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On the road from the Early to High Middle Ages: Glass of the 9th–13th centuries in Bohemia

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The paper discusses the main changes in the glass and glass artefacts in Bohemia in the Early and at the beginning of the High Middle Ages (AD 850–1300) from an archaeological and archaeometric point of view. The results of chemical analyses (SEM-EDS) presented in the VITREA database identify the different chemical types of glass used for personal glass ornaments (beads and rings), glass windowpanes, vessels and other products. A major complex change, both in the type of artefacts and sites, and in the chemical composition of glass, occurred in Bohemia shortly after 1000. Changes in the following period took place gradually, culminating in the second half of the 13th century when glass-making started in local glasshouses.

KEY-WORDS: Bohemia, Middle Ages, archaeometry, chemical type of glass, glass-working, glass-making, glass ornaments, vessel, window panes

Different approaches can be applied to research on glass objects and evidence of glass production from prehistoric to modern times: typological, chronological, culture-historical, ethnological, and, last but not least, chemical. The results of archaeometric investigations, presented in the VITREA database since 2010, are coupled with archaeological observations to provide the essential body of evidence for this study focusing on changes in glass production in Bohemia during the period between 850 and 1300[1].

TYPES OF GLASS ARTEFACTS

The collection of analysed glass artefacts from the period between 850 and 1300 comprises all the main categories of objects made during this time: beads, rings, vessels, windowpanes and other small objects (Černá *et al.* 2015).

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[1] Regarding periodization of the Middle Ages in Bohemia, the period 850–1200 is known as the Early Middle Ages, while the period 1200–1300 is part of the High Middle Ages.

Beads occurred in Bohemia between 850–1000 in a variety of types, classified by Z. Krumphanzlová in the 1960s (Krumphanzlová 1965). Necklaces consisted of rounded, annular and cylindrical beads, olive beads, G-beads[2] and regular or irregular miniature beads. Segmented and segmented foiled[3] beads were also represented in high numbers. In contrast, prismatic beads were relatively rare. Throughout the 9th century monochrome beads prevailed over polychrome ones. Beads decorated with trails (in the shape of waves, crossing lines and bands), dots, eyes or *millefiori* eyes and *millefiori* beads occurred in limited quantities.

However, the information of beads for the 11th–13th centuries is insufficient for a full typological classification due to the low number. The range of beads is significantly narrower. Several types were known from the earlier period, i.e., segmented, regular rounded and cylindrical beads, but the types that were the most characteristic of the period are irregular cylindrical, annular and conical wound beads. There were also new variants of earlier types, such as red rounded and prismatic beads (Žalany) or beads with raised dots (Prague, Loretánské Square).

Rings/finger rings were an integral part of early medieval production and, from the 10th century onwards, were distributed over a large territory in central and eastern Europe. They appeared in Bohemia in the 11th century and continued to be present until the end of the 13th century, in exceptional cases through the beginning of the 14th century. Czech scholars have studied these artefacts from the 1960s (Nechvátal and Radoměrský 1963; Hejdová and Nechvátal 1967). As of 2000, 14 sites with finds of rings/finger rings were registered and published (Černá 2000), but at least 40 sites are currently known assuming that Prague is a single site (Fig. 1). One of the most important sites beside Prague is the town of Žatec (Černá 2007) with about 40 completely or partly preserved rings. From a typological point of view, the types most frequently represented in Bohemia are simple monochrome rings, rings with polychrome glass trails and shield rings with a plate fused onto the rim (types A, B and C according to Olczak 2000). Simple monochrome rings clearly dominate the other types in the archaeological record. This group also includes, in our opinion, a specific shape called *Ringperlen* by some scholars, which occurred at the end of the 12th and especially in the 13th century. As a rule, these rings are smaller and more corroded, making them difficult to analyze. It was usually impossible to determine the chemical type of glass used in their manufacture. The corrosion has made them an opaque black, pink or ochre color. In sporadic cases, the original greenish translucent color of the glass could be established.

Vessel glass was also present. The earliest vessels, dated to the second half of the 9th century, were found in the so-called princely grave at Kolín. One of the two vessels

[2] For olive and G-beads see Košta and Tomková 2011: 199–214; Košta *et al.* 2011: 586–607; Košta and Tomková 2012: 199–214.

[3] For segmented foiled beads and differences in making of segmented beads see Greif and Nalbani: 2015, 355–375; Staššíková-Štukovská and Plško 2015: 389–399.

discovered was a unique flat bowl, the other a beaker with trailed decoration. Both are occasionally encountered on other sites in Europe, e.g., in neighbouring Moravia, Slovakia, the Netherlands, Sweden, etc. (Košta *et al.* 2011; Košta and Lutovský 2014: 120–121).

Other vessels date to the 11th–12th centuries. Drinking glass from this period is attested by rare and atypical small fragments from Prague-Prague Castle, Prague-Old Town, Stará Boleslav and Žatec, that it is almost impossible to determine the original form. Only in the cases of Prague-Konvikt and Stará Boleslav the fragments evidently belonged to ribbed beakers (Černá 2000).

In the 13th century, especially in the second half of the century, there was a considerable increase in the number of finds. Vessels often were preserved fragmentarily, complete shapes being very rare. Compared to the earlier phase, the range of vessel shapes used in Bohemia in this period can be reconstructed more easily and precisely. It is surprisingly rich and includes four basic forms of vessel: beakers, bottles, jugs and goblets. The beakers, in particular, appear in a number of variants. There are: prunted beakers, ribbed beakers, beakers with optic-blown decoration, gilded and enameled beakers, etc. Bottles, although less common, took on several forms, such as bottles

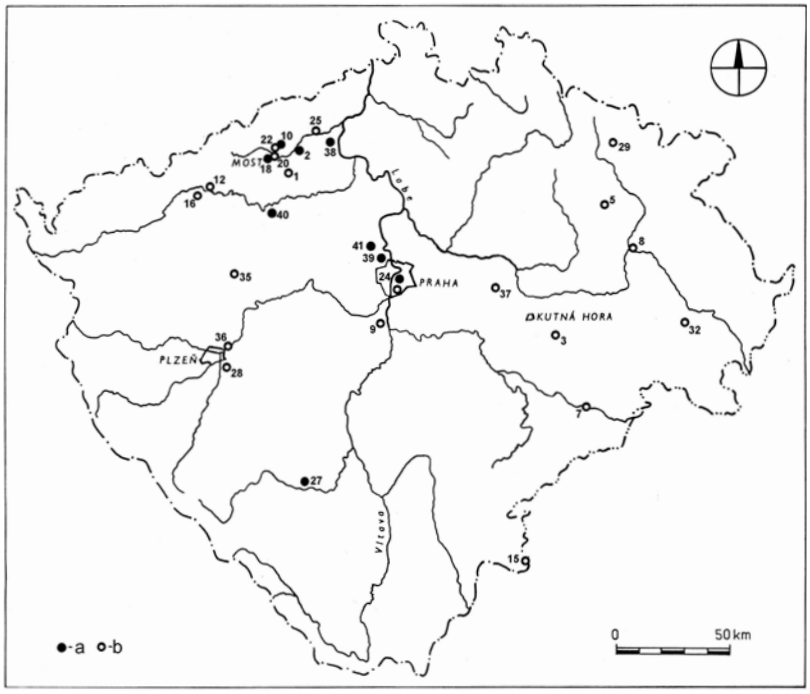


Fig. 1. Bohemia. Glass rings from the 11th to the end of the 13th centuries.
a – 11th–12th centuries; b – 13th century (after Černá *et al.* 2015)

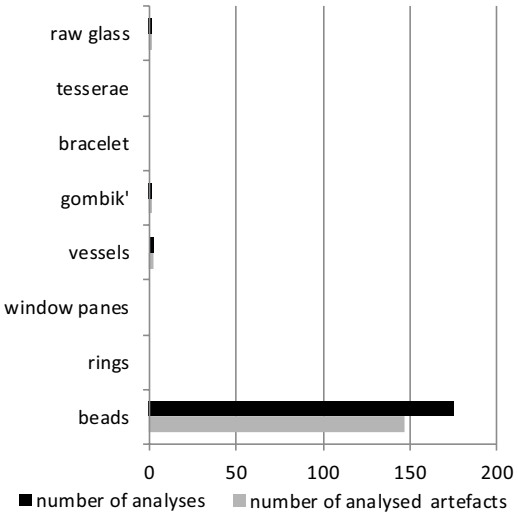
with a ribbed body and bottles with a tubular ring inside. All vessels from the time between the 11th and mid-13th centuries were imported to Bohemia from regions in the Near East, south, southwest or northwest of Europe. Local products appeared next to imports only among the later finds dating from the second half of the 13th century.

Window glass occurred infrequently from the 11th–12th century onwards (Prague, Stará Boleslav) and the 13th century only yielded a slightly higher number of finds (Černá 2004). From a technological-typological point of view panes manufactured by casting can be differentiated from those manufactured by cutting from larger panes. Earlier finds are monochrome, but there is a fragment of a painted window pane from Prague – Richter's house, dating from the mid-13th century.

Other glass objects were very rare in Bohemia during the Early Middle Ages. Looking at the 9th–10th centuries, one observes buttons made of soda-lime glass and glass inlays in metal decorations, metal globular buttons and so-called *kaptorgas*. Objects of this kind are not present among finds from the 11th–13th centuries, but tesserae, raw glass, fragments of an arm ring[4] (all from Žatec) and smoothers (Tisová, Prague) have been documented sporadically (Černá *et al.* 2015).

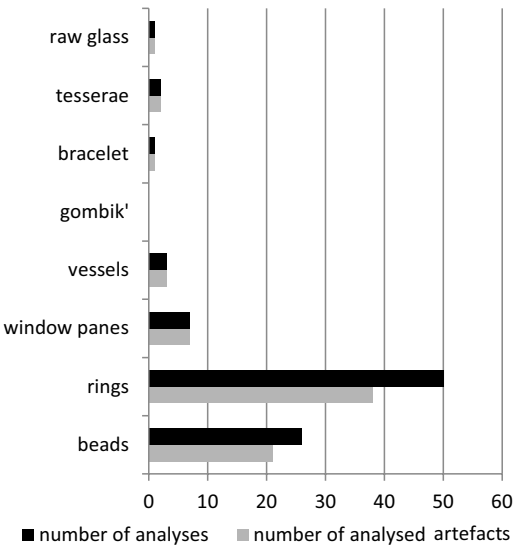
The changes in the range of glass artefacts which took place during the period in question (AD 850–1300) are also reflected in the samples selected for EPMA-SEM-EDS analyses (charts in Fig. 2). Beads predominated in the second half of the 9th and in the 10th century while vessels and other artefacts were rather rare (Fig. 2a). During the 11th–12th centuries, the number of beads dropped (due to their absence in cemeteries) and rings came to the fore (Fig 2b). Arm rings, tesserae and amorphous lumps of

[4] Two more fragments of arm rings are known from Prague-Na Poříčí (Bureš et al. 2000: 23, obr. 3).



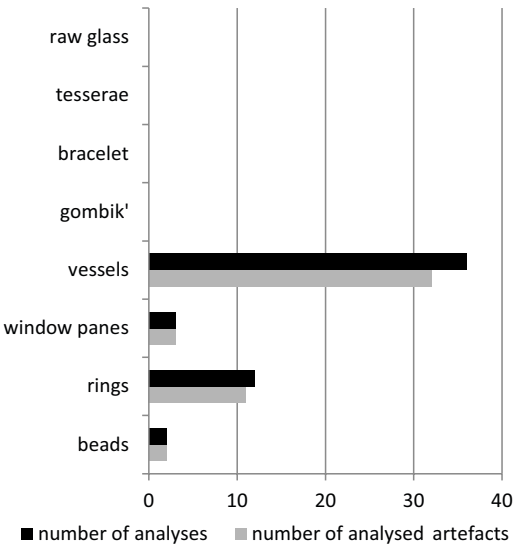
a)

object	number of analysed artefacts	number of analyses
beads	147	175
rings		
window panes		
vessels	2	2
gombik'	1	1
bracelet		
tesserae		
raw glass	1	1
TOTAL	**151**	**179**



b)

object	number of analysed artefacts	number of analyses
beads	21	26
rings	38	50
window panes	7	7
vessels	3	3
gombik'		
bracelet	1	1
tesserae	2	2
raw glass	1	1
TOTAL	**73**	**90**



c)

object	number of analysed artefacts	number of analyses
beads	2	2
rings	11	12
window panes	3	3
vessels	32	36
gombik'		
bracelet		
tesserae		
raw glass		
TOTAL	**48**	**53**

Fig. 2. The changing source base from the mid-9th to the 13th centuries: glass artifacts shown by types in the context of quantity of finds and number of analyses: a – mid-9th to 10th century; b – 11th–12th centuries; c – 13th century (after Černá *et al.* 2015)

raw glass were extremely rare. Window glass appeared in addition to vessel glass, which occurred on a more or less similar level as in the previous period. During the 13th century, the range of glass objects became significantly narrower and glass vessels took a primary role (Fig. 2c).

These changes are correlated to a large extent with the changes in site types/find contexts from which the glass originated. For the 9th–10th centuries, the study of glass is almost exclusively based on finds from cemeteries and only to a limited extent from settlement layers inside strongholds. During the 11th–12th centuries, the situation is almost exactly the opposite. By the 13th century, glass objects had completely disappeared from cemeteries and occurred instead in proto-urban settlements, towns, manor houses, castles, monasteries and glasshouses.

PROVENANCE OF GLASS, GLASS-WORKING AND GLASS-MAKING

Glass vessels and most of the glass beads were imported into Bohemia in the 9th–10th centuries. Olive beads and G-beads (Fig. 3), according to J. Košta and K. Tomková, prove that glass jewellery was manufactured in central Europe from imported raw materials and show that some of the beads may also have been produced directly in Bohemian territory (Košta and Tomková 2011: 335–337; Košta *et al.* 2011: 604).

A similar trend is to be observed throughout the 11th and 12th centuries, glass-working is presumed in the case of some rings/finger rings. There is no archaeological evidence for it from Bohemia, but from neighbouring Moravia the production of rings is documented from at least one site, the lowland hillfort of Vysoká Zahrada near Dolní Věstonice, and there is also some evidence for the existence of a similar workshop in Brno (Himmelová and Měřínský 1987: 129–133; Sedláčková and Zapletalová 2012: 538).

The 13th-century Bohemian small rings may also be imports, possibly from glasshouses located west of Bohemia. If glass artefacts can be dated from the second half of the 13th century, their local provenance is possible as well. It is well known that there were glasshouses in Bohemia at that time where glass was melted from primary raw materials and then processed (Fig. 4). Further, it is precisely from that time onwards that the general trend in the occurrence of glass in settlements begins to change. The total quantity increases and the share of local products seem to grow at the expense of imports, although it is sometimes quite difficult to determine the origin of individual artefacts, i.e., vessels. The determination of their provenance is further complicated by the absence of evidence of finished goods or semi-products from the earliest Bohemian glassworks (with the exception of two sites)[5] that could enable a reconstruction

[5] Several small atypical fragments come from a glasshouse in Svor, whereas excavations at the glasshouse Dolní Podluží I yielded a small fragment of a clay mould with a partly preserved geometric motif (Černá *et al.* 2015).

Fig. 3. Glass-working in central Europe. Olive (1) and G-beads (2) from Bohemia

of their product range. Apart from artefacts made of other materials (pottery or metals), only large amounts of production waste characteristic of the melting phase of glass production are known from these types of sites.

ARCHAEOMETRIC INVESTIGATION

Methods and research limitations

The following conclusions are based on the results of chemical analyses carried out with the EPMA – SEM-EDS method[6] which are stored in the VITREA database (Tab. 1)[7]. As of 2013, it contained data on more than 270 objects from Bohemia dating

[6] Artefacts analyzed before 2000 were measured on a JEOL JSM 25-IIIS scanning electron microscope equipped with a NORAN EDS analyzer. From 2002 to June 2008, a Hitachi 4700 microscope equipped with a Thermo NORAN D 6823 EDS analyzer was used. Since 2008 measurements have been carried out on a Hitachi S-4700 electron microscope equipped with an SDD photon detector.

[7] The database is online on the website of the Institute of Archaeology of the Czech Academy of Sciences in Prague (http://www.arup.cas.cz/VITREA/index.htm).

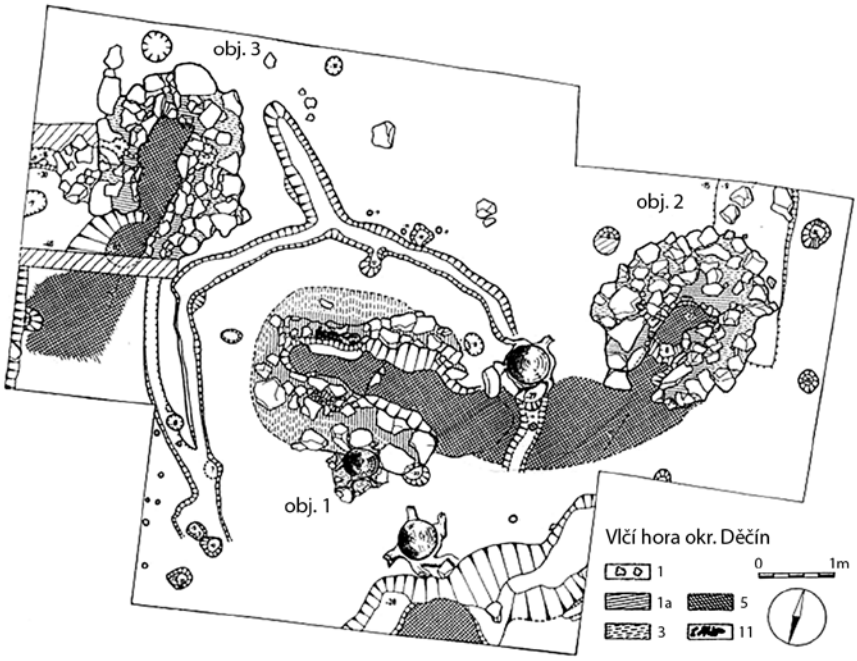


Fig. 4. Vlčí Hora, Děčín district. Medieval glasshouse. Site plan showing remains of three furnaces. 1– burnt daub, 1a – reddish bedrock, 3 – charcoal, 5 – layer of black opaque glass, 11 – clayey-stony sides. Drawing by H. Jonášová

from the period 850–1200. The results of earlier analyses, both chemical and semi-quantitative spectral, were also considered[8]. Two factors at the very least were found to encumber the investigation of glasses dating from the 11th–13th centuries as compared to glasses from 850–1000. First is the insufficient number of well-published finds and second, the often unclear chronology of accompanying pottery on which the chronological classification of glasses is based to a large extent. Since the dating of individual pieces could not be revised for obvious reasons, the previously published chronological classifications were generally respected. Another complication is the low chemical resistance of wood-ash glass and certain lead glasses, which corrode easily and heavily, limiting therefore the analytical potential of these artefacts. This situation pertains especially to finds dating from the 13th century, because the amount of less resistant

[8] In the Czech Republic, both prehistoric and high medieval glasses have been studied with the help of analytical methods from the 1950s onwards. Classic chemical or semi-quantitative spectral methods and, since the early 1980s, also NAA (neutron activation analysis) have been used. Microanalysis of glasses, especially early medieval ones, has been used from the late 1990s onwards. The development of archaeometric studies has been conditioned by projects supported by Czech grant agencies.

wood-ash glass increases during that period. Despite these limitations, archaeometric investigation has provided a number of findings, concerning not only the chemical composition of glass, but also the links between chemical types and various kinds of artefacts.

Chemical composition of glass artefacts

Six different chemical types of glass, designated A to F, have been identified for the territory of Bohemia (Černá *et al.* 2001; Černá *et al.* 2015). For the purposes of this paper, these chemical types of glass have been treated as wholes and the inner variability within the main groups has been ignored. First, let us consider which chemical types of glass were used for the production of specific studied glass objects.

Beads (Fig. 5). In the 9th–10th centuries, the typological variability of beads corresponds to the variability of chemical types of glass. Alongside the prevailing soda-lime glass beads (type A1, A2), beads made of high-lead (B), mixed-alkali (E), and wood-ash (F) glass also occurred. In the 11th–13th centuries, even though some of the analyzed

Fig. 5. Glass beads from the mid-9th to 10th century representing different chemical groups: A1 – natron glass, A2 – plant ash glass, B – lead glass, D – soda-lead glass, E – mixed-alkali glass, F – wood-ash glass (after Černá *et al.* 2015)

beads from Prague (Prague Castle – Loretánské Square), Malé Březno, Žalany, Žatec were made of soda-lime natron or plant-ash glass, or possibly mixed-alkali glass (Tab. 1: samples 98, 186), most of them were made of high-lead or lead-ash glass (e.g. Tab. 1: samples 213–215). In contrast to the previous period, no beads made of wood-ash glass have been identified so far.

Rings (Fig. 6). Most of the analyzed rings were made of high-lead, high-lead or lead-ash glasses (B and C) and only exceptionally of wood-ash glass (F).

Fig. 6. Glass rings and other small artefacts from the 11th–13th centuries representing different chemical groups: A1 – natron glass, B – lead glass, C – lead-ash glass, F – wood-ash glass

Vessel glass (Fig. 7). Vessels from the Kolín grave dating from the second half of the 9th century were made of soda-lime natron glass (A1). However, in comparison with other glasses in this group, they contain a lower amount of Na_2O and a slightly increased proportion of K_2O. Such a composition is not too extraordinary, as it was also identified in several analogous beakers from Great Moravian find contexts, earlier Frankish vessels of the Merovingian period, as well as Anglo-Saxon vessels from the mid-6th to 7th–8th centuries.

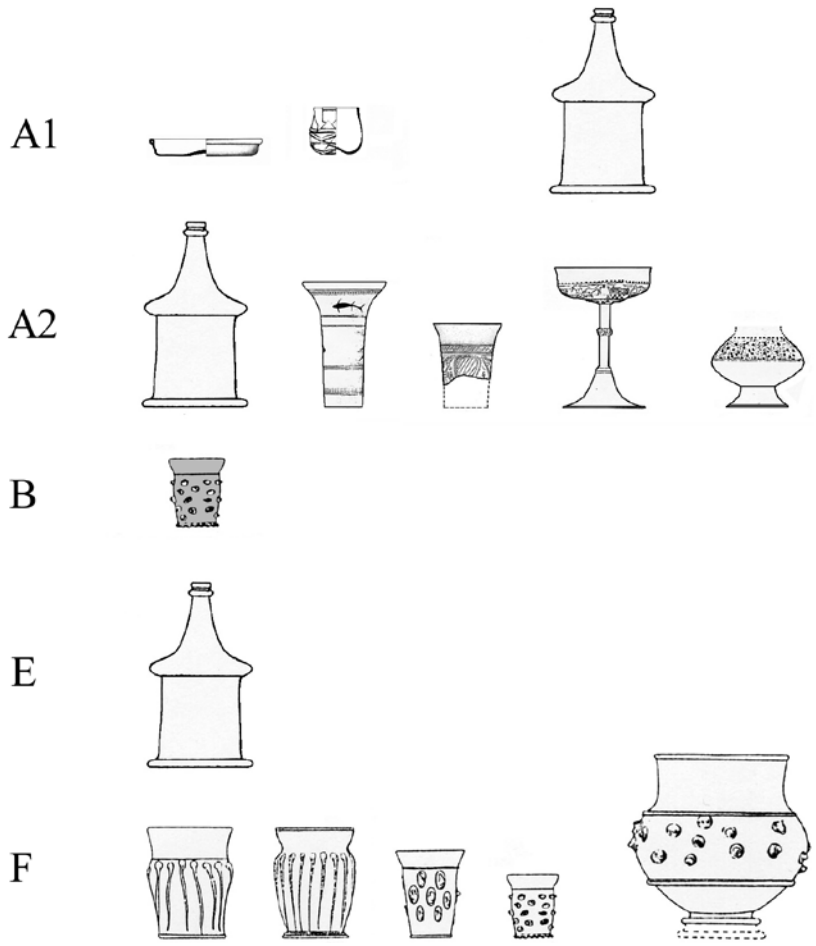


Fig. 7. Types of vessels from the 9th–13th centuries representing different chemical groups: A1 – natron glass, A2 – plant ash glass, B – lead glass, E – mixed-alkali glass, F – wood-ash glass. Drawing by H. Jonášová, compiled by Š. Martinková

Table 1. Analyses of selected artefacts from 10th–13th century Bohemia showing the principal chemical types of glass

Chemical type – sample	Object, colour	Location	Age	Na2O	MgO	Al2O3
A 1						
264	bead, blue	Kolín	850–870	16,54	0,60	2,32
195	bead, green	Prague, Prague Castle-Jízdárna	870–950	17,67	0,67	2,84
98	bead, blue	Malé Březno	11	14,52	0,00	2,74
156	tessera, blue	Žatec	11	17,29	0,56	2,37
157	fr. of vessel, blue	Žatec	11	15,17	0,65	2,39
139	raw glass, greenish	Žatec	11	18,40	0,89	2,66
417	bottle	Nymburk	13	15,01	0,75	0,51
A2						
228	bead, colourless	Žalov-Na panenské	870–950	15,06	6,12	0,53
943	bead, blue	Prague Castle – Lumbe´s Garden	10	11,2	4,4	1,30
186	bead, brown-yellow	Prague, Prague Castle	11–12	12,82	4,35	1,37
475	fr. of vessel, pink	Žatec	11	11,77	2,49	3,09
333	beaker	Prague	13	14,01	5,14	0,1
B						
803	bead, green	Prague Castle – Lumbe´s Garden	10	1,50	0,00	0,7
213	bead, black matrix	Prague 1, Loretto Square	12	0,00	0,00	0,89
214	bead, yellow	Prague 1, Loretto Square	12	0,00	0,17	1,51
675	ring, yellow	Žatec	11	0,19	0,01	1,58
120	shield finger ring	Liptice-Hrdlovka	12	0,00	0,00	0,00
168	window pane	Stará Boleslav	11	0,00	–	–
474	bracelet, green	Žatec	11	0,69	0,00	0,89
C						
215	bead, green	Prague 1, Loretto Square	12	0,07	0,00	1,65
146	ring grey-black	Žatec	11	3,22	0,00	0,66
489	ring turquoise	Prague, Prague Castle	11–13	0,93	0,17	2,16
479	window pane	Prague, Prague Castle	11–13	0,70	2,07	1,52
E						
219	bead, black	Prague-Motol	10	8,06	1,69	3,05
694	bead, brown-red	Žalany	11–12	6,81	0,52	1,56
81	bead, green	Žatec	13	6,10	0,00	1,67
419	bottle	Nymburk	13	7,91	1,88	2,56
F						
233	bead, green	Žalov-Na panenské	870–950	2,73	5,76	0,53
174	vessel	Stará Boleslav	11?	0,20	1,90	1,03
613	ring, light green	Žabonosy	11–13	1,96	3,82	4,16
754	ring, light green	Prague, Prague Castle	11–13	2,19	3,82	6,54
839	jug	Most	13	0,71	3,56	2,22

SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	CoO	CuO	SnO_2	Sb_2O_3	PbO
70,34	0,13	0,00	0,76	0,91	7,63	–	0,12	0,43	0,10	0,15	0,00	0,00	0,00
69,18	0,00	0,00	0,99	0,59	6,30	0,00	0,65	1,11	0,00	0,00	0,00	–	0,00
69,41	0,00	0,33	0,63	0,70	7,72	0,00	0,63	0,88	0,67	1,77	0,00	–	0,00
68,96	0,00	0,43	1,17	0,41	7,14	0,00	0,00	1,27	0,00	0,39	0,00	–	0,00
68,14	0,00	0,00	0,87	0,86	8,33	0,00	0,50	1,29	0,00	0,61	0,00	–	0,65
66,66	0,00	0,93	0,99	0,74	7,26	0,00	0,68	0,78	0,00	0,00	0,00	–	0,00
74,08	0,00	0,00	0,22	1,31	7,53	0,00	0,41	0,18	–	–	–	–	–
69,09	0,00	0,15	0,48	2,36	4,20	–	0,21	0,26	0,04	0,00	1,08	0,18	0,26
69,20	0,20	0,20	0,70	2,60	7,70	0,10	0,50	1,50	0,20	0,20	–	–	–
66,43	0,00	0,30	0,78	4,20	8,73	0,00	0,52	0,51	0,00	0,00	0,00	–	0,00
66,24	0,22	0,28	0,84	2,28	11,13	0,09	1,24	0,35	0,00	0,00	0,00	–	0,00
65,24	0,67	0,84	0,50	2,27	9,65	–	0,78	0,24	0,07	0,00	0,52	0,00	0,00
18,01	0,20	0,00	1,70	0,30	0,20	0,10	0,10	0,20	–	0,60	–	–	76,2
22,45	0,00	0,00	0,00	0,00	0,43	0,00	0,00	2,47	0,00	0,59	0,00	–	73,17
25,64	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	–	72,68
25,86	0,00	–	0,16	0,09	0,00	0,13	0,05	0,24	0,00	0,00	0,00	–	71,71
21,81	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	–	78,19
18,70	–	–	–	–	–	–	–	–	–	0,00	–	–	81,3
24,46	0,00	0,00	0,06	2,56	0,00	0,18	0,00	0,15	0,00	0,93	0,00	–	70,09
35,91	0,00	0,00	0,00	5,57	0,79	0,00	0,00	0,00	0,00	0,00	0,00	–	56,02
32,28	0,00	0,00	0,00	9,83	3,55	0,00	0,00	0,37	0,00	2,12	0,00	–	47,97
26,98	0,00	0,00	0,23	4,73	0,15	0,00	0,00	0,11	0,00	0,51	0,00	0,00	64,03
39,89	0,73	0,00	0,31	11,52	11,97	0,26	0,58	0,50	0,00	1,46	0,00	–	28,49
62,98	0,58	0,46	0,65	7,65	4,27	0,61	7,04	2,96	0,00	0,00	0,00	–	0,00
76,86	0,07	0,00	0,13	9,07	1,41	0,35	0,03	0,61	0,00	1,83	1,01	0,00	0,00
74,50	0,22	1,30	0,30	13,94	1,44	0,00	0,29	0,24	0,00	0,00	0,00	–	–
62,57	0,39	0,26	0,58	11,35	10,87	0,11	1,16	0,35	–	–	–	–	–
56,09	3,65	0,12	0,62	16,03	12,19	–	0,47	0,49	0,05	0,09	0,79	0,24	0,19
63,76	0,99	0,00	0,00	15,24	13,46	0,63	2,48	0,31	0,00	0,00	0,00	0,00	0,00
45,89	1,77	0,44	0,05	16,41	24,42	0,24	0,24	0,61	–	–	–	–	–
44,84	1,19	0,28	0,05	17,01	21,93	0,35	0,93	0,85	0,00	0,00	0,00	0,00	0,00
–	–	–	–	14,69	17,11	–	0,71	0,56	–	–	0,01	–	0,02

Archaeometric studies show that vessels of the 11th–13th centuries were made of various chemical types of glass. Soda-lime glasses are relatively common, both from types A1 (Tab. 1: sample 417) and A2 (Tab. 1: sample 333). In contrast, high-lead glass is rare; it has been determined only in Prague-Ungelt and, with a certain degree of probability, in Most. The use of glass of the mixed-alkali type (E) is documented in the case of bottles with a tubular ring inside (Tab. 1: sample 409) which, according to the analysis results, were also manufactured of soda-lime natron glass, group A1 (Tab. 1: sample 417). Last but not least, the use of wood-ash or wood-ash-lime glasses (F) is also documented: initially in the 12th century, but more frequently from the mid-13th century onwards (Tab. 1: sample 839).

The earliest windowpanes (Stará Boleslav) dated to the 11th century were made of high-lead glasses (B). The specimen from Prague Castle – Theresian Wing, dating from the 11th–13th centuries, was made of lead-ash glass (C). Wood-ash-lime glass (F: K_2O-CaO-SiO_2) was used for the production of the painted windowpane from Prague – Richter's house, dating from around the mid-13th century.

In the case of other small objects, a fragment of an arm ring from Žatec was made of lead-ash glass in the 11th–12th century. The same site also yielded two tesserae and a piece of raw natron glass. The smoother found at Tisová near Staré Mýto dates from around the mid-13th century, but it was analyzed only by semi-quantitative spectral methods because of the corrosion.

Chemical types of glass

Soda-lime-silica glass occurs in two variants, differing in the source of alkali.

Type A1 – soda-lime glass, for the production of which naturally occurring natron was used – hence the name natron glass. In Bohemia of the second half of the 9th and 10th centuries, it is represented by vessels from the Kolín grave and numerous imported beads. In the period 850–950, this very glass penetrated into central Europe and probably also into Bohemia, where olive beads were made from it (Košta and Tomková 2011; Košta and Lutovský 2014).

Type A2 – plant-ash glass with ash of halophytic plants used for its production. In the Early Middle Ages, its production centre is associated with the Islamic world where this glass was produced from the 8th and especially the 9th century onwards (e.g., Henderson 2014). In Bohemia of the second half of the 9th and the 10th century, it can only be documented in the case of beads.

In the 11th–12th centuries, soda-lime-silica glass (A1, A2) are infrequently documented in several new and also earlier known types of beads, where it is not possible to decide whether they are products of that period or earlier intrusions (Tab. 1: samples 98, 186). In Germany, the use of this type of glass for the production of rings/finger rings as late as the 11th century is documented, for instance, by finds from Höxter

(Stephan 1977: 158, 163). Soda-lime-silica glass was used also for the production of vessels, as proved by the analyzed fragments from Žatec dating from the 11th–12th centuries (e.g., Tab. 1: samples 157 and 475) by the 12th-century fragment from Prague which came from a vessel decorated with gold and enamel. Only in the 13th century, which was generally richer in vessel glass, samples of soda-lime-silica glass (A1 and A2) became more frequent. For example, we can mention a bottle with tubular ring inside from Nymburk, which was made of A1 type-glass (Tab. 1: sample 417) and fragments of gilded vessels (A 2) imported to Bohemia from developed glassmaking centers situated in the south or southeast of Europe (e.g., Tab. 1: sample 333, a detailed classification of the results is provided after Černá *et al.* 2012: 401–408).

Type B – high-lead glass. This type of glass already existed in early medieval Europe in the 8th–9th centuries. In Bohemia, it appeared in the form of imported beads, in the 10th century. From the 11th century onwards, it was used for the production of almost all kinds of existing glass artefacts (see Černá *et al.* 2015: Tab. 2). As well as beads, this type of glass was used also for the manufacture of rings, rings/finger rings, and arm rings, although the latter category is represented only by fragments from Žatec (Tab. 1: sample 474) and Prague. It was also used to make windowpanes (Tab. 1: sample 168). According to our findings, high-lead glass remains a rarity in 13th-century Bohemia. They are a small bead from Hrdlovka (VITREA, sample 457), whose dating to the 13th century is not fully convincing, however, and a fragment of a ring with fused grains from Kadaň. The manufacture of rings from high-lead glass at that time has been proven by recent excavations of a glassworking workshop at Erfurt (Mecking 2013: tab. 1). Vessel from high-lead glass are recorded exceptionally (Prague-Ungelt and Most), and especially much later than other types of artefacts, at the earliest in the 13th century in Bohemia as well as in other Europe (Černá *et al.* 2015: 98; Baumgartner and Krueger 1988: 162). Their origin is still not quite clear, but like the cited authors, we believe that the production centers of this specific group of vessels (predominantly of a bright yellow colour) should be sought somewhere in the northwest of Europe, in the Hansa cities or possibly also in the southern part of Lower Saxony.

The provenance of Bohemian finds of lead glasses from the 11th–13th centuries, especially in the case of simple rings and beads, has been sought in Poland or in the more distant parts of eastern Europe. Correlation of the results of analyses of Bohemian and European finds led to the observation of a particularity of the chemical composition of several Bohemian glass with a remarkably high content of lead oxide (see Černá *et al.* 2001: 77–79 for more details about their occurrence and provenance, as well as about the possible existence of independent production centers using similar recipes). When looking for an answer to the still open question of the origin of Bohemian finds made from lead glass, one must not forget the early knowledge of the production of lead glass in Lower-Saxon monasteries, which is attested both by

archaeological sources from, e.g., Brunshausen (Stephan and Wedepohl 1997), and by written ones[9]. With reference to O. Mecking (2013: 648, 656), it could be pointed out that the increase in production of lead glasses in the 10th–14th centuries can be placed in context with the growing production of silver. Lead-isotope analyses have proved that the same source of lead (Harz Mountains) was used for the wood-ash lead glass and the high-lead glass in western Germany and the two types of lead glass from Erfurt.

Type C – lead-ash glass. This type of glass, which frequently occurred in Bohemia and other European territories from the 11th century onwards, probably has earlier roots (for a list of solitary finds from antiquity and the early Middle Ages, see Dekówna 2000: 187–191; for new analyses of artefacts dated since the second half of the 10th century from Silesia; see Pankiewicz et al. 2017). Similarly as in the previous case, this type was used for the manufacture of beads, rings and rings/finger rings, and on rare occasions, also window glass. The last mentioned category is represented by only one find: a glass windowpane from Prague Castle, which cannot be dated more precisely within the studied period. Most of the lead-ash glasses identified up to now in Bohemia belong to a type which Mecking (2013) classifies as the newly defined *Central European lead-ash glass* and for which a low content of CaO is characteristic (most often less than 1%). However, there are also exceptions, such as the Žatec ring dated to the 11th century, where the CaO content is slightly higher, up to 3.55% (Tab. 1: sample 146), or the windowpane from Prague Castle – Theresian Wing, where the CaO content is even higher, up to 11.8% (Tab. 1: sample 479). With its CaO content, the glass of both these objects is closer to glasses from western Europe, which Mecking calls *wood-ash lead glass* and of which such a high content of CaO is characteristic. In the 11th–12th centuries, the range of artefacts is nearly as wide as in the case of the previous chemical group (only the arm rings are missing, see Černá *et al.* 2015: Tab. 2). However, the total number of finds is apparently lower and no artefacts made of glass with this composition are known during the subsequent period.

Type D – so far, soda-lead glass among Bohemian finds has only been proved in the case of polychrome eye beads dating from the 10th century, found in a cemetery in Lumbe's Garden in Prague (Tomková *et al.* 2014: 157–158).

Type E – mixed-alkali glass containing soda, potash and lime (usually with a Na_2O content of 4 to 12% and a K_2O content of 4 to 13%). The process of its production still remains an open question. There are some speculations that early medieval glasses emerged by mixing soda-lime glass with wood-ash glass melted from the ash of European tree species. It appears only rarely in Bohemia. Only a few beads are known from the period 850–1000. The following period is represented both by beads (Žalany, 11th–12th centuries and Žatec, 13th century) and vessels (bottle with a tubular ring inside

[9] The use of lead in the batch mixture is mentioned by Theophilus Presbyter in his treatise entitled 'Diversarum Artium Schedula', as already noted in Theobald 1933.

from Nymburk, 13th century). This type of glass features a much higher fluctuation of individual element content. These differences are prominent especially when one compares the amounts of chemical elements in objects distant in time as demonstrated by a comparison of CaO content in three of the above mentioned samples (Tab. 1: samples 81, 694, 419).

Type F – wood-ash glass was melted from the ash of European tree species. The beginning of the use of wood-ash alkali on the European continent can be dated to the 8th century (Wedepohl 2003: 91–92). In the period 850–950, one of the olive beads found in Bohemia shows this type of composition. Analysis of two G-beads indicates that this type of glass was also used for the production of these kinds of beads, the occurrence of which is limited to Bohemia, and in particular to central Bohemia. This fact, as well as their simultaneous occurrence with olive beads and the tendency to imitate them indicate that wood-ash glass might have been imported to Bohemia during the period 850–950 and processed locally (Košta *et al.* 2011).

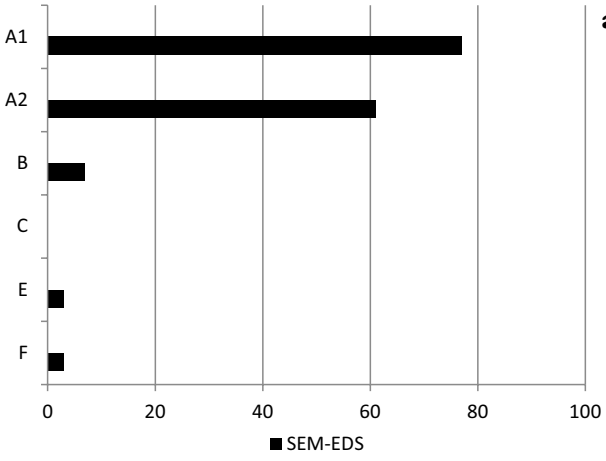
Somewhat later, a ring from Prague Castle – Jiřské Square with a core consisting of colourless, translucent, slightly greenish glass with a surface covered by corrosion products forming a black opaque layer, and a non-corroded ring from Žabonosy (Tab. 1: samples 613 and 754) were made of this type of glass. Both these finds are roughly dated to the 11th–13th centuries. The presence of objects made of wood-ash glass in the 11th–12th centuries is also confirmed by analyses of other specimens made of secondarily opaque glass, carried out by the semi-quantitative spectral method, which, however, does not provide absolutely exact data on the content of individual elements.

Wood-ash glass is convincingly documented again as late as the 13th century, in window glass and vessels. Both find categories are preserved in the form of fragments that are often not suitable for archaeometric investigations due to corrosion. Despite the negatives which are associated with wood-ash alkali, the production of glass from ash of wood species became so widespread in central Europe that it gradually replaced all other chemical types of glass during the 13th century. From the very beginning (from the mid-13th century onwards) Bohemian glasshouses produced glass according to the same formula as the glass-making centers in neighbouring countries. When the results of chemical analysis of the windowpane from Prague – Richter's house (Dragoun 2000: 13) are compared with glasses from Germany (so-called *Holzasche-Glas* 1050–1200; Wedepohl 2008: Tab. 1), the similarity of their chemical compositions, i.e., the content of the main represented elements, is apparent. However, over the following decades, in the context of gradual development of the glass-making craft, the newly established production centers became more differentiated through their range of products, in the spheres of both typology and chemistry. A formula based almost exclusively on wood-ash alkali was used in central European glasshouses, however, the resultant melt did not contain completely identical quantities of main and trace elements.

CONCLUSIONS

A comparative analysis of archaeometric data revealed that soda-lime glasses were without doubt dominant in the collection of 9th–10th century Bohemian finds. The share of lead glass is somewhat lower and both mixed-alkali and wood-ash glass are hardly represented (Fig 8: a). In the 11th–12th centuries, a surprising boom in lead glasses, both the high-lead ones, and the ternary ones containing wood-ash alkali is recorded, while soda-lime glasses became less frequent. Wood-ash glass was documented in exceptional cases only (Fig. 8: b). Thirteenth-century finds reveal a permanent, although insignificant representation of soda-lime glasses and, at the same time, an increasing proportion of wood-ash glass (Fig. 8: c). Less frequent artefacts made of soda-lime glasses can be considered without doubt as imports from more distant glass-making areas, either in the southwest, south or southeast of Europe, or even in the Near East. In contrast, the origins of wood-ash glasses can be sought in glass-making centres located near Bohemia or in western Europe. Lead and mixed-alkali glasses are only marginally represented. With regard to ongoing archaeometric research, which enlarges the range of finds investigated with modern methods, it is reasonable to suppose that future analyses will demonstrate an even higher proportion of wood-ash glass.

Most chemical types of glass were used over a longer period and, with the exception of wood-ash glass (F) and lead-ash glass (C), they have their roots in prehistory (Tomková and Venclová 2014). Except for the lead-ash glass, the other types can be encountered both in the period of the 9th–10th centuries and in the 11th–13th centuries. However, the ratios in which they are used for the manufacture of different products are

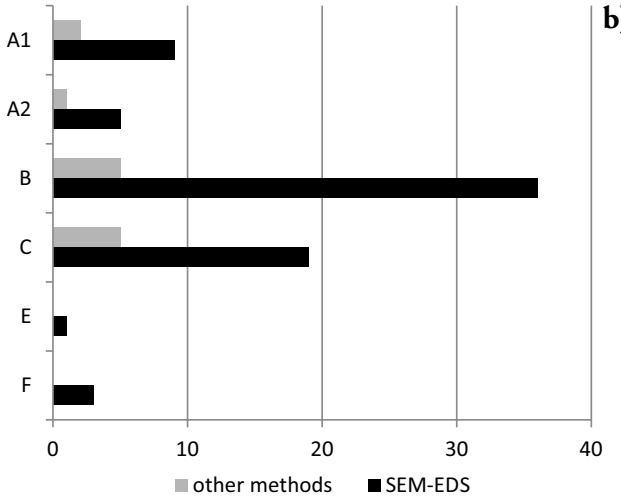


a)

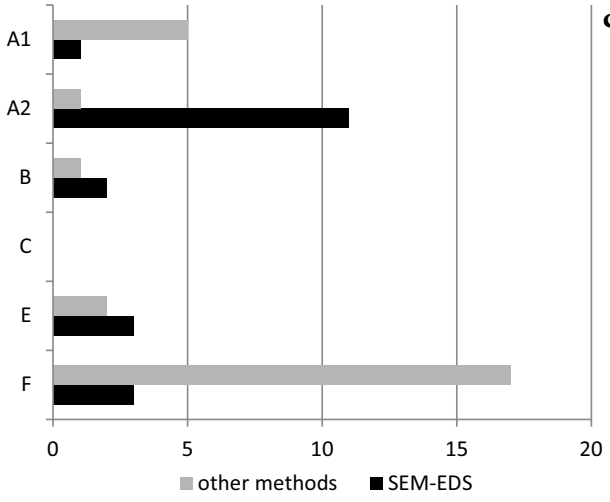
	SEM-EDS	other methods
F	3	
E	3	
C	0	
B	7	
A2	61	
A1	77	
	151	

changeable. Although we are able to notice an inner variability within the basic chemical types at the present stage of our research, we leave aside the evaluation of their transformations which take place during both time periods.

When archaeometric data are linked to archaeological observations, two significant changes become apparent. The first change happened around the year 1000, or more



	SEM-EDS	other methods
F	3	
E	1	
C	19	5
B	36	5
A2	5	1
A1	9	2



	SEM-EDS	other methods
F	3	17
E	3	2
C		
B	2	1
A2	11	1
A1	1	5

Fig. 8. Share of different chemical types of glass in different periods from the mid-9th to the 13th century: a –mid-9th to 10th century; b – 11th–12th centuries; c – 13th century (after Černá *et al.* 2015)

markedly at the beginning of the second millennium. In a way, it can be characterized as a complex change occurring in all the mentioned parameters very quickly and practically simultaneously. The other change took place over a longer time period, during the 12th–13th centuries. In contrast to the previous one, this transformation can be interpreted as an evolutionary change. Its characteristic feature is the asynchronous appearance of the aforementioned elements: in the range of glass artefacts and in the use of chemical types as well as in the find contexts.

If we compare these findings with the situation abroad, we may notice certain common patterns. A similar case can be found, for instance, on the Baltic coast, where in context with the gradual decline of Haithabu in the course of the 11th century, a certain population growth occurred in neighbouring Schleswig. This transfer of settlements was also accompanied by changes in the range of glass artefacts, both from the typological and the chemical point of view (Steppuhn 2002: 103–105, Fig. 55). A comparable situation for the period of the 12th to the mid-13th centuries is represented by the scarcity of window and vessel glass in both the settlement and the production milieu, which can be observed in Bohemia as well as in the neighbouring central European countries. In this context, we have to mention the obstacles faced while trying to put our findings into a broader European context. Both at the practical and at the theoretical level, they are caused by the variability of analysis results and the differences in their interpretation. Apart from the application of different analytical methods and the continuous progress in the level of our knowledge, there are also changes in the dating of artefacts and the presence of different scholarly milieus.

If we acknowledge the changes in fashion in Bohemia around the year 1000, which are demonstrated by the arrival of new types of beads and, initially, as the apparent preference for embellishments in the form of rings and finger rings, it is also necessary to notice several signs of continuity. The origins of several types of beads dating from the 11th to 12th centuries reach deeper into the past. Eventual differences between the earlier and later specimens may be related, although not necessarily, to different techniques of manufacture or different chemical types of glass.

Early and high medieval glass-making technologies were, and still are, studied separately. Such isolated studies have resulted in the creation of an artificial barrier, which is usually dated around the year 1200 and which is thought to separate the manufacturing practice of these two cultural-historical periods. This fact is also accepted without criticism by professional glassmakers, although, as our research shows, the reality was different. Our study proves that significant changes reflecting the development of the glassmakers' craft in Bohemia took place earlier than expected, during the early medieval period, more precisely shortly after the year 1000. Additional changes associated with the development of a local production of glass took place after the middle of the 13th century. Since that time onwards, apart from luxurious imported vessels, the more common drinking (i.e., table) glassware appeared, which was

produced in the newly established glasshouses in the mountain border regions of Bohemia. The growth in local production enabled the spread of glassware among the lower social strata and caused a drop in the number of imported goods.

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