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한국 전통 도자기의 화학 조성에 대한 연구 (III): 분청에 대한 고려자기와 조선백자와의 비교

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A Study of the Chemical Composition of Korean Traditional Ceramics (III): Comparison of *Punch'ŏng* with Koryŏ Ware and Chosŏn Whiteware

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초 록 분청사기는 조선초기에 고려상감청자의 무늬가 간소화 된 상태로 시작되었다. 그 후 200여 년 동안에 다양하고 활달한 문양의 민속공예로 발달하였고, 점점 백자를 닮아가는 방향으로 변해가다가, 임진왜란이후에 생산이 중단되었다. 이 논문에서는 분청의 태토와 유약에 대한 화학조성을 분석하고, 여러 도요지들의 결과들을 서로 비교하였다. 또한 다른 논문들에서 중국의 경우와 비교 관찰된 고려청자와 조선백자들에 대한 결과들과 비교 하였다. 생산도요지와 고고학적인 특성에 의하여 28 그룹으로 나누었으며, 각 각의 그룹에서 셋에서 다섯편의 도편을 분석하고, 그들의 평균값을 비교자료로 사용하였다. 분청태토는 한국청자와 백자와 같이 중국 남쪽의 월주요, 경덕진요에서 사용된 운모-석영계의 도석으로 만들어졌다. 유약은 점토질의 원료에 나무재, 태운 석회석과 곱게 빻은 석회가루를 다양한 비율로 혼합되었다. 분청유약의 특성은 조선백자보다는 고려청자와 고려백자에 더 가깝다. 다만 티타늄산화물의 함량은 조선백자와 같이 낮은데, 그 이유는 글래이즈 스톤으로 알려진 도석계의 점토가 분청유약을 제조 하는데 혼합 되었기 때문으로 추정된다. 이 연구의 체계적인 비교방법과 물질적 특성에 대한 내용들은 현재 빠른 속도로 발굴되고 있는 도요지들에 대해서 적용될 수 있을 것이다.

중심어: 한국전통자기, 한국자기, 한국도기, 전통도자기의 태토성분, 전통도자기의 유약성분, 청자, 분청, 백자

ABSTRACT At the beginning of the Chosŏn dynasty, *punch'ŏng* began as a simplified form of inlaid celadon, and in the two following centuries it developed into a popular folk craft in various styles and expressive decorations; overtime,

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it was increasingly made to resemble whiteware, and its production stopped after the Japanese invasion of Korea. In the present study, the body and glaze compositions of *punch'ŏng* were examined and compared with those of celadon and whiteware, whose compositions have previously been compared with those of Chinese ceramics. Here, the analyzed shards were organized into 28 groups based on their production sites and archaeological characteristics. For each group, the body and glaze compositions of several shards(usually three to five) were obtained, averaged, and compared with those of the other groups. These comparisons showed that the majority of the *punch'ŏng* bodies were formed, like those of celadon and whiteware, with mica-quartz porcelain stone, which was commonly used in Yuezhou, Jingdezhen, and other southern Chinese kilns. The glazes consisted of clay materials and flux components made from various proportions of wood ash, burnt limestone (glaze ash) and crushed limestone. Overall, the *punch'ŏng* glazes resembled the Koryŏ celadon and Koryŏ whiteware glazes more closely than the Chosŏn white wareglazes. However, the TiO_2 levels found in the tested *punch'ŏng* were low, similar to those of Chosŏn whiteware; this indicated that glaze stone was used as the clay component of the *punch'ŏng* glazes, as was the case for Chosŏn whiteware. This study of the material characteristics of *punch'ŏng* may be used as a comparative framework for analyzing ceramic shards discovered at current and future excavations within Korea.

Key Words: Korean traditional ceramics, Korean porcelain, Korean stoneware, Body composition of traditional ceramics, Glaze composition of traditional ceramics, Celadon, *Punch'ŏng* , Whiteware

1. Introduction

The cultural heritage of Korean ceramic art and technology only began to gain worldwide recognition in the 20^{th} century. This delay in recognition may be due to the fact that Korea never developed the colorful overglaze porcelain that China and Japan so successfully exported to European countries. Instead, four major types of ceramics were developed and produced in Korea with each type succeeding and mostly replacing the prior: *togi*, unglazed earthenware that was often fired to high temperature to the range of porcelain, during the Three Kingdoms period and the Unified Silla period (AD 676-935); celadon during the Koryŏ dynasty (AD 918-1392); *punch'ŏng*, a powder-decorated folkware during the first two centuries of the Chosŏn dynasty (AD 1392-1910); and whiteware, also during the Chosŏn dynasty.

While celadon and whiteware, which were the favored types during the Koryŏ and Chosŏn dynasties, respectively, were typically produced under state supervision, *punch'ŏng* evolved into a popular folk craft and eventually became an art form that was truly unique to Korea. Free from the constraints of the state ideals that applied to celadon and whiteware, the *punch'ŏng* potters made wares that were spontaneous in form and decoration, often reflecting the local characteristics of artistry and free expression. The existence of *punch'ŏng* is one of the main reasons that Korean ceramics are known for the quiet, classic and subtle aesthetics that have long been appreciated in China and Japan, and are now acclaimed as representing the quintessence of the Oriental spirit.[1]

Excavation of the major kiln sites in Korea was initially led by Japanese scholars during the first three decades of the 20^{th} century. Korean scholars continued the work after the Korean War, and systematic excavations became increasingly common beginning in the 1980s. Some important sites, including Kuwandong and Ch'unghyodong, were found to have multiple layers of ceramic deposits containing different ware types, styles, and decorations. The shards recovered from these systematic excavations are archaeologically well-characterized, making them ideal samples for scientific analysis. In the authors' laboratory alone, well over 1000 such shards have been analyzed for their chemical and (in some cases) mineralogical compositions since the early 1990s.

From a large compilation of results, 369 shards analyzed with comparable methods were selected and used as samples for an investigation into the material characteristics of Korean traditional ceramics. They were divided into 80 groups according to their excavated locations and archaeological characteristics. Recent papers have reported the results from 31 groups representing celadon and whiteware ceramics from the Koryŏ dynasty[2] and 21 groups representing whiteware from the Chosŏn dynasty.[3] In these prior papers, the Korean results were compared with those of the corresponding ceramic groups from China.

The present paper reports the results from the final 28 groups, which represent *punch'ŏng* from the first two centuries of the Chosŏn dynasty. The bulk of this work was initially carried out for a doctoral thesis,[4] and several other scientific studies on *punch'ŏng* have been reported, including examinations of firing parameters and microstructural characteristics.[5~7] Here, we examined the compositional characteristics of *punch'ŏng* bodies and glazes, compared them with those of Korean celadon and Korean whiteware, and sought to map the material characteristics of Korean ceramics over the span of more than 1000 years.

2. Experimental

2.1. Selection and Archaeological Background of the Sample Shards

The data analysis and presentation on the *punch'ŏng*

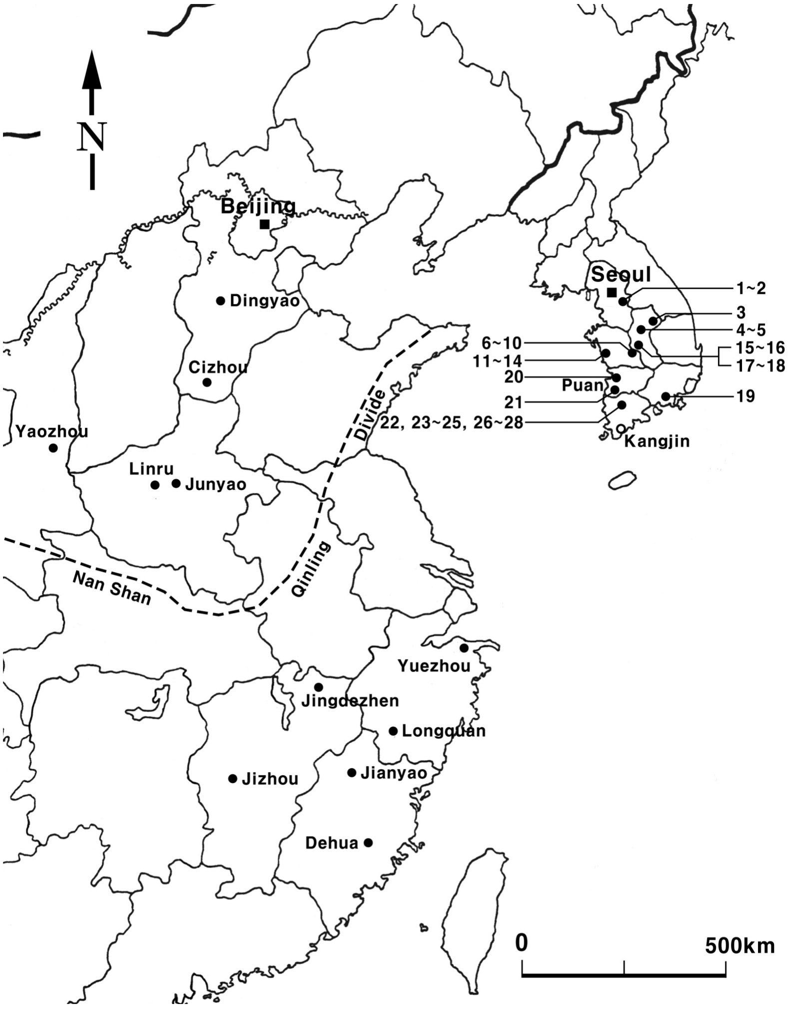

Figure 1. Map of the Korean kiln sites from which the analyzed shards were collected. The Nan Shan Qinling dividing line, some historically important kiln sites in China, and the most important Koryŏ celadon center, Kangjin (open circle), are also shown.

shards are similar to those given in the previous reports on Koryŏ ceramics and Chosŏn whiteware.[2,3] The kilns from which the selected shards were excavated are shown on the map in Figure 1(numbers). The numbers correspond to the group numbers given in Table 1 and in the graphs of seger and other characteristics of the body and glaze compositions (Figures 2 and 3, Figures 6-8b). For each group, the table gives archaeological information on the excavation site (first of two lines), the chemical composition of the body (second line, left), and the chemical composition of the glaze (second line, right). Because porcelain is heterogeneous, three to five shards were analyzed for each group (given in parentheses) and average values are reported in the table.

Punch'ŏng represents a transition between the celadon of the Koryŏ dynasty and the whiteware of the Chosŏn dynasty. The first types of *punch'ŏng* were a simplified type of inlaid celadon, while later types increasingly resembled whiteware. *Punch'ŏng* production ceased entirely after the Japanese invasion of Korea (1592-98), partly because so many potters and ceramic products were taken to Japan during this period.

The shards from the Kuwandong (Groups 6~10) and Yongsuri (Groups 11~14) kilns clearly reflected the evolution of *punch'ŏng* from inlaid celadon. Kuwandong was a site of celadon production during the 11th and 12th centuries (Koryŏ dynasty). Three centuries later, a *punch'ŏng* kiln[8] was built about 500 meters away from the Koryŏ kiln site. The *punch'ŏng* kiln first produced inlaid wares that up until now were considered celadon based on their decorative features. However, the present study found that the glaze compositions of these wares were so similar to those of the stamped *punch'ŏng* group that it would be more appropriate to consider them *punch'ŏng*. The same was found in a comparison of four groups of celadon from the Yongsuri kiln.[9] One group that was initially considered celadon was found to have a glaze composition very similar to that of later *punch'ŏng* types, whose rough bodies were brushed or coated with white slip.

The later transition from *punch'ŏng* to whiteware is represented by shards from the Ch'unghyodong site (Groups 22~28). The kiln was first excavated in 1963, followed by a much more thorough examination in 1992, which identified

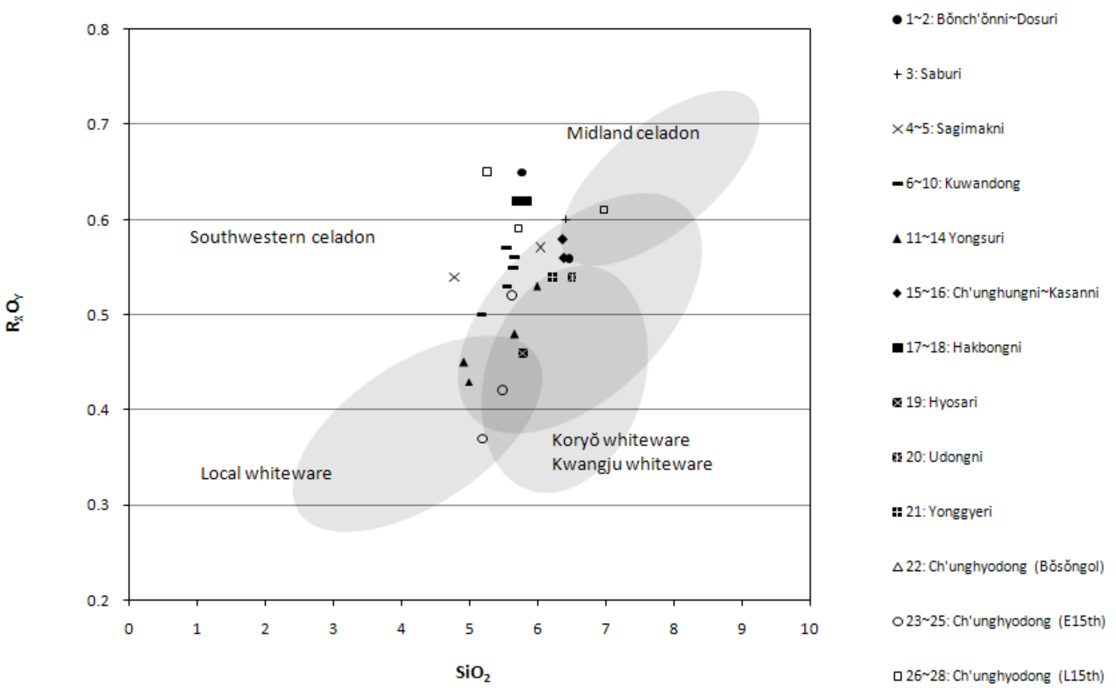

Figure 2. Seger graph of body compositions (SiO_2 as a function of R_xO_y) .

Table 1. Archaeological information on the analyzed shards and their composition of body and glaze (C: century; E: early; M: middle; L: late; No.: Number of shards analyzed for the average value of composition)

Group	Kiln address, specific location, shard type														Operational date (C)				Excavational year					Shard provider			
(No.)	Body composition (wt.%)														Glaze composition (wt.%)												
	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	L.O.I.	Total	SiO_2	R_xO_y	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	Total	SiO_2	R_xO_y
1	Kyŏnggido Kwangjusi Chungbumyŏn Bŏnch'ŏnni, 2nd kiln, stamped, inlaid, plain														15				-					Chungpuk University Museum			
(6)	71.51	18.83	2.91	0.96	0.40	0.61	3.47	0.56	0.03	0.06	0.40	99.72	6.45	0.56	58.36	15.84	1.68	1.77	18.13	0.83	3.29	0.11	0.07	0.66	100.75	2.24	0.36
2	Kyŏnggido Kwangjusi Toich'onmyŏn Dosuri, inlaid														around1420				-					Chungpuk University Museum			
(5)	68.05	20.06	4.00	1.19	0.99	0.92	2.65	0.88	0.04	0.06	1.12	99.96	5.76	0.65	58.52	14.87	2.67	2.21	17.55	0.94	2.41	0.14	0.20	0.70	100.20	2.24	0.34
3	Ch'ungch'ŏngpukdo Yongdonggun Ch'upungryŏngmyŏn Saburi, Hwangbo, 1st kiln														15				2002~'03					Chungpuk University Museum			
(7)	70.52	18.65	2.74	0.80	0.64	1.08	3.25	0.70	0.02	0.05	1.13	99.59	6.42	0.60	59.83	15.22	1.29	1.99	16.30	0.92	3.29	0.05	0.46	0.82	100.16	2.42	0.36
4	Ch'ungch'ŏngpukdo Koisangun Ch'upungryŏngmyŏn Sakimakni, 3rd kiln														M15~E16				-					Chungpuk University Museum			
(10)	65.42	23.16	3.28	0.86	0.51	1.03	4.66	0.31	0.09	0.05	1.13	99.73	4.79	0.54	58.60	16.46	2.71	1.92	14.63	1.14	3.22	0.20	0.50	0.99	100.35	2.47	0.41
5	Ch'ungch'ŏngpukdo Koisangun Ch'upungryŏngmyŏn Sakimakni, 5th kiln														E16~L16				-					Chungpuk University Museum			
(5)	69.89	19.67	2.14	0.61	0.83	0.35	5.37	0.17	0.06	0.04	0.63	99.75	6.03	0.57	61.07	15.72	2.02	1.34	13.67	0.56	4.59	0.05	0.33	0.55	99.91	2.85	0.43
6	Taejŏnsi Chunggu Kuwandong, punch'ŏng kiln, top layer, inlaid celadon														1400~1430				1996					Haegang Ceramics Museum			
(2)	68.85	21.05	3.50	1.21	0.34	0.64	3.62	0.73	0.03	0.03	-0.02	99.99	5.55	0.57	58.28	13.61	1.27	0.79	20.52	1.08	3.07	0.14	0.23	0.17	99.15	2.16	0.30
7	Taejŏnsi Chunggu Kuwandong, punch'ŏng kiln, top layer, plain celadon														1400~1430				1996					Haegang Ceramics Museum			
(3)	69.12	20.71	3.44	1.16	0.35	0.64	3.58	0.73	0.03	0.03	0.17	99.84	5.67	0.56	58.61	15.37	1.99	1.20	17.79	1.03	3.24	0.16	0.27	0.24	99.90	2.33	0.36
8	Taejŏnsi Chunggu Kuwandong, punch'ŏng kiln, bottom layer, inlaid celadon														1400~1430				1996					Haegang Ceramics Museum			
(3)	67.87	22.30	3.33	1.06	0.32	0.63	3.45	0.73	0.03	0.03	0.21	99.95	5.17	0.50	55.82	17.05	1.64	1.01	19.75	0.70	3.22	0.15	0.31	0.18	99.82	2.11	0.38
9	Taejŏnsi Chunggu Kuwandong, punch'ŏng kiln, bottom layer, plain celadon														1400~1430				1996					Haegang Ceramics Museum			
(3)	68.94	21.11	3.31	1.06	0.30	0.61	3.56	0.73	0.03	0.03	0.28	99.96	5.54	0.53	56.75	16.52	1.85	1.04	19.35	0.77	2.89	0.16	0.28	0.19	99.79	2.18	0.37
10	Taejŏnsi Chunggu Kuwandong, punch'ŏng kiln, top layer, stamped														1400~1430				1996					Haegang Ceramics Museum			
(5)	69.42	20.85	3.35	1.16	0.34	0.60	3.37	0.77	0.03	0.04	0.04	99.96	5.65	0.55	58.44	15.23	1.50	1.09	19.59	0.82	2.66	0.10	0.33	0.17	99.91	2.24	0.34
11	Ch'ungch'ŏngnamdo Poryŏngsi Misanmyŏn Yongsuri														L14~E15				1995					Ewha Womans University Museum			
(9)	69.41	20.82	2.61	0.81	0.50	0.52	3.27	0.70	0.02	0.05	0.96	99.67	5.66	0.48	56.30	14.95	1.62	1.96	18.72	0.68	3.19	0.30	0.21	0.78	98.70	2.09	0.33
12	Ch'ungch'ŏngnamdo Poryŏngnsi Misanmyŏn Yongsuri, inlaid and stamped														L14~E15				1995					Ewha Womans University Museum			
(4)	67.02	22.84	3.55	0.82	0.35	0.50	2.83	0.68	0.04	0.06	0.82	99.50	4.98	0.43	56.16	14.44	2.24	2.22	18/.27	0.91	3.32	0.31	0.28	0.85	99.00	2.04	0.31
13	Ch'ungch'ŏngnamdo Poryŏngsi Misanmyŏn Yongsuri, brush painted white slip														L14~E15				1995					Ewha Womans University Museum			
(4)	66.73	23.07	3.88	0.92	0.37	0.43	2.92	0.68	0.02	0.08	0.50	99.58	4.91	0.45	55.43	14.60	1.66	2.24	18.91	0.80	3.39	0.24	0.30	0.90	98.43	1.98	0.31
14	Ch'ungch'ŏngnamdo Poryŏngsi Misanmyŏn Yongsuri, coated white slip														L14~E15				1995					Ewha Womans University Museum			
(3)	69.86	19.81	4.28	0.88	0.34	0.61	2.49	0.83	0.04	0.05	0.45	99.65	5.98	0.53	57.71	15.80	2.58	2.81	13.66	0.98	2.94	0.44	0.35	1.47	98.74	2.42	0.39

Table 1. (continued).

Group	Kiln address, specific location, shard type														Operational date (C)				Excavational year					Shard provider			
(No.)	Body composition (wt.%)														Glaze composition (wt.%)												
	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	L.O.I.	Total	SiO_2	R_xO_y	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	Total	SiO_2	R_xO_y
15	Ch'ungch'ŏngnamdo Kongjusi Uidangmyŏn Chunghŏngri														around 1420				-					Chungpuk University Museum			
(6)	71.36	18.94	2.44	0.80	0.46	1.24	2.83	0.86	0.02	0.04	1.06	100.04	6.39	0.56	61.76	14.20	1.62	1.91	15.47	1.45	3.02	0.06	0.18	0.88	100.55	2.58	0.35
16	Ch'ungch'ŏngnamdo Kongjusi Uidangmyŏn Kasanni														1430~1440				-					Chungpuk University Museum			
(7)	71.47	19.04	2.66	0.76	0.54	1.33	2.94	0.84	0.02	0.04	0.36	100.01	6.37	0.58	59.73	15.38	1.78	1.37	16.27	1.51	2.77	0.10	0.19	0.36	99.47	2.51	0.38
17	Ch'ungch'ŏngnamdo Kongjusi Panpomyŏn Hakbongni, 3rd kiln														L15~E16				Japanese, 1992~'93					Chungpuk University Museum			
(6)	68.83	19.98	3.96	0.93	0.61	1.08	3.35	0.75	0.03	0.06	0.35	99.92	5.85	0.62	61.04	13.75	3.44	2.55	12.54	1.33	2.95	0.08	0.43	1.23	99.34	2.70	0.36
18	Ch'ungch'ŏngnamdo Kongjusi Panpomyŏn Hakbongni, 5th kiln														L15~E16				Japanese, 1992~'93					Chungpuk University Museum			
(4)	68.76	20.45	3.43	1.02	0.68	1.27	3.30	0.75	0.04	0.05	0.23	99.97	5.71	0.62	59.74	12.73	1.67	2.04	17.45	1.61	3.13	0.06	0.12	1.01	99.57	2.26	0.28
19	Kyŏngsangnamdo Chinyanggun Sugokmyŏn Hyojari, 2nd kiln														1430~1440				-					Chungpuk University Museum			
(3)	70.24	20.61	3.08	0.88	0.41	0.25	2.83	0.75	0.03	0.05	0.75	99.87	5.78	0.46	59.07	14.77	1.90	2.24	17.14	0.28	2.67	0.04	0.36	1.13	99.60	2.34	0.35
20	Chŏllapukdo Puangun Poanmyŏn Udongni														15				Japanese					Ewha Womans University Museum			
(5)	71.48	18.65	2.53	0.81	0.49	0.76	2.77	0.93	0.02	0.05	1.36	99.84	6.50	0.54	58.12	15.94	1.83	1.78	17.09	0.68	2.87	0.19	0.23	0.85	99.56	2.34	0.38
21	Chŏllapukdo Koch'anggun Asanmyŏn Yonggyeri, stamped, coated, brush painted white slip														L15~E16				-					Chungpuk University Museum			
(6)	71.03	19.37	2.68	0.70	0.37	0.70	3.96	0.66	0.02	0.04	0.41	99.93	6.22	0.54	58.68	16.62	1.28	3.77	13.68	0.73	3.29	0.16	0.57	0.88	99.64	2.39	0.40
22	Kwangjusi Pukgu Ch'unghyodong Bŏsŏngol, CHBS, spamped, inlaid														before 1420				1963, '91					National Kwangju Museum			
(4)	68.71	20.11	3.93	1.10	0.81	0.95	2.62	0.94	0.03	0.06	0.50	99.75	5.80	0.62	55.43	14.74	1.83	1.82	20.75	0.70	3.29	0.15	0.02	0.78	99.49	1.92	0.30
23	Kwangjusi Pukgu Ch'unghyodong Kŭmgok, CHE-2, stamped														1424~1431				1963, '91					National Kwangju Museum			
(4)	68.81	22.46	2.43	0.46	0.28	0.28	3.54	0.56	0.03	0.03	1.07	99.94	5.20	0.37	66.10	14.18	1.25	1.46	10.01	1.23	4.74	0.01	0.14	0.49	99.62	3.69	0.47
24	Kwangjusi Pukgu Ch'unghyodong Kŭmgok, CHW-3L, stamped														around 1457				1963, '91					National Kwangju Museum			
(2)	69.46	21.46	3.24	0.54	0.30	0.16	3.56	0.68	0.02	0.04	0.41	99.86	5.49	0.42	62.63	13.89	1.33	2.03	14.28	0.84	4.46	0.07	0.15	0.61	100.29	2.73	0.36
25	Kwangjusi Pukgu Ch'unghyodong Kŭmgok, CHW 2-8, stamped														around 1457				1963, '91					National Kwangju Museum			
(3)	69.14	20.83	3.72	0.86	0.44	0.54	3.17	0.85	0.03	0.05	0.39	100.01	5.63	0.52	61.52	13.53	1.44	1.95	14.94	1.17	3.91	0.10	0.19	0.83	99.58	2.60	0.34
26	Kwangjusi Pukgu Ch'unghyodong Kŭmgok, CHW 2-6, stamped														1451~1477				1963, '95					National Kwangju Museum			
(3)	68.41	20.29	3.78	0.79	0.61	1.31	2.91	0.80	0.04	0.05	1.04	100.03	5.72	0.59	58.51	13.48	1.32	2.21	17.65	1.75	3.01	0.05	0.32	1.17	99.48	2.16	0.29
27	Kwangjusi Pukgu Ch'unghyodong Kŭmgok, CHW 2-3, stamped														1477~1483				1963, '91					National Kwangju Museum			
(3)	72.49	17.65	2.74	0.84	0.52	0.81	3.31	0.71	0.02	0.05	0.53	99.68	6.97	0.61	60.22	15.36	1.19	1.78	14.06	1.37	4.35	0.00	0.22	0.86	99.41	2.64	0.40
28	Kwangjusi Pukgu Ch'unghyodong Kŭmgok, CHW 2-2, plain, brush painted white slip														1490~1510				1963, '91					National Kwangju Museum			
(3)	66.49	21.44	3.16	0.76	1.02	2.60	2.58	0.70	0.03	0.04	0.80	99.63	5.26	0.65	63.17	12.94	1.36	2.05	14.54	2.30	2.45	0.03	0.20	0.92	99.95	2.69	0.32

nine layers of *punch'ŏng* and whiteware shards representing over 100 years of kiln operations.[10] Initially located at Bŏsŏngol, the kiln was moved to Kŭmgok around 1420, and thereafter succeeded in producing very high-quality *punch'ŏng* characterized by a very fine and dense light-gray body and a light-blue glaze. Thereafter, the kiln increasingly turned its developmental efforts to the production of whiteware, first making soft-textured whiteware and later producing hard-textured whiteware with a quality similar to that produced in Kwangju royal kiln complex and Jingdezhen. During this period, the *punch'ŏng* produced at the kiln was made to appear very similar to whiteware. Toward the end of the kiln's operation, in particular, the *punch'ŏng* bodies were brush-painted with white slip.

Hakbongni (Groups 17 and 18) was a large complex famed for producing diverse varieties of *punch'ŏng*, particularly those decorated with iron-rich pigments that were painted or inlaid onto dark gray or dark brown bodies. This kiln was founded around the same time as Ch'unghyodong and operated over the same period of approximately 100 years. Unfortunately, the site has not been systematically excavated. In 1927 it was subjected to a rushed, 10-day excavation by Japanese researchers. A 1992 joint excavation undertaken by the National Museum of Korea and the Hoam Art Museum found that earlier excavation had disrupted the kiln structures and shard layers too thoroughly to enable a systematic study.[11] After the 1992 excavation, the site was designated Historically Important Site No. 333.

2.2. Experimental Procedures

The methods used to analyze the body and glaze compositions were similar to those described in the previous papers on Koryŏ ceramics and Chosŏn whiteware.[2,3] For analysis of the body composition, the glaze was ground off the body and the body was powdered and made into cylindrical beads, which were then analyzed by a PW1480 X-ray Fluorescence Sequential Spectrometer (Philips Inc.). The analytic conditions were set to 40 kV and 30 mA. For analysis of the glaze composition, shards were embedded in epoxy resin, polished, and subjected to cross-sectional measurements. Both the

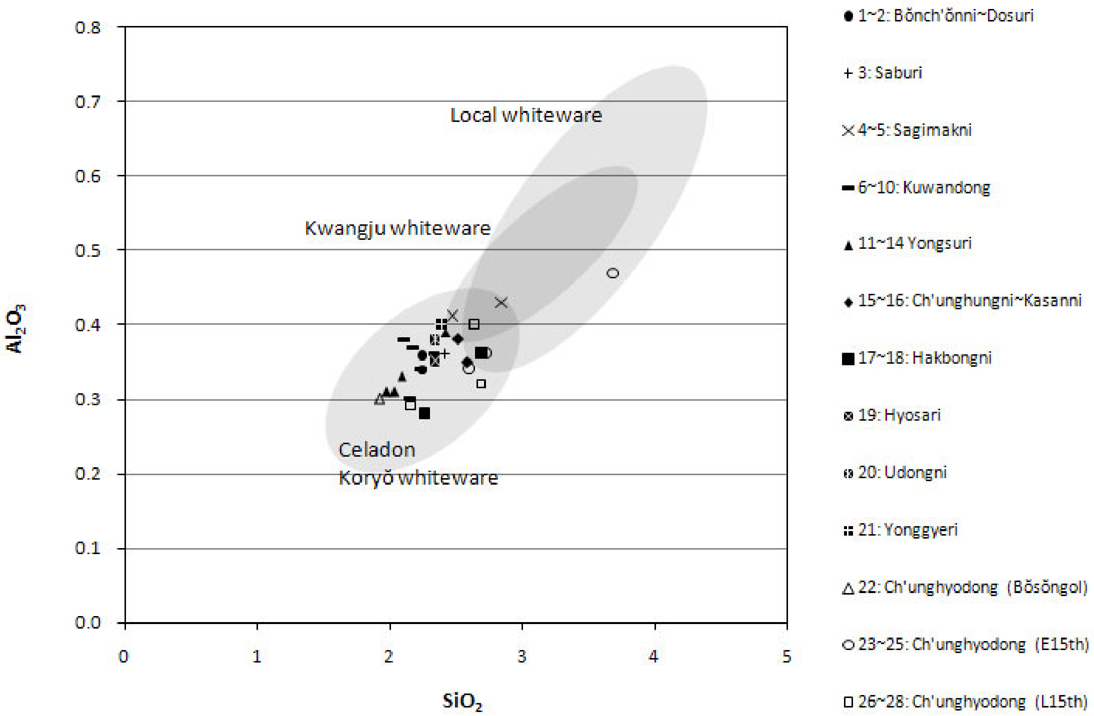

Figure 3. Seger graph of glaze compositions (SiO_2 as a function of Al_2O_3).

Table 2. Korean traditional ceramic types and information on their representative kilns.

Period	Ware type	Location	Representative sites	Active date	Kiln material	Firing method
Unified Silla Kingdom*	Togi	Terra Cotta				
		Unglazed high fired	Youngam Kurimni		Clay	
Koryŏ	Celadon	Midland	Bangsandong	L9	Brick	One-step
		(Midland celadon)**	Sŏri	M9-E11	Brick	One-step
				L10	Brick	One-step
		Southwestern	Kangjin	9th to 14th	Clay	Two-steps
		(Southwestern celadon)**	Puan	12th to 14th	Clay	Two-steps
	Whiteware	Midland	Bangsandong	L9	Brick	One-step
		(Koryŏ whiteware)**	Sŏri	M9-E11	Brick	One-step
			Chungamni*	L10	Brick	One-step
Chosŏn	*Punch'ong*	Kwangju	Kŏnŏbri	M15	Clay	Two-steps
			Bŏnchŏnni	L15-16	Clay	Two-steps
			Kŭmsari	1721-1751	Clay	Two-steps
			Punwŏnni	M18-L19	Clay	Two-steps
		Local	Ch'unghyodong	E15-E16	Clay	Two-steps
			Yonggyeri	L15 -E 16	Clay	Two-steps
	Whiteware	Kwangju	Kŏnŏbri	M15	Clay	Two-steps
		(Kwangju whiteware)**	Bŏnchŏnni	L15 - 16	Clay	Two-steps
			Kŭmsari	1721-1751	Clay	Two-steps
			Punwŏnni	M18-L19	Clay	Two-steps
		Local	Ch'unghyodong	E15-E16	Clay	Two-steps
		(Local whiteware)**	Yonggyeri	L15 -E 16		

*: Togi ware of the Unified Silla Kingdom and Koryŏ whiteware from Chungamni are not included in this study.
**: In Figures 2-3 and Figures 6-8b, *punch'ŏng* groups are compared with celadon and whiteware from the Chosŏn dynasty. When the material characteristics differ significantly, the celadon is divided into the midland celadon and the southwestern celadon, and the Chosŏn whiteware into the Kwangju whiteware and the local whiteware. The five categories of the compared wares are presented here in bold letters.

body and glaze compositions were analyzed using an Electron Probe Microanalyzer (Jeol Superprobe JXA-8600SX) equipped with SEM and EDS (Oxford Pentafet$_{ATW}$ Detector). The analytic conditions were set to 15 kV and 2.5 nA. Four to six different measurements on areas of either 48 × 36 μm^2 or 34 × 25 μm^2 were taken for each shard, and the results are reported as averages.

3. Results and Discussion

3.1. Comparison of Body Compositions

Seger graphs of the analytic results for the body and glaze compositions are shown in Figures 2 and 3, respectively. In calculating the Seger values, all oxides other than Al_2O_3 and SiO_2 were included in the term R_xO_y. The results from the separate *punch'ŏng* groups were plotted over the composition ranges representing the major Korean ceramic types, as determined in the two previous papers.[2, 3] Table 2 summarizes where and when the major types were made, whether the kilns were constructed with clay or brick, and whether the wares were fired in one step or two. The *punch'ŏng* results were usually compared with three categories of celadon, Koryŏ whiteware, and Chosŏn whiteware. When the characteristics varied in a wide range, the celadon results were further divided into midland celadon and southwestern celadon, and the Chosŏn whiteware results were divided into Kwangju whiteware and local whiteware.

As shown in Figure 2, the circles representing Koryŏ whiteware and Chosŏn Kwangju whiteware overlapped in the middle of the graph, and the southwestern celadon circle overlapped considerably in the same space. Moreover, most of the *punch'ŏng* groups examined herein distributed to the left side of this overlapped range. The Seger ranges for most Korean wares coincided with those of celadon and whiteware from southern China. Only the elliptical circles representing midland celadon (upper right corner) and local Chosŏn whiteware (lower left corner) distributed substantially outside the overlapped area.

The material characteristics of the vast majority of Korean ceramic wares were found to be similar to those from the southern Chinese kilns, reflecting the region's geology. The geological dividing line called Nan Shan Quiling in China extends northeast through the ocean into the Korean peninsula (Figure 1). South of this line (i.e., South Korea and southern China) porcelain stone formed the majority of the available pottery clay. In contrast, that found north of the line was typically kaolinitic clay.[12,13]

Figures 4 and 5 show the mineralogical relationship between these two types of clay. Porcelain stone represents an intermediate stage in the disintegration process of igneous rocks composed largely of feldspar into primary clay kaolinite (Figure 4). It comprises the hydromical minerals of muscovite, sericite, and illite, as shown in Figure 5 (graph, lower middle portion). These minerals include some alkali oxides of K_2O and Na_2O retained from the original feldspar; when all the alkali oxides are removed, the end product of kaolinite [$Al_2Si_2O_5(OH)_4$] is formed. In porcelain stone, hydromica and a small amount of newly formed primary clay provide the plasticity, hydromica and the remnant feldspar the fluxing property, and quartz the refractory property needed to support high-temperature sintering. Thus, porcelain stone with all three tri-axial properties is naturally suited for the production of hard-textured ceramic wares. Only simple mechanical refinements were necessary for potters to use this clay in forming ceramic bodies, and glaze batches could

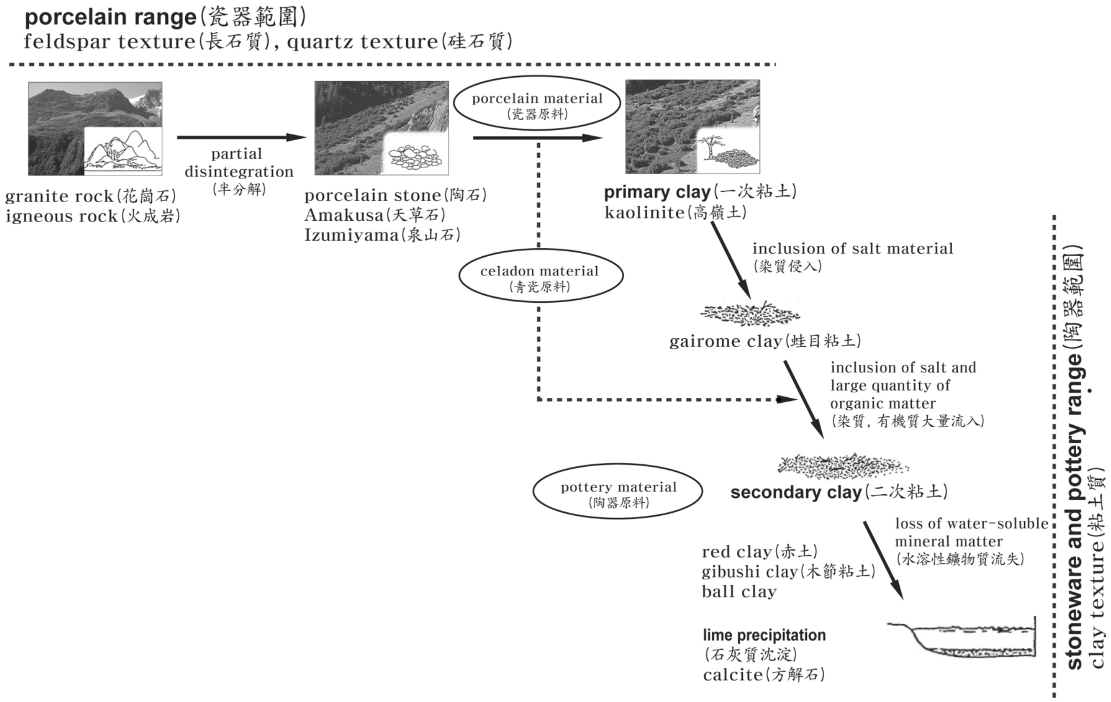

Figure 4. Diagram of how igneous rocks decay into the raw materials used for the production of various types of ceramic wares. (Substantially modified from the diagram on p218 in *A Study on the Developmental History of East Asian Ceramic Industry and its Interactions* by Tai Hai Tang, Nanjing University Press, 1995, in Chinese).

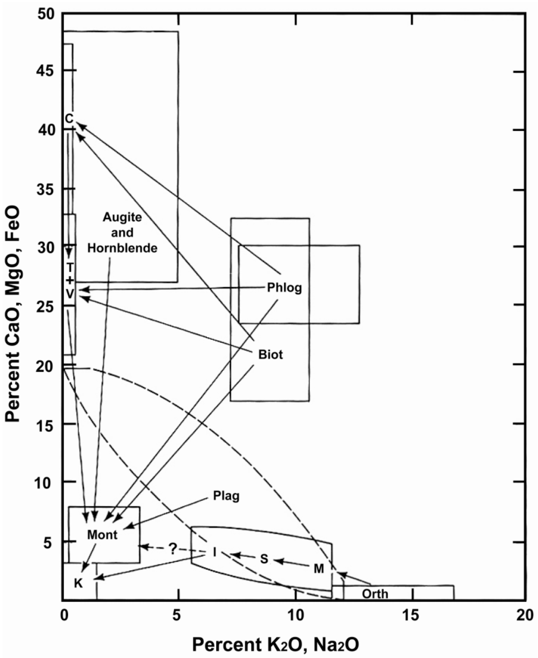

Figure 5. The weathering transformation path of of the primary silicate minerals. The feldspar minerals of orthoclase and plagioclase lose eventually all the alkali and alkaline earth oxides to transform into the clay mineral kaolinite. Observed and suspected paths of weathering are shown by solid and dashed arrows respectively. (Source: *Petrology-Igneous, Sedimentary, and Metamorphic* by Ernest G. Ehlers and Harvey Blatt, W. H. Freeman and Company, 1982, p. 280).
Abbreviations: Orth = orthoclase, $(K, Na)AlSi_3O_8$; Plag = plagioclase, $Na(AlSi_3O_8)$-$Ca(Al_2Si_2O_8)$; M = muscovite, $KAl_2(AlSi_3O_{10})(OH)_2$; S = sericite, fine-grained muscovite; I = illite, $K_{1.5\text{-}1.0}Al_4[Si_{6.5\text{-}7.0}Al_{1.5\text{-}1.0}O_{20}](OH)_4$; Mont = montmorillonite, $Al_2Si_4O_{10}(OH)_2 \cdot xH_2O$; K = kaolinite, $Al_2Si_2O_5(OH)_4$; Phlog = phlogopite, $KMg_3(AlSi_3O_{10})(OH)_2$; Biot = biotite, $K(Mg, Fe)_3(AlSi_3O_{10})(OH)_2$; C = chlorite, $Mg_5Al(AlSi_3O_{10})(OH)_8$; T = talc, $Mg_3Si_4O_{10}(OH)_2$; V = vermiculite, $Mg_3Si_4O_{10}(OH)_2 \cdot xH_2O$.

be formulated from it by the addition of appropriate fluxing materials.

The Seger values for all traditional Korean wares studied herein, with the exception of the midland celadon and local whiteware, fell within a narrow range (Figure 2) because their bodies were made with porcelain stone. The bodies of the midland celadon groups were made of the same material, but their aluminum contents were slightly lower (15 to 18 wt.%) and their R_xO_y values were slightly higher than those of the other ceramic types. The oxides in R_xO_y function as flux, and bodies with higher levels of R_xO_y could be vitrified at lower firing temperatures and/or with less firing time. The availability of such material may explain why ceramics could be fired in a single step at the midland kilns, rather than in two steps (before and after glazing) as was done in contemporary kilns of southwestern celadon kilns in Kangjin and during the Chosŏn dynasty in Korea.

The ellipse containing the results from local whiteware produced in Ch'unghyodong and Yonggyeri during the 15th and 16th centuries represents an unusual point in the history of Korean ceramics. The bodies of these wares were made with a kaolinitic clay material similar to that used in Chinese kilns north of the Nan Shan Qinling dividing line (e.g., Dingyao and Yaozhou). This material, which was high in aluminum (around 30 wt.%), would have required a much higher firing temperature. To date, its use in Korea has only been documented at a few local whiteware kilns. However, later-era local kilns are presently being excavated, and the future analysis of shards recovered from these kilns may help shed light on the importance of kaolinitic clay in the development of Korean ceramics.

Although celadon, *punch'ŏng*, and whiteware had similar Seger values, their body compositions differed in terms of the various minor oxides included in the term, R_xO_y. As shown in Figure 6, the bodies of *punch'ŏng* tended to contain more Fe_2O_3 than those of celadon or (more notably) whiteware. As presented in Figure 2, porcelain was made from a type of primary clay that was formed from and colocalized with feldspar rock. Celadon and *punch'ŏng* may be considered more stoneware than true porcelain, and some (less meticulously made) examples of celadon and *punch'ŏng* were even produced using secondary clay that had been blown or washed from its original location. These secondary clays contained increased levels of Fe_2O_3 and organic impurities that were probably picked up along the way. In contrast, some of the high-quality examples of celadon, such as those with *pisaek* glaze from Kangjin, are likely to have been made from a highly pure primary clay similar to that used to make whiteware porcelain.

The level of TiO_2 (Figure 7) also differed between whiteware bodies (< 0.4 wt.%) and those of celadon and *punch'ŏng*

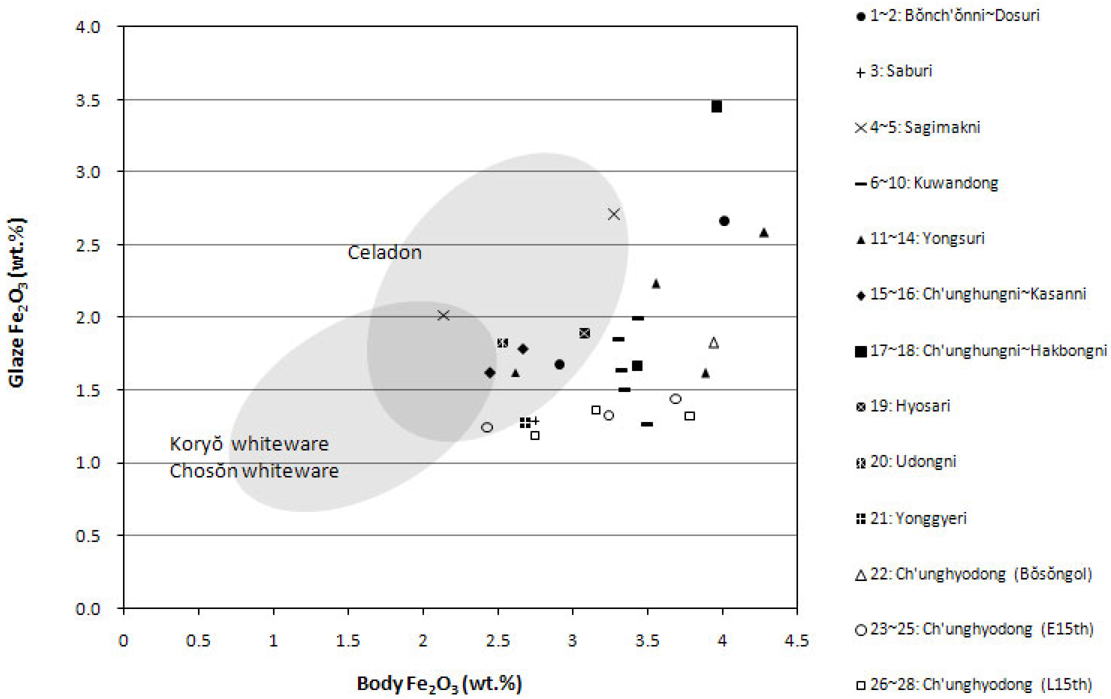

Figure 6. Graph showing Fe_2O_3 content in the body vs. that in the glaze.

(0.5 to 1.0 wt.%). In fact, the higher amount of TiO_2 is essential in celadon for the bodies to turn gray upon firing. In contrast, the *punch'ŏng* shards found at Sagimakni (Groups 4 and 5) contained an unusually low level of TiO_2 (0.2~0.3 wt.%), and their bodies resembled whiteware. One of the most striking finding of this study was that *punch'ŏng* glazes contained much less TiO_2 than celadon glazes (see below for details), whereas their bodies contained similar amounts of TiO_2.

3.2. Comparison of Glaze Compositions

The Seger graph representing the glaze results (Figure 3) shows that the Koryŏ whiteware and Chosŏn whiteware glazes formed separate clusters in the lower left and upper right, respectively, and overlapped only slightly. This clear differentiation in the whiteware glaze characteristics of the two dynasties contrasted sharply with the similarities in their body compositions. The celadon glazes from the midland and southwestern kiln complexes clustered with those of the Koryŏ whiteware, while the local Chosŏn whiteware glazes distributed with the Kwangju whiteware glazes.

These two separate clusters might be conveniently designated "Koryŏ glaze" and "Chosŏn glaze." However, with the exception of one Ch'unghyodong group (Group 23), the *punch'ŏng* glazes also fell within the Koryŏ circle. Although whiteware and *punch'ŏng* were made at the same time (in the first two centuries of the Chosŏn dynasty), often in the same kilns, the glaze compositions of *punch'ŏng* seem to have followed the Koryŏ tradition, while the whiteware glazes significantly departed from this tradition.

As shown in the graph representing the levels of calcium and alkali oxides (Figure 8a), the *punch'ŏng* glazes again distributed with the Koryŏ samples, which were characterized by a higher calcium content. The Chosŏn whiteware glazes from Kwangju overlapped substantially with those of the Koryŏ and *punch'ŏng* groups, but the range was shifted toward a lower calcium content and higher alkali content. The distribution of the local whiteware glazes was shifted even further toward lower calcium and higher alkali levels. According to the system of categorizing high-fired glazes

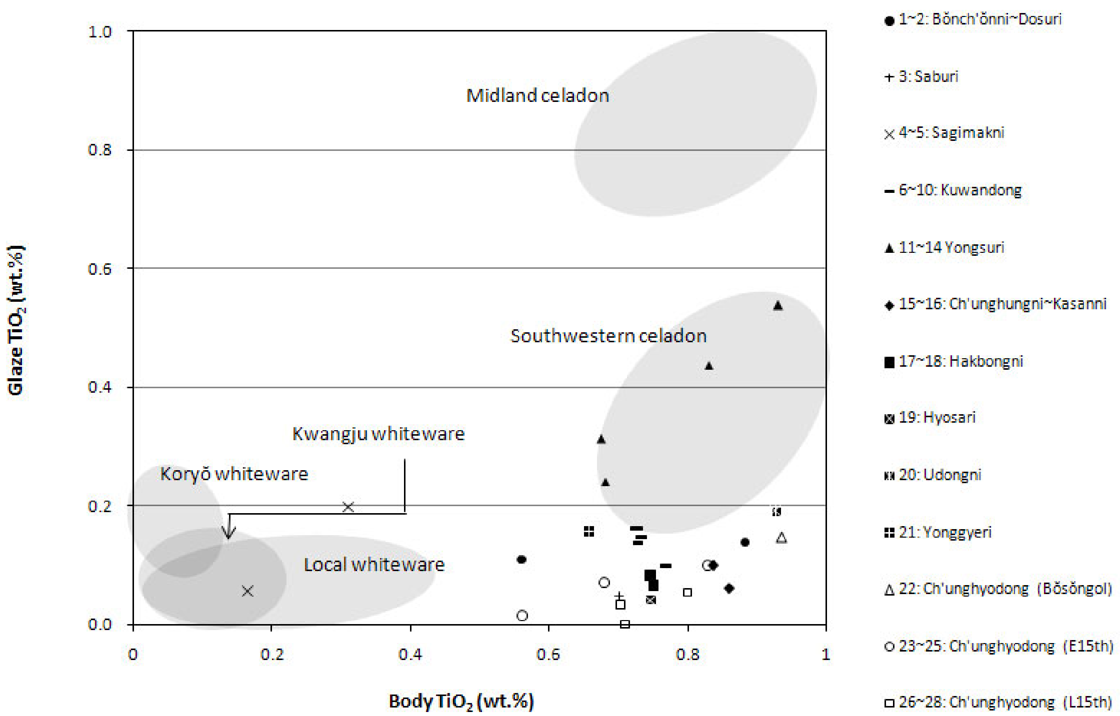

Figure 7. Graph showing TiO_2 content in the body vs. that in the glaze.

based on their calcium oxide contents, the Koryŏ and *punch'ŏng* glazes could be categorized as high-lime and lime; the Chosŏn whiteware glazes were lime and a few lime-alkali; and the local whiteware glazes were acid-rock.[14]

High-lime and lime glazes were used for Koryŏ and *punch'ŏng* wares. Similarly, the lime-type glazes were used for several centuries in China as the main glaze formula for the delicately shaped whiteware, *yingqing*, even after the more attractive lime-alkali glazes were developed during the Five Dynasties (AD 906-960).[15] In short, when the high-lime and lime glazes were fired to a high temperature and then cooled quickly, the high lime content produced a transparent glaze that showed off underlying decorations, such as the incised and molded decorations of *yingqing* and celadon. A similar level of transparency was required for the underglaze-inlaid techniques that Koryŏ potters developed in the 12th century and continued to use until the end of the dynasty at Kangjin Sadangni and Puan Uch' ŏlli, as well as for the modified inlay techniques that were developed for *punch'ŏng* during the first 200 years of the Chosŏn dynasty. Indeed, the centers that produced inlaid wares, as well as several early *punch'ŏng* kilns, were found to have used high-lime glazes containing upwards of 20 wt.% calcium oxide.

When the CaO content was compared with the P_2O_5 content (Figure 8b), the results for the *punch'ŏng* glazes again distributed with those of Koryŏ celadon and Koryŏ whiteware. The Chosŏn whiteware glazes, in contrast, contained much less P_2O_5, indicating that these glazes included crushed limestone instead of wood ash as the chief flux material. By the 10th century in China, limestone in either burnt form (glaze ash) or crushed form had replaced wood ash as the favored flux material at the major kilns. In Korea, too, limestone was almost certain to have been used at a similarly early time period.[2] As shown in Figure 8b, however, wood ash remained as an important ingredient in Korea throughout the Koryŏ dynasty, and was used liberally at some kilns (e.g., Ch'unghyodong) as late as the 15th century. The high P_2O_5 content in the most recent shards from Yongsuri (Group 14), representing wares from the 15th

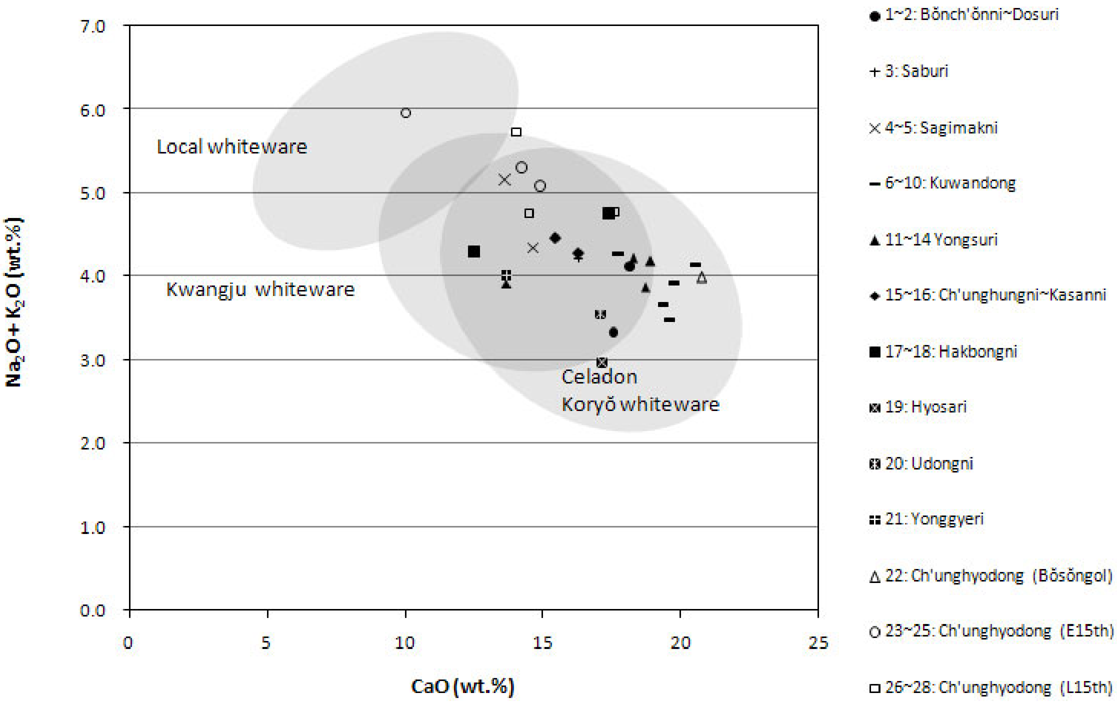

Figure 8a. Graph showing CaO content vs. that of $Na_2O + K_2O$ in the glaze.

century, indicated that wood ash could have been the sole flux component even at that point.

Compared to limestone, wood ash contains three additional oxides: P_2O_5, MnO, and MgO. Glazes that contained higher levels of these oxides were likely to have been made with a greater proportion of wood ash than glaze ash or crushed limestone. The Kwangju whiteware glazes contained little or no P_2O_5 (< 0.2 wt.%), indicating that they were made with crushed limestone and perhaps a small amount of burnt limestone (glaze ash). The five groups of Kuwandong *punch'ŏng* were exceptional among the *punch'ŏng* groups in that their P_2O_5 values were similar to those of the Chosŏn whiteware glazes. This finding indicates that this early *punch'ŏng* kiln, which operated in the first decades of the 15th century, used limestone in formulating its glazes, as was done for whiteware. The plain and inlaid *punch'ŏng* shards from this kiln were very similar to the celadon shards excavated from the earlier Kuwandong celadon kiln (11th and 12th centuries), but the glaze composition departed markedly from that of the celadon kiln, which appears to have used only wood ash.

The wide range of P_2O_5 contents found in the Koryŏ and *punch'ŏng* glazes suggests that wood ash, glaze ash, and crushed limestone were combined in various proportions. Glazes with P_2O_5 values > 1.5 wt.% were probably formulated with wood ash alone, while those with P_2O_5 values between 1.5 and 1.0 wt.% may have included wood ash plus a small amount of limestone. Several *punch'ŏng* groups (including two from Hakbongni) fell into the latter category. More than half of the *punch'ŏng* groups had P_2O_5 values between 0.5 and 1.0 wt.% and CaO values between 13.0 and 21.0 wt.%. Among these groups, those with higher P_2O_5 versus CaO ratios probably contained a greater proportion of wood ash in their glazes, whereas those with lower P_2O_5 versus CaO ratios most likely contained a greater proportion of burnt or even crushed limestone. With the exception of the very first kiln operating at Bŏsŏngol (Group 22), the P_2O_5 versus CaO ratios were high for all of the groups representing Ch'unghyodong, indicating that wood ash was employed as the main ingredient throughout the 100-year history of this

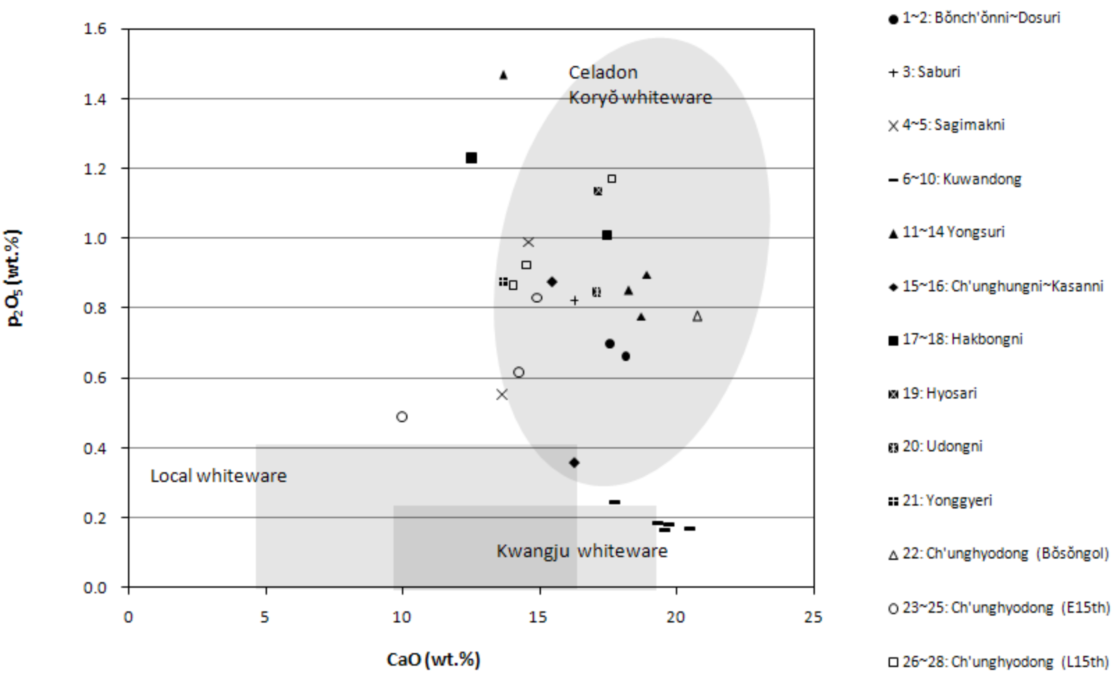

Figure 8b. Graph showing CaO content vs. that of P_2O_5 in the glaze.

complex.

The Ch'unghyodong *punch'ŏng* and whiteware glazes also had substantially higher contents of alkalis, especially potassium oxide, compared to other glazes with similar lime contents (Figure 8a). In fact, for all of the *punch'ŏng* groups and some of the whiteware groups, the K_2O contents in the glazes were the same as or higher than those in the bodies. This unusually high content of potassium oxide suggests that Ch'unghyodong may have employed potassium feldspar as an important glaze ingredient.

Although the *punch'ŏng* glazes were largely similar to the Koryŏ glazes, the former shared one common characteristic with the Chosŏn whiteware glazes, namely low TiO_2 levels (Figure 7). This characteristic reflects an innovative practice that was adopted from Chinese whiteware production: the use of glaze stone as the chief clay component. Glaze stone, which was another form of the weathered quartz-hydromica porcelain rock used as the body material, was typically finer-grained and often had a higher feldspar content. It was regularly employed in *yingqing* glazes produced in Jingdezhen during the 13^{th} and 14^{th} centuries,[16] and is also likely to have been used centuries earlier in Koryŏ whiteware glazes.[2] In the literature of the Chosŏn dynasty, such glaze stone is referred to as *multo*, which means "water clay". In Yongsuri, which was the source of the earliest *punch'ŏng* groups included in this study, the TiO_2 contents were as high as those of the Koryŏ glazes, indicating that the Koryŏ use of body material in making glaze batches persisted in some *punch'ŏng* kilns.

4. Conclusions

This three-part study on Korean traditional ceramics identified several important overall material characteristics. The majority of the studied celadon, Koryŏ whiteware, *punch'ŏng* and Chosŏn whiteware samples were made using porcelain stone that arose from weathered rock and possessed the three key properties necessary for making ceramic bodies. This material was very comparable to that used in the kilns of southern China (e.g., Yuezhou and Jingdezhen), reflecting the fact that Korea shares common geological feature with Chinese regions that are also south of the Nan Shan Quiling dividing line. An unexpected finding in the study was the Korean innovation of using kaolinitic clay (similar to that used in northern China) to produce hard-textured whiteware at Ch'unghyodong and Yonggyeri.

The characteristics of the Korean glazes were also largely similar to those of southern China. Usually the body materials were mixed with wood ash and limestone as flux materials. The glazes of the Koryŏ ceramics and Chosŏn whiteware differed from one another, and the *punch'ŏng* glazes were more similar to those of the Koryŏ dynasty than those of the Chosŏn dynasty. Wood ash was the chief flux ingredient used in the majority of the Koryŏ and *punch'ŏng* glazes, and the ratios of calcium oxide to alkali oxide placed these glazes within the high-lime and lime categories. Although limestone was used as early as the 10^{th} century in some kilns (e.g., Yongunni of Kangjin), it was not adopted as the chief flux material until the very beginning of the Chosŏn dynasty, when Korea was once again directly influenced by ceramic technologies of the Chinese. Chosŏn whiteware, in contrast, had less calcium oxide in its glazes, which were mostly lime type or even some lime-alkali type. The glazes of Ch'unghyodong and Yonggyeri contained high levels of potassium oxide and magnesium oxide, respectively, and represented the acid- rock type.

The *punch'ŏng* glazes, however, contained much less titanium oxide than the celadon glazes; in fact, the *punch'ŏng* levels were similar to those of the Chosŏn whiteware glazes. In this way, *punch'ŏng* is reminiscent of *pisaek* Kangjin celadon, which was characterized by glazes that contained only about 30% of the TiO_2 content found in the body. In the case of the Kangjin glaze, the clay component came from a large mine of porcelain stone characterized by low TiO_2 and Fe_2O_3 (and therefore appropriate for making whiteware). In contrast, the low levels of TiO_2 in the *punch'ŏng* glazes probably reflects the use of glaze stone, which was also regularly used in Chosŏn whiteware production.

The general characteristics of traditional Korean ceramics deduced in this comparative study should be viewed a starting point for further study rather than a set of conclusions. An analysis of 369 shards separated into 80 groups cannot represent the porcelain-producing technology and culture that flourished for more than 1000 years throughout Korea. Continued efforts in careful shard selection from these and future excavations, detailed studies on their archaeological and visual features, accurate compositional analysis, and systematic compilation and analysis of the data should eventually lead to a comprehensive understanding of traditional Korean ceramics.

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