fl	Ohře / Eger	CZ, DE
79	Orlicze fl	Orlicze fl	Orlicze fl	Orlicze fl	Orlice	CZ
80	Oslawa, Woslawa fl	Oslawa, Woslawa fl	Oslawa, Woslawa fl	Oslawa, Woslawa fl	Oslava	CZ
81	Ottawa fl	Ottawa fl	Ottawa fl	Ottawa fl	Otava	CZ
82	Czirla fl	Czirla fl	Czirla fl	Czirla fl	Peřčnica	PL
83	Pf[reimbd] fl	Pfreimbd fl	Pfreimbd fl	Pfreimbd fl	Pfreimd	CZ, DE
84	Pleisa fl	Pleisa fl	Pleisa fl	Pleisa fl	Pleißebach	DE
85	Pulsnicz fl	Pulsnicz fl	Pulsnicz fl	Pulsnicz fl	Ploučnice	CZ
86	–	–	–	–	Pošna	PL
87	–	–	–	–	Pulkava / Pulkau	AT
88	–	–	–	–	Purzelkamp	AT
89	–	–	–	–	Radbuza	CZ
90	Teya	Teya	Teya	Teya	Rakouská Dyje	AT
91	–	–	–	–	Rakovnický p.	CZ
92	–	–	–	–	Retzbach	AT
93	Rosla fl	Rosla fl	Rosla fl	Rosla fl	Reslav / Röslau	CZ, DE
94	–	–	–	–	Řezná / Regen	CZ, DE
95	Sazawa fl	Sazawa fl	Sazawa fl	Sazawa fl	Sázava	CZ
96	–	–	–	–	Schmida	AT

	Aretin 1st edition, 1619	Aretin 2nd edition, 1632	Aretin 3rd edition, 1665	Aretin 4th edition, before 1747	Current name	State
97	–	–	–	–	Nemanický p. / Schwarzach	DE
98	–	–	–	–	Smědá / Witka	CZ, PL
99	–	Spre fl	Spre fl	Spre fl	Spréva / Spree	CZ, DE
100	Steina fl	Steina fl	Steina fl	Steina fl	Stěna / Ścinawka	CZ, PL
101	–	–	–	–	Střela	CZ
102	–	–	–	–	Sulzbach	DE
103	Zwota fl	Zwota fl	Zwota fl	Zwota fl	Svatava / Zwota	CZ, DE
104	Switawa fl	Switawa fl	Switawa fl	Switawa fl	Svitava	CZ
105	Sswartzawa fl	Sswartzawa fl	Sswartzawa fl	Sswartzawa fl	Svratka	CZ
106	–	–	–	–	Šlapanka	CZ
107	–	–	–	–	Taffa	AT
108	–	–	–	–	Teplá	CZ
109	–	–	–	–	Tichá	CZ
110	Orlicze fl	Orlicze fl	Orlicze fl	Orlicze fl	Tichá Orlice	CZ
111	–	–	–	–	Tismenický p.	CZ
112	–	–	–	–	Trojanský p.	CZ
113	–	–	–	–	Třebovka	CZ
114	–	–	–	–	Třebůvka	CZ
115	–	–	–	–	Úhlava	CZ
116	–	–	–	–	Úslava	CZ
117	Vpawa fl	Vpawa fl	Vpawa fl	Vpawa fl	Úpa	CZ
118	Wltawa, Wulda fl	Wltawa, Wulda fl	Wltawa, Wulda fl	Wltawa, Wulda fl	Vltava	CZ
119	Nab fl	Nab fl	Nab fl	Nab fl	Lesní Nába / Waldnaab	DE
120	Ssopa fl	Ssopa fl	Ssopa fl	Ssopa fl	+Zschopau	DE
121	–	–	–	–	Zwettl	AT
Water areas						
1	Badhamer See	Badhamer See	Badhamer See	Badhamer See	Betlémský	CZ
2	–	–	–	–	Bílý Halštrov	CZ
3	Jordan	Jordan	Jordan	Jordan	Jordán	CZ
4	–	–	–	–	Mladotický r.	CZ
5	–	–	–	–	Rožmberk	CZ
6	–	–	–	–	u Blatné	CZ
7	–	–	–	–	u Eslarn	CZ?
8	–	–	–	–	u Lam	DE
9	–	–	–	–	u pramene Labe	CZ
10	–	–	–	–	u Třeboně	CZ
11	–	–	–	–	u Třeboně	CZ
12	–	–	–	–	u Třeboně	CZ
13	–	–	–	–	u Třeboně	CZ
14	–	–	–	–	u Třeboně	CZ
15	–	–	–	–	u Třeboně	CZ
16	–	–	–	–	u Třeboně	CZ
17	–	–	–	–	Všerubský r.	CZ

Notes to table:

fl, flu from Latin fluvius, a river; – unnamed watercourse; X watercourse is not plotted; AT watercourse flows through Austria; CZ watercourse flows through the Czechia; DE watercourse flows through Germany; PL watercourse flows through Poland; + two watercourses are connected into one (Bóbr+Kamienna, Bystrice+Černá, Flöha+Zschopau)