http://dx.doi.org/10.5012/bkcs.2012.33.12.4173

A Comparison in Characteristics of Chemical Composition of Glass Vessels Excavated from Neungsalli Temple in Buyeo, Korea, from Baekje Period

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Received June 26, 2012, Accepted September 12, 2012

From Neungsalli Temple located in Buyeo, ancient glass vessel fragments were discovered along with hundreds of glass beads. In this research, we used SEM-EDS to analyze glass vessel fragments and beads excavated from Neungsalli Temple. Then, we analyzed their chemical composition and examined their characteristics. In particular, we investigated a relationship between glass vessels from Neungsalli temple and Hwangnamdaechong (South tomb). The result of our experiment showed that the glass artifacts from Neungsalli temple were all soda glass. To be specific, the vessel fragments were soda-lime glass and spherical beads were high-alumina soda glass. Then, we compared glass vessel fragments from Neungsalli temple to glass vessels excavated from Hwangnamdaechong. Glass vessels from both sites turned out to be soda lime glass. We classified them further based on raw material used for soda - natron and marine plant ash.

Key Words : Glass vessels, Chemical composition of glass, Soda lime glass, Neungsalli temple, Baekje period

Introduction

Glass has been widely used throughout history because it can be easily molded and manufactured, can express various colors and is inorganic material not subject to quality degradation over time. In addition, glass artifacts are found widely across the ancient world and therefore very useful research material for those who study ancient society, *e.g.*, history, archeology and art history.

Various types of glass artifacts, including glass beads and vessels, have been discovered in archeological sites of ancient Korea. Glass vessels, in particular, are found throughout the world and therefore important artifacts in studying international trading relationships and trading routes in the ancient world, allowing us to trace movement of economic goods during that period. In Korea, 26 glass vessels have been discovered in large-scale royal class Tombs from the regions under cultural influence of Silla and Gaya kingdom: Wolseong-ro Tomb No. Ga-13, Angye-ri tomb No.4, Hwangnamdaechong, Geumgwanchong, Seobongchong, Cheonmachong, Geumnyeongchong and Hapcheon Okjeon tomb No.M1.

Based on vessel shapes and decoration methods used, it is believed that they are later period Roman glass from the 4th-5th century and were probably manufactured in manufacturing sites located in what is today Syria-Palestine region, the east Mediterranean coastal region of Israel, Lebanon and Syria. Accordingly, there have been researches to find out relationships between Silla and West Asia and determine how Roman glass was imported from West Asia to Silla.[1-9] Furthermore, there have been attempts to use scientific analysis to verify the research results thus obtained.[10,11]

To date, glass vessels were discovered primarily from Silla period sites and Neungsalli temple was the first Baekje period site from which they were discovered, which deserves attention. Neungsalli temple is located in Buyeo and is a royal tomb where many artifacts of national treasure level were discovered, *e.g.*, gilt-bronze incense burner of Baekje and sarira shrine with inscription. According to record, the temple was constructed in A.D. 567 in the 13th year of king Chang.[12] The glass fragments were discovered in the center-room of manufacturing site during the second excavation in 1993. Along with vessel fragments, hundreds of beads in various types (spherical, cylindrical, oval, soot, gold, *etc.*) and color (purple-blue, greenish blue, green, yellow, orange, *etc*.) were also discovered. The vessel fragments discovered in Neungsalli temple had either purple-blue color or yellow-brownish color with wood grain-pattern. Considering the color, it appears that there were at least two types of glass vessels in Neungsalli temple.

In this research, in addition to vessel fragments, we chose spherical beads with various colors, including gold foil beads, for comparison study. We performed chemical analysis to classify them and compared them to seven glass vessels excavated from Hwangnamdaechong (South tomb) from Silla period in order to suggest a relationship in chemical composition characteristics among glass beads found in Korea.

Experimental

For this research, 23 specimens were selected: 16 spherical beads (3 yellow, 2 orange, 4 greenish-blue, 4 green, 1 red, 1 yellowish brown and 1 black color), 1 gold foil bead, 5 purple-blue vessel fragments and 1 yellowish-brown vessel

fragment with wood-grain pattern.

Spherical beads were mostly 1.5-3.0 mm in diameter and were formed into a spherical form via heat treatment at both ends. In particular, we observed that particles and air bubbles inside the beads were vertically distributed, showing directionality that was not random. This led us to speculate that a stretching technique was used. When purple-blue vessel fragments were discovered, they were in shattered pieces and their shape could not be identified. However, after putting together some of the fragments, we were able to identify the mouth part. We were also able to identify the mouth part in the yellowish-brown vessel fragments with wood-grain pattern (Figure 1).

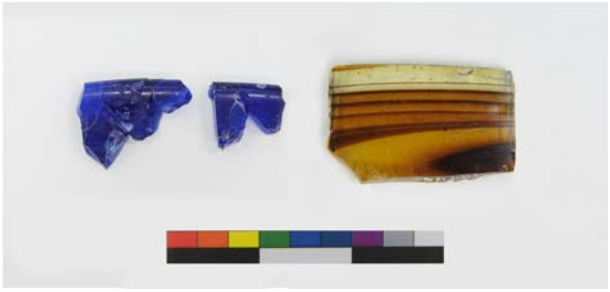

Figure 1. Glass fragments excavated from Neungsalli temple site in Buyeo. Blue-purple vessel fragments (Left) Yellowish brown vessel fragments wood-grain pattern (Right).

Using Stereoscopic Microscope, we examined the specimens' shape, color, transparency and closing part at each end. Also, as preparation for chemical composition analysis, we used Epoxy Resin to fix the specimens and, after the resin solidified, grinded them using sandpaper (#600, 800, 1000, 1200) Finally, we used a diamond suspension (6 μm and 1 μm) to polish the specimens. In order to prevent specimens from being contaminated, we used an ultrasonic washer and washed the specimens 3 times for 5 minutes in each step and 5 times for 5 minutes in the final step. Then, we took the specimens and analyzed them, 5 points per each glass, using Energy Dispersive X-ray Spectrometer (EDS, QUANTAX, Bruker axs, Germany) attached to Scanning Electron Microscope (SEM, VEGA II LMH, TESCAN, Czech) with the acceleration voltage of 20 kV for 120 seconds. SEM-EDS have known and have used the general analytical method in research of ancient glass.[13-15] Prior to analysis, we verify the accuracy and precision of EDS by analyzing standard glass specimen Corning B and MBH/231GS 6, and EPMA mineral standard (SPI #02753-AB) Albite. For primary chemical elements of glass (with content 5% and above) - silica, soda, lime and alumina - our instrument had accuracy and precision lower than 9.6% and 4.1%, respectively (Table 1).

Results and Discussion

The spherical beads, gold foil beads and glass vessel fragments from Neungsalli temple are all classified under soda glass group and are 13.7-25.0% in soda (Table 2). However, unlike soda, each artifact shows different chemical composition characteristics in lime and alumina, which contain stabilizer element, and magnesia and potash, which are related to raw material used to make soda.

Spherical beads, regardless of color, are all high alumina soda glass where alumina is higher in content than lime, with lime 1.1-3.3% and alumina 4.3-11.9% (Table 2, Figure 2). On the other hand, their magnesia and potash content are 0.01-0.08% and 0.57-1.8%, respectively, mostly showing low figures at less than 1.5% (Figure 3). In addition, examination of coloring elements used in them reveals that iron was used as a coloring element for beads with yellow, yellowish-brown and black color whereas copper was used

Table 1. Analytical results of standard glass specimen; Corning B, MBH/231GS 6, Albite

Reference Sample		Oxide Concentration (wt %)										
		SiO_2	Na_2O	K_2O	CaO	Al_2O_3	MgO	TiO_2	MnO	Fe_2O_3	CuO	PbO
Corning B	Certified value	61.6	17.0	1.0	8.6	4.4	1.0	< 0.1	0.25	0.34	2.7	0.61
	This work	62.6	16.4	1.0	9.4	4.1	0.84	0.13	0.22	0.31	3.1	0.27
	Standard deviation	0.3	0.7	0.0	0.4	0.1	0.09	0.03	0.03	0.03	0.1	0.26
	Accuracy	1.7	3.5	0.1	9.6	5.7	18.1	-	10.0	9.7	15.3	55.9
	Coeficient of variation	0.4	4.0	3.9	4.1	2.7	10.9	-	15.4	10.0	4.6	98.5
MBH 231GS 6	Certified value	73.1	14.7	0.10	10.0	1.7	0.10	< 0.1	-	< 0.1	-	-
	This work	73.2	14.3	0.05	9.3	2.5	0.51	0.00	-	0.02	-	-
	Standard deviation	0.2	0.1	0.01	0.1	0.0	0.00	0.00	-	0.02	-	-
	Accuracy	0.1	2.2	47.7	6.5	46.6	412.3	-	-	-	-	-
	Coeficient of variation	0.2	0.8	27.2	0.7	1.9	0.3	-	-	-	-	-
Albite	Certified value	68.5	11.6	0.22	0.13	19.5	-	-	-	-	-	-
	This work	68.2	11.6	0.15	0.09	20.0	-	-	-	-	-	-
	Standard deviation	0.0	0.1	0.03	0.06	0.0	-	-	-	-	-	-
	Accuracy	0.5	0.1	32.0	32.9	2.5	-	-	-	-	-	-
	Coeficient of variation	0.1	0.5	20.4	68.4	0.0	-	-	-	-	-	-

Table 2. Major composition of spherical beads and glass vessel fragments excavated from Neungsalli temple site[14]

Shape	Color	Sample Number	Oxide Concentration (wt %)														
			SiO_2	Na_2O	K_2O	CaO	Al_2O_3	MgO	Cl	TiO_2	MnO	Fe_2O_3	CuO	SnO_2	PbO	SO_3	Ag	Au
Bead	Yellow	NS-1	60.2	19.2	1.4	2.8	10.6	0.61	0.75	0.39	0.07	2.2	0.01	0.08	1.7	-		
			0.5	0.2	0.0	0.1	0.1	0.02	0.01	0.04	0.02	0.1	0.02	0.03	0.8			
		NS-2	60.4	19.4	1.4	2.7	10.6	0.59	0.75	0.38	0.07	2.3	0.01	0.06	1.3	-		
			0.4	0.2	0.1	0.1	0.1	0.04	0.02	0.03	0.04	0.1	0.01	0.03	0.5			
		NS-3	61.1	18.3	1.1	2.7	9.5	0.76	0.66	0.49	0.11	3.0	0.01	0.05	2.2	-		
			0.4	0.1	0.1	0.1	0.1	0.03	0.03	0.05	0.03	0.1	0.01	0.04	0.5			
		Average	60.5	19.0	1.3	2.7	10.3	0.7	0.7	0.4	0.1	2.5	0.0	0.1	1.7			
		Standard deviation	0.5	0.6	0.1	0.0	0.6	0.1	0.1	0.1	0.0	0.5	0.0	0.0	0.4			
	Orange	NS-4	56.8	13.9	1.2	2.4	9.8	0.57	0.60	0.48	0.12	3.8	10.3	0.02	0.16	-		
			0.4	0.1	0.1	0.1	0.1	0.04	0.03	0.04	0.09	0.1	0.5	0.02	0.13			
		NS-5	56.3	13.7	1.2	2.4	9.7	0.60	0.60	0.49	0.08	3.7	11.2	0.01	0.07	-		
			0.5	0.5	0.1	0.1	0.1	0.04	0.01	0.03	0.01	0.1	1.0	0.02	0.10			
		Average	56.6	13.8	1.2	2.4	9.7	0.6	0.6	0.5	0.1	3.7	10.7	0.0	0.1			
		Standard deviation	0.3	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.6	0.0	0.1			
	Greenish blue	NS-6	64.9	21.8	1.4	1.4	6.7	0.05	0.69	0.64	0.14	1.6	0.59	0.05	0.10	-		
			0.2	0.2	0.1	0.1	0.1	0.07	0.04	0.06	0.01	0.1	0.03	0.06	0.11			
		NS-7	64.9	21.9	1.3	1.4	6.8	0.00	0.69	0.61	0.14	1.6	0.59	0.02	0.08	-		
			0.2	0.1	0.1	0.1	0.1	0.01	0.02	0.05	0.03	0.1	0.03	0.03	0.08			
		NS-8	65.4	20.7	1.6	2.9	6.6	0.01	0.35	0.41	0.05	1.2	0.72	0.06	0.07	-		
			0.1	0.1	0.1	0.1	0.1	0.02	0.03	0.04	0.04	0.0	0.02	0.02	0.10			
		NS-9	65.4	20.5	1.7	2.9	6.6	0.01	0.35	0.37	0.06	1.2	0.72	0.06	0.18	-		
			0.1	0.1	0.1	0.1	0.1	0.02	0.03	0.02	0.03	0.1	0.03	0.01	0.11			
		Average	65.1	21.2	1.5	2.2	6.7	0.0	0.5	0.5	0.1	1.4	0.7	0.0	0.1			
		Standard deviation	0.3	0.7	0.2	0.8	0.1	0.0	0.2	0.1	0.0	0.2	0.1	0.0	0.1			
	Red	NS-10	64.2	20.4	1.5	1.8	7.6	0.14	0.82	0.67	0.06	1.9	0.68	0.04	0.16	0.04		
			3.7	1.2	0.4	0.9	2.7	0.09	0.11	0.10	0.02	0.1	0.81	0.04	0.02			
	Green	NS-11	64.5	16.8	1.4	2.1	8.1	0.47	0.76	0.51	0.06	2.5	0.78	0.09	1.9	-		
			0.4	0.1	0.1	0.1	0.1	0.02	0.06	0.02	0.02	0.1	0.02	0.01	0.6			
		NS-12	63.3	16.1	1.4	2.9	9.0	0.80	0.72	0.46	0.07	2.9	0.95	0.10	1.3	-		
			0.2	0.1	0.1	0.1	0.1	0.02	0.02	0.04	0.03	0.1	0.04	0.02	0.3			
		NS-13	67.1	19.8	0.57	1.1	4.3	0.40	1.0	0.53	0.08	1.7	1.1	0.08	2.3	-		
			0.6	0.3	0.02	0.1	0.1	0.03	0.0	0.04	0.04	0.1	0.1	0.04	0.8			
		NS-14	61.2	22.4	1.1	2.4	7.8	0.46	0.86	0.38	0.08	2.0	0.66	0.03	0.54	0.02		
			0.3	0.3	0.1	0.1	0.1	0.01	0.04	0.02	0.01	0.1	0.08	0.02	0.18	0.04		
		Average	64.1	18.8	1.1	2.1	7.3	0.5	0.8	0.5	0.1	2.3	0.9	0.1	1.5	0.00		
		Standard deviation	2.4	2.9	0.4	0.8	2.1	0.2	0.1	0.1	0.0	0.5	0.2	0.0	0.8	0.01		
	Yellowish brown	NS-15	54.3	25.0	0.65	3.3	11.9	0.37	0.59	0.37	0.08	3.2	0.02	0.02	0.08	0.06		
			0.3	0.2	0.03	0.1	0.1	0.04	0.02	0.03	0.02	0.1	0.02	0.03	0.11	0.03		
	Black	NS-16	64.2	15.3	1.8	3.1	11.5	0.76	0.82	0.41	0.07	1.9	0.04	0.11	0.01	-		
			0.1	0.1	0.1	0.1	0.1	0.02	0.02	0.03	0.03	0.1	0.02	0.03	0.02			
	Gold foil	NS-17	58.0	19.6	3.0	6.1	2.8	2.5	1.0	0.15	0.31	6.2	0.02	0.21	0.10	-		
			1.9	0.9	0.1	0.8	0.3	0.1	0.1	0.04	0.09	1.9	0.04	0.03	0.12	-		
		Foil	3.0	0.85	0.83	0.1	2.6	1.1	0.0	0.02	0.00	11.7	0.07	0.67	0.00	-	76.2	2.8

Table 2. Continued

Shape	Color	Sample Number	Oxide Concentration (wt %)														
			SiO_2	Na_2O	K_2O	CaO	Al_2O_3	MgO	Cl	TiO_2	MnO	Fe_2O_3	CuO	SnO_2	PbO	SO_3	Ag	Au
Vessel	Purple blue	NS-18	67.5	19.8	0.69	6.3	1.8	0.78	0.96	0.07	0.59	1.1	0.19	0.06	0.21	-		
			0.2	0.2	0.05	0.1	0.1	0.05	0.02	0.03	0.03	0.1	0.02	0.02	0.11			
		NS-19	67.5	20.0	0.60	6.3	1.8	0.72	0.99	0.07	0.58	1.1	0.13	0.06	0.16	-		
			0.1	0.1	0.02	0.1	0.1	0.02	0.02	0.01	0.03	0.1	0.04	0.02	0.22			
		NS-20	66.3	21.7	0.63	5.4	2.2	1.2	0.96	0.09	0.44	0.80	0.08	0.10	0.02	-		
			0.2	0.6	0.03	0.3	0.1	0.1	0.07	0.01	0.02	0.09	0.04	0.01	0.04			
		NS-21	68.3	19.3	0.60	6.2	1.8	0.78	0.97	0.08	0.55	1.1	0.14	0.06	0.15	-		
			1.6	2.0	0.05	0.2	0.1	0.04	0.09	0.04	0.04	0.1	0.04	0.01	0.09			
		NS-22	67.0	20.6	0.59	5.9	1.9	0.89	1.0	0.08	0.51	1.0	0.16	0.07	0.20	-		
			0.2	0.1	0.03	0.1	0.1	0.04	0.0	0.03	0.04	0.1	0.04	0.02	0.18			
		Average	67.3	20.3	0.6	6.0	1.9	0.9	1.0	0.1	0.5	1.0	0.1	0.1	0.1			
		Standard deviation	0.7	0.9	0.0	0.4	0.2	0.2	0.0	0.0	0.1	0.1	0.0	0.0	0.1			
	Yellowish brown (wood grain-patterned)	NS-23	64.9	17.5	4.6	5.5	3.1	2.4	0.86	0.07	0.03	0.66	0.02	0.38	0.05	-		
			0.3	0.2	0.1	0.1	0.1	0.1	0.05	0.03	0.01	0.05	0.02	0.02	0.09			

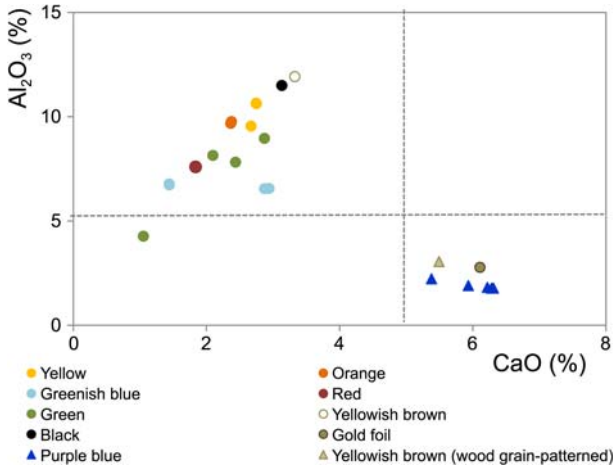

Figure 2. Relationship in CaO and Al_2O_3 among glass artifacts from Neungsalli temple.

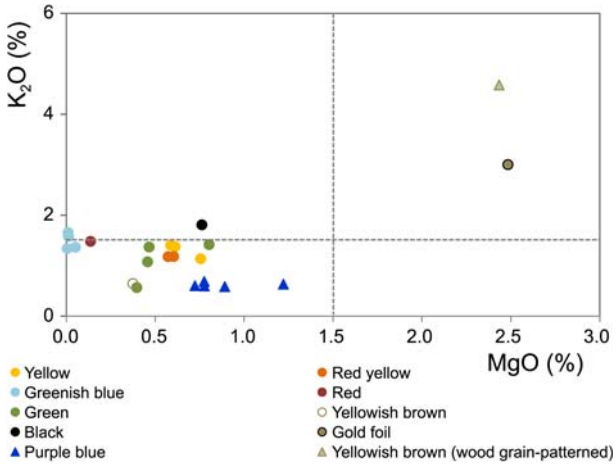

Figure 3. Plot of MgO versus K_2O for glass artifacts from Neungsalli temple.

for beads with orange, dark-blue, red and green color. Furthermore, spherical beads with murky yellow and green color are high in lead oxide content, which leads us to believe that it is due to the effect of $PbSnO_3$, which is known as cloudifier. Finally, dark-blue coloring element is speculated to be cobalt but, with cobalt having characteristic of exhibiting strong color even in miniscule quantity (below 0.1%), other analytical methods, such as trace analysis, are required to determine precise quantity of its content.

The gold foil beads, which consist of interior glass, gold foil and exterior glass layer, show different chemical composition than that of spherical beads with various colors discussed above. The interior and exterior glass layers are 6.1% in lime and 2.8% in alumina, exhibiting characteristics of soda lime glass where lime is higher in content than alumina (Table 2, Figure 2). Moreover, they are 2.0% in magnesia and 3.0% in potash in content, both elements being higher than 1.5%. This leads us to believe that marine plant ash was used as raw material to make soda (Table 2, Figure 3). A thin foil layer between exterior and interior glass layer is 76.2% in silver and 2.8% in gold, *i.e.*, silver was used as primary material. To summarize, gold foil beads from Neungsalli temple are soda lime glass that used marine plant ash as soda material while silver was used to make foil. This type of glass was also discovered in king Muryeong's tomb in Gongju, the same 6th century site as Neungsalli temple.[16] However, this is a peculiar result because, in most gold foil beads discovered to date, natron was used as soda material and gold to make foil.

The five purple-blue color vessel fragments show similar chemical composition and are likely to have come from a same vessel. Therefore, we speculate that vessel fragments excavated from Neungsalli temple are of two types - purple-blue color and yellowish-brown with wood-grain pattern.

Figure 4. Analyzed vessels from Hwangnamdaechong South and North; (a) glass beaker with Trefoli mouth HNV-01, (b) glass vessel with wave pattern HNV-02, (c) glass vessel with ring shaped-mouth HNV-03, (d) glass bowl HNV-04, (e) glass vessel fragments HNV-05, (f) glass beaker fragments HNV-06, (g) glass cup with wood-grain pattern.

The chemical composition of two vessel fragments are lime 5.4-6.3% and alumina 1.8-3.1% and they are classified as soda lime glass, same as gold foil beads (Table 2, Figure 2). However, they have different magnesia and potash content and exhibit different chemical composition characteristics (Table 2, Figure 3). The purple-blue vessel is 0.72-1.2% in magnesia and 0.59-0.69% in potash, both below 1.5%, which leads us to conclude that natron was used as raw material for soda. On the other hand, yellow-brownish vessel with wood-grain pattern is 2.4% in magnesia and 4.6% in potash, and probably used marine plant ash as raw material, same as in gold foil beads.

To summarize, all glass artifacts from Neungsalli temple were classified under soda glass group, where spherical beads were high alumina soda glass but glass vessel fragments were soda lime glass, which leads us to speculate that it is of West Asia origin. Furthermore, like glass vessel fragments, gold foil beads were also soda lime glass, most likely of West Asia origin as well. Examining glass vessel fragments and gold foil beads, we analyzed raw material used to make soda. We learned that natron was used for purple-blue vessel fragments and marine plant ash was used for gold foil beads and yellowish-brown vessel fragments with wood-grain pattern. Therefore, vessel fragments from Neungsalli temple can be classified into two groups depending on the raw material used for soda.

We compared Neungsalli temple vessel fragments with seven vessels excavated from Hwangnamdaechong (South Tomb) and examined their relationships in chemical composition.

Hwangnamdaechong is the 98th tomb located in Hwango-dong, Gyungju-si, Gyongsangbuk-do. It is a twin-tomb where two tombs are lying alongside each other in the north and south direction. As one of the tombs that typify Silla period, the southern tomb was built in the early~mid-5th century and the northern one in the mid-late to mid-5th century. A huge number of glass beads and vessels were discovered in these tombs.[18,19]

In particular, it is interesting that a glass cup with wood-grain pattern with decoration technique similar to the one used for yellowish-brown vessel fragments with wood-grain pattern from Neungsalli temple was found in the northern tomb. It was discovered in almost perfect condition and bears close similarity in form and manufacturing technique to glass vessels with West Asia origin (Figure 4(g)).

The seven vessels from Hwangnamdaechong (South tomb) include a glass jug with Trefoli mouth, glass beaker with wave pattern, glass beaker with ring-shape mouth and *etc.*, and they have various shapes and color (colorless, purple-blue, greenish-blue and *etc.*) (Figure 4(a~f)). According to analysis, these vessels are 17.0-20.5% in soda content and belong to soda glass group. Also, with 4.9-7.1% in lime and 0.98-2.9% in alumina content, they are determined to be soda lime glass (Table 3). This is typical chemical composition of West Asia-origin glass, similar to glass vessel fragments from Neungsalli temple. Furthermore, in terms of magnesia and potash content, six vessels (HNV-01~06) from Hwangnamdaechong had 1.8-3.3% magnesia and 3.7-5.1% potash in content, respectively. Their magnesia and potash content were both above 1.5%, which implies that marine plant ash was used for soda material. One vessel (HNV-07) had both elements less than 1.5%, implying that natron was used as raw material for soda (Table 3, Figure 5).

The vessels excavated from Neungsalli temple and Hwangnamdaechong (South tomb) were all soda lime glass. In terms of raw material used for soda, natron was used for purple-blue vessel fragments (NSV-01, HNV-07) and marine plant ash was used for yellowish-brown glass vessel fragments with wood-grain pattern from Neungsalli temple and colorless, blue and purple-blue glass vessel fragments (HNV-01~06) from Hwangnamdaechong.

Using the soda material identified from analyzing magnesia

Table 3. Average of major composition for glass vessels from Neungsalli temple and Hwangnamdaechong[10,11]

Mark	Vessel Shape	Color	Oxide Concentration (wt %)												Total
			SiO_2	Na_2O	K_2O	CaO	Al_2O_3	MgO	TiO_2	MnO	Fe_2O_3	CuO	Cl	SO_3	
NSV-01	Fragments of a glass vessel	Purple blue (n=5)	67.3	20.3	0.62	6.0	1.9	0.88	0.08	0.53	1.0	0.14	1.0	-	99.8
			0.7	0.9	0.04	0.4	0.2	0.20	0.01	0.06	0.1	0.04	0.0		
NSV-02	Fragments of a glass vessel	Yellowish brown (wood grain-patterned) (n=1)	64.9	17.5	4.6	5.5	3.1	2.4	0.07	0.03	0.66	0.02	0.86	-	99.6
			0.3	0.2	0.1	0.1	0.1	0.1	0.03	0.01	0.05	0.02	0.05		
HNV-01-1	Glass jug with trefoil mouth	Colorlessness (n=2)	65.9	17.2	3.7	7.1	0.98	3.2	< 0.1	< 0.1	0.48	< 0.1	1.3	0.31	100.2
			0.4	0.4	0.1	0.1	0.06	0.1			0.07		0.1	0.05	
HNV-01-2		greenish blue belt (n=1)	63.1	18.2	3.9	6.1	2.0	3.0	0.13	< 0.1	0.70	1.4	1.2	0.32	100.1
			0.2	0.2	0.1	0.1	0.1	0.1	0.1		0.09	0.1	0.1	0.02	
HNV-02	Glass beaker	Colorlessness (n=3)	63.1	17.0	5.1	6.7	3.1	1.9	0.12	< 0.1	1.0	< 0.1	1.3	0.31	99.6
			0.2	0.2	0.1	0.1	0.2	0.1	0.04		0.1		0.1	0.06	
HNV-03	Glass beaker (wave pattern)	Colorlessness (n=1)	63.6	17.5	5.0	5.6	2.8	1.8	< 0.1	< 0.1	0.91	< 0.1	1.4	0.35	99.0
			0.8	0.3	0.1	0.1	0.1	0.1			0.08		0.1	0.05	
HNV-04	Glass bowl	Dark purplish blue (n=1)	61.9	17.5	3.9	6.2	1.3	3.3	< 0.1	< 0.1	0.60	3.7	1.2	0.33	99.9
			0.3	0.2	0.1	0.1	0.1	0.1			0.08	0.1	0.1	0.09	
HNV-05	Fragments of a glass beaker	Purple blue (n=8)	61.6	19.9	3.9	4.9	1.9	2.4	< 0.1	0.48	0.60	1.8	1.5	0.40	99.4
			0.3	0.2	0.1	0.1	0.1	0.1	0.06	0.06	0.08	0.1	0.1	0.06	
HNV-06	Fragments of a glass beaker	Colorlessness (n=7)	64.1	19.0	4.2	6.1	1.0	2.8	< 0.1	-	0.48	< 0.1	1.4	0.40	99.5
			0.4	0.2	0.1	0.1	0.1	0.1			0.06		0.1	0.05	
HNV-07	Fragments of a glass beaker(?)	Purple blue (n=10)	65.9	20.5	0.33	5.6	2.9	1.2	0.10	0.05	1.5	0.26	1.3	0.35	100.0
			0.3	0.2	0.03	0.1	0.1	0.1	0.01	0.02	0.1	0.02	0.1	0.05	

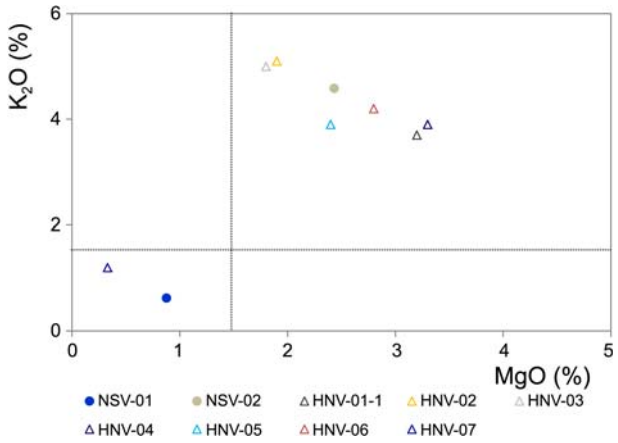

Figure 5. Plot of MgO and K_2O for glass vessels from Neungsalli temple and Hwangnamdaechong.

and potash content of West Asia-origin glass, researchers classified natron-based glass as Roman glass and marine plant ash-based glass as Sasanian.[20-22] Based on this criteria, two natron-based purple-blue vessel fragments (NSV-01, HNV-07) from both sites were classified as Roman glass while marine plant ash-based yellowish-brown vessel with wood-grain pattern and six vessel fragments (HNV-01~06) from Hwangnamdaechong were classified as Sasanian.

Conclusion

Spherical beads, gold foil beads and glass vessels from Neungsalli temple site are all classified under soda glass group. However, spherical beads are high alumina soda glass, which are found in big quanitity in India, Sumatra, Japan and Korea, and are considered having Asian-type chemical composition. On the other hand, gold foil beads and glass vessels are soda lime glass, chemical composition that is typical for glass with West Asia-origin. Thus, it is very likely that these two types of glass have two different origins. Furthermore, among the glass artifacts speculated to be of West Asia origin, purple-blue vessels used natron, and yellowish-brown glass vessel with wood-grain pattern and gold foil beads used marine plant ash as raw material for soda.

We also compared our result to glass vessel fragments from Hwangnamdaechong (South tomb) that had been discovered and reported to date. It was confirmed that glass vessels from both sites were soda lime glass. Based on this, we can classify West Asia origin glass artifacts as follow: purple-blue vessel fragments from Neungsalli temple and Hwangnamdaechong (NSV-01, HNV-07), which used natron as soda material, were Roman glass. On the other hand, yellow-brownish glass vessel with wood-grain pattern from Neungsalli temple (NSV-02) and glass vessel fragments from Hwangnamdaechong (HNV-01~06), which used marine plant ash as soda material, were Sasnian.

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