Late Bronze Age mixed-alkali glasses from Bohemia

Skla typu *mixed alkali* mladší doby bronzové v Čechách

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Besides monochrome blue-green glass beads, polychrome beads appear, for the first time in Bohemian prehistory, in Late Bronze Age contexts of the Knovíz culture (Ha A, 12th – early 11th cent. B.C.). They are formally similar to the beads made in Frattesina and/or other glass workshops in northern Italy. According to the chemical analyses in this paper, the beads from Bohemia also correspond to the North Italian products because they have a mixed alkali composition, a compositional type unique for its time, thus providing evidence of a likely provenance.

Late Bronze Age – Knovíz culture – glass beads – chemical analyses

V mladší době bronzové, v kontextu knovízské kultury (Ha A, 12. až 1. pol. 11. stol. př. Kr.), se vedle monochromních modrozelených skleněných korálků objevují, poprvé v českém pravěku, také polychromní korálky. Formálně se shodují s korálky zhotovovanými ve Frattesině, a případně v dalších dílnách v severní Itálii. Podle chemických analýz, které jsou v článku prezentovány, se tyto korálky z Čech shodují s výrobky této dílenské oblasti také svým specifickým sklem typu mixed alkali, ve své době unikátním, které tuto provenienci jednoznačně dokládá.

mladší doba bronzová – knovízská kultura – skleněné korálky – chemické analýzy

Introduction

The earliest vitreous products – faience beads – appear in Bohemia in the Early Bronze Age. Since the Middle Bronze Age, the assortment of products was enriched by glass beads which however do not increase in number in Central Europe until the Late Bronze Age. The glass necklaces from the Northern Urnfields – Lausitz and Silesian-Platěnice Cultures of that period in East Bohemia were considered to be most numerous, but recent finds have substantially increased glass finds dated to the contemporary Upper Danubian Urnfields – Knovíz Culture in Central and NW Bohemia. It is in the Knovíz context where polychrome beads of various shapes appear for the first time in Bohemia, and their culturally and chronologically diagnostic value is greater than in the case of the monochrome and formally limited (annular or round) beads (*Venclová 1990*, 40–41, 216–221). All the Knovíz culture beads belong probably to the Ha A phase, that is to the 12th – early 11th cent. B.C., according to the Central European absolute chronology (*Jiráň ed. et al. 2008*, 145, tab. 4).

Similar types of beads are known from South Moravia from the context of the Velatice culture. The small annular blue-green undecorated beads of the Br D to Ha A-B Lausitz and Silesian-Platěnice cultures in East Bohemia and Moravia (*Venclová 1990*, 40–42, 178–179, 218–219, and some recent finds) seem to be typologically very close. However, as mentioned below, the different chemical composition of glass found in samples from East Bohemia suggests a different origin of – at least some – beads from this more eastern cultural area. Up to now, Moravian beads have not yet been submitted to modern chemical analyses.

When the Late Bronze Age (Final Bronze Age in the Italian chronology) glass-working site of Frattesina came to light, the origin of Late Bronze Age beads from Bohemia and other parts of Central Europe was naturally sought there (*Venclová 1990*, 41–44 with refs.). This assumption was however based on typological grounds alone. The growing volume of analytical data based on not only glasses from Frattesina, but also from a number of other sites, now offer a very precise identification of the technology and an indication of the provenance for Late Bronze Age glass. This applies also to finds from Bohemia whose chemical composition is known thanks to analyses conducted recently as part of the research project IAA800020903 'Glassmaking in prehistory and Middle Ages: cultural and technological transformations' supported by the Grant Agency of the Academy of Sciences of the Czech Republic.

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Beads in the Late Bronze Age Knovíz culture context (Ha A) in Bohemia

The state of research as in late 1980s has been summarised by *Venclová* (*1990*, 42–44) and the somewhat limited set of additional data gained since then is reviewed below. More information may be found in the references attached. The description of the beads submitted to chemical analysis is given in the List of samples.

Dolánky (distr. Louny). Rubín hill, no context. Rounded blue-green bead with four blue-white eyes. The bead was recorded by *Haevernick* (*1978*) in her list of *Pfahlbaunoppenperlen*, and the information was then followed by further authors. The bead, presumably deposited in the Oblastní muzeum of Chomutov, cannot now be identified in the collections. According to E. Černá, it could be inv. no. 9083 of the Steiner Collection – a blue-green bead with two-layered blue-white eyes, but it was missing already during the revision in 1985. Refs.: *Haevernick 1978*, 146; *Venclová 1990*, 220.

Holubice (distr. Praha-západ). Western border of the village. Part of a larger cremation cemetery, group of eight graves (Ha A). Investigations of J. Hložek, 2008. Deposited in Institute of Archaeological Heritage in Central Bohemia, Prague. Ref.: *Hložek 2009*.
Urn grave 3: nine blue-green annular beads including one double (two-coiled) bead; traces of red glass on two beads; accompanied by bronze artefacts: thirteen small bronze sheet tutuli, small ring and pin. Analysed samples 620–628.

Levousy (distr. Litoměřice). Forest of Borová. Barrow cemetery. Investigations of Z. Smrž, 1974. Deposited in Institute of Archaeological Heritage in NW Bohemia, Most. Refs: *Smrž 1975*; *Venclová 1990*, 220.
Barrow 6, cremation grave A: one fusiform faience bead, light green surface, white grainy core, decorated by white spiral and wavy lines; accompanied by bronze spirals, pin and bracelet (Ha A).

Noutonice (distr. Praha-západ). Plot no. 40/47. Part of a larger cremation cemetery, group of six graves (Ha A). Investigations of L. Šulová, 2008. Deposited in Institute of Archaeological Heritage in Central Bohemia, Prague. Ref.: *Šulová 2010*.
Urn grave: fusiform blue-green bead and small annular blue-green bead. Associated with bronze pin and quartz pebble.

Obory (distr. Příbram). Site Hromádky. Cremation cemetery, 87 urn graves (Ha A2). Investigations of J. Hrala, 1983–1984. Deposited in Hornické muzeum, Příbram. Refs: *Venclová 1990*, 220; *Hrala 2000*.
Grave 106: two blue-green annular beads, traces of red glass on one bead. Data on find assemblage not available.
Grave 126: four blue-green annular beads. Associated with bronze objects: two pins, two bracelets, finger-ring, belt clasp, two small tutuli, button, small spiral; small gold ring. Analysed samples 734, 735.

Praha-Zbraslav (distr. Praha). Main square. Discovered 1929. Deposited in National Museum, Prague inv. no. 40812. Refs.: *Horáková-Jansová 1931*; *Venclová 1990*, 220.
Urn grave: about fifteen blue-green annular beads; accompanied by bronze objects: belt clasp, two pins, several small rings, small spirals; quernstone.

Řepín (distr. Mělník). Plot no. 13. Gift of V. Jansa, no context. Two blue-green fusiform beads decorated by white spirally wound thread. Regionální muzeum, Mělník inv. no. 4734, 4735. Ref.: *Venclová 1990*, 220. Analysed samples 736–739.

Středokluky (distr. Praha-západ). Plot no. 331/IC, from a building site. Hoard of bronzes, 1956 (Ha A2). The hoard contained one small blue-green annular bead. Deposited in Středočeské muzeum, Roztoky u Prahy inv. no. 23135. Refs.: *Venclová 1990*, 220; *Kytlicová 1991*, 24; 2007, 306.

Tuchoměřice (distr. Praha-západ). Southern part of the village. Cremation cemetery, 32 urn graves (Ha A). Investigations of L. Šulová, 2005–2007. Deposited in Středočeské muzeum, Roztoky u Prahy and Institute of Archaeological Heritage in Central Bohemia, Prague. Ref.: *Šulová 2006*, 135–136; 2007.
Grave 4/05 (juvenile, age 17–20): 25 small blue-green annular beads; accompanied by bronze objects: bead, two small rings, pin fragment; two quartz pebbles. Analysed samples 740–742.
Grave 6/05 (child): four small blue-green annular beads; accompanied by 1 quartz pebble. Analysed sample 743.
Grave 12/05: one blue-green four-horned bead decorated with white rings; accompanied by two ceramic vessels, bronze objects: three small buttons, c. sixteen rings; gold spiral. Analysed samples 744–745.
Grave 16/05: five glass beads: one blue-green fusiform bead with white spirally wound thread, four small blue-green annular beads; accompanied by bronze pin fragment. Analysed samples 746–747.
Grave 22/07: twenty small annular beads.

Archaeological observations

With the exception of the bead from the Středokluky hoard, all the other beads probably come from burial contexts forming part of the inventory of urn graves. Forty-four graves, of which seven contained glass beads, were available for the following assessment. One grave out of eight at Holubice and five graves out of 32 at Tuchoměřice contained glass beads. A maximum of some twenty beads were found in the grave inventories though this need not have been the original total. It can be deducted that beads were mostly not cremated with the dead as they usually show no sign of damage by fire. A higher number of the – very small – glass beads from recent finds undoubtedly corresponds to the systematic sieving of the grave contents. Anthropological determinations are available only in two cases from Tuchoměřice where in grave 4/05 beads accompanied a young person 17–20 years of age while in grave 6/05 there was an infant. Burials with typical male accessories such as weapons are not included among graves associated with glass beads. Grave inventories containing gold objects (Tuchoměřice grave 12/05; Obory grave 126) must indicate a higher social status for the dead. This may be true also of the burials containing several bronze ornaments, a class to which belong most of the Knovíz graves with glass beads. The social hierarchy of burials on the basis of their inventory cannot however be easily assessed. The significance of glass in the Late Bronze Age is demonstrated by the presence of a single glass bead in the Středokluky hoard of bronze objects (containing both vessels and ornaments). Considering the associations described above and at the same time the fact that glass beads were interregional imports in the Central European Knovíz culture, it may nevertheless be surmised that beads were associated with the local élites, perhaps assuming an apotropaic protective rôle for children and young individuals, particularly females.

The glass beads were made by winding. The glass is translucent but not quite homogeneous and sometimes may appear opaque. The colour is typically blue-green on a scale of bluish or greenish tints, exceptionally with traces of red. The decoration, if any, is produced by applying opaque white glass and in one case perhaps also blue glass (Dolánky). In another case (Levousy) the bead was made of white grainy faience, green on the surface; its manufacturing technique has not been established. From a typological point of view, small monochrome annular beads prevail, up to twenty being found in individual graves, while polychrome beads seem to occur as single specimens. This however may be due to the low visibility of the smaller monochrome beads in cases when sieving has not formed part of the recovery process.

In Bohemia, the following types of beads were identified (see the List of samples for abbreviations):

- Annular bead, blue-green glass, D 4.5–6.5 mm, d 2–4 mm, h 1–3 mm. *Venclová 1990*, 41, type 2. *Bellintani – Stefan 2009*, type 1.2. This most frequent type of bead is present on most Bohemian sites. Formally non-diagnostic and, in the absence of chemical analyses, undistinguishable from other contemporary or even later beads.
- Annular bead, blue-green glass, traces of red glass, D 5–5.5 mm, d 1–3 mm, h 1.5–2.5 mm. *Bellintani – Stefan 2009*, type 1.2 to 1.3. Traces of red glass (as at Holubice, Obory) are exceptional. The red colour of glass could have been created accidentally depending on the furnace conditions (see below) and its use has been observed on several bead types from Frattesina (*Bellintani – Stefan 2009*).
- Fusiform bead, blue-green glass, decorated with opaque white spirally wound thread, D min. 5–5.5 mm (at the bead ends), D max. 6.5–9.5 mm, d 2.5–3.5 mm, h 10.5–23.5 mm. *Venclová 1990*, 41, type 4; *Bellintani – Stefan 2009*, type 12.3. Beads from Řepín and Tuchoměřice belong to the typical *Pfahlbauperle* class of *Th. E. Haevernick* (*1949–1950*), which occurs on almost all known sites where the mixed alkali glasses have been found (*Bellintani – Stefan 2009*, tab. 2, fig. 3–6) and on many others; in some assemblages it even represents the majority of all beads (Hauterive-Champréveyres: *Rychner-Faraggi 1993*, 64).
- Fusiform bead, light green faience, decorated by a white wavy-line between spirally wound threads, D max. 19 mm, d 6 mm, h 30 mm. *Venclová 1990*, 41, type 5. In the whole Bohemian assemblage the bead from Levousy is an exception. A similar bead, but made of brown glass, of unknown chemical composition, occurred in Frattesina (*Bellintani – Stefan 2009*, tipo 14.1). It has been previously suggested that the Levousy bead could represent an unsuccessful product of this or some other workshop (*Venclová 1990*, 43).

- Four-horned bead, blue-green glass, decorated by white rings on the horns, D 12.5–15 mm, d 3 mm, h 7–8.5 mm. The bead (Tuchoměřice) belongs to *Haevernick*'s (*1978*) group of *Pfahlbaunoppenperlen*. *Bellintani – Stefan 2009*, type 22.1 (?).
- Rounded bead, blue-green glass, decorated by four blue-white eyes made of two layers (?), dimensions unknown. *Venclová 1990*, 41, type 3; *Bellintani – Stefan 2009*, type 21.3 (?). The type of decoration is uncertain in the case of the presumed eye-bead from Dolánky. Beads decorated by eyes or rings nevertheless represent a relatively prominent type made of mixed alkali glass and are known from Frattesina and other sites (*Bellintani – Stefan 2009*, tab. 3).

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European archaeological context of beads of the Late Bronze Age „Frattesina type"

The first to study Late Bronze Age polychrome beads was *Th. E. Haevernick* (*1949–1950*; *1978b*), who named them, according to their frequent occurrence on the so-called *Pfahlbausiedlungen* in Switzerland as *Pfahlbauperlen* or *Pfahlbaunoppenperlen.* Beads of this type were found on the north Italian Proto-Villanovan culture (12th–10th cent. B.C.) production site of Frattesina where archaeological traces of glass-working, if not glass-making, were discovered (*Bietti-Sestieri 1981*, 143–148). Another impulse for the study of this bead group resulted from the settlement at Rathgall in Ireland of unusual blue-green beads decorated by simple or multiple rings. These are supposed to belong to 9th to 7th cent. B.C., contexts slightly later than at Frattesina, but radiocarbon dates in the 11th cent. B.C. were also obtained from the site (*Raftery – Henderson 1987*). Typologically, and, as it turned out, also chemically similar assemblages of beads have been found in Late Bronze Age sites in Switzerland (Hauterive-Champréveyres: *Rychner-Faraggi 1993*), northern Italy (*Towle et al. 2001*), France (*Billaud – Gratuze 2002*) or Germany (*Hartmann et al. 1997*; *Lorenz 2006*). *Bellintani* and *Residori* (*2003*) provide a list of locations with a map of Late Bronze Age beads, where as well as Western Europe and the Mediterranean Bohemia and Moravia also appear, but, apart from Italy, the distribution relies mainly on *Haevernick* (*1978*) and needs a thorough revision.

Today, the quantity of relevant beads can be estimated as several thousand; from Frattesina itself come almost 3,000 pieces, from other sites in Italy a further c. 2,500, and hundreds have been recorded in Switzerland (*Bellintani et al. 2006*; *Bellintani – Stefan 2009*) and possibly in France (pers. inf. by B. Gratuze). The highest cummulations of *Pfahlbauperlen* have been discovered in northern Italy and perhaps Switzerland, and their overall distribution (*Towle et al. 2001*) reaches France, Britain and Ireland in the west, Central Germany, Bohemia and Moravia in the north and the Mediterranean in the south. One of the easternmost sites seems to be Kaman in Central Anatolia (pers. comm. Dr. Omura).

The site of particular importance for Late Bronze Age beads is the aforementioned settlement of Frattesina in the lower Po valley not far from the Adriatic coast, investigated in the 1970s by *A.-M. Bietti-Sestieri* (*1980*; *1981*). The site is considered an important production and settlement centre, apparently a seat of a local élite and exceptional in the region. Bronze metallurgy was carried out there and in addition the working of lead, gold, bone, ivory and amber. Finds of imported objects attest to current interregional contacts (*Arenoso Callipo – Bellintani 1994*; *Towle et al. 2001*). The glass from Frattesina has recently been studied by *Bellintani* and *Stefan* (*2009*), who date the beginnings of the settlement to *Bronzo recente*, that is, to 13th cent., the main occupation of the site to *Bronzo finale* (*protovillanoviano*), 12th–10th cent. and its end in the Early Iron Age, while glass-making and glass-working would have taken place from the 12th cent. onwards. Archeological finds connected with glass manufacturing include crucibles coated inside with glass, blocks of raw glass of blue, turquoise, blue-green and red colour, and waste. According to the detailed typological analysis the assemblage comprises large and small annular monochrome beads, cylindrical and fusiform beads as well as some other forms, in dark blue, light blue and blue-green, red and white colours. Polychrome beads show either linear decoration – spirally wound thread, sometimes combed – in white, but also red, brown to brown-black, or circular decoration of rings or bosses, mostly in white, or two-layered (stratified) blue-white eyes. The authors acknowledge that glass workshops could have been established on other sites, namely in northern Italy. Glass beads made in Frattesina belong to the class of mixed alkali, or LMHK, glass (see below).

The assemblage of 51 beads from the hoard of Allendorf (Stadtallendorf) in Hessen, dated to Ha B3–B3/C, known already to Haevernick and recently studied by *Lorenz* (*2006*), is of major significance for Central Europe. It contained beads of the *Pfahlbauperlen* type, but also other beads of varying forms, apparently black but actually dark green, and blue polychrome beads which so far have few parallels. These beads are cylindrical with zigzag decoration, or flattened globular decorated with rings, multiple diagonal lines or dots in white, yellow, orange, and red, brown or turquoise colours. Apparently the latter beads have a different provenance from that of the Pfahlbauperlen beads.

Archaeometry of the Late Bronze Age mixed alkali glasses

Chemical analyses of glasses from Frattesina and elsewhere were carried out by Henderson (*Raftery – Henderson 1987*; *Henderson 1988a*; *1988b*) and *Brill* (*1992*; *1999*) and their results have offered a new insight into the research of *Pfahlbauperlen* beads. Both authors characterised the glass as a mixed alkali type, or – following Henderson – LMHK or low magnesium – high potassium. This glass contains c. 6–9 % Na_2O, 8–11 % K_2O, 0,5–1,0 % MgO and has a low content of c. 2 % CaO. The authors stated that this was a new and previously unknown type of glass with no parallels outsides of continental Europe. *Brill* (*1992*) has discussed the possible source of alkalis in this glass and put forward the following alternatives: 1. ash of local woody plants, purified by leaching, 2. an impure form of natron contaminated by potassium salts (as for example the evaporites from Wadi Natrun in Egypt), 3. efflorescent salts from latrines or manurial soils containing, for example, salpetre (KNO_3) and sodium salts ($NaNO_3$). Most of the analysed blue glasses from Frattesina were, according to Brill, coloured by copper accompanied by tin and the colourant could have been derived from bronze. He considered the occasional occurence of red glass on blue beads to be due to reduced copper in the form of Cu_2O as a result of reheating the blue beads at moderate temperatures, perhaps even accidentally.

Mixed-alkali glass was also identified by further analyses by *Henderson* (*1993a*) of the large assemblage of beads from Hauterive-Champréveyres in Switzerland. He also published results of mixed-alkali and the first high potassium glass for beads from the island of Thasos in northern Greece (*Henderson 1993b*). Furthermore, he drew attention to the fact that contemporary glasses of the Bronze Age, and also some Hallstatt period glasses, could have a different composition characterised as HMG (high magnesium), while another type, LMG (low magnesium) was common in the Iron Age. The HMG glass was probably produced in the Mediterranean or Near East, and ingots of this glass were traded in the Bronze Age, as it is attested by the ship-wreck off the Turkish coast at Ulu Burun dated to around 1300 B.C. (*Henderson 1988b*, 447–448, fig. 3). The ship carried ingots of turquoise, cobalt blue and violet glass, which could have been produced in Egypt, but also in Mesopotamia; ingots of different shapes and colours can indicate their origin in several different workshops (*Henderson – Evans – Nikita 2010*, 2, 15–16). Recent analyses of three samples from the Ulu Burun wreck have shown a similarity to Egyptian glass (*Jackson – Nicholson 2010*).

Henderson regarded the local production of the LMHK glass in the north of Italy as possible and explained this by the scarcity of raw glass due to the decline of Mycenaean civilisation in the 12th cent. B.C. when Europe had to find its own sources for glass-making. He considered the possible development of LMHK glass during earlier phases of the Bronze Age. Blue-green colouring of LMHK glasses is due to the addition of CuO but also Co + Ni while green (or rather dark green) colour is caused by FeO. White opaque decorative glass was found to contain small amounts of Sb or none at all (*Henderson 1993a*).

According to some experimental work carried out by *Hartmann et al.* (*1997*), the potash in the mixed-alkali glass could have been acquired from beechwood ash through a process of leaching.

Santopadre and *Verità* (*2000*) have compared glass from Frattesina with earlier faience beads and buttons from Italy and with some later glasses and they found a similar ratio of $Na_2O : K_2O$ in faience and in the LMHK glasses. They presumed that the red colour on the surface of some beads was the result of intentional application of a powdered layer of cuprite and metallic copper.

Results of analyses of more than hundred LMHK glasses from Frattesina, Mariconda and other sites were compared to other glasses and evaluated by *Towle et al.* (*2001*) who also discussed LMG and HMG glasses and compared the element contents in plant ash glass, natron glass and mixed alkali glass. The opacity of glass was ascribed to crystals of Si. The Cu: Sn ratio did not, in their opinion, show any regularity and the dependence on bronze, often assumed, could not be confirmed. Copper could have been used for colouring; also cobalt of unknown origin was found.

Analyses by laser ablation of Final Bronze Age beads have been conducted as part of a large research project in France, but to date only a summary of results without detailed analytical data is currently available (*Billaud – Gratuze 2002*; *Gratuze – Billaud 2003*).

An Italian research project enabled Angelini and her collaborators to play a principal rôle in the archaeometrical research of LMHK glasses, as well as of Bronze Age glasses in Italy in general (for an introduction to the project see *Angelini et al. 2002*). The LMHK composition was found not only to characterise north Italian Final Bronze Age glass beads, that is after 1200 B.C., but also the vitreous component of glassy faience buttons of the Middle Bronze Age, c. 1700–1450 B.C. Also, according to samples from different parts of Europe, the glass phase of the faience beads dating to the Early Bronze Age could have been produced with LMHK glass (*Angelini et al. 2006b*; *Bellintani et al. 2006*; *Tite – Shortland – Angelini 2008*). Given the variability in texture of Bronze Age vitreous materials, *Bellintani et al.* (*2006*) have suggested the following classification: 1. faience: glass phase scarcely distributed, Xm < 0.25–0.30; 2. glassy faience: glass and crystalline phases are of a comparable volume, 0.40 < Xm < 0.60; 3. glass: glass phase forms almost the whole material, 0.80 < Xm. Crystalline phases in Bronze Age glasses have been the subject of further studies (*Artioli – Angelini – Polla 2008*).

An assemblage of eleven samples of glass waste and beads from Frattesina was analysed by *Angelini et al.* (*2004*) using EPMA a SEM-EDS, atomic absorption spectrometry (AAS) and X-ray photoelectron spectroscopy (XPS). Three components of LMHK glass were considered apart from colourants: 1. almost pure Si, 2. glass stabilisers CaO, MgO, and 3. alkali (Na_2O, K_2O) possibly from plant ash. Non-homogenities in glass, such as quartz inclusions, were also documented. The authors suggested that a controlled production process was involved because of the existence of two classes of glass amongst the Frattesina samples showing two different ratios of $Na_2O : K_2O$, which indicate two different sources of alkali. Dark blue glass was coloured using Co+Mo (+Ni, As) and a metallic source for Co may also be presumed. Red colour could have been achieved by control of Cu oxidation.

A considerable number of further analyses of LMHK glasses from Italy were conducted by Angelini and her team (see references to the map *fig. 1*). In spite of using chemical, mineralogical and Pricipal Components Analysis on a large number of samples, they were unable to help to suggest whether one or more centres produced LMHK glass (*Angelini et al. 2009*). Based on analyses of over 130 objects, *Angelini et al.* (*2011*) have been able to characterise the development of chemical glass types during the Italian Bronze Age and Early Iron Age.

Following *Hartmann et al.* (*1997*), archaeometric research of LMHK beads has been carried out by *Lorenz* (*2006*), who analysed beads from the hoard of Allendorf, mentioned above. The origin of the LMHK glass of the *Pfahlbauperlen* beads present in the hoard is presumed to be ash from plants such as beech, fern or Salicornia, and pure siliceous sand. Typologically different beads from the hoard belong, though, to other, HMG (plant ash) and LMG (natron) glasses. If the change from plant ash to natron glass occurred c. 9th century in the Middle East then the occurrence of plant ash glass, natron glass and mixed-alkali glass in the Ha B3/Ha C Allendorf assemblage is a reflection of when the three chemical glass types – products of the Middle East and Europe – met north of the Alps at the turn of the Late Bronze Age and Hallstatt period, and demonstrates the diversified origin of beads at that time.

The LMHK glass from Elateia in Greece shows some differencies in its composition compared to north Italian glass, representing perhaps another manufacturing centre (*Nikita – Henderson 2006*).

Today, over 30 sites in Europe (including the Bohemian sites described in this paper) provided the Late and Final Bronze age glasses of the LMHK type (*fig. 1*). To that, a number of sites from France unpublished as yet will undoubtedly be added.

Recognition of the development of chemical types of glass used in the Bronze Age and Early Iron Age in Europe can be regarded as one of the principal results of archaeometric research in recent decades. Using the Central European periodisation and following, a.o., *Henderson 1988a*; *Hartmann et al. 1994*; *Billaud – Gratuze 2002*; *Angelini et al. 2011* it may be summarised thus: The HMG glass, where alkalis were gained from plant ash, was supposedly made in the Near East from about the Middle Bronze Age up to the beginning of the Early Iron Age or Hallstatt period (1500 to c. 800 B.C.). The LMHK glass (with a mixed alkali content) is considered to be a local continental European achievement found already in the glass phase of faience beads or buttons of the Early and Middle Bronze Age, and particularly in the glass of Late Bronze Age and Final Bronze Age beads (c. 1200–900 B.C.). The LMG glass (containing alkalis of mineral origin – natron) was produced in the Mediterranean since the 9th century, with early examples from the tomb of Nesikhons in Egypt dated to 975/974 (*Schlick-Nolte – Werthmann 2003*), when it largely replaced the plant ash glass and remained in use until c. the 9th century AD.

List of analysed glass samples from Bohemia

Twenty-three samples from nineteen beads found at four sites were submitted for analysis. Blue-green glass was analysed in all beads, and also the white decoration in the four polychrome beads. The sample numbers given below correspond to the numbering in the VITREA database of prehistoric to post-medieval glass analyses results from the Czech Republic (http://www.arup.cas.cz/cz/VITREA/index.htm; see *Venclová et al. 2010*). Dimensions of beads given in mm. Abbreviations: D – outer diameter, d – perforation diameter, h – height (for measuring of beads, see *Venclová 1990*, 315, Pl. 1). For find contexts see above. *Figs. 2* and *3*.

Holubice, distr. Praha-západ
Sample 620: bead no. 1 – double bead, or two fused annular beads; blue-green translucent, some red inclusions. D 5.5, d 2, h total 3.5, h of individual beads 1.5 and 2.
Sample 621: bead no. 2 – annular, blue-green translucent. D 4.5, d 2, h 2.
Sample 622: bead no. 3 – annular, blue-green translucent. D 5, d 2, h 1.5.
Sample 623: bead no. 4 – annular, blue-green translucent. D 5, d 2.5, h 2–2.5.
Sample 624: bead no. 5 – annular, blue-green translucent. D 5.5, d 3, h 1–2.5.
Sample 625: bead no. 6 – annular, blue-green; semi-translucent. D 5, d 2, h 2–2.5.
Sample 626: bead no. 7 – annular, blue-green; semi-translucent. D 5.5, d 2.5, h 2–3.
Sample 627: bead no. 8 – annular, blue-green translucent. D 5.5, d 2, h 2.5.
Sample 628: bead no. 9 – annular, blue-green; deformed by fire, dull surface, traces of red glass inside the perforation. D 5, d 1–3, h 1.5–2.5.

Obory, distr. Příbram
Sample 734: annular bead, blue-green translucent, traces of red glass at the perforation. D 5–5.5, d 2, h 2–3. Grave 106.
Sample 735: annular bead, blue-green translucent. D 5, d 2.5, h 2. Grave 126.

Řepín, distr. Mělník
Sample 736: fusiform bead, blue-green translucent with white spirally wound thread fused into the surface. D 5–6.5, d 2.5, h 11. Museum (M) Mělník inv. no. 4734.
Sample 737: same bead, white decoration.
Sample 738: fusiform bead, blue-green translucent with white spirally wound thread in relief. D 5–5.5, d 2.5, h 10.5. M Mělník inv. no. 4735.
Sample 739: same bead, white decoration.

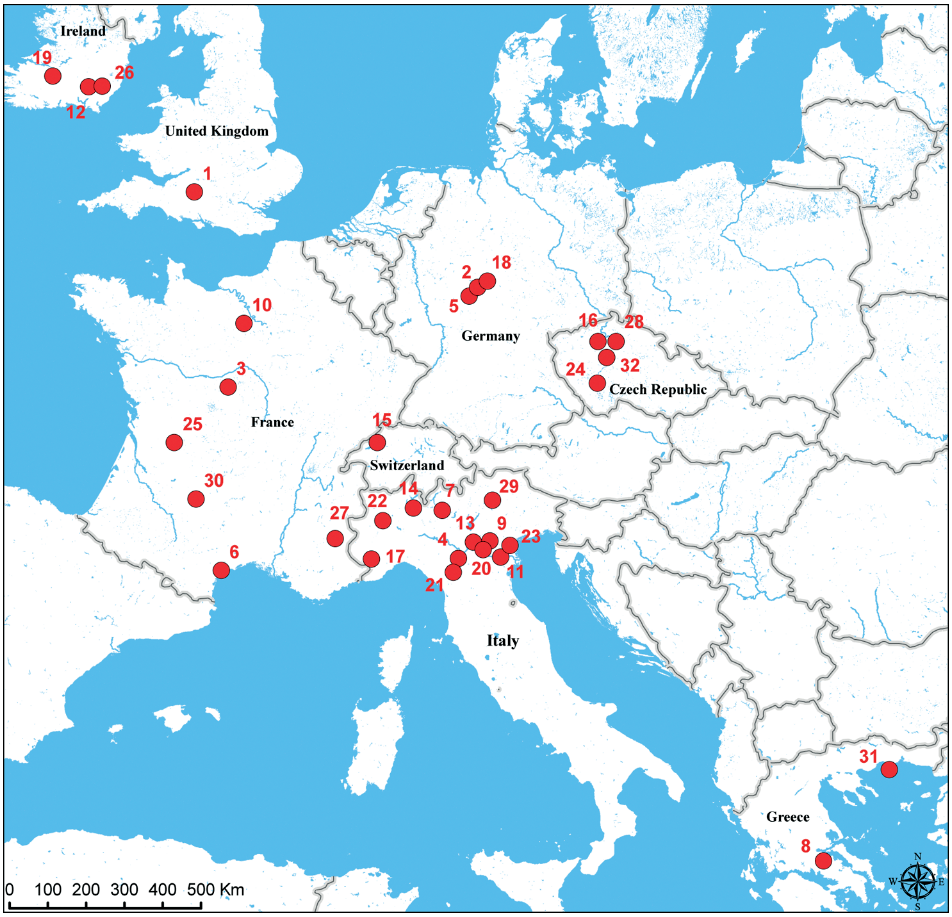

Fig. 1. Sites of chemically analysed Late to Final Bronze Age (12th to 9th cent. B.C.) LMHK glasses. After *Angelini 2009*, *Angelini et al. 2002*, *Angelini et al. 2004*, *Angelini et al. 2005*, *Angelini et al. 2009*, *Angelini et al. 2010*, *Angelini et al. 2011*, *Angelini – Nicola – Artioli 2006*, *Angelini – Polla – Artioli 2007*, *Angelini – Polla – Molin 2010*, *Hartmann et al. 1997*, *Henderson 1988b*, *Henderson 1993a*, *Henderson 1993b*, *Lorenz 2006*, *Nikita – Henderson 2006*, *Raftery – Henderson 1987*, *Towle et al. 2001*. Further sites from France could not be mapped as their list remains unpublished (cf. *Billaud – Gratuze 2002*).
Obr. 1. Nálezy chemicky analyzovaných skel typu LMHK z mladší až pozdní doby bronzové (12. až 9. stol. př. Kr.).
1 All Cannings Cross, 2 Allendorf, 3 Billy-le-Theil, 4 Bismantova, 5 Borken-Kleinenglis, 6 Bringairet–Grotte (Armissan), 7 Clanezzo, 8 Elateia, 9 Fondo Paviani, 10 Fort Harrouard (Sorrel-Moussel), 11 Frattesina, 12 Freestone Hill, 13 Gazzo Veronese, 14 Golasecca – Ca' Morta, 15 Hauterive-Champréveyres, 16 Holubice, 17 Chiusa di Pesio, 18 Lohfelden-Vollmarshausen, 19 Lough Gur, 20 Mariconda di Mellara, 21 Monte Valestra, 22 Morano sul Po, 23 Narde, 24 Obory, 25 Rancogne, 26 Rathgall, 27 Réallon, 28 Řepín, 29 Salorno-Cava Girardi, 30 Sindou–Grotte (Sénaillac-Lauzès), 31 Thasos, 32 Tuchoměřice.

Tuchoměřice, distr. Praha-západ
Sample 740: annular bead, blue-green translucent. D 6, d 2.5, h 2–3. Grave 4. M Roztoky acc. no. 05/4, bag 1.
Sample 741: annular bead, blue-green translucent. D 5.5, d 3, h 2–2.5. Grave 4. M Roztoky acc. no. 05/4, bag 6.

Fig. 2. Analysed beads from Holubice, distr. Praha-západ. Samples 620–628. Photo H. Toušková.
Obr. 2. Analyzované korálky z Holubic, okr. Praha-západ. Vzorky 620–628. Foto H. Toušková.

Fig. 3. Analysed beads from Obory, distr. Příbram (samples 734–735), Řepín, distr. Mělník (samples 736–739) and Tuchoměřice, distr. Praha-západ (samples 740–747). Photo H. Toušková.
Obr. 3. Analyzované korálky z Obor, okr. Příbram (vzorky 734–735), Řepína, okr. Mělník (vzorky 736–739) a Tuchoměřic, okr. Praha-západ (vzorky 740–747). Foto H. Toušková.

Sample 742: annular bead, blue-green translucent. D 5–5.5, d 3, h 1.5–2. Grave 4. M Roztoky acc. no. 05/4, bag 77.
Sample 743: annular bead fragment, blue translucent. D 6, d 3, h 1–2. Grave 6. M Roztoky acc. no. 05/6.
Sample 744: four-horned bead, green-blue translucent, white rings on the horns. D 12.5–15, d 3, h 7–8.5. Grave 12. M Roztoky acc. no. 05/12.
Sample 745: same bead, white decoration.
Sample 746: fusiform bead, blue-green translucent with white spirally wound thread fused into the surface. D 5.5–9,5, d 3–3.5, h 23.5. Grave 16. M Roztoky acc. no. 05/16.
Sample 747: same bead, white decoration.

NV

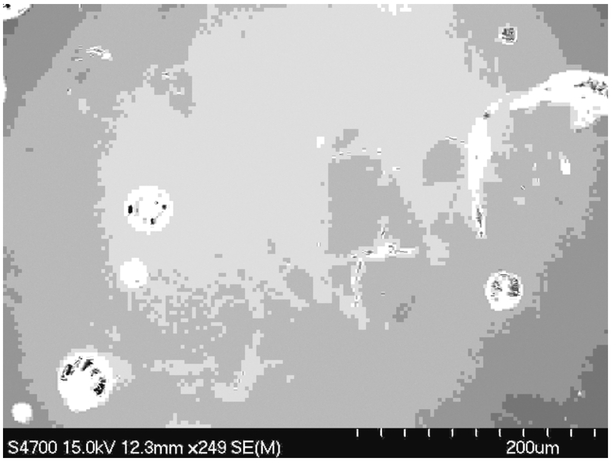

Fig. 4. SE-BSE image of the polished cross section of the sample 620 from Holubice.
Obr. 4. SE-BSE obraz leštěného řezu vzorku 620 z Holubic.

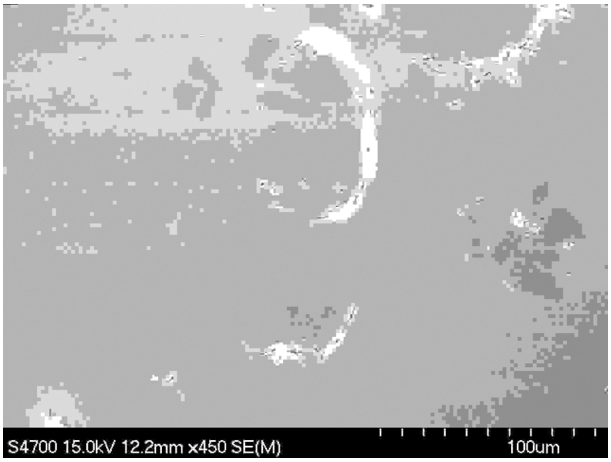

Fig. 5. SE-BSE image of the polished cross section of the sample 621 from Holubice.
Obr. 5. SE-BSE obraz leštěného řezu vzorku 621 z Holubic.

SEM-EDS chemical analysis

The results obtained (*tab. 1*) can be considered as quantitative, with c. 5 % relative accuracy for each element. The detection limits of the measured X-ray intensities for individual elements of 0.05–0.1 %wt. are given. This depends on the relative atomic numbers of the elements and matrices of the samples. The results for Sb are problematic because of the almost complete coincidence of the CaKα and SbLα lines, and they must be considered unreliable. Also, in some cases the signal of back-scattered and secondary electrons was used to check the homogeneity and presence of inclusions and other phases in the analysed samples (see *Hulínský – Černá 2001*).

The analysis was conducted in the Laboratory of the Department of Glass and Ceramics of the Institute of Chemical Technology in Prague. The glasses were analysed by scanning electron microscopy (SEM) using a Hitachi S4700 field emission scanning microscope fitted with a energy dispersive spectrometer (EDS) Thermo Scientific Ultra Dry Detector, model 4457G-IUES-SN-USA. An accelerating voltage of

Site	Sample	Glass	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	MnO	Fe_2O_3	CoO	CuO	SnO_2	Sb_2O_3	PbO
Holubice	**620**	bg	8.54	0.44	1.75	74.64	n.d.	n.d.	0.14	7.54	1.90	n.d.	0.61	n.d.	4.21	n.d.	n.d.	n.d.
Holubice	**621**	bg	8.00	0.62	2.20	75.45	0.16	n.d.	n.d.	7.86	1.93	n.d.	0.44	n.d.	3.13	n.d.	n.d.	n.d.
Holubice	**622**	bg	8.77	0.63	1.82	75.12	n.d.	0.11	0.20	7.24	1.88	n.d.	0.35	n.d.	3.74	n.d.	n.d.	n.d.
Holubice	**623**	bg	7.20	0.81	1.97	75.78	n.d.	n.d.	0.21	8.00	1.83	n.d.	0.37	n.d.	3.83	n.d.	n.d.	n.d.
Holubice	**624**	bg	6.89	0.83	1.95	75.74	0.28	n.d.	0.24	7.91	1.88	n.d.	0.52	n.d.	3.76	n.d.	n.d.	n.d.
Holubice	**625**	bg	5.88	0.62	1.93	78.12	n.d.	n.d.	0.11	8.63	1.12	n.d.	0.59	n.d.	3.01	n.d.	n.d.	n.d.
Holubice	**626**	bg	6.55	0.55	2.19	75.07	n.d.	n.d.	0.13	8.88	1.54	n.d.	0.67	n.d.	4.41	n.d.	n.d.	n.d.
Holubice	**627**	bg	6.77	0.70	2.06	75.84	n.d.	0.15	0.12	9.29	1.10	n.d.	0.53	n.d.	3.46	n.d.	n.d.	n.d.
Holubice	**628**	bg	6.53	0.82	1.94	75.81	n.d.	n.d.	0.23	8.78	1.73	n.d.	0.44	n.d.	3.72	n.d.	n.d.	n.d.
Obory 106	**734**	bg	5.10	0.29	1.47	76.66	n.d.	0.07	0.17	10.05	1.85	0.33	0.55	n.d.	3.17	n.d.	n.d.	0.29
Obory 126	**735**	bg	5.62	0.47	0.64	77.29	n.d.	0.11	0.04	9.71	1.83	n.d.	0.55	0.13	3.60	n.d.	n.d.	n.d.
Řepín 4734	**736**	bg	7.51	0.48	0.95	78.10	n.d.	n.d.	n.d.	8.54	1.53	n.d.	0.25	0.30	2.34	n.d.	n.d.	n.d.
Řepín 4734	**737**	w	2.59	n.d.	2.36	53.82	n.d.	0.52	0.42	15.66	12.56	n.d.	1.45	2.77	1.87	5.15	0.37	0.46
Řepín 4735	**738**	bg	1.95	n.d.	0.21	65.52	n.d.	0.57	n.d.	15.75	3.01	n.d.	1.68	n.d.	9.55	n.d.	1.76	n.d.
Řepín 4735	**739**	w	2.91	0.31	0.20	73.84	n.d.	0.02	n.d.	14.02	7.66	n.d.	0.61	0.14	n.d.	n.d.	n.d.	0.29
Tuchoměřice 4	**740**	bg	4.92	0.04	0.86	74.19	n.d.	0.09	0.16	10.98	2.11	n.d.	0.56	n.d.	4.42	0.79	0.65	0.22
Tuchoměřice 4	**741**	bg	3.55	0.33	0.76	74.97	n.d.	n.d.	0.03	10.99	2.14	0.27	0.53	0.31	5.81	n.d.	0.22	0.09
Tuchoměřice 4	**742**	bg	4.92	0.22	1.01	75.48	n.d.	n.d.	0.14	10.14	2.04	n.d.	0.30	0.11	4.35	0.69	0.43	0.16
Tuchoměřice 6	**743**	bg	9.22	0.83	1.68	75.46	0.26	0.03	0.10	7.24	1.03	0.05	0.58	n.d.	2.97	0.45	n.d.	0.09
Tuchoměřice 12	**744**	bg	6.81	n.d.	0.60	76.37	n.d.	n.d.	0.14	10.85	1.99	n.d.	0.90	n.d.	2.34	n.d.	n.d.	n.d.
Tuchoměřice 12	**745**	w	2.98	0.17	0.65	88.35	n.d.	n.d.	n.d.	5.44	1.41	n.d.	0.38	n.d.	0.27	0.31	n.d.	n.d.
Tuchoměřice 16	**746**	bg	9.65	1.84	1.15	72.04	0.27	n.d.	0.42	6.38	4.78	n.d.	0.07	0.12	1.85	0.89	0.52	n.d.
Tuchoměřice 16	**747**	w	7.01	1.29	0.97	73.06	0.71	n.d.	0.67	6.86	5.94	n.d.	0.96	n.d.	1.45	0.24	0.83	n.d.

Tab. 1. SEM-EDS microanalysis. Contents in %wt. Glass: bg blue-green matrix, w white decoration.
Tab. 1. Mikroanalýza SEM-EDS. Obsahy v %hm. Sklo: bg modrozelená matrice, w bílá výzdoba.

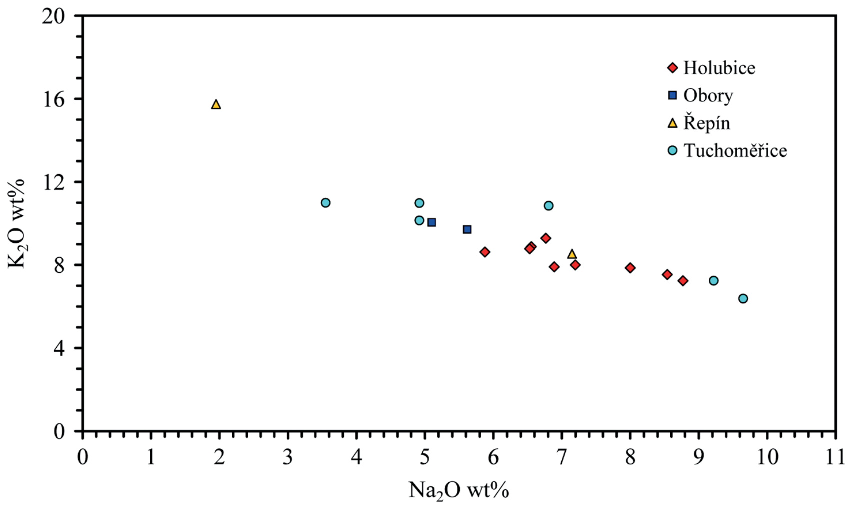

Fig. 6. Correlation of K_2O and Na_2O contents in the analysed glasses.
Obr. 6. Korelace obsahů K_2O a Na_2O v analyzovaných sklech.

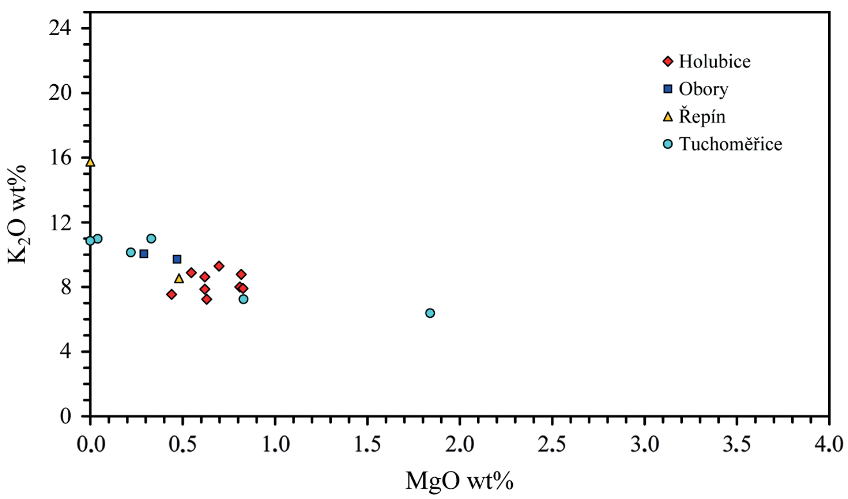

Fig. 7. Correlation of K_2O and MgO contents in the analysed glasses.
Obr. 7. Korelace obsahů K_2O a MgO v analyzovaných sklech.

15 kV and beam current of primary electrons c. 120 pA were used. Polished areas of c. 0.5–1 mm^2 were prepared on selected points of each glass object so that the corrosion layer on the surface was removed and geometric conditions precisely determined so as to define the take-off angle of the spectrometer. The smooth surface of the glass was then analysed. Analytical spectra were produced for at least three places on the archaeological sample in an area of 100x100 micrometres; the spectra were collected for 100s. Thus the migration of alkali ions from the analysed volume was minimised. The quantification of measured spectra was performed by a ZAF iteration program using the reference glass standard Corning Glass B which was obtained thanks to R. Brill, The Corning Museum of Glass, USA.

Homogeneity of analysed glasses

Prior to the analyses, it was necessary to study the samples by means of back-scattered and secondary electrons imaging so that homogeneous areas of the glass could be identified. Samples were more or less translucent and sometimes even opaque. The latter indicates that they contain primary unfused particles or secondary phases that disperse light (*figs. 4* and *5*). Corresponding to the analyses carried out elsewhere (*Angelini et al. 2004*; *Towle et al. 2001*; *Henderson 1993a*; *Santopadre – Verità 2000*) it was found that the blue-green glass of the samples can be characterised as a mixture of undissolved grains up to 200 micrometres in size, apparently tridymite (the high-temperature phase of quartz, where the transformation temperature reaches 870 °C), containing cracks as a result of the differential thermal expansion/contraction of the glass and crystals during cooling. Besides these large crystals of tridymite, small dendritic crystals could also be observed as products of the secondary crystallisation of glass during cooling. Moreover, the glass contains pale inclusions rich in Ti (similar observations have been made by *Henderson 1993a* and *Angelini et al. 2004*) and mostly globular particles of metallic character (Cu). In the glass phase there is also a quantity of bubbles. All samples can be characterised as being a transitional phase between glassy faience and glass, with a large volume of the glass phase.

Analytical results

The analytical results are shown in *tab. 1* and *figs. 6* and *7*. With the exception of one sample (see below), all glasses contained both sodium and potassium (alkali) ions and can be identified as the so-called mixed-alkali glasses. This class of glass is characterised, a.o., by a high resistance to corrosion. This is demonstrated in archaeological finds by the exceptional preservation of such glass objects, which otherwise would not be possible, considering the very low presence of stabilising bivalent ions in the oxide (CaO).

Matrix glass. The largest group of analysed glasses (94.7 % of all matrix glasses, with the exception of sample 738) have average contents of Na_2O = 7.24 %wt., K_2O = 8.24 %wt. and CaO = 1.66 %wt., with an average sum of the alkalis K_2O+Na_2O = 15.48 %wt., ratio K_2O/Na_2O = 1.66 and average contents of MgO = 0.58 %wt. (with the exception of sample 746). These glasses undoubtedly belong to the LMHK chemical type which has been found in high concentrations in the Frattesina workshop and on other sites in north Italy, and is characterised by the ratio K_2O/Na_2O = 1–2 and MgO contents under 1 %wt. (*Henderson 1988a*; *Angelini et al. 2004*; *Angelini – Polla – Molin 2010*). A negative correlation between the contents of K_2O and Na_2O can also be observed.

As already stated, one exception was found. In sample 738 from Řepín (a bead with white decoration) K_2O markedly prevails and the glass could be described as a potassium-rich silica glass. This sample also has high contents of CuO, Fe_2O_3, CaO and a very low content of SiO_2. Also the total alkaline oxides are much higher than 15.48 %wt. Similar finds have been published from Frattesina, sample FRV4 by *Angelini et al.* (*2004*) and sample 236 by *Towle et al.* (*2001*), and Thasos (*Henderson 1993b*). This could indicate a different source of K-ions, or a different method of ash leaching.

Another sample, 746 from Tuchoměřice, again a bead with white decoration, differs from the others by the content of MgO exceeding 1 %wt., and by a much higher content of CaO than other samples. The high content of P_2O_5 established in this sample was also found in samples 621, 624 a 743. A similar value of P_2O_5 was provided by the Frattesina sample FRBR-R (*Angelini et al. 2004*). Again, a different leaching process of the plant ash may be responsible.

Samples 740, 742, 743 and 746 show a higher content of SnO_2. In some cases it may correspond to the content of Pb, and both elements could have been introduced from bronze. The same applies to the presence of Cu.

Colourants in the matrix glass. The colouring of the analysed blue-green glass of the bead matrices is in all cases the result of the content of CuO in a range of c. 2.5–11.79 %wt. Also cobalt was found in samples 736, 741, 742 and 746 with CoO present at up to 0.3 %wt. In samples 738 and 744 the colour of glass could have also been influenced by the higher content of Fe_2O_3 of around 1 %wt. (FeO around 0.9 %wt.).

White glass used as decoration. The white opaque glass of bead decoration is represented by samples 737, 739, 745 a 747. Apart from sample 745, the white glass of the other three samples is correlated with a higher content of CaO. In all cases, white glass has a lower content of CuO compared to the blue-green glass. In sample 737, a very small amount of SiO_2 was found and at the same time a very high content of CoO and SnO_2. Samples 737 and 739 are remarkable by their high contents of K_2O (15.66 and 14.02 %) and low contents of Na_2O, which can indicate a different source of raw materials used and was also found in sample 738 (the matrix of sample 739). Sample 745 was characterised by a higher content of SiO_2 and low content of CaO. Sample 747 had higher P_2O_5 and MgO contents together with a higher Cl content.

The high content of calcium oxide was noticed in white glass from Hauterives-Champréveyres by *Henderson* (*1993*). Quartz grains were found in white glass of some French samples by *Billaud* and *Gratuze* (*2002*) who pointed out that the white material used for decoration resembles faience rather than glass, and that no opacifying agent was added. However, calcium antimonate crystals were found in the white glass from Elateia (*Nikita – Henderson 2006*, 101) and antimony was also present in the white sample 747 from Tuchoměřice. Many crystalline inclusions and the nucleation of Ca silicates in white glass were observed by *Angelini – Polla – Artioli* (*2007*, 146) and *Artioli – Angelini – Polla* (*2008*, 249–250). According to the high content of Ca (CaO 5.94 to 12.56 %) and Fe (FeO 0.55 to 1.3 %wt.), samples 737, 739 and 747 could belong to Group 1 of the white glasses from Narde (*Angelini – Polla – Molin 2010*, 128), but sample 745 seems to be atypical and might be classified as siliceous faience.

VH

Trace element analysis

Three samples of turquoise glass from Holubice were chemically analysed using Laser-ablation inductively coupled plasma mass spectrometry (LAICPMS) at the British Geological Survey, Keyworth, UK, in order to determine their trace element concentrations. The LA-ICP-MS consisted of a NewWave UP193FX excimer (193nm) laser system with built in microscope imaging coupled to an Agilent 7500 series ICP-MS. Data was collected in a time resolved analysis mode, with a glass blank being measured before a series of glass ablations, including on the standards, were carried out. Three replicate ablations were performed on each sample. Each ablation peak was individually integrated. Calibration was performed using the NIST SRM612 glass standard (nominal 500 mg/kg concentrations) with quality control being provided by the NIST SRM610 glass (nominal 500 mg/kg concentrations). Element concentrations were taken from the GeoRem website preferred values compilation (http://georem.mpch-mainz.gwdg.de). The results were normalised to the silica content as determined by electron microprobe analysis to account for differences in laser ablation efficiency. There is a generally good agreement between the elements determined using electron microprobe and the LAICPMS.

The presence of trace element impurities in ancient glass can help to suggest the types and purities of the raw materials used to make it. Clearly the presence of trace elements should be seen in association with the electron microprobe results (*tab. 2*). Certain trace elements can be assumed to be associated with the silica used to make glass, such as neodymium (Nd), zirconium (Zr), titanium (Ti), thorium (Th) and uranium (U); their presence being the result of their high concentrations within detrital minerals such as zircon, rutile etc. that may be found within sand sources. Others, like alumina (Al) and iron (Fe) are almost certainly also associated with silica, although both of these can also be introduced with colorant-rich minerals. Chromium is also often associated with minerals like chromite found in sands, but can also be found in ashed plants suitable for glass making (*Henderson et al. 2010*, 12, fig. 4). Overall, the variation in the trace element concentrations in the three samples, as reflected by the standard deviations, is relatively low. This provides a degree of confidence that the analytical points have not included crystals.

The neodymium (Nd) levels found in the three glass samples are at levels of between 2 and 3 ppm. This shows that the silica source used to make the glasses was relatively pure, perhaps a quartz sand. The Nd levels are slightly higher than the levels found in Mesopotamian Late Bronze Age glasses for which it has been suggested crushed quartz pebbles were used as a silica source. The Nd levels are lower than found in virtually all Egyptian Late Bronze Age glasses for which we have results (*Henderson – Evans – Nikita 2010*, tab. 1, fig. 3c) and for which a relatively impure sand has been suggested as the probable silica source. While not especially surprising, this indicates that silica of a different purity, and probably from a different source from the silica used to make Egyptian and Mesopotamia glass was used to make the Holubice glasses. The three samples contain between 1.75 % and 2.2 % alumina which supports the idea that a sand source was involved in their production, being associated with the presence of feldspar in sand. The very low levels of thorium and uranium show that the sand source is unlikely to be of a granitic origin. Zirconium has been detected at between 15 and 20 ppm in the three samples. This again suggests that the sand used was relatively pure and is at a distinctively lower level than found in Levantine sand (for example).

Turning to the type of alkali used to manufacture the three glasses, the trace and minor elements normally associated with plant ashes are magnesium (Mg), potassium (K), strontium (Sr), and sometimes barium (Ba). Barium is often found at elevated levels in wood ashes. If purified plant/wood ashes were used as a source of alkali to make the glass, then the relatively low strontium (at between 110 and 130 ppm) associated with calcium is possibly to be expected, because the calcium levels would have been reduced by the ash purification

Sample	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
	Li7	**B11**	**Na23**	**Mg24**	**Al27**	**Si28**	**P31**	**K39**	**Ca42**	**Ti47**	**V51**	**Cr52**	**Mn55**	**Fe56**	**Co59**	**Ni60**	**Cu63**	**Zn66**	**As75**	**Rb85**	**Sr88**	**Y89**	**Zr90**	**Nb93**
620	29	29	54667	4044	7262	348898	468	60879	12072	325	7.4	8.3	118	3827	14	20	33862	42	50	80	135	2.7	15	1.1
620	20	17	53640	4051	7228	348898	415	58581	11779	310	7.2	8.0	114	3683	14	19	31792	39	44	76	130	2.6	15	1.1
620	22	19	55192	4179	7833	348898	459	60069	12367	320	7.8	8.5	119	3864	14	21	32709	41	50	78	137	2.7	15	1.2
mean	23	22	54500	4091	7441	348898	447	59843	12073	318	7.5	8.2	117	3791	14	20	32788	41	48	78	134	5.3	15	1.1
s.d	4.576	5.979	789.506	75.804	339.731	0.000	28.398	1165.827	294.280	8.046	0.325	0.237	2.660	95.635	0.099	0.978	1037.349	1.361	3.348	2.324	3.732	0.051	0.350	0.063
	Mo95	**Sn120**	**Sb121**	**Cs133**	**Ba138**	**La139**	**Ce140**	**Pr141**	**Nd146**	**Sm147**	**Eu153**	**Gd157**	**Tb159**	**Dy163**	**Ho165**	**Er166**	**Tm169**	**Yb172**	**Lu175**	**Hf178**	**Pb208**	**Th232**	**U238**	
620	0.4	2873	29	0.40	67	3.2	6.0	0.69	2.4	0.60	0.13	0.51	0.08	0.50	0.10	0.25	0.031	0.24	0.047	0.5	133	1.1	0.3	
620	0.4	2762	27	0.37	63	2.9	5.7	0.61	2.5	0.51	0.13	0.55	0.08	0.50	0.10	0.23	0.027	0.22	0.040	0.4	121	1.0	0.2	
620	0.4	2831	29	0.44	65	3.0	5.9	0.58	2.6	0.65	0.11	0.54	0.08	0.56	0.09	0.27	0.040	0.28	0.044	0.4	130	1.1	0.3	
mean	0.4	2822	28	0.40	65	3.0	5.9	0.63	2.5	0.59	0.12	0.53	0.08	0.52	0.10	0.25	0.033	0.25	0.043	0.4	128	1.1	0.3	
s.d	0.005	55.853	1.001	0.036	1.921	0.129	0.171	0.055	0.074	0.068	0.014	0.019	0.000	0.031	0.004	0.020	0.007	0.028	0.003	0.057	6.417	0.083	0.019	
	Li7	**B11**	**Na23**	**Mg24**	**Al27**	**Si28**	**P31**	**K39**	**Ca42**	**Ti47**	**V51**	**Cr52**	**Mn55**	**Fe56**	**Co59**	**Ni60**	**Cu63**	**Zn66**	**As75**	**Rb85**	**Sr88**	**Y89**	**Zr90**	**Nb93**
621	39	24	58812	5135	9904	352684	667	71369	13743	471	10.0	8.8	127	4893	17	28	32943	48	54	77	126	3.2	18	1.5
621	37	22	52098	4733	10210	352684	646	62034	13094	424	9.0	8.8	118	4613	15	25	29216	44	50	73	125	3.4	20	1.4
621	35	20	50766	4278	8838	352684	549	56936	11535	383	8.4	8.1	111	4246	14	22	26043	41	48	67	107	2.8	16	1.4
mean	37	22	53892	4715	9650	352684	621	63446	12790	426	9.1	8.6	119	4584	15	25	29401	45	51	73	119	3.2	18	1.4
s.d	1.845	2.209	4312.533	428.744	720.447	0.000	62.767	7319.848	1134.961	44.131	0.783	0.394	7.987	324.462	1.488	2.773	3453.900	3.665	3.305	4.947	10.866	0.320	1.970	0.053
	Mo95	**Sn120**	**Sb121**	**Cs133**	**Ba138**	**La139**	**Ce140**	**Pr141**	**Nd146**	**Sm147**	**Eu153**	**Gd157**	**Tb159**	**Dy163**	**Ho165**	**Er166**	**Tm169**	**Yb172**	**Lu175**	**Hf178**	**Pb208**	**Th232**	**U238**	
621	0.4	3180	34	0.49	58	3.2	7.2	0.78	3.0	0.57	0.13	0.54	0.08	0.58	0.11	0.30	0.039	0.32	0.037	0.4	118	1.1	0.4	
621	0.4	2649	29	0.47	59	3.6	7.1	0.78	3.1	0.68	0.13	0.66	0.11	0.65	0.12	0.30	0.063	0.29	0.049	0.5	106	1.2	0.3	
621	0.3	2373	28	0.44	50	2.9	6.3	0.68	2.6	0.56	0.12	0.46	0.07	0.37	0.11	0.32	0.037	0.26	0.049	0.4	100	1.0	0.3	
mean	0.4	2734	30	0.47	56	3.2	6.9	0.75	2.9	0.61	0.13	0.55	0.09	0.53	0.11	0.31	0.046	0.29	0.045	0.4	108	1.1	0.3	
s.d	0.053	410.442	3.223	0.025	4.486	0.328	0.505	0.057	0.294	0.068	0.008	0.101	0.020	0.144	0.006	0.013	0.014	0.031	0.007	0.065	9.116	0.126	0.043	
	Li7	**B11**	**Na23**	**Mg24**	**Al27**	**Si28**	**P31**	**K39**	**Ca42**	**Ti47**	**V51**	**Cr52**	**Mn55**	**Fe56**	**Co59**	**Ni60**	**Cu63**	**Zn66**	**As75**	**Rb85**	**Sr88**	**Y89**	**Zr90**	**Nb93**
622	21	21	60925	4515	7330	351141	516	58933	12135	323	7.6	8.5	123	3928	15	21	35202	42	49	79	128	2.4	13	1.0
622	22	20	59314	4197	6960	351141	476	60179	12274	317	7.4	8.3	120	3855	15	20	34532	40	52	77	131	2.4	13	1.0
622	19	20	53622	3909	6558	351141	426	53876	11083	310	7.4	7.7	111	3466	13	19	30678	37	44	68	112	2.0	12	1.0
mean	21	20	57954	4207	6949	351141	473	57663	11830	317	7.5	8.2	118	3750	14	20	33471	40	49	75	124	2.3	13	1.0
s.d	1.559	0.784	3836.722	303.163	386.232	0.000	45.082	3338.046	651.278	6.204	0.128	0.405	6.293	248.569	0.808	1.042	2441.842	2.608	3.891	6.072	10.316	0.238	0.832	0.043
	Mo95	**Sn120**	**Sb121**	**Cs133**	**Ba138**	**La139**	**Ce140**	**Pr141**	**Nd146**	**Sm147**	**Eu153**	**Gd157**	**Tb159**	**Dy163**	**Ho165**	**Er166**	**Tm169**	**Yb172**	**Lu175**	**Hf178**	**Pb208**	**Th232**	**U238**	
622	0.4	2811	29	0.42	61	2.6	5.6	0.59	2.2	0.56	0.13	0.41	0.06	0.46	0.09	0.28	0.043	0.23	0.036	0.4	131	1.0	0.3	
622	0.5	2758	29	0.40	63	2.7	5.7	0.56	2.2	0.59	0.09	0.52	0.06	0.46	0.09	0.23	0.030	0.23	0.039	0.3	131	0.9	0.2	
622	0.4	2610	27	0.40	55	2.5	5.1	0.55	2.2	0.63	0.12	0.47	0.05	0.39	0.06	0.21	0.027	0.23	0.029	0.3	117	0.9	0.2	
mean	0.4	2726	28	0.41	60	2.6	5.5	0.57	2.2	0.59	0.11	0.46	0.06	0.44	0.08	0.24	0.033	0.23	0.035	0.3	127	0.9	0.2	
s.d	0.048	103.961	1.109	0.011	3.856	0.095	0.328	0.023	0.034	0.035	0.021	0.054	0.007	0.042	0.014	0.037	0.009	0.002	0.005	0.023	7.981	0.048	0.021	

Tab. 2. LAICPMS analysis. Trace element concentrations in three samples of glass from Holubice (3 analytical spots per sample; mean and standard deviations) normalised to silica.
Tab. 2. Analýza LAICPMS. Koncentrace stopových prvků ve třech vzorcích skla z Holubic (analyzována 3 místa na vzorku; průměrné a standardní deviace) normalizované vzhledem k Si.

(see above). The low barium levels at between 50 and 65 ppm however could indicate that a mixed potassium and sodium-rich *mineral* source of alkali cannot be ruled out. If this is the case, then it could also explain the low levels of strontium, magnesium and calcium in the glasses and it would not be necessary to resort to explaining the low levels of magnesium and calcium as resulting from ash purification.

As noted above the levels of copper and tin in the glass samples suggest that scrap bronze was used to colour the glass. The very low trace levels of some transition metals (Zn, Co, Ni) show that they did not form significant impurities in the original copper ore bodies used. Iron may well have been introduced as part of a mineral impurity in the sand.

Thus it can be seen that these three sets of trace element results for mixed alkali glasses provide additional, though not definitive, evidence for the purities and types of raw materials used to make the glass.

JH, SC

Discussion of the analytical results

According to chemical analyses, the glasses studied from Bohemia belong, with one exception, to the LMHK glass of the Late Bronze Age (Final Bronze Age in Italian terminology) described by several authors (namely *Henderson 1988a*; *1993a*; *Brill 1992*; *Santopadre – Verità 2000*; *Towle et al. 2001*; *Angelini et al. 2004*; *Lorenz 2006*; *Angelini – Polla – Molin 2010*). The composition of these glasses is comparable to the glass produced in Frattesina and perhaps other sites in north Italy. Also the texture of the analysed glasses is almost identical with that of the Frattesina glasses according to *Angelini et al.* (*2004*), *Towle et al.* (*2001*, sample 221) or *Santopadre – Verità* (*2000*). The contents of the main glass constituents as well as colouring elements indicate a high level of specialisation in the glass production. The source of alkali is still a matter of debate; most often a leached plant ash is considered to be the cause. In our opinion, the explanation of the mixed alkali and the low Mg and Ca contents in this glass could be the use of leached ash either from the mixture of local continental and maritime plants, the latter perhaps from the nearby Adriatic shore, or from local plants containing a similar Na/K ratio. However, these explanations must remain hypothetical until such marsh plants are identified and analysed. Their composition could be related to the specific fluvial conditions at the site of Frattesina in the Italian Final Bronze Age (*Arenoso Callipo – Bellintani 1994*). Moreover, since not all components of plants are transferred directly into the glass when it is made because of the melting conditions, it can be difficult to establish which plant genera and/or species were used using the chemical analyses of the glasses (*Barkoudah – Henderson 2006*). In addition, we hypothesise that a mineral source of alkali is an alternative.

Matrix glass of the sample 738, but also the white glasses – samples 737 and 739 from Řepín – are conspicuous because of their high K_2O contents, at around 15 %, resulting in a much higher K_2O/Na_2O ratio than in other samples. This could indicate a different source of alkali, a different geological source for the plant or that a different plant ashing procedure was used. Sample 746 from Tuchoměřice with its MgO content over the normal 1 % (at 1.8 %) and high content of CaO (4.78 %) and P_2O_5 (0.27 %) could also reflect a differing ash leaching process. The last two samples could most probably be considered as random deviations from the commonly and rather precisely followed formula of typical LMHK glasses, although other explanations are possible. One such possibility is that the glass was made in a different location from the mixed-alkali glasses.

The matrix colouring agent CuO has been identified in almost all cases. It may have been introduced from bronze, especially when Sn is also present. Sometimes, another colourant – cobalt was present, possibly introduced from a mineral source.

VH, JH

Archeological considerations

The results of chemical analyses correspond to the typological properties of the investigated beads. Most beads are visually similar in their colour, translucency and quality of glass. It is remarkable that the exceptional bead – sample 738, and also sample 746 – belong to the polychrome beads decorated by white glass. The other polychrome beads, samples 736 and 744, do not differ in their matrix glass from other beads. The white glasses are quite variable; samples 737 and 739 from Řepín both have a very high content of K_2O. It is a fact that polychrome beads are visually considerably different each from the other. However the number of samples are too low for drawing significant conclusions. The theory can be advanced that the raw glass used in some of the polychrome beads could have been made in different workshops, or resulted from different melting conditions for that used to make glass in the simple monochrome beads. The more or less similar chemical composition of the LMHK glass beads found in the context of the Knovíz culture in Bohemia could be the result of a one-time delivery of glass products from one or more than one workshop distributed there during a relatively short time span.

It should be noted here that Late Bronze Age glass of different chemical properties have also been identified in Bohemia. A few beads of the Lausitz culture from Mladá Boleslav-Čejetičky (B C2-D) and Jeřice (Ha A) and others of the Silesian-Platěnice culture from Dražkovice (Ha B1), all in east Bohemia, and also one Lausitz culture bead from Gorszewice in Greater Poland (Ha C or earlier) analysed by Frána and Maštalka (*Frána – Maštalka – Venclová 1987*, tab. 3, samples 17 and 47; *Frána – Maštalka 1990*, tab. 7; for the archaeological context see *Venclová 1990*, 218–219; *Malinowski 1990*, 23–25) belong not to LMHK but to HMG (plant ash) glass (see also *Henderson 1988b*, fig. 3).

The typological and chemical properties of glass beads found in the Late Bronze Age Knovíz culture context of Bohemia provide very strong evidence for their origin in north Italy. These beads are a prominent marker of interregional contacts between regions north and south of the Alps. The glass workshop at Frattesina, where – as well as some other possible sites in the same region – the beads were apparently produced, was active at a settlement with some central functions and with trans-alpine contacts (*Towle et al. 2001*, 11). Hypothetically, glass beads could have been one of the reciprocal articles in the trade with Alpine copper as indicated in the territory north of the Alps including Bohemia with the support of the chemical analyses of bronzes in local hoards (*Jiráň ed. et al. 2008*, 242).

The different chemical types of glass beads in the Knovíz culture area on one hand and in the Lausitz and Silesian-Platěnice Urnfield cultures of east Bohemia and Greater Poland on the other could reflect differently oriented trade (in glass, if not other items) in the Late

Bronze Age. The LMHK glass in the Knovíz context indicates a more or less direct south-north route from north Italy across the Alps to the western Urnfield cultures including west and central Bohemia, while the HMG glasses from the contemporary Lausitz culture context in east Bohemia (Jeřice, Mladá Boleslav-Čejetičky, Dražkovice) and Greater Poland (Gorszewice) perhaps show that a more easterly route was used for the eastern Mediterranean products. The inter-connection between east Bohemia and Moravia in the Late Bronze Age is attested by the content of bronze hoards (*Jiráň 2010*, 53), and further contacts are noticeable across the Carpathian Basin and to the south-east. These can be identified in the Moravian Lausitz Urnfields in Ha A and Ha B in contrast to the Middle Danubian Urnfields (*Salaš 2005*, 146–154). However, the small number of chemically analysed glasses of the east Bohemian and Moravian Late Bronze Urnfield culture so far obtained makes it at present impossible to regard this as more than a hypothesis.

NV

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Skla typu *mixed alkali* mladší doby bronzové v Čechách

V mladší době bronzové, v kontextu knovízské kultury (Ha A, 12. až 1. pol. 11. stol. př. Kr.), se vedle monochromních modrozelených skleněných korálků objevují, poprvé v českém pravěku, také korálky polychromní. Podle formálních vlastností byl jejich původ hledán v severoitalské Frattesině (*Venclová 1990*, 41–44 s lit.). Možnost exaktní identifikace sklářských výrobků této doby z hlediska jejich provenience a technologie však umožnila teprve analytická data k chemickému složení skel z Frattesiny i dalších lokalit. To se nyní týká také českých nálezů, k nimž jsou k dispozici chemické analýzy, provedené v posledních letech v rámci projektu IAA800020903 „Sklářství v pravěku a středověku: kulturní a technologické proměny“, podporovaného Grantovou agenturou AV ČR.

NV

Korálky z kontextu knovízské kultury

Výsledky bádání na konci 80. let 20. stol. shrnula *N. Venclová* (*1990*, 42–44) a současný stav předvádí připojený soupis skel z 9 lokalit (detailně v anglickém textu). Přibyly početné nálezy z knovízských hrobů v Holubicích, Noutonicích a Tuchoměřicích (vše okr. Praha-západ), za něž vděčíme zejména důslednému plavení výplní hrobů a obsahu uren.

Archeologická zjištění. S výjimkou jednoho korálku z depotu bronzů pocházejí všechny ostatní pravděpodobně z popelnicových hrobů. Skleněné korálky obsahoval v Holubicích jeden z 8 hrobů, v Tuchoměřicích 5 ze 32 hrobů. Antropologické určení pohřbených osob s korálky je k dispozici jen ve dvou tuchoměřických případech: v hrobě 4/05 to byla mladá osoba ve věku 17–20 let a v hrobě 6/05 malé dítě. K následujícímu přehledu bylo k dispozici 44 výbav hrobů z pohřebišť, kde se vyskytly skleněné korálky. Typicky mužská výbava korálky nedoprovázela v žádném případě. Inventář obsahující zlaté předměty (Tuchoměřice hr. 12/05 a Obory hr. 126) naznačuje vyšší sociální status pohřbených osob nosících korálky. Týká se to také hrobů obsahujících několik bronzových předmětů, což platí o většině hrobů se sklem. Význam skla v této době naznačuje také přítomnost zmíněného skleněného korálku v depotu bronzových nádob a ozdob ze Středokluk. Vzhledem k uvedenému nálezovému kontextu a k faktu, že korálky představují v knovízské kultuře nadregionální importy, lze soudit, že byly spíše majetkem elity a že snad sloužily k ochraně dětí a mladších jedinců (dívek?).

Formální vlastnosti korálků. Skleněné korálky byly zhotoveny technikou navíjení. Jejich sklo je průsvitné, ale nehomogenní, takže se může jevit i jako opakní. Mají modrozelenou barvu v různých odstínech, výjimečně se stopami červeného skla (Holubice, Obory). Vzácně se vyskytující výzdoba je provedena bílým opakním sklem, v jednom případě snad i sklem modrým (Dolánky). Výjimečný korál z Levous byl vyroben z bělavé, na povrchu světle zelené zrnité fajánse a technika jeho výroby nebyla zjištěna. Z typologického hlediska převažují drobné monochromní kroužkovité korálky; ze zdobených se vyskytl vřetenovitý korál s bílou šroubovicí (Řepín, Tuchoměřice; v Levousech v provedení z fajánse), čtyřcípý korál s bílými kroužky (Tuchoměřice) a oblý korál se čtyřmi snad modrobílými oky (nezvěstný exemplář z Dolánek-Rubína).

NV, LŠ, JHlo

Evropský archeologický kontext korálků „typu Frattesina“ mladší doby bronzové

Polychromních korálků mladší doby bronzové (*Final Bronze Age* v italské periodizaci) si jako prvá povšimla *Th. E. Haevernick* (*1949–1950*; *1978b*), která je podle nálezů ze švýcarských sídlišť na březích jezer označila jako nákolní perly – *Pfahlbauperlen* nebo *Pfahlbaunoppenperlen* (varianta s pupky). Později byly tyto korálky objeveny spolu s doklady jejich místní výroby v severoitalské výrobní lokalitě protovillanovské kultury Frattesina (*Bietti-Sestieri 1980*; *1981*). Následovaly další nálezy vizuálně podobných korálků v Irsku, Británii, České republice, Švýcarsku, Itálii, Německu, Francii, Řecku a jinde zásluhou celé řady badatelů (zejména Raftery, Henderson, Rychner-Faraggi, Gratuze, Hartmann, Lorenz, Bellintani). Lokalita Frattesina má pro studium těchto korálků mimořádný význam. Jde o výjimečné sídliště s řadou výrobních aktivit včetně bronzové metalurgie a s doklady interregionálních kontaktů (*Arenoso Callipo – Bellintani 1994*; *Towle et al. 2001*; *Bellintani –*

Stefan 2009). Nálezy odtud, z 12.–10. stol. př. Kr., zahrnují tyglíky se sklovinou, surové sklo a sklářský odpad a také kolem 3000 „nákolních“ skleněných korálků. Po chemické stránce jde o sklo typu *mixed alkali*, jaký je popsán níže.

Archeometrie skla typu *mixed alkali* mladší doby bronzové

Chemické analýzy skel z Frattesiny a dalších nalezišť, které zahájili J. Henderson (*Raftery – Henderson 1987*; *Henderson 1988a*; *1988b*) a *R. Brill* (*1992*; *1999*), nabídly zcela nový pohled na tzv. nákolní korálky. Sklo bylo označeno jako *mixed alkali*, resp. podle Hendersona jako typ LMHK (*low magnesium – high potassium*). Toto sklo obsahuje ca 6–9 % Na_2O, 8–11 % K_2O, 0,5–1,0 % MgO a 2 % CaO. Bylo konstatováno, že jde o zcela nový, do té doby neznámý chemický typ skla bez paralel mimo kontinentální Evropu. *R. Brill* (*1992*) se zabýval alternativami zdrojů alkálií použitých v tomto skle (loužený popel velkých dřevin, nečistá forma natronu kontaminovaná draselnými solemi jako jsou evapority v Egyptě, nebo přirozeně se vyskytující nitráty, např. z hnoje). Chemicky totožné sklo bylo pak identifikováno dalšími analýzami v Hauterive-Champréveyres ve Švýcarsku a *Henderson* (*1993a*) upozornil, že současná mladobronzová a některá halštatská skla mohou mít také jiné složení, které označil jako HMG (*high magnesium*), zatímco další typ – LMG (*low magnesium*) byl běžný až od doby železné. Vystoupil s tezí, že skla typu LMHK byla vyráběna v severní Itálii v době nedostatku skla v důsledku kolapsu mykénské kultury ve 12. stol. př. Kr. Zdroje surovin byly dále zkoumány a některé experimenty vedou k domněnce, že potaš pro skla typu LMHK mohla být získána loužením bukového popela (*Hartmann et al. 1997*). Analýzy více než stovky skel typu LMHK ze severoitalských lokalit (*Towle et al. 2001*) vedly k poznání příčin opacity skla a jeho barvidel. Výsledky velkého francouzského projektu analýz korálků mladší doby bronzové pomocí laserové ablace (LA-ICP) nebyly ještě detailně publikovány (*Billaud – Gratuze 2002*; *Gratuze – Billaud 2003*). Projekt realizovaný v Itálii zajistil I. Angelini a jejímu týmu významnou roli při výzkumu skel LMHK i dalších skel doby bronzové a počínající doby železné. Chemický typ LMHK byl zjištěn v Itálii také ve skelné fázi fajánsových předmětů, a to již od starší doby bronzové (*Angelini et al. 2002*; *Angelini et al. 2006b*; *Bellintani et al. 2006*; *Tite – Shortland – Angelini 2008*). Zároveň byly klasifikovány rozdíly mezi fajánsí, skelnou fajánsí a sklem podle podílu skelné fáze v materiálu (*Bellintani et al. 2006*; *Artioli – Angelini – Polla 2008*). Řada dalších výzkumů vedla k rozlišení dvou různých zdrojů alkálií, k předpokladu existence více dílenských lokalit a také k poznání vývoje chemických typů skel v době bronzové v Itálii (*Angelini et al. 2004*; *2009*; *2011*). Archeometrický výzkum skel ze známého depotu v Allendorfu v Hessensku, provedený *A. Lorenz* (*2006*), ukázal na současný výskyt skel typu LMHK, HMG a LMG v Ha B3/C, tedy přesně v období nástupu skel typu LMG, který nahradil předchozí typy, a také různorodý původ skleněných korálků nalézaných v Evropě. Odlišnosti ve složení skel LMHK z lokality Elateia v Řecku oproti severoitalským korálkům naznačily možnou existenci dalšího výrobního centra (*Nikita – Henderson 2006*). Podle současných chemických analýz jsou skla typu LMHK mladší až pozdní doby bronzové (12. až 9. stol. př. Kr.) známa z více než 30 lokalit v Evropě, k čemuž bude nutno ještě přičíst další nálezy z Francie, dosud nepublikované (*obr. 1*).

Za jeden z hlavních výsledků archeometrického výzkumu skla v posledních desetiletích lze bezpochyby označit poznání vývoje chemických typů skel v době bronzové a na počátku doby železné v Evropě. Typ HMG byl vyráběn na Předním Východě z alkálií získaných z popela rostlin zhruba od střední doby bronzové do počátku halštatského období (1500 až 800–750 př. Kr.). Typ LMHK (*mixed alkali*) se považuje za kontinentální evropský (severoitalský) vynález; byl zjištěn ve skelné fázi fajánsových korálků a knoflíků starší a střední doby bronzové a zejména ve skleněných korálech mladší, a případně pozdní doby bronzové (ca 1200–900 př. Kr.). Typ LMG s alkáliemi minerálního původu, resp. natronové sklo, byl vyráběn ve Středomoří od doby halštatské, resp. od 8. stol. př. Kr. přes dobu laténskou nejméně až do doby římské a stěhování národů.

Analyzované vzorky skla z Čech

K analýze bylo předloženo 19 korálků, z nichž bylo analyzováno modrozelené sklo matrice a ve čtyřech případech polychromních korálků také jejich bílá výzdoba, takže celkový počet vzorků činil

23. Čísla vzorků odpovídají číslování v databázi chemických analýz pravěkých až novověkých skel VITREA (*http://www.arup.cas.cz/cz/VITREA/index.htm*; srov. *Venclová et al. 2010*). Soupis vzorků je uveden v anglickém textu. *Obr. 2* a *3*.

NV

Chemická analýza SEM-EDS

Skla byla analyzována touto metodou v Ústavu skla a keramiky VŠCHT v Praze (k metodě srov. *Hulínský – Černá 2001*).

Homogenita analyzovaných skel. Analyzovaná skla obsahují neprotavená zrna tridymitu, drobné dendritické krystalky a inkluze obsahující Ti a Cu. Tento materiál lze charakterizovat jako přechodnou fázi mezi skelnou fajánsí a sklem (*obr. 4–5*).

Výsledky analýz. Výsledky předvádí *tab. 1* a *obr. 6–7*.

Sklo matrice. S výjimkou jednoho vzorku (738) byla všechna skla identifikována jako typ *mixed alkali*. Mají průměrný obsah Na_2O = 7,24 %hm., K_2O = 8,24 %hm. a CaO = 1,66 %hm., součet alkálií K_2O+Na_2O = 15,48 %hm., poměr K_2O/Na_2O = 1,66 a průměrný obsah MgO = 0,58 %hm. (s výjimkou vzorku 746). Tato skla nepochybně patří k chemickému typu skla LMHK, který byl rozpoznán jako produkt sklářské dílny ve Frattesině v severní Itálii. Toto sklo charakterizuje poměr K_2O/Na_2O = 1–2 a obsah MgO nižší než 1 %hm. (*Henderson 1988a*; *Angelini et al. 2004*; *Angelini – Polla – Molin 2010*). Ve zmíněném výjimečném případě korálku z Řepína, vz. 738, výrazně převažuje K_2O a objevuje se vysoký obsah CuO, Fe_2O3, CaO a velmi nízký obsah SiO_2; to může odrážet jiný zdroj alkálií nebo jiný způsob loužení rostlinného popela. Další vzorek 746 z Tuchoměřic se odlišuje vyšším obsahem MgO. Vzorky 740, 742, 743 a 746 vykazují vyšší obsah SnO_2.

Barvící prvky ve skle matrice. Zbarvení je ve všech případech výsledkem obsahu CuO; zjištěny byly i kobalt a železo.

Bílé výzdobné sklo. Tři vzorky (737, 739, 747) mají vyšší obsah CaO (5,94 to 12,56 %), což neodporuje výsledkům z jiných lokalit (*Henderson 1993a*). Opacitu bílého skla způsobují zřejmě krystalické křemičité inkluze a nukleace Ca silikátů (*Angelini – Polla – Artioli 2007*, 146; *Artioli – Angelini – Polla 2008*, 249–250; *Angelini – Polla – Molin 2010*, 128). Vzorek 745 se svým vysokým obsahem SiO_2 zdá být atypický.

VH

Analýza stopových prvků LAICPMS

Modrozelené sklo tří korálků z Holubic (vzorky 620, 621, 622) bylo analyzováno metodou laserové ablace v British Geological Survey v Keyworth ve Velké Británii (*tab. 2*). Stopové prvky mohou indikovat typ použitých surovin. Obsah neodymia ukazuje, že křemík byl získán z jiného zdroje než egyptská a mesopotámská skla. Nízký obsah thoria a urania svědčí o jiném než granitickém zdroji písku. Obsah zirkonia ukazuje na poměrně čistý písek a jeho obsah ve zkoumaných sklech je nižší než např. v levantském písku. Malý obsah barya nevylučuje využití minerálního zdroje se smíšeným obsahem potaše a sody. Obsah mědi a cínu snad souvisí s barvením skla s užitím bronzoviny.

JH, SC

Diskuse výsledků analýz

Studovaná skla z Čech patří, s jednou výjimkou, k chemickému typu *mixed alkali*, resp. LMHK mladší doby bronzové, jaký popsala řada autorů (zejm. *Henderson 1988a*; *1993a*; *Brill 1992*; *Santopadre – Verità 2000*; *Towle et al. 2001*; *Angelini et al. 2004*; *Lorenz 2006*; *Angelini – Polla – Molin 2010*). Složení i textura těchto skel souhlasí se sklem vyráběným v lokalitě Frattesina, popř. v dalších severoitalských dílnách. Zdroj alkálií je stále předmětem diskuse; většinou se uvažuje o louženém rostlinném popelu. Podle našeho názoru může být vysvětlením mixu alkálií a obsahu hořčíku použití louženého popela ze směsi místních kontinentálních a zároveň i přímořských rostlin, nebo z popela místních rostlin pocházejících z oblastí se specifickými fluviálními podmínkami, jaké charakterizovaly právě lokalitu Frattesina na konci doby bronzové (*Arenoso Callipo – Bellintani 1994*). Vyloučen ovšem není ani minerální zdroj.

VH, JH

Archeologická pozorování

Výsledky chemických analýz odpovídají typologickým vlastnostem zkoumaných korálků, z nichž většina se shoduje barvou, průsvitností a kvalitou skla. Složením výjimečné vzorky 738, příp. 746 náleží polychromním korálkům a nabízí se představa, že by surové sklo pro takové korálky mohlo být vyrobeno v jiných dílnách, nebo pocházet z jiných taveb než sklo pro monochromní korálky. Polychromní korálky se také nejvíc navzájem vizuálně odlišují. Počet vzorků byl nicméně příliš malý k vyvození významných závěrů. Víceméně jednotné chemické složení korálků z kontextu knovízské kultury naznačuje, že mohlo jít o jednorázovou dodávku z jedné či více dílen, distribuovanou zde v průběhu krátké doby. Na tomto místě je třeba připomenout, že v Čechách bylo v mladší době bronzové zjištěno také sklo jiných chemických vlastností. Korálky lužické kultury z Mladé Boleslavi – Čejetiček (B C2-D) a Jeřic (Ha A), slezskoplatěnické kultury z Dražkovic (Ha B1), a také korálek lužické kultury z Gorszewic ve Velkopolsku (Ha C či starší) nepatří ke sklu typu LMHK, ale HMG (*Frána – Maštalka – Venclová 1987*, tab. 3, vzorky 17 a 47; *Frána – Maštalka 1990*, tab. 7; archeologický kontext viz *Venclová 1990*, 218–219; *Malinowski 1990*, 23–25; viz též *Henderson 1988b*, fig. 3).

Typologické a chemické vlastnosti skleněných korálků knovízské kultury jsou jednoznačným dokladem jejich původu v severní Itálii, a tedy interregionálních kontaktů mezi územím severně a jižně Alp. Korálky mohly být jedním z recipročních artiklů v obchodu s alpskou mědí, která byla chemickými analýzami indikována v bronzech z depotů na území střední Evropy včetně Čech (*Jiráň ed. et al. 2008*, 242). Rozdílné složení skel knovízské kultury na jedné straně a východočeských lužických a slezskoplatěnických popelnicových polí na druhé straně může odrážet různě orientovaný obchod (přinejmenším se sklem) v mladší době bronzové. Typ skla LMHK v knovízském kontextu ukazuje na víceméně přímý směr importu ze severní Itálie přes Alpy na území západních popelnicových polí včetně západních a středních Čech, zatímco typ skla HMG ze současných kontextů ve východních Čechách a ve Velkopolsku naznačují východnější cestu používanou pro produkty z východního Středomoří. Spojení mezi východními Čechami a Moravou v mladší době bronzové dokládají mj. bronzové depoty (*Jiráň 2010*, 53), a další kontakty jsou zřetelné napříč Karpatskou kotlinou a dále k JV. Platí to zejména pro moravská lužická popelnicová pole v Ha A a Ha B na rozdíl od středodunajských popelnicových polí (*Salaš 2005*, 146–154). Malý počet chemicky analyzovaných skel z východočeských a moravských popelnicových polí mladší doby bronzové však neumožňuje tyto předpoklady zobecnit.

NV

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