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The question of ash glasses in the Roman period focusing on finds from Poland

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This paper presents the results of physico-chemical analyses of approximately 170 products, beads and vessels from the Roman period coming from the territory of Poland. These are the soda high potassium artifacts, which may be considered as ash glasses. Glasses with higher potassium content (HKG) were melted using the ash from halophyte plants in the workshops of the Roman East and probably other places in the Mediterranean. These were mainly coloured glasses used to produce ornaments, mosaic vessels, decorative plaques and tesserae. In the Roman period, especially in its later stages, and in the Franconian period, ash glasses began to be produced also in the western provinces of the Empire, and these were mainly the low magnesium specimens (LMG). However, questions about the frequency of ash glasses in the Roman period and the location of production centres as well as the kinds of alkaline raw materials require further research.

KEY-WORDS: Roman ash glasses, beads and vessels from Poland, technique of forming, ash glasses from Roman Empire

INTRODUCTION

Compared to other periods the basic recipe used for glass melting in the Roman period was quite uniform. It was the soda recipe and the chief differences in it was the alkaline raw material used. Most researchers agree that it was a mineral soda, mainly natron, and that soda-rich plant ash was used to melt glasses at a later time, already in the early Islamic period (e.g., Freestone and Gorin-Rosen 1999). However, the 'ash' technology was known in the Middle East from the Bronze Age and such glasses were made also in Mesopotamia in the Sassanid period (Mirti *et al.* 2008: 443–444). Consequently, finds of glasses with higher K_2O content in the Roman period clearly pose an important research issue.

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In the Roman period, low-potassium glasses ('sodium'), LKG, were the predominant group, whereas specimens with higher potassium oxide content (which may be called 'ash') glasses, HKG, were in the minority[1].

The classification of artifacts into respective technological sub-groups is made difficult by, among others, the difference in opinions on the degree of potassium concentration in glasses that suffices to indicate the addition of plants rich in soda (halophytes). R.H. Brill (1992: 15) sets the line at 2% K_2O. Other researchers (among others, Forbes 1957: 115ff.; Rehren 2000: 1225; Freestone 2002: 68) have adopted similar values, considering specimens with less than 1% K_2O and MgO as typical Roman soda glasses.

In turn, some specialists (Sayre and Smith 1961: 1824ff.; Smith 1963a: 283–290) believe that typical Roman glasses melted using a mineral soda contained less than 1.5% of potassium oxide and just as much of magnesium (similar degrees of concentration: 1.5% both for K_2O and MgO adopted by Freestone, Bimson and Buckton 1990: 271–279). Also V.A. Galibin (2001: 75) believes that ash glass should contain no less than 1.5% K_2O, whereas Na_2O:K_2O should be 7.5. Still lower degrees of concentration were assumed by J. Scapova (1975: 34–35) and M. Dekówna (1980: 31): K_2O lower than (or equal to) 1.3%, with the proportion of Na_2O:K_2O less than 1:13. This author had adopted similar criteria until recently (Stawiarska 1984; 1993b; 1999), but now believes a more cautious approach is in order: 1.5% K_2O.

This paper presents the soda high potassium artifacts with a K_2O content ranging from 1.5% to 4% (including a few with 6%), which may be considered as ash glasses. Their potassium fraction in the general sum of the alkaline content, i.e., the K_2O:(Na_2O+K_2)x100%, is between about 8% and 20% (see Tab. 1 and Fig. 4), which is equivalent to the proportion of that fraction in the ashes of many halophyte plants such as *Kalidium caspicum*, *Keli*, *Salicornia herbacea*, *salsola kali* and others[2]. The chemical composition of halophyte ashes has been analysed by several researchers, especially M.A. Bezborodov (1969: Tab. 5), R.H. Brill (1970; 1999) and Y. Barkoudach and J. Henderson (2006).

One should also note the ambiguities regarding the content of the other glass-making component, magnesium oxide, in the recipes. Items with the MgO content below 1%, which dominated in the discussed period, are considered as low magnesium (LMG) glasses. For the high magnesium (HMG) glasses there are no degrees of concentrations; T. Rehren (2000: 1225–1226) speaks of typical values. For the high potassium-magnesium glasses (HKMG), it is 4% MgO.

As an indicator of alkali use for melting one can use the phosphorus content in the glass, e.g., it is more than 1000 ppm in the raw material of products from the Sassanid

[1] Some researchers, including Tomasz Purowski (2012: 155), divide the glasses melted according to the soda recipe into 'mineral' and 'ash' variants.

[2] Halophytes grow on salty soils, near the sea, mainly on marshy coasts, in mainland salty areas and in some deserts and semi-deserts.

workshop of Veh Ardašīr in Mesopotamia (Mirti *et al.* 2008: 443). In artifacts made with the use of mineral soda, the content of P_2O_5 usually reaches several hundredths of one per cent, but in some glasses it reaches 0.25% (Velde 1990: Tab. 3). However, phosphorus has not been taken into account in the published results of most analyses of glasses from the territory of the Empire, as well as from Poland.

Another controversial issue are the extra-recipe reasons why potassium can be found in the raw material. Small concentrations of K_2O may have got into the glass mass from the crucibles (Jackson, Cool and Wager 1998: 58). It has also been suggested that it may have been the ash from the wood-burning furnaces (Tal, Jackson-Tal and Freestone 2008: 91), but these claims are not well documented. When making technological assessments of respective glasses one should keep in mind the error threshold in the analysis. For this reason it is advisable to use due caution when determining the K_2O concentrations that will be threshold values for distinguishing soda and ash sub-groups.

The description of a sub-group of glasses cannot be limited to observations of the chemical properties of the raw material; other features include form, morphology of the artifacts, and technology of production.

GLASSES WITH HIGH POTASSIUM CONTENT (ASH GLASSES) FROM THE TERRITORY OF POLAND

There are currently for consideration results of physico-chemical analyses of approximately 170 products from the Roman period coming from the territory of Poland. The analyses, which were carried out at the Institute of Archaeology and Ethnology, PAS, in Warsaw, applied the spectral emission method (for 23 components) and the flame photometry method for determining the alkali (cf. Stawiarska 1993a). A small group of glasses: 26 specimens of mostly beads and just a few vessels, turned out to have increased potassium oxide content (HKG). The beads came mainly from northern and central Poland, whereas the vessels from the same areas as the beads and from southern Poland as well. The author has had personal access to most of the finds, which were found in well dated burial assemblages (for more details, cf. Stawiarska 1984: 102–106; 1985: 64–78; 1987; 1999).

Beads

More than 22 beads are made of soda glass with a higher K_2O content, which is more than 25% of all such analysed ornaments from the territory of Poland. The remaining 75% were made from Roman low potassium sodium glass typical of the Roman period (cf. Stawiarska 1984: 41). The former come from burials from the second half of the 2nd–early 3rd century (Phase B_2–C_{1a} after Eggers 1955) from the Wielbark and Bogaczewo cultures, from sites in Lubowidz, Odry, Pruszcz Gdański,

Table 1. Chemical features of Roman ash glass from Poland. Type III – Na-K-Ca-Mg-Al-Si; Type IV – Na-K-Ca-Mg-Si; Type V – Na-K-Ca-Al-Si; Type VI – Na-K-Ca-Si; n.d. – not analysed; *supposed ash glasses, ash type-glasses uncertain; cat. no.: see Stawiarska 1987. For a description of the artifacts and full analysis results, cf. Stawiarska 1984: 102–106, Appendix 1; Stawiarska 1999: Appendix 1

App. no	Site, grave, cat. no.	Na_2O	K_2O	CaO	MgO
54*	Pruszcz Gdański g. 168, no. 133	16.80	1.30	7.60	2.40
55a	Lubowidz g. 105, no. 139	16.60	1.55	7.60	2.33
55b	Lubowidz g. 105	~16	~1.5	6.70	1.35
56	Lubowidz g. l05, no. 137	17.00	1.65	8.20	2.47
57a	Lubowidz g. 249, no. 134	16.80	1.75	8.90	2.65
57b	Lubowidz g. 249	~17	~1.7	~8	~2
58a	Lubowidz g. 52, no 138	16.00	1.75	8.00	2.80
58b	Lubowidz g. 52	~16	~1.7	~8	~2
58b	Lubowidz g. 52	~16	~1.7	~8	~2
59	Wyszembork g. 27, no. 33	~15	2.70	9.80	2.75
60a	Odry g. 127, no. 164	10.00	1.80	9.00	2.0
60b	Odry g. 127	~10	≤1	~9	~2
61	Wyszembork g. 19, no 147	9.20	2.00	12.50	2.60
62	Rusinowo lose, no. 152	15.20	2.80	10.40	2.15
63	Szwajcaria h VII, g. 2, no. 144	15.00	2.50	14.00	2.90
64	Niedanowo g. 426, no. 136	15.60	2.10	7.60	2.75
65	Wyszembork g. 313, no. 145	13.00	2.75	10.00	2.45
66	Wyszembork g. 321, no. 11	~12	~3.5	13.00	2.45
67	Borkowice g. III, no 146	14.00	3.10	11.20	2.45
68	Borkowice g. III, no. 151	12.60	2.05	10.80	1.77
69*	Rusinowo stray find no. 58	18.40	1.45	8.20	1.10
70	Wyszembork g. 319, no. 60	16.00	1.85	7.60	1.70
71*	Odry g. 137, no. 19	15–20	≤1	9.40	2.80
72*	Pruszcz g. 210, no. 14	15–20	~1	9.90	1.45
74	Kowalki g. 7, no. 77	~15	~2	7.00	0.59
76*	Wyszembork g. 321, no. 34	15–20	1–2	8.00	1.65
92	Brześce Kolonia g. 22, no. 49a	~18	2.50	7.80	0.83
184	Pajewo Szwelice g. 3, no. 76	17.00	2.50	11.00	2.85
186	Wrocław-Zakrzów g. 1, no. 199	13.87	2.02	5.76	2.64
187*	Wrocław-Zakrzów g. 1, no. 2–4	16.35	1.41	4.38	2.07
115	Konopnica, stray find, no. 214	7.80	2.40	19.00	2.10

Al_2O_3	Fe_2O_3	PbO	CuO	Type	RN	(K_2O)	(MgO)
2.55	2.50	~3.0	1.500	III	1.81	(7.2)	(24.0)
2.30	2.24	>2.5	1.800	V	1.82	(8.6)	(23.5)
2.25	2.18	>2.5	1.800	III	2.10	(8.6)	~(16.8)
2.40	2.45	>2.5	1.270	III	1.75	(8.9)	(23.1)
2.27	2.00	>2.5	0.800	III	1.60	(9.4)	(22.9)
~2	~2	>2.5	3.060	III	~1.9	~(9)	(20)
2.22	2.60	>2.5	0.750	III	1.64	(9.8)	(25.9)
~2	~2	>2.5	3.800	III	~1.7	~(9.6)	~(20)
~2	~2	>2.5	0.750	III	~1.8	~(9.6)	~(20)
2.00	2.00	>2.5	0.700	III	~1.4	~(15.2)	~(17.7)
2.20	2.35	>2.5	3.500	III	1.07	(15.2)	(18.2)
~2	~2	0.26	0.115	III	~1	~(10)	~(18)
2.20	2.20	> 2.5	0.150	III	0.74	(11.9)	(17.2)
2.15	1.80	0.36	2.250	III	1.43	(15.5)	(17.1)
2.28	1.80	0.72	3.200	III	1.04	(14.3)	(17.2)
1.90	2.25	2.00	0.960	IV	1.71	(11.8)	(26.5)
1.75	2.10	>2.5	2.200	IV	1.23	(17.4)	(19.7)
1.70	1.95	>2.5	10.000	IV	~1	~(22)	(15.9)
1.88	2.00	0.80	2.560	IV	1.25	(18.1)	(17.9)
2.05	2.20	1.95	7.500	V	1.16	(14.0)	(13.4)
2.15	1.08	0.68	1.200	V	2.13	(7.3)	(11.8)
1.62	2.30	1.15	0.830	VI	1.90	(10.4)	(18.3)
1.70	1.65	0.06	0.110	IV?	~1.5	....	(22.9)
2.12	~5	>2.5	6.500	V?	~1.6	......	(12.7)
2.15	1.80	0.46	0.240	IV?	~2.2	~(11)	(7.9)
1.80	1.80	>2.5	0.330	VI?	~1.9	.....	(17.1)
1.95	1.19	0.35	1.500	VI?	~2.4	~(12.5)	(9.6)
2.55	1.60	0.10	0.000	III	1.40	(12.8)	(20.57)
2.97	0.94	n.d.	1.960	III	1.89	(12.7)	(31.4)
3.24	1.68	n.d.	3.230	III	2.75	(7.9)	(32.0)
3.00	2.60	0.03	0.030	III	0.53	(23.5)	(11.05)

Wyszembork, Szwajcaria, Niedanowo, Brześce Kolonia (Tab. 1: app. nos 54–60, 63–64, 71–73, 75–76, 92), from assemblages from the 3rd century (Phase C_{1a}–C_2) from Wyszembork (Tab. 1: app. nos 65–66) and from the 3rd–4th century (Phases C_{1b}–C_2 and D) from Wyszembork, Borkowice, Kowalki (Tab. 1: app. nos 61, 66–68, 70, 74). These specimens were submitted to physico-chemical analyses as well as microscopic analyses of petrographic thin sections (Stawiarska 1984; 1987).

Beads nos 54–58, 60, 64 are mosaic barrel-shaped specimens with an ornament of transverse or oblique stripes or eyes (in four cases also the chemical composition of the decorative elements was analysed). The remaining beads are monochromatic: mainly barrel-shaped or in the form of short cylinders, dark-red, orange, sand-orange, bright green and black in colour (Fig. 1). They were shaped using various techniques, as evidenced in the thin sections and microscopic photos (cf. Fig. 3).

11 beads were made with the use of more sophisticated methods: fusing of elements (mosaic technique) and stretching of the glass tube (nos 59, 66, 71–72, 75–79). Quite complex operations were performed for the purpose: on the core of a bent rod (Fig. 3:1), then stretched possibly and the mosaic elements fused (Stawiarska 1987: 3:1). Also some of the undecorated beads were made of two layers: the outer red layer was placed on a core made of glass of another colour with lateral structure (Stawiarska 1987: 39–40). The remaining plain beads were made with the simple techniques of free-forming (Fig. 3:2–4, nos 61, 62, 65, 67–68, cf. Stawiarska 1987: 84–85, 88, 94) and winding glass paste on a core (nos 69–70, 74, 92, cf. Stawiarska 1987: 45–48, 52).

The glass used to make the discussed beads from the territory of Poland contains between 1.5% and 3.5% K_2O (Tab. 1). Slightly lower concentrations of potassium oxide were found in the case of glasses nos 54, 69, 71–72, 76. These specimens were included in the discussed group because of other technological and morphological similarities. More than 70% of the glasses with the higher potassium oxide content have also higher concentrations of MgO: more than 2% (or slightly less: app. nos 54–68, 70–71), so they should be classified as high magnesium ones (HMG). The remaining glasses have low concentrations of magnesium oxide: between 0.59% and 1.65% (these are LMGs, cf. Fig. 4). In almost all the specimens the Al_2O_3 concentration is about 2%.

The greatest similarities of chemical composition, forming technique and morphology can be found among the mosaic beads (nos 54–58, Fig. 1). Considerable, also formal similarities indicate that the beads were probably produced in the same workshop. Several red and orange barrel-shaped beads (nos 62–63, 67) have similar chemical compositions and were made using similar techniques. Artifacts made of stretched tubes, which share the chemical composition, are also similar in their morphology and these include specimens nos 59 and 66. Parallels for the chemical composition exist between miniature beads nos 72 and 73 formed by the same technology (observed despite the lack of full analyses of the alkali). Thus, in the group of glasses with higher potassium content, in many cases, morphological similarities are accompanied by

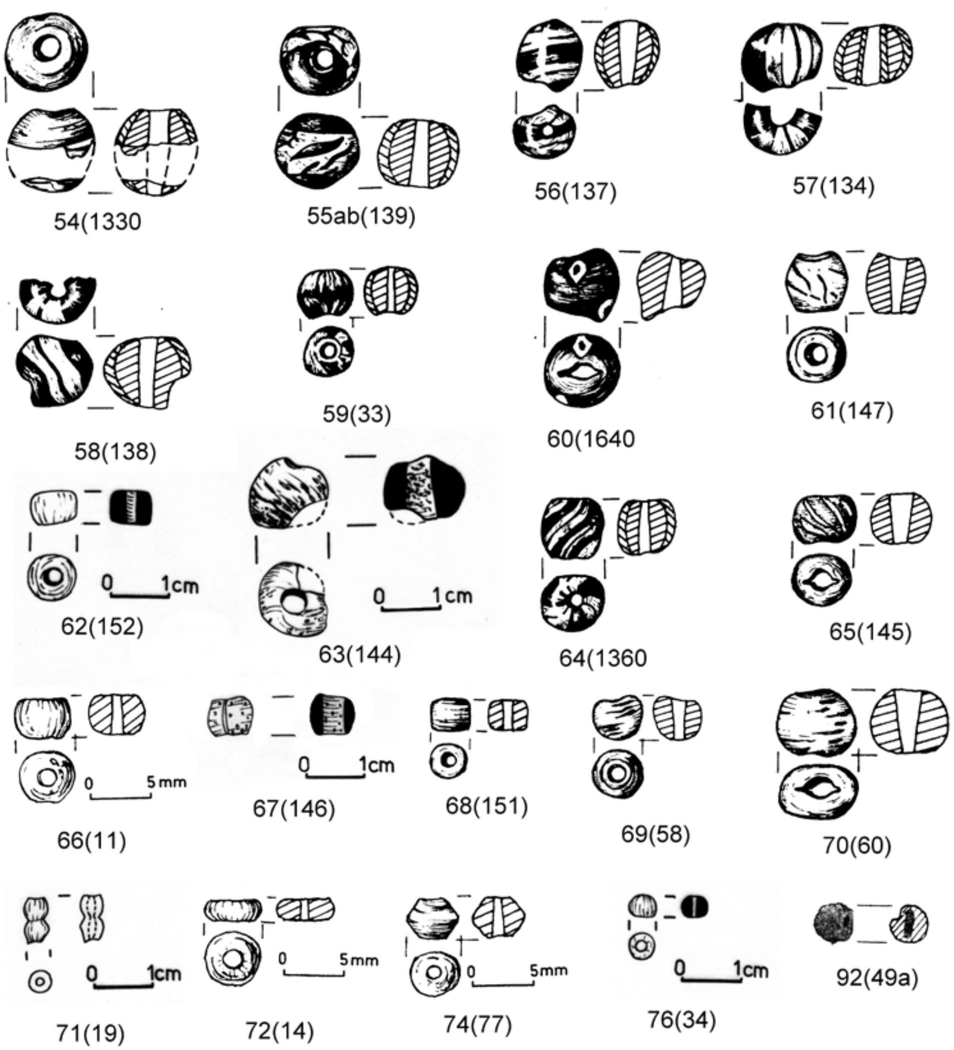

Fig. 1. Beads of ash-type glass from Poland. Borkowice, zachodniopomorskie voivodeship: 67–68; Brześce Kolonia, lubelskie voivodeship: 92; Kowalki, zachodniopomorskie voivodeship: 74; Lubowidz, pomorskie voivodeship: 55–58; Niedanowo, warmińsko-mazurskie voivodeship: 64; Odry, pomorskie voivodeship: 60, 71; Pruszcz Gdański, pomorskie voivodeship: 54, 72; Rusinowo, zachodniopomorskie voivodeship: 62, 69; Szwajcaria, podlaskie voivodeship: 63; Wyszembork, warmińsko-mazurskie voivodeship: 59, 61, 65–66, 70, 76 (in brackets: catalogue numbers after Stawiarska 1987). Drawing by E. Fido

technological ones: chemical composition and forming technique. Relatively close similarities of technology and morphology of the discussed glasses from Poland can be found in specimens from the bead workshop in Tibiscum, Dacia, dated to the 2nd–3rd century (Fig. 4: *T1–7*) (see also Stawiarska 2014: 30–34).

Vessels

Very few vessels made of glass with higher potassium content were found at the territory of Poland (four specimens, Fig. 2, nos 184, 186, 187, 115). They were unearthed in Przeworsk and Wielbark culture cemeteries. A miniature beaker of emerald colour (no. 184) was discovered in a grave from the first half of the 3rd century from Pajewo-Szwelice. A fragment of a thin-walled vessel of unknown form (very deformed due to melting) was discovered in a Late Roman cemetery in Konopnica (no. 115, cf. Stawiarska 1999: cat. nos 76 and 214). The remaining artifacts come from the princely grave in Wrocław-Zakrzów, dated to the second half of the 3rd century. These are fragments of a luxury two-layer (blue-green) artifact, cold-decorated with concentric grooves (no. 186) and a mosaic vessel (no. 187), which, like the other mosaic vessels from that burial, was dated to the early Roman period (glasses from Wrocław-Zakrzów, cf. Stawiarska 1999: 96–97, 159, cat. no. 199, 3–4).

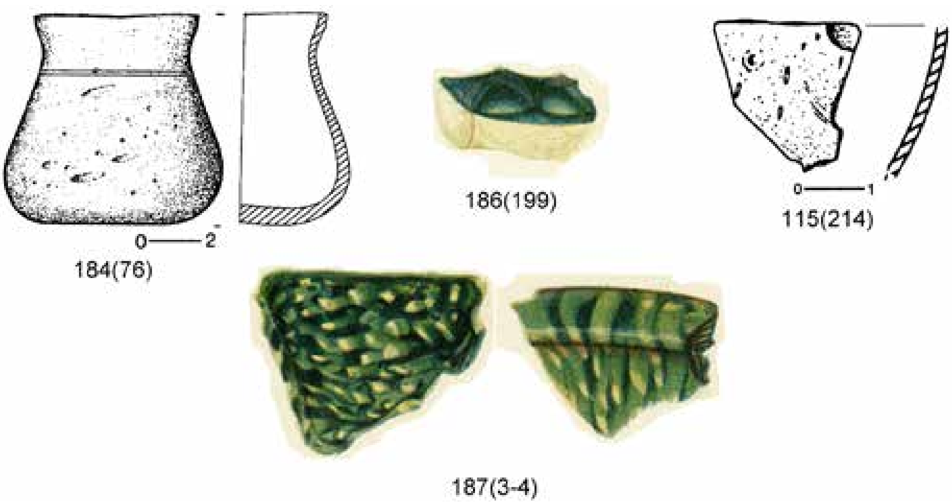

Fig. 2. Vessels of ash-type glass from Poland. Konopnica, łódzkie voivodeship: 115; Pajewo Szwelice, mazowieckie voivodeship: 184; Wrocław-Zakrzów, dolnośląskie, voivodeship: 186–187. Nos 186–187, scale 1:1 (in brackets: catalogue numbers after Stawiarska 1999). Fig. nos 115, 184 after L. Kobylińska; nos 186–187, cf. Grempler 1887: Tab. VI

The potassium oxide content in the three glasses is more than 2%, in the mosaic specimen, only 1.4%. The MgO concentrations do not exceed 2%, thus these are high magnesium glasses, HMG (cf. Tab. 1, Fig. 4).

As regards the raw material of both the beads and the vessels with the higher content of K_2O coming from the territory of Poland, one should note several regularities. Most are HMG glasses and only a few are LMG; almost all of them are low or medium-alkaline, where the relation of the sum of the alkali to the alkaline earth elements, called the recipe norm (RN), is between 0.74 and 1.8. The one exception is the glass of the mosaic vessel, which is high alkaline (the relation is 2.75).

ASH GLASSES FROM THE EMPIRE AND OTHER AREAS OF THE *BARBARICUM* *

Glasses from the Roman period with a higher content of potassium oxide (HKG), found on various sites in the Empire and in some other areas of the *Barbaricum* (outside Poland), are not very numerous (about 90 specimens) compared to 1000 of the analysed items (it is difficult to establish their exact number).

Some of these artifacts were analysed in the early 20th century (cf. Stawiarska 1984: Appendix 2, nos *6–7, 10, 12–13, 20–21, 33, 35, 37, 48–49, 122, 128, 131–133*). E.R. Caley (1962: 20–21) assessed the results of these analyses as correct and comparable with those conducted later on. However, their publication is not sufficiently detailed, which makes it impossible to use them in full (among others, there are no detailed descriptions and drawings of the artifacts). The remaining specimens were submitted to various physico-chemical analyses in recent decades. For this material there is generally a full dossier on their chronology and their important formal-morphological and other features.

These artifacts, called ash glasses below, are presented in the graph (Fig. 4, cf. also Appendices 1 and 2) with indications of the chemical type of glass, recipe norms (RN) and the values of the potassium fraction (K_2O) in the sum total of the alkali.

These glasses can be divided into two groups (Appendix 2) and one of them, definitely larger (45 specimens), may be considered as relatively uniform. These are artifacts produced in secondary workshops: opaque, coloured and mosaic beads, mosaic vessels, decorative *opus sectile* plates, game pieces and dice as well as *tesserae*. They are production remains, half-products and finished products (Elephantine, Hambach); some of the were found in workshops producing ornaments (among others in Tibiscum in Dacia).

The second group comprises the remaining glasses, which are not identified more precisely for lack of source data. They include mainly blown vessels and remains of their production (among others from Ardašīr), one lamp and very few

* The numbers of the items of this group are written in italics

windowpanes. Some of the artifacts are glasses, the use of which could not be determined. Some pieces could represent raw glass, which should also be linked with glass processing.

The specimens with higher potassium oxide content (ash glasses) dated to earlier times come from Egypt: Elephantine, dated to the 2nd–1st century BC (nos *128*, *131–133*); Alexandria, 1st century BC–1st century AD (no. *83*); La Négade, 1st century BC–2nd century AD (nos *530–534*), Rome, 1st century BC (no. *37*) and Salona, 1st century (no. *393*) and 2nd century (nos *6–7*, *10*, *12–13*). The remaining ones are dated to the 2nd–4th century AD and most of them to the 3rd–4th century (cf. Stawiarska 1984: Appendix 2).

In comparison with artefacts from the territory of Poland, high magnesium (HMG) ash glasses with more than 2% MgO are less numerous than the low magnesium (LMG) glasses (35:53). The low magnesium glasses include more specimens melted following the high alkaline norms, in which the RN is more than 3. These are, among others, the early Roman mosaic finds nos *85–87*, *411*, glasses from Alexandria, nos *83* and *122*, Rome, no. *37*, Salona, no. *393* and Elephantine, no. *128*.

A considerable part of the products made in the processing workshops of the Empire (first group) and the above discussed beads from the territory of Poland are opaque. They were coloured with copper and iron compounds, often with high concentrations of lead (PbO 2–16%). According to R.H. Brill and Cahill (1988: 17–19), glasses may have been coloured with copper compounds, among others, this may have taking place at different stages of melting of the glass mass.

Several authors, including M.A. Bezborodov (1969: 130), J.E. Dayton (1993), J.L. Maas, M.T. Wypyski, R.E. Stone (2002), have indicated that coloured glasses may have been obtained using slag of bronze and other metals (also silver) and other metallurgical waste, as well as products of bronze corrosion. The use of 'copper filings' for colouring blue frit is mentioned in some written sources, including Vitruvius (*De Architectura*, VII.xi). According to the so-called Theban Papyri from the 3rd century, malachite, 'purified copper', verdigris, and minium were used for colouring ('seasoning') imitations of semi-precious stones (Stawicki 1987: 122).

The probability of using metallurgical waste for colouring glasses is confirmed by the results of analyses of glasses from the two sets. This may have been both waste from iron production (Salona, no. *10*, Fe_2O_3 8.2%) and lead-bronze (Elephantine, no. *132*, CuO 4.4%, PbO 6.28%; Wyszembork, no. 66, CuO 10%, PbO >2.5%; Borkowice, no. 68, CuO 7.5%, PbO 1.95%) or iron and copper together with lead (specimens from Tibiscum *T11* and *T12*, Fe_2O_3 3–5%, CuO 7.5%, PbO >2.5%, Pruszcz no. 72, Fe_2O_3 5%, CuO 6.5%; Odry, no. 73, Fe_2O_3 5%, CuO 9%).

The majority of the high potassium glasses (HKG) of the second group, representing mostly vessels and windowpanes, are translucent, greenish, blue, natural and colourless glasses. Some of them, found in the western provinces, are specimens with a low magnesium content (LMG, among others nos *33*, *181*, *183*, *353*, *556*, *C1*, cf. Fig. 3).

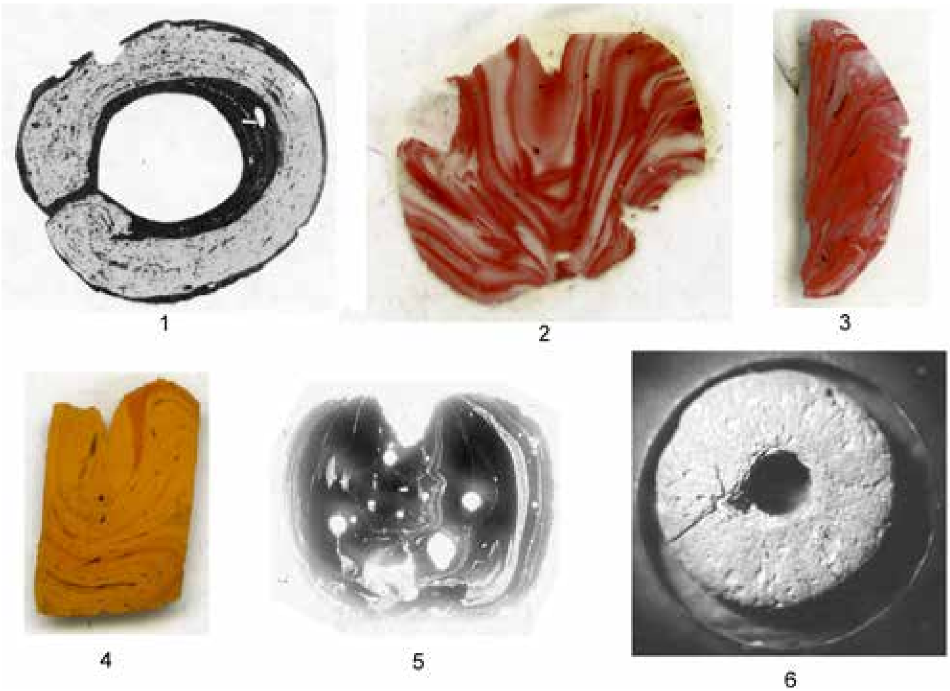

Fig. 3. Thin-section and microscopic photograph of beads from Poland. 1 – glass rod folding technique (bead no. 57); 2–4 – semi-liquid glass melt boring technique (beads nos 60, 65, 61); 5–6 – drawing technique (beads nos 66, 72). Photo by S. Biniewski

SUMMING UP

Although artifacts with increased potassium oxide content comprise a small percentage of the Roman glasses, one cannot ignore their evidently distinct character in comparison to other typical soda glasses made with the use of mineral alkali. To melt the former, other raw materials were used, mainly ashes of halophyte plants. There is no agreement as to when the ash technology appeared and how long it lasted.

According to R.W. Smith (1963a: 284–290; 1963b: 521ff.), soda glasses with higher content of potassium and magnesium oxides (HKMG) occurred mainly in the 2nd millennium BC in Egypt, Greece, Mesopotamia, and Persia, and in the early Islamic period (8th–9th century) in broadly understood Mesopotamia and Egypt. However, this researcher suggests that in Mesopotamia such glasses were continually produced from antiquity until the Middle Ages. In the Mediterranean, they can be found in the Roman period. Cautious confirmation of this comes on the grounds of an analysis of a considerable number of glasses from the territory of the Empire and the *Barbaricum* with clearly higher concentrations of potassium presented in this paper. Ash from halophyte plants was used probably also to make glasses in the Mediterranean and, as said below, in the western provinces.

In order to melt a large block of raw glass from Beit Shearim in Israel, halophyte ashes were certainly used. Although the find cannot be dated precisely (the block was found without any archaeological context), it is generally assumed that it was not melted before the Islamic period (Freestone and Gorin-Rosen 1999), when the alkaline raw material is said to have been replaced by plant ashes. The raw material of the block has similar chemical features as the raw glasses and production waste from the Sassanid-period workshops from Veh Ardašīr and Choche in Mesopotamia: these artifacts are ash high magnesium (KHMG) specimens (cf. Fig. 4: nos *134–137*, *V1–7*, *185*). Thus, it is not excluded that the glass mass (which was intended to be coloured) from Beit Shearim was melted in the late Roman period (Stawiarska 2009: 189ff.). This was production on a large-scale (export?).

The trade in raw glass in the form of lumps, cakes and rods was probably a normal procedure in the Roman period; areas where workshops melting such glass were located, the range of the export and recycling issues are the main topics of research. Large quantities of coloured glasses were necessary mainly to produce the *tesserae* commonly used for interior decoration.

At present it is difficult to determine which of the many halophyte plant species to be found in the Mediterranean among others were used for glass melting. The chemical composition also depended on which part of the plant was used and how old it was (Bezborodov 1969: Tab. 5; Brill 1970: Tab. 2). It is even more difficult to establish which plants were used based on the MgO concentration in the glass. Namely, this component may have come from ash equally well as from calcium-magnesium raw material (cf. Stawiarska 1984: 35). Ashes were also subjected to many purifying treatments (rinsing, drying, etc.) in the same way as in later periods.

The glasses melted from halophyte plant ashes can be found also in the West, including among others the remains of glassmaking workshops in Köln (app. no. *397*) and Coppergate (Britain, no. *C1*). Some of them came from the late Roman and Franconian periods: the workshop in Hambach (no. *373*) and the settlement in Runde Berg (nos *556–557*). All of them are low magnesium (LMG) glasses. Similar features are evidenced for the glass mass from the workshop in Macquenoise (Tierarche region) from the 5th–6th century and a beaker Type Kempston from Spong Hill from the 5th–7th century (Hunter and Sanderson 1982: Fig. 3; Stawiarska 2000: Tab. 2: e, w).

According to R.H. Brill (1992: 17) mixed alkaline glasses were produced already in the early Iron Age. They were melted using soda combined with potash. The results of analyses of the late Roman and Franconian specimens (second half of 4th–first half of 5th century) found in the settlement of Runde Berg near Urach may suggest that ashes of continental trees may have been added earlier on to glass melted in the West. Beside the ash glasses, finds included five potassium glasses, evidently melted with the use of the ash of continental plants (Czygan 1987; cf. Stawiarska 2000: app. nos *556–557* and *537–541*). It is assumed that potassium technology appeared at the earliest in the second half of the 8th century (Dekówna 1981). However, researchers have stressed that some western glasses contained increased potassium and they believe that the process of replacing imported alkaline raw material with the ash of continental trees could have begun already during the division and decentralisation of the Empire (Filarska 1952: 26). According to E.M. Stern (1977: 153ff.), this first occurred, among others, in the Franconian forest glassworks. These glassworks, which existed from the late 2nd century, were established by the Romans in the area of Thierache, for example. The change of raw material was a gradual process. Probably mixed raw material was used for the first time and initially a low proportion was added of the ash from the local trees, which were used at the beginning to heat the glass furnaces.

Questions about the frequency of ash glasses in the Roman period and the location of production centres as well as the kinds of alkaline raw materials certainly require further research. To sum up, it is worthwhile to present the following more or less controversial hypotheses:

1. The least controversial is the general statement that glasses with higher potassium content (HKG) were melted using the ash from halophyte plants in the Mesopotamian–Egyptian–Syrian tradition: in the workshops of the Roman East and probably other places in the Mediterranean. These were mainly coloured glasses used to produce ornaments, mosaic vessels, decorative plaques and *tesserae*.
2. More questionable is the assumption that in the Roman period, especially in its later stages, and in the Franconian period, ash glasses (mainly vessels) began to be produced also in the western provinces of the Empire, and these were mainly the low magnesium specimens (LMG).
3. It remains an open question whether in the discussed period mixed, sodium-potassium glasses were produced. They were probably melted with the use of natural soda with an addition of small amounts of ash of continental plants. Such recipes were probably first applied in the West, in the late Roman and Franconian glass-producing centres.

APPENDIX 1. GLASSES FROM THE COMPARATIVE ASSEMBLAGE (Fig. 4)

The correlation table of technological features of ash glasses (Fig. 4) was compiled using the results of analyses of specimens from the territory of the Roman Empire and some parts of the *Barbaricum* presented by T. Stawiarska (1984: Appendix 2; ibid. 1999: Appendix 3). These glasses are marked with numbers.

Fig. 4. Correlation of technological features of Roman Period ash-type glasses: red – glasses from Poland; black – glasses from Europe,* ash-type glasses uncertain

Chemical types		$RN = \frac{Na_2O + K_2O}{CaO + MgO}$	Alkaline raw material $(K_2O) = \frac{K_2O}{Na_2O + K_2O} \times 100\%$				
			overground portion annual	Kalidium caspicum roots	overground portion perennial		Salicornia herbacea
			8%	16.8%	19.2%	22%	
High magnesium (HMG)	Na – K – Ca – Mg – Al – Si	3.0		187*			
		2.0	54*	55a 57b 58bc 186 534 V7		V1-2	
		1.5		56 57a 58a 238 T5 280 562 F3 561 Cr3 59	185 132	184	V4 133
		1.0		60b 137 T3 136 T4 60a T2	134-135 61	F1-2	115 131 ....T1
	Na – K – Ca – Mg – Si	>3.0		234			
		2.5		N1 48			
		2.0		74	V6		
		1.5		565 64 V5 V3 563 62	564 67		
		1.0		63	65	Cr1	66
Low magnesium (LMG)	Na – K – Ca – Al – Si	>3.0	86-7	411 20 85 37 7			
				C1 397 294			
		2.5	21	74 240 3 120 6			
		2.0	69* 181*	13 55b 49 T6 373 556 353 88			
		1.5		T7 412 F4-5 557 1 Cr2 33 S1		35	
		1.0		68			
	Na – K – Ca – Si	>3.0		83 128 393			....209...122
		2.5		298 92	183		
		2.0		10 70			
		1.5		171 260 K4 K5-8 K1-2 K9 K3			

Other analysed glasses are marked with letters: *C1* – Coppergate (Jackson, Cool and Wager 1998: Tab. 1), *Cr1-4* – Corinth (Brill 1999, vol. I: 129, V.W. 3285–3288), *F1-5* – Faragola (Santagostino Barbone *et al.* 2008: FN1, FC1, FE1, FC2, FC3), *K1-9* – Kenchreai (Brill 1999, vol. I: 100, V.H. 973–976, 3060–3064), *N1* – Novae (Olczak 1998: Tab. 1:2), *S1* – Shikmona (Freestone, Bimson and Buckton 1990: 277, 29351U), *T1-7* – Tibiscum (Stawiarska 2014: Appendix 2. no. 31, 39–45), *V1-7* – Veh Ardašīr (Mirti *et al.* 2008: Tab. 2: VA 15, 17, 26, 27, 33, 35, 36).

APPENDIX 2. ARTIFACTS FROM THE COMPARATIVE COLLECTION

Group I. Products and production waste from processing workshops:

– mosaic vessels and decorative plaques: Weisenau, no. *3*, Alexandria, no. *83*, 'Roman millefiori', nos *85–88*, Wechmar, no. *411*.
– beads and enamels: Larbro, no. *280,* Lithuania, no. *209*, Abidnia, no. *234*.
– game pieces and dice: Mainz, nos *48*, *49*, Sedeinga, no. *565*.
– *tesserae* and *opus sectila*: Salona, nos *6–7*, *10*, *13*, Faragola, no. *F1-5*, Kenchreai, no. *K1-9*, Shikmona, no. *S1*.
– remains of glass processing, including finished products: Elephantine, nos *128*, *131–133*, Tibiscum, no. *T1-7*, Hambach, no. *373*.

Group II. Other finds:

– waste from the production of vessels and other artifacts, raw glass: Novae, no. *238*, *N1*, Köln, no. *397*, Coppergate, no. *C1*, Sentinum, no. *294*, Vah Ardašīr, no. *V1–7*, Beit Shearim, nos *134–137*, Corinth, no. *Cr1-3*.
– vessels and lamp: Weisenau, no. *1*, Mainz, nos *20*, *21*, Alzey, no. *35*, Rome, no. *37*, Novae, no. *120*, Alexandria, no. *122*, Komarovo, Ukraine, no. *171*, Intercisa, no. *183*, Choche, no. *185*, Saintes (vessel?), no. *240*, Heis, no. *260*, Luni, no. *298*, Rouen, no. *353*, Salona, no. *393*, La Négade, no. *534*, Runde Berg, nos *556*, *557*, Sedeiga, nos *561*, *562*, *564*.
– window panes: Bonn, no. *33*, Caerleon, no. *181*, Sedeinga, no. *563*.

REFERENCES

Barkoudah, Y. and Henderson, J. 2006. Plant ashes from Syria and the manufacture of ancient glass: ethnographic and scientific aspects. *Journal of Glass Studies* 48: 297–321.

Bezborodov, M.A. 1969. *Chimija i technologija drevnich i srednevekovych stekol*. Minsk.

Brill, R.H. 1970. The Chemical Interpretation of the Texts. In A.L. Oppenheim et al. (ed.), *Glass and Glassmaking in ancient Mesopotamia*, 105–128. Corning-New York.

Brill, R.H. 1992. Chemical analyses of some glasses from Frattesina. *Journal of Glass Studies* 34: 11–22.
Brill, R.H. 1999. *Chemical analyses of early glasses*, I–II. Corning-New York.
Brill, R.H. and Cahill, N.D. 1988. A red opaque glass from Sardis and some thoughts on red opaques in general. *Journal of Glass Studies* 30: 16–27.
Caley, E.R. 1962. *Analyses of ancient glasses*, 1790–1957. Corning.
Czygan, W. 1987. Chemische Zusammensetzung der Gläser. In U. Koch (ed.), *Der Runde Berg bei Urach VI: die Glass- und Edelsteinfunde aus den Plangabungen 1967–1983*, I–II, 278–295, Heidelberg.
Dayton, J.E. 1993. *The discovery of glass. Experiments in the smelting of rich, dry silver ores, and the reproduction of Bronze Age-type cobalt blue glass as a slag*. Harvard.
Dekówna, M. 1980. *Szkło w Europie wczesnośredniowiecznej*. Wrocław.
Dekówna, M. 1981. Remarques sur la chronologie de l'introduction dans la verrerie europpéenne médiévale de la technologie potassique et de celle au plomb non-alcaline. *Annales du Congrès de l'Association Internationale pour l'Histoire du Verre* 8 (1979): 145–160.
Eggers, H.J. 1955. Zur absoluten Chronologie der Römischen Kaiserzeit im freien Germanien. *Jahrbuch des Römisch-Germanischen Zentralmuseums Mainz* 2: 196–244.
Filarska, B. 1952. *Szkła starożytne. Katalog naczyń*. Warszawa.
Forbes, R.J. 1957. Glass. In *Studies in Ancient Technology* V. Leiden.
Freestone, I.C. 2002. Composition and affinities of glass from the furnaces on the Island site,Tyre. *Journal of Glass Studies* 44: 67–77.
Freestone, I.C., Bimson, M. and Buckton, D. 1990. Compositional categories of Byzantine glass tesserae. *Annales du Congrès de l'Association Internationale pour l'Histoire du Verre* 11 (1988): 271–281.
Freestone, I.C. and Gorin-Rosen, Y. 1999. The great glass slab at Bet Shearim: an early Islamic glass-making experiment? *Journal of Glass Studies* 41: 105–116.
Galibin, V.A. 2001. *Sostav stekla kak archeologiceskij istocnik. Ars vitraria experimentalis*. Sankt--Peterburg.
Grempler, W. 1887. *Der Fund von Sackrau*. Brandenburg–Berlin.
Hunter, J. and Sanderson, D. 1982. The Snartemo/Kempston problem. *Fornvännen* 77 (1): 22–29.
Jackson, C.M., Cool, H.E.M. and Wager, E.C.W. 1998. The manufacture of glass in Roman York. *Journal of Glass Studies* 40: 55–61.
Maas, J.L., Wypyski, M.T. and Stone, R.E. 2002. Malkata and Lisht glassmaking technologies: towards a specific link between second millennium BC metallurgists and glassmakers. *Archaeometry* 44 (1): 67–82.
Mirti, P., Pace, M, Negro Ponzi, M.M. and Aceto, M. 2008. ICP-MS analysis of glass fragments of Parthian and Sasanian epoch from Seleucia and Veh Ardašīr (Central Iraq). *Archaeometry* 50 (3): 429–450.
Olczak, J. 1998. *Produkcja szkła w rzymskim i wczesnobizantyjskim Novae w* świetle źródeł *archeologicznych (Mezja Dolna). Glass production in Roman and Early Byzantin Novae in the light of archaeological sources (Moesia Inferior)*. Toruń.
Purowski, T. 2012. *Wyroby szklane w kulturze* łużyckiej *w międzyrzeczu Noteci i* środkowej *Odry. Studium archeologiczno-technologiczne*. Warszawa.
Rehren, Th. 2000. Rationales in Old World Base Glass Compositions. *Journal of Archaeological Science* 27 (12): 1225–1234.
Santagostino Barbone, A., Gliozzo, E., D'Acapito, F., Memmi Turbanti, I., Turchiano, M. and Volpe G. 2008. The sectilia panels of Faragola (Ascoli Satriano, Southern Italy): a multi-analytical study of the red, orange and yellow glass slabs. *Archaeometry* 50 (3): 451–473.
Sayre, E.V., Smith, R.W. 1961. Compositional categories of ancient glass. *Science* 133: 1824–1826.

Ščapova, J. (Shchapova, J.). 1975. Le verre byzantin du Ve – XVe siècles. In *Srednjovekovno staklo na Balkanu (V–XV vek)*, 33–48. Beograd.

Smith, R.W. 1963a. Archaeological evaluation of ancient glass. In *Advances in Glass technology, II: Sixth International Congress on Glass 1962*, 283–290.Washington.

Smith, R.W. 1963b. The analytical study of glass in archaeology. In *Science in Archaeology*, 519–528. Bristol.

Stawicki, S. 1987. *Papirusy Tebańskie. Antyczne źródło wiedzy o technikach artystycznych*. Wrocław.

Stawiarska, T. 1984. *Szkła z okresu rzymskiego z północnej Polski. Studium technologiczne*. Wrocław.

Stawiarska, T. 1985. *Paciorki szklane z obszaru Polski północnej w okresie wpływów rzymskich*. Wrocław.

Stawiarska, T. 1987. *Katalog paciorków szklanych z obszaru Polski północnej w okresie wpływów rzymskich*. Wrocław.

Stawiarska, T. 1993a. Technological analyses of cut glasses from Central and East Europe from the Roman Period. *Annales du Congrès de l'Association Internationale pour l'Histoire du Verre* 12 (1991): 141–151.

Stawiarska, T. 1993b. Chemical studies of ancient glasses in Poland (with particular reference to the Roman Period). *Archaeologia Polona* 31: 219–228.

Stawiarska, T. 1999. *Naczynia szklane okresu rzymskiego z terenu Polski. Studium archeologiczno-technologiczne*. Warszawa.

Stawiarska, T. 2000. Naczynia szklane z ornamentem „pętelkowym" z okresu wędrówek ludów znalezione w Polsce. *Archaeologia Historica Polona* 8: 153–182.

Stawiarska, T. 2009. Raw glass and its role in ancient glass industry. Problems of organization of production. A critical assessment. *Archeologia* 58 (2007): 185–196.

Stawiarska, T. 2014. *Roman and Early Byzantine glass from Romania and northern Bulgaria. Archaeological and technological study*. Warsaw.

Stern, E.M. 1977. *Ancient glass at the Fundation Custodia (Collection Frits Lugt)*. Paris–Groningen.

Tal, O., Jackson-Tal, R.E. and Freestone, I.C. 2008. Glass from a Late Byzantine secondary workshop at Ramla (South) Israel. *Journal of Glass Studies* 50: 81–95.

Velde, B. 1990. Alumina and calcium oxide content of glass found in Western and Northern Europe, first to ninth centuries. *Oxford Journal of Archaeology* 9 (1): 105–117.