Ceramics and Society in Mahan and Paekche: A Comparison of Pottery Geochemistry and Craft Production Patterns at the Sites of P'ungnap T'osŏng and Kwangju Palsan

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ABSTRACT

The archaeological cultures of the Korean peninsula provide numerous case studies of the formation, structure, and function of ancient complex societies and states. In southwestern Korea, the Mahan (ca. 50 B.C.E.–C.E. 475) occupied a large region marked by similarities in material culture, but decentralized politically. The Paekche kingdom (ca. C.E. 250–660) had its origins as a Mahan polity in the Han River valley, later centralizing its authority and expanding its territory. This article discusses two sites: the Paekche capital of P'ungnap T'osŏng in modern Seoul and a large Mahan town recently excavated in Chŏlla Province known as Kwangju Palsan. The political economy and social structure of each site is investigated using ceramic remains, artifacts that played a large role in daily life across classes and in the elaboration of elite culture. With high-resolution chemical data from Instrumental Neutron Activation Analysis (INAA) on potsherds, specific production signatures can be identified for each site. This allows comparison of the proportion of locally produced and imported pottery at each site and even reveals when P'ungnap T'osŏng and Kwangju Palsan exchanged ceramic goods. These patterns reveal similarities and differences in Mahan and Paekche political economies, ultimately illuminating the Mahan roots of Paekche social organization. KEYWORDS: Korea, complex societies, Instrumental Neutron Activation Analysis, craft production.

INTRODUCTION

THE PERIOD IMMEDIATELY PRECEDING THE THREE KINGDOMS in the southern Korean peninsula goes by various names: the Proto-Three Kingdoms, a straightforward if teleological label; the Samhan 三韓, a historically-based name that effectively excludes the northern half of the peninsula; and the Iron Age, an appeal to the generality of the three-age system. This lack of agreement in nomenclature reflects a greater lack of clarity on the Korean state formation process itself. In the southwest, where histories

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Fig. 1. Map showing locations of Seoul and Kwangju, where the sites of P'ungnap T'osŏng and Palsan, respectively, have been excavated. Gray shading indicates possible geographical extent of three Han societies: Mahan, Chinhan, Pyonhan (adapted from [Byington 2009](#)).

present stories of centuries-old royal lineages and swift conquests, the archaeological record of the first few centuries C.E. clearly demonstrates that the Paekche 百濟 (RR: Baekje) kingdom (ca. C.E. 300–660) shared a great deal of material culture with its predecessor. This earlier society is identified in the archaeological and historical tradition as Mahan 馬韓, one of three supposed ‘Han’ groups described in the *Sanguozhi* 三國志 known collectively as the Samhan (Byington 2009) (Fig. 1). Whether the Mahan was in fact one society or several has been increasingly called into question (Kwŏn Oyŏng 2015; Davey and Lee this issue), as has the geographical extent and internal variation of its culture. In the midst of this reexamination of Mahan and in hopes of contributing to it, this article uses the label Mahan heuristically and provisionally to refer to the people who predated Paekche and also coexisted alongside the kingdom for the entirety of the Hansŏng 漢城 (RR: Hanseong) period (ca. C.E. 300–475). The effort to better define Mahan cultures and conceptualize Paekche state formation requires a thorough evaluation of the social, political, and economic ties between Mahan and Paekche communities and questioning how the people of these societies constructed their identities as separate from each other.

Excavations in Chŏlla (RR: Jeolla) Province over the past decade have demonstrated that the Mahan cultures that developed there before the start of the Three Kingdoms period continued to thrive through the fourth and fifth centuries (Im 2014; Kim S. 2014; Pak 2015; Sŏ 2014; Yang 2013; Yi N. 2013). Even after the Paekche capital was moved south for the first time in C.E. 475, Mahan-style settlements, burials, and pottery persisted, with some incorporation of Paekche styles. This study looks to address the relationship between Mahan and Paekche culture by examining ceramic remains, common everyday objects that were used by people of all social classes in both societies. Geochemical analyses and provenance determination of ceramics allow for detailed investigation of the internal political economies and inter-societal exchange relationships of two sites, one Mahan and one Paekche. Using the analytical precision allowed by Instrumental Neutron Activation Analysis (INAA), this study explores similarities in patterns of ceramic production and consumption that reveal a fundamental connection between the strategies deployed at these sites, even as these two systems supported political leadership at very different scales.

BACKGROUND

This study compares two sites: P’ungnap T’osŏng (RR: Pungnap-toseong), the fortified Paekche city that has been excavated since the 1990s, and Kwangju Palsan (RR: Gwangju Balsan), a recently discovered large settlement site in Chŏlla Province for which an excavation report is still to be published. While radiocarbon dates are not yet available for Palsan, relative dates on pottery suggest these sites were roughly contemporaneous, with both sites likely occupied throughout the fourth century C.E., P’ungnap T’osŏng abandoned in C.E. 475, and Palsan sometime in the sixth century. The pottery remains at Palsan lack the elaborate forms associated with the Paekche kingdom and which would be expected at a Paekche site of this size. Palsan therefore falls into the general category of ‘Mahan’.

The identity and nature of Mahan culture is unclear given the current state of historical and archaeological evidence. The *Sanguozhi* account of the Mahan describes a society of allied polities based on an infrastructure of towns and territories (Best 2006). Such an organizational system has been difficult to corroborate archaeologically,

as relatively few Mahan settlements have so far been recovered. Mahan culture has primarily been recognized through its burials, which in the early period typically consist of a coffin, generally two large jars made to interlock at the rims or sometimes a wooden casket, overlaid with a mound of earth or stone (Yi N. 2013). Members of the same clan were buried in proximity, and sometimes even together, as demonstrated by DNA testing on rare surviving human remains (Im 2014). This mortuary system existed with very little variability for the first three centuries C.E., but began to incorporate new forms and styles after approximately C.E. 300, leading to a highly varied burial system among the Mahan cultures located in modern Chŏlla Province (Kwŏn 2015). Paekche tombs from the Hansŏng period cemetery at Sŏkch'on-dong (Revised Romanization: Seokchon-dong) were also remarkably variable, mimicking Koguryŏ 高句麗 (RR: Goguryeo) tombs as well as the domed Silla style and other forms, but built with techniques not common in the other regions (Kim W. et al. 1989; Seoul 1975; Yi S. et al. 2013). More distinctly Paekche style monumental tombs such as that of King Muryŏng (r. 501–523) appear during the Ungjin (C.E. 476–538) and Sabi (C.E. 538–660) periods, when mounded Mahan tombs in the Yŏngsan (RR: Yeongsan) River region began incorporating the keyhole shape that typified tombs of the Kofun period in Japan. Lee (2014) suggests this may have been an expression of the local Mahan elites' connection to contemporaneous Japanese societies, one meant to reinforce their political and cultural distinction from southward-advancing Paekche while reminding the neighboring kingdom of their own prowess in overseas trade.

More information on the relationship of Mahan and Paekche in the fourth through sixth centuries is becoming available as the number of excavated settlements increases. In Chŏlla Province, known as Korea's "rice bowl," the relatively low modern population, coupled with a recent rise in development projects, has allowed for the discovery of over 150 settlements so far (Kim S. 2014). While further excavation, analysis, and dating are required to fully understand the settlement patterning of Mahan sites, Kim Sŭngok (2014) has compiled existing data for a provisional classification. The vast majority of sites contain between one and one hundred houses, which Kim groups into small (1–24 houses), medium (25–69), and large (more than 70) settlements. A few extra-large settlements (1000+ houses) appear later in the local sequence. Larger settlements in Kim's study tend to contain smaller houses, and may include an internal division between large and small houses. Sites of all sizes have above-ground granary structures that are larger in correlation with settlement size. Kilns within settlements tend to occur in the largest and smallest sites. In large sites, these kilns are assumed to have produced pottery for intra-site use, whereas kilns in very small settlements of two to five houses may have been used by more specialized producers.

Mahan ceramics are largely utilitarian in nature, with forms including multi-purpose short-necked jars, deep bowls, horn-handled steamers, and boiling pots (Sŏ 2014). The basic paddle-and-anvil construction of Mahan pottery was carried forward from earlier traditions, but the central Mahan region adopted wheel finishing earlier than the southern Samhan groups, as early as the second century C.E. (Yi S. 2013). A frequent stylistic feature of pots from this region is the use of a decorated paddle to finish the clay surface, creating marks known as *t'analmun* 打捺文 (RR: *tanalmun*). Two distinct types of *t'analmun* appear, depending on whether impressions were made in the clay with a cord-wrapped paddle or from a grid design carved into the paddle (Tsuchida 2013). The same types of *t'analmun* decorated vessels used in daily life are found as burial offerings, and the ceramics themselves do not appear to have been used

to mark social status either by quality or quantity (Choi 2008). In the fourth and fifth centuries, Mahan pottery incorporated Paekche forms such as pedestal bowls with lids, tripod vessels, and bottles, but in the Yōngsan River basin, a core Mahan region, these were made with local construction and firing techniques (Sō 2014).

Listed in the *Sanguozhi* as one of over 50 Mahan polities, Paekche came to power as a separate political entity in the late third or early fourth century C.E. (Kwōn 2011). Perhaps the most striking, and certainly the largest, difference in material culture introduced by Paekche was the construction of earthen-walled fortresses called *t'osōng* 土城 (RR: *toseong*). The earliest of these appears to have been P'ungnap T'osōng on the Han River's southern bank, where large-scale excavations began in 1997 (Kwōn 2008). The compound was enclosed by earthen walls constructed in the late third century, estimated to have been 43 meters thick, 11 meters tall, and over 3.5 kilometers in circumference. This would have required control over a large labor force, and the organization of the site suggests an extensive central area for the conduct of elite rituals. Several large pits have been recovered in this area with the remains of thousands of pottery vessels, sacrificial cows and horses, small figurines, mica, apricot pits, and other signifiers of elite behavior.

Compared with contemporaneous sites in the northern Paekche region, houses at P'ungnap T'osōng contain high levels of both storing and serving vessels, and only moderate numbers of cooking vessels (Kim M. et al. 2016). Several large storage jars found in both houses and refuse pits in the central Kyōngdang (RR: Gyeongdang) area of the site are glazed stoneware of Chinese manufacture (Hansōng and Hansin 2011, 2015; Kim M. et al. 2016). The majority, however, are Paekche-produced jars, bowls, lidded vessels, and tripod dishes. Two styles of Proto-Three Kingdoms pottery continued into the Paekche period: gray *yōnjil* 軟質 (soft-fired earthenware [RR: *yeonjil*]) and reddish-brown *yōnjil*. The first evidence for local Korean production with firing temperatures above 1000 °C come from the Hansōng Paekche period, with bluish-gray *kyōngjil* 硬質 (stoneware [RR: *gyeongjil*]) and black *mayōn* 磨研 (RR: *mayeon*) or 'burnished' pottery appearing in P'ungnap T'osōng and other sites. The development of blackware began in Mahan cultures (Nam 2013), but its popularity among Paekche elites was likely influenced by Chinese porcelain traditions, as some designs appear similar to Yue 越 and Western Jin 西晉 styles (Choi 2008).

Footed bowls, short neck jars, and broad-shouldered jars are common forms of blackware that do not appear to have Mahan roots (Sō 2014). This new style of pottery, often called 'Paekche style', has been conceptualized as a prestige ware owing to its distinctive shapes, and, in the case of blackware, attractive sheen. Paekche style pots begin to appear around the completion of construction of P'ungnap T'osōng's walls, and the vessels appear mostly to be related to food practice, which Yi Sōngju (2015) attributes to the elaboration of elite culinary culture. For decades, the working assumption was that Paekche-style wares would have been distributed throughout the kingdom from the Paekche core (Nam 2013). This interpretation followed from the *Samguk sagi*'s 三國史記 narrative of state formation, which not only conceived of Paekche as something separate from Mahan and with leaders foreign to the area, but also told of a sudden and thorough expansion of Paekche territorial control using primarily military means. This model of statehood supposes a powerful central authority, echoing that of Imperial China, elevated above the rest of the population to such an extent that even the production of certain kinds of pottery would have been its exclusive purview. In contrast, Cho Daeyoun (2006) demonstrated that the black

pottery in question was in fact produced in various places throughout the Paekche region, using techniques modified from local traditions. The production locations for blackware were, however, fewer in number than those for plainer styles. [Nam Sangwŏn \(2013\)](#) points out that not only did various producers in the Mahan region produce black or dark gray pottery predating Paekche blackware, but that when Paekche-style black jars were both imported and copied locally later in the sequence, they would have had different meanings outside of a central Paekche setting. This is borne out in the types of sites from which these jars are recovered. In Paekche core areas, blackware jars have been found in storage pits, houses, road works, and burials, but in Mahan cultural sites they are common only in burials. Some allowance must be made for the greater representations of burials in Mahan archaeological remains, but clearly these socially valuable items tell us less about Paekche's political expansion than the complex relationship between various reaches of Mahan and Paekche. While these studies focused on blackware jars, all categories of ceramics in Mahan and Paekche have the potential to yield such insights.

CRAFT PRODUCTION AND SOCIAL IDENTITY

The production of craft goods is a crucial economic activity in a complex society, but the behaviors involved in craft production also express, influence, and reify the social order in which craftspeople operate. Elites often invoke connections with remote entities both mundane and divine to justify their privileged position in this order, which are materialized in goods traded in from exotic locations as well as city walls, roads, ritual objects, personal adornments, and other locally produced goods ([Helms 1993](#)). Though made by non-elites, such objects represent the efforts of elites to bring the immediate world into accordance with the cosmic order to which they have particular access. Materializing elite connections in this way serves to institutionalize them, turning ideological authority into concrete control over resources and their distribution ([DeMarrais et al. 1996](#); [Vaughn 2006](#)). Recent work by a number of scholars has re-examined these processes by shifting the focus for behavioral explanation to non-elites, with cooperation emerging as a crucial component of increasing social complexity ([Blanton and Fargher 2008, 2016](#); [Carballo and Feinman 2016](#)). Though elites use authority to consolidate power and control, non-elite members of society retain at least some level of power no matter their place in the hierarchical or heterarchical order, and with it the ability to resist elite authority ([McIntosh 1999](#)). Dispersed power is also materialized in the archaeological record through architecture ([Blanton and Fargher 2011](#); [DeMarrais 2007](#); [Kristiansen 2007](#); [Monroe 2010](#)), trade goods ([Monroe 2013](#)), ceramics ([Dueppen 2015](#); [Kohring et al. 2007](#); [Wynne-Jones 2007](#)), and more. Craft goods provide an ideal lens through which to study these complex relationships, as production, exchange, and use patterns encode socially relevant identities and connections on multiple scales.

[Costin \(1991\)](#) provided a classic scheme for conceptualizing the framework of craft production in order to explicate these issues with archaeological data. The degree of craft specialization expresses, in broad terms, the ratio of producers to consumers, and the type of specialization is considered in four dimensions: the context of production, on a scale from fully independent specialists to those 'attached' or fully dependent on the sponsorship of a government or institution; the concentration of production, from nucleated to dispersed; the scale of production, with goods being made primarily for

kin on one extreme and modern wage labor on the other; and the intensity of production, from casual and part-time to full time and the exclusive means of economic support. Costin (1998:8) warned that the identity of the craft producer will not be a simple matter of age, gender, or affiliation, but essentially related to the “autonomy, control, power, privilege, and prestige” of their position in society. As Schortman and Urban (2004) argued, craft products possess value beyond the economic, and the identities of the people making them is not always defined in terms of their relationships to elites or each other, but rather are multiscalar and dynamic. Elites can engage in the consumption of craft goods without creating monopolies that result in dependence of craftspeople, who lose control over the exchange and consumption patterns of their produced goods. Inequality is one of many variables in this approach, and goods which are used to enforce political domination can also be used to resist it.

How these relationships and identities become encoded in ceramics is best examined through the concept of “technological style” (Lechtman 1977) as a reification of behaviors that take on particular patterns because of how they are shaped by society (in ways both recognized and unrecognized by members of that society). In this way, the concept of style cannot be divorced from that of function, as style is present in every aspect of how an object is made (Chilton 1999). Rather, distinctions must be drawn among the various stages of production and even further to distribution, use, and discard, as each of these processes is subject to its own variables. The chain of mutually contingent decisions that dictate technological style is known as the *chaîne-opératoire*, or operational sequence, of craft production (Lemonnier 1992, 1993). Every action taken by the craftspeople is part of this *chaîne-opératoire*, though only some of these actions will be apparent from the final product.

The problems, then, are to identify traits in any given collection of pottery that correspond to specific stages of the ceramic *chaîne-opératoire* and recognize how these traits encode the social context of the potter. Through ethnographic work in southern Cameroon, Gosselain (1998) found a strong correlation between language group and the method used for vessel formation. The reason for this is crucial to the concept of a technological style: vessel formation was the portion of the learning process where new potters had the most in-depth, hands-on, and prolonged instruction from their teachers. As knowledge of pottery manufacture was passed down through time, and the populations of certain ethnic groups moved through space, this particular stage in the *chaîne-opératoire* was preserved due to the private and personal nature of its transmission. Being a relatively early stage in the creation of the pot, vessel formation is difficult to recreate simply by seeing a finished pot. This stands in direct contrast to stages like decoration, where established potters can easily adopt or adapt techniques they observe on pots with or without direct contact with the original producer (Gosselain 2000).

Compositional data, as used in this study, most directly address the first two stages of the *chaîne-opératoire*, raw material procurement and paste preparation, with exchange patterns possible to infer after clay sources are successfully identified. As an operational stage, the procurement of clay is somewhat intermediate between conservative and malleable, with several variables at play. Although clay is often widely available in a landscape, different occurrences of clay can be of varying quality. While it may seem prudent to assume that potters will use the highest quality clay available within a reasonable distance, this is not necessarily borne out by ethnographic data. In a study on Kalinga potters in the Philippines, Stark and colleagues (2000) found that the clay source a potter used was highly contingent on personal relationships, and did not

correlate with the clay's plasticity. Michelaki, Braun, and Hancock (2015; 2012) examined all the possible clay sources near a Neolithic site to investigate not only which were used, but which were not. They determined that a cultural concept of what constitutes an appropriate source for pottery material was of paramount importance, with some high-quality clays available near coastlines ignored in favor of inland clays considered more socially appropriate to the task.

Once identified, a ceramic compositional signal can then provide information on the movement of pots across landscapes. Minc (2006, 2009; Minc et al. 2016) has used INAA compositional data to map the dynamic market economy of the Basin of Mexico, finding that sub-regional exchange patterns persisted during integration into the wider Aztec market economy. Stahl and colleagues (2008) found patterns of change in ceramic composition over two millennia in western Ghana that did not match the region's working chronology, making straightforward explanations impossible. They suggested that technological styles and exchange relationships were dynamic rather than directional, with some clay sources and consumption patterns fluctuating over time while others were maintained. A large trace element analysis project on pottery from the Iranian region found that the composition of potters' tools did not match the geology of the location in which they were found, indicating that Proto-Elamite potters were highly mobile, traveling long distances to practice their craft (Alden and Minc 2016). A subset of this pottery from an Uruk colony in western Iran demonstrated that Uruk-style vessels were made with local clays and that the colonists engaged in trade with local and nearby communities (Gopnik et al. 2016). Quite recently, Grave and colleagues (2017) found that INAA was able to differentiate between products of different kilns in Cambodia where X-Ray Fluorescence (XRF) could not, laying the groundwork for investigation into pottery consumption patterns in Khmer society.

Compositional analysis of ceramics can provide data on clay sourcing and paste preparations, the first two major stages of pottery production (Arnold et al. 1991; Neff et al. 1988, 1989). These sources can be identified with various degrees of precision in different geological and cultural contexts to assist in understanding the nature of past ceramic economies. The degree of specialization observable in chemical and other traits of pottery has important ramifications for the organization of production in political economies. The social status of ceramic producers, their relationships with other economic specialists, their multiscalar identities, and the prestige of their craft can all be supported by evidence of the geochemical variation observed in pottery.

GEOCHEMICAL ANALYSIS

A total of 42 sherds from the pit feature at P'ungnap T'osǒng and 30 sherds from residences at Kwangju were subjected to INAA and subsequently divided into two major groups based on geochemical composition. The processing of sherds and statistical handling of the data are outlined in the Methods section below. The distinction apparent between these groups can be seen in Figures 2 and 3, with the majority of sherds from each site forming a group that more or less excludes the sherds from the other. The first group contains mostly sherds from P'ungnap T'osǒng and is called the 'Hansǒng' group, since, as is explained below, most constituent sherds were likely not produced at P'ungnap T'osǒng itself but elsewhere in the Hansǒng Paekche region. The second group contains mostly sherds from Kwangju Palsan, so is called

Fig. 2. Bivariate plot of principal components 1 and 2. Groups are shown with 95% confidence intervals including all members.

'Kwangju'. Three sherds from P'ungnap T'osŏng tested into the Kwangju group and two from Palsan tested into Hansŏng. Table 1 provides a list of all sherds that were not assigned to the composition group corresponding to their site of origin.

The sherds from Kwangju Palsan that form the Kwangju composition group ($n = 26$) are mostly *yŏngil* earthenware, often with grid-paddled decoration. A subset of this group consists of three *kyŏngil* and intermediate sherds that share a distinct chemical pattern within the range of variation for the Kwangju group. This subset, called the 'Kwangju stoneware group' below, also closely resembles the Kwangju group sherds from P'ungnap T'osŏng when viewed in parallel coordinate plots showing compositional profiles (Fig. 4).

Two Kwangju Palsan sherds contain the high transition metals (particularly Sc, V, and Cr) and rare earth elements (i.e., La, Ce, Sm, Eu, Tb, Dy, Yb, Lu) consistent with northern sherds, so were assigned to the Hansŏng group. These sherds are of intermediate and *yŏngil* hardness and one is grid-paddled. Of the 34 sherds from

Fig. 3. Bivariate plot of the chemical components sodium and scandium. Groups are shown with 95% confidence intervals including all members.

P'ungnap T'osǒng assigned to the Hansǒng group, only two are *yǒngjil*, with *t'analmun* paddling and stamped parallel lines the most common decorative techniques. A chemically distinct subset is visible within the Hansǒng group as it was in Kwangju, this time consisting of 16 sherds of intermediate or *kyǒngjil* hardness. Comparison with INAA results from other Korean sites determined the production origin of this group to be the kiln complex at Sansu-ri/Samnyong-ni (Walsh 2017), so this subset is referred to as the 'Hansǒng Sansu-ri' group. All sherds in this subset are *kyǒngjil* or intermediate in hardness, but they are otherwise not of consistent appearance or quality. Two sherds show obvious if not catastrophic flaws: one sherd has a large mineral inclusion breaking through to the exterior surface, with a pattern of cracks surrounding it roughly 1 cm across; another has an air bubble roughly 2 cm in diameter, probably from expansion during the firing process. Six have evidence of the parallel line stamping associated with Sansu-ri production, one shows cord-wrapped

TABLE 1. LIST OF SHERDS PLACED INTO COMPOSITION GROUPS NOT MATCHING THEIR SITE OF ORIGIN

SHERD	SITE	COMPOSITION GROUP	HARDNESS	DECORATION
L02	P'ungnap	None (exotic)	Intermediate	Parallel lines
L09	P'ungnap	Kwangju	Yŏnjil (earthenware)	None
L11	P'ungnap	None (exotic)	Intermediate	Dragged comb
L13	P'ungnap	None (exotic)	Yŏnjil (earthenware)	Cord-wrapped paddling
L19	P'ungnap	None (exotic)	Yŏnjil (earthenware)	Cord-wrapped paddling
L24	P'ungnap	None (exotic)	Intermediate	None
L25	P'ungnap	Kwangju	Intermediate	None
L41	P'ungnap	Kwangju	Kyŏngjil (stoneware)	Carved grid paddling
P04	Palsan	None (exotic)	Kyŏngjil (stoneware)	Slip
P15	Palsan	None (exotic)	Yŏnjil (earthenware)	Carved diamond paddling
P16	Palsan	Hansŏng	Intermediate	Possible paddling
P28	Palsan	Hansŏng	Yŏnjil (earthenware)	Carved grid paddling

t'analmun paddling, two have a mottled glaze on their exterior surfaces, and one has the dark and shiny surface of a *mayŏn* blackware.

Five sherds from P'ungnap T'osŏng and two from Kwangju could not be assigned a geochemical group and are considered exotic to the regions. The five exotics from P'ungnap T'osŏng are of various hardness, and decorations include cord-wrapped *t'analmun* paddle marks and parallel lines of unclear application technique. Chemically, these sherds are highly variable, with two showing unusual levels of aluminum, calcium, and potassium that suggest a fundamentally different geologic origin. One of the Palsan exotics shows peaks in iron and chromium that are unique to any sherds even in the larger Korean assemblage of 290 examined by Walsh (2017). This sherd also shows a slipped surface treatment that does not appear on other *kyŏngjil* sherds at Palsan. The other is a *yŏnjil* sherd unusually low in transition metal content, including titanium, scandium, vanadium, and chromium. While this sherd bears grid-paddled decoration, the grid is more diamond in shape than square or rectangular. These findings are summarized in Table 2.

DISCUSSION

The two composition groups identified above demonstrate that geochemical differentiation is possible among clay sources in the Korean peninsula. Production signatures from the sites of Palsan and P'ungnap T'osŏng, nearly 300 km apart, are readily distinguished with multivariate analysis. The variation within these composition groups cannot be fully understood before the completion of clay survey in the vicinities of both sites, but certain patterns are clear in the current data. Both the Kwangju and Hansŏng composition groups contain subsets of sherds that are markedly similar in chemistry, suggesting not only a common origin but potential standardization of production (Arnold 2000). In the case of the Hansŏng group, this can be traced to a specific production location, the Sansu-ri kiln complex roughly 75 km southwest of P'ungnap T'osŏng. As these sherds still clearly fall into the chemical parameters of the Hansŏng group as a whole, the geographical range of potential production locales in these composition groups must be understood as fairly

Fig. 4. Parallel coordinate plots showing profiles of selected composition groups. Each parallel line represents one of 29 elements, in order: Al, Ca, K, Na, Fe, Ti, Sc, V, Cr, Mn, Co, Zn, As, Sb, Rb, Cs, Ba, La, Ce, Sm, Eu, Tb, Dy, Yb, Lu, Hf, Ta, Th, U.

TABLE 2. RELATIVE COMPOSITION OF *Yŏnjil* AND *Kyŏngjil* SHERDS IN P'UNGNAp T'OSŎNG AND KWANGJU PALSAN SAMPLES, AND INTERPRETATION OF SHERD COMPOSITION GROUPS AS GENERALIZED PRODUCTION, SPECIALIZED PRODUCTION, OR EXOTICS

SITE	YŎNJIL SHERDS	INTERMEDIATE HARDNESS SHERDS	KYŎNGJIL SHERDS
	N (% OF TOTAL)	N (% OF TOTAL)	N (% OF TOTAL)
Kwangju Palsan	23 (77%)	4 (13%)	3 (10%)
P'ungnap T'osŏng	5 (12%)	12 (28.5%)	25 (59.5%)

SITE	GENERAL REGIONAL	SPECIALIZED REGIONAL	LONG-DISTANCE
	PRODUCTION	PRODUCTION	IMPORTS
	N (% OF TOTAL)	N (% OF TOTAL)	N (% OF TOTAL)
Kwangju Palsan	23 (77%)	3 (10%)	4 (13%)
P'ungnap T'osŏng	18 (43%)	16 (38%)	8 (19%)

Fig. 5. Geological maps of Seoul (top) and Kwangju (bottom) regions, showing relatively granite-rich environment surrounding Kwangju, contrasting with extensive sedimentary and metamorphic deposits in Seoul.

large. This homogeneity could be due to the extent of geological formations such as Daebo granite and the Gyeonggi Metamorphic Complex (Fig. 5), cultural preferences for clay with certain qualities, or a combination of both. For now, the operating assumption is that sherds in the Hansŏng group could potentially have been produced anywhere in the territory controlled by Hansŏng Paekche and those in the Kwangju group anywhere in Chŏlla Province.

The composition groups and their subsets speak to practices surrounding craft specialization and standardization in their respective societies. The Hansŏng Sansu-ri and Kwangju stoneware subsets meet the essential criterion for standardization (Blackman et al. 1993; Underhill 2015), that is, a reduction in variety. These sherds are less variable in hardness (with no *yŏnjil* represented in either subset) and in the chemical makeup of their raw materials. In terms of *chaîne-opératoire*, this indicates that the choices craftspeople were making when gathering clay, preparing paste, and firing pots were stable in these contexts, with the same decisions made repeatedly through time and by numerous individuals. This kind of standardization can be used as proxy evidence for specialization; the identification of the Sansu-ri production signature makes this particularly straightforward. The large number of kilns and workshops excavated at Sansu-ri (Hannam 2006) and the lack of chemical variation in the pots recovered there (Walsh 2017) provide a strong connection between standardization and specialization in Hansŏng Paekche. Given its chemical similarity in the midst of variation, the same logic can be applied to the Kwangju stoneware group, though Arnold (2000) has cautioned that social and geological factors affecting the availability of raw materials can interfere with such interpretations. In this case, the lack of *yŏnjil* sherds in the subset when the vast majority of sherds sampled from Palsan were *yŏnjil* makes it more likely that these pots came from specialized producers, rather than ones who had only extremely limited access to raw materials. Such specialization has a basis in evidence from Chŏlla Province, where kilns appear mainly at very large and very small sites (Kim S. 2014). If sites with kilns next to 2–5 houses were the locus of specialized pottery production, the Kwangju stoneware group might well have originated from such a site.

At both Palsan and P'ungnap T'osŏng, the ceramics that were produced in the immediate region fall into two groups: generalized production, typified by sherds of various hardness that show relatively more variation in geochemistry; and specialized production, *kyŏngjil* and intermediate sherds with extremely similar chemical signatures (Table 2). This pattern is evident at a larger scale in P'ungnap T'osŏng, where high-fired (if not always flawless quality) pottery was brought into the city over a 75 km distance. The distance involved in moving the Kwangju stoneware group sherds into Palsan cannot currently be determined, but if specialized production did indeed take place at small sites, this pottery was at least from outside the settlement's immediate vicinity. Specialized craftspeople may choose to practice their trade in locations near their preferred raw materials, and clay quality is certainly not uniform across a landscape. There is no reason to believe, however, that an appropriate source of clay was not available closer than 75 km from P'ungnap T'osŏng, or that a kiln complex could not have been established nearer to the fortress. Similarly, high-fired pottery could have been produced at large settlements in the Mahan, but evidence suggests its production was restricted to small, specialized locales (Kim S. 2014). Pottery is both heavy and fragile, and the Korean peninsula is mountainous, but as Costin (1991) has pointed out, transportation costs can add to the value of craft goods.

If the purpose of keeping major ceramic production centers away from major settlements was to increase their value, this would appear consistent with the use of Sansu-ri vessels in elite feasting activities at P'ungnap T'osŏng, but does not explain the use of specialized stoneware pots at Palsan, where no elite connection is evident from the household contexts. As Paekche centralized as a state, it may have amplified existing Mahan strategies to the extent that we see in the relationship between Sansu-ri and P'ungnap T'osŏng. Another possibility, given that stoneware was not produced widely in Mahan cultures prior to C.E. 300, is that Palsan and other Mahan cultures adapted this practice from Paekche as their own production and use of stoneware increased. In either of these cases, the appearance of this pattern in both P'ungnap T'osŏng and Palsan suggests a set of cultural understandings about value and distance that was shared between these two communities and may have been common to all Mahan and Mahan-derived cultures.

The related factors of high firing temperatures, value, and distance in the standardized subsets of the Hansŏng and Paekche groups all point to the status of these ceramics as prestige, rather than utilitarian, wares. While the terminology has been flexible, this dichotomy is popular in archaeology as a way for examining changes in craft production and consumption when elite classes are present in a society (Costin 2001; Hayden 1998; Helms 1993; Junker 1999; Peregrine 1991). As Flad and Hruby (2007) pointed out, however, the labels 'prestige' and 'utilitarian' are not mutually exclusive when applied to objects. Making a thing into a symbol of power or prestige requires its use as such, so is contingent on behaviors involving the object that are recognized as meaningful in social context. A craft good can therefore be highly prestigious at one moment and wholly utilitarian the next, so the attempt by archaeologists to identify one class of ceramic vessels as either prestigious or not is often misguided. Costin (2007) went so far as to say that the concept of value should be replaced with that of function to shift focus onto observable patterns of consumption rather than artifact traits that may signify more to the archaeologist than to the community that produced and used these objects. Though the Kwangju stoneware group pots were not recovered from obviously prestigious contexts, they may have been highly prestigious goods at specific points in their use lives. This status would likely have been temporary; after a vessel had served its prestige function, it might have become available for use by any Palsan resident. In stark contrast, the prestige function of these specialized goods at P'ungnap T'osŏng involved their burial, which cut off all possibility of future usage.

As opposed to the specialized pottery produced in the Hansŏng and Kwangju regions, pottery imported from other societies was not consistently high-fired or otherwise obviously prestigious. The social context of exchange over inter-societal distances may have been different from internal political economics, focusing more on human interaction or the contents of the containers than the pots themselves. Economic exchange can be manipulated by elites for a variety of purposes (Brumfiel and Earle 1987; Hirth 1996; Smith 2004; Vaughn 2006), but these purposes have generally required class-based restrictions on consumption. The existence of such restrictions are not necessarily supported by Mahan/Paekche data, where even Sansu-ri vessels have been excavated from a variety of sites and contexts (Sŏng 2012, 2016). Helms (1993) emphasized long-distance exchange as a venue for elites to reinforce their connection to places both literally and figuratively beyond, but this need not be restricted to elites. Pailes (2016) demonstrated that emergent elites need not monopolize long-distance exchange networks and that complexity can involve

small-scale exchanges of relatively mundane goods in order to maintain social alliances. Long-distance trade may have been an essential component of Mahan identity, as seen with the keyhole-shaped tombs discussed above (Lee 2014), and historical records of exchange with Chinese and other nearby societies (Best 2006). Inter-societal exchange was also crucial to Paekche statecraft, as the ritual feasting pit at P'ungnap T'osŏng contained pots from Mahan territories and unknown long-distance origins alongside vessels from Paekche territories. In this case, the symbolism of the objects was far from ephemeral, and Paekche elites sent the message that they had particular access to and control over these connections.

Just as exchange relationships with distant communities reinforced social ties in a way that could be wielded as cultural capital, the non-centralized production of specialized ceramics would have served to maintain domestic cohesion economically, politically, and socially. At Palsan, this fits with the historical picture of a Mahan polity as a political unit with a distinct identity, where villages and towns with a dispersed power structure maintained unity through various rituals and events (H. Yi 2009). Some level of town sponsorship may have been involved in *kyŏngjil* production to ensure that specialists had the means to make these wares and bring them into town, but the pots themselves were not as important as the practice of this exchange.

Multiple scales of physical distance were involved in the interactions revealed by patterns of geochemical composition; the value of these distances is also multi-scalar and dynamic. While long-distance exchange is evidenced at these sites, the value of distance also plays out on the intra-societal level, with the production of *kyŏngjil* occurring away from major population centers at P'ungnap T'osŏng and potentially Palsan for the purpose of social alliances and territorial integration. At the same time, choosing to have *kyŏngjil* rather than *yŏnjil* produced at this distance was closely related to a cultural sense of appropriateness for special things to come from outside the immediate community. This pattern is suggested by the limited data currently available from Mahan settlements, where evidence for strict social classes and centralized leadership is lacking; it becomes starkly visible in the Paekche period, where the same cultural underpinnings of prestige in distance were used by elites to consolidate political control.

Several important similarities and differences in pottery production and use have been identified for the sites of Kwangju Palsan and P'ungnap T'osŏng. A specialized pattern of production for *kyŏngjil* was common to both sites, though at a much larger scale at P'ungnap T'osŏng. The much higher rate of specialized *kyŏngjil* versus generalized *yŏnjil* at the Paekche fortress, as well as the great distance between producer and consumer, provides evidence for how Paekche intensified its craft economy and notions of elite identity to suit the needs of an expansive kingdom. The similarity in consumption patterns at Palsan and P'ungnap T'osŏng, including evidence for non-centralized production of highly valued craft goods and the importance of long-distance trade, suggests a locally articulated form of social complexity based in sensibilities common to both societies.

METHODS

Each sherd in this study was prepared for INAA at the TRIGA reactor at Oregon State University's Radiation Center by removing exterior portions with a tungsten carbide burr, pulverizing approximately 2.5 g of the remaining material, and placing approximately 250 mg of each sample in a vial for neutron bombardment. By placing

samples near the reactor core and irradiating them with extra neutrons, this process creates artificially radioactive isotopes of elements present, whose identity and abundance can be determined precisely from their decay products. A suite of 30 elements was measured through multiple counts of resultant gamma activity over several weeks following irradiation. Element concentrations were determined through comparison with three replicates of a known standard material, NIST1633A (coal fly ash). For more information on irradiation and data protocols at the OSU reactor, see [Minc \(2016\)](#). The full results are available in [Appendix A](#) (aluminum through rubidium) and [Appendix B](#) (cesium through uranium).

INAA is a firmly established method for detecting geochemical variation in archaeological ceramics, but its application to Korean material is fairly novel and presents certain challenges ([Cho 2006](#); [Kwŏn and Kim 2008](#)). Firstly, the differentiation of soil groups is likely to be subtle, as the Korean peninsula is built primarily of granites created in large-scale orogenic events, resulting in similar soil chemistries from sometimes far-flung regions ([Dong et al. 2015](#)). A particular Jurassic granite known as the Daebo formation appears in much of the Mahan/Paekche region, including the areas around Kwangju Palsan and P'ungnap T'osŏng ([Han'guk 2016](#)). Granite, a felsic, intrusive igneous rock, weathers well into clay and tends to be high in silica and potassium, but the frequent presence of granite in the geological landscape can be a homogenizing factor for Korean clays. As seen in [Figure 5](#), the site of Palsan is located on alluvium surrounded by Daebo granite and Precambrian granite gneiss ([Chough 2013](#); [Han'guk 2016](#)), but P'ungnap T'osŏng lies on sedimentary rock with the nearest granite roughly 3 km across the Han River. Therefore, despite the granitic mountain sources of Korean rivers, the clay weathering processes at these two sites likely included mineral contributions from multiple and distinct geological sources, creating a degree of chemical dissimilarity detectable through INAA.

The second major challenge in this study is the lack of comparative materials, either from previous archaeological studies from Korea or the geologically similar Chinese mainland or direct clay samples from the area around the sites. The latter is actively being addressed with further fieldwork, while the former two will simply require continued research along these lines. For this article, the paucity of comparative material means that those groups that can be identified have only each other for context, making the social meaning behind their chemical variation difficult to parse.

Sample size, which is limited by the number of sherds excavators are willing to submit to destructive analysis, presents a third challenge. A sample of 42 sherds was obtained from a single feature at P'ungnap T'osŏng. Pit 170, in the central Kyŏngdang area of the site, has not yet been included in the published site reports, but includes the refuse of ritualized feasting activities. Similar features excavated in the same year, Pits 196 and 206, contained typical Paekche jars, bowls, and cooking pots, as well as a small number of glazewares ([Hansŏng and Hansin 2011](#)). The sherds in this sample are those that remained after more intact pots from Pit 170 had been pieced together, so these sherds were sampled with the primary goal of avoiding the collection of two sherds from the same pot. Each sherd was determined to be visually dissimilar from the others in some way. While this cannot entirely rule out the possibility of cross-sampling, no major concerns were later raised by the INAA results. The sample from Kwangju Palsan is comprised of 30 sherds from 29 different house features. These sherds were collected with the goal of creating an approximately representative sample of Palsan ceramics. This strategy effectively eliminates the possibility that any two sherds originated from the same vessel.

Despite the limitations presented by a relatively high degree of geological uniformity, lack of a comparative dataset, and sampling issues, the INAA data on these 72 sherds were sufficient to distinguish groups using multivariate analysis. The initial detection of groups was done through Principal Components Analysis (PCA), a multivariate method that finds the maximum variation in a dataset when plotted in n -dimensional space, and comparison of these results with bivariate plots of elements. For this analysis, parts per million values for all INAA data were utilized with the exception of the results from neodymium, which were deemed unreliable in this case. As seen in [Figure 2](#), two major groups appear in a plot of the first two principal components (the two greatest axes of variation), and promisingly, membership in either group is strongly correlated with the sherds' site of origin. These distinctions held true through examination of bivariate plots of individual elements and core group membership was then determined (illustrated in [Fig. 2](#), [Fig. 3](#)). A total of 27 sherds were placed into the Hansǒng group (for pottery most likely produced in the Hansǒng Paekche region) and 17 into the Kwangju group (likely originating from producers in and around modern Kwangju). Three sherds from P'ungnap T'osǒng (L09, L25, and L41) fell within the parameters of the Kwangju group, but were not included as core group members, in order to be as conservative as possible given the lack of comparative material. The same was true for two sherds from Palsan (P16 and P28), which were not included as core members of the Hansǒng group despite their chemical similarities.

With the core geochemical groups identified, group membership was rigorously tested and, when possible, remaining sherds were placed in either Hansǒng or Kwangju. Data for each sherd (transformed into $\log_{10}$ values) were tested using Mahalanobis Distance (MD), a measure of distance from a multivariate group centroid that allows the calculation of probability for membership without assuming that each observation (sherd) must belong to a defined group ([Neff 2002](#)). The major limitation of this test is that the number of group members should ideally be several times the number of variables with which the centroid is calculated. Some researchers reduce dimensionality by using Principal Component scores as variables in MD calculation, but this was deemed inappropriate for this dataset as the two groups are only effectively separated by the first principal component and including more components could add noise to the results. Using geochemical data rather than statistical results also reduces mathematical abstraction, our preference as these data are intended as the beginnings of a large comparative collection and the origins of variability are not yet fully understood. The elements used were therefore reduced by stepwise discriminate analysis, resulting in the selection of six elements that represent bulk and trace minerals that best distinguish between the core groups: Al, Na, Sc, Cr, La, and Ta. These results were treated with caution. Though no outliers were found within the core groups, we remain aware that the reduction of variables reduced the likelihood of outlier identification. Using MD results to assign non-core members to groups must also be undertaken with care. In fact, 13 additional sherds tested into the Hansǒng group with $p \geq 0.05$, but several of these were rejected when placed back into full dimensional context in the PCP (Parallel Coordinate Plot) compositional profile analysis below. Eight additional sherds were initially assigned to the Kwangju group, only one of which was later rejected, perhaps indicating a more unified geochemistry for this southern region. MD failed to classify several sherds that appear geochemically consistent with either the Hansǒng or Kwangju group when viewed over the full set of variables. With the present data, the limitations of MD analysis cannot be fully

overcome, but this method has provided a basic check on the core groups as well as initial insights into exchange patterns between these two sites. One sherd from Palsan (P16) could be added to the Hansŏng group and one from P'ungnap T'osŏng (L09) to the Kwangju group on the basis of MD scores.

Further analysis was necessary to refine and expand group membership. Linear Discriminant Analysis (LDA), which uses Mahalanobis distance but attempts to place every observation into a defined group, placed both Palsan sherds suspected to be Hansŏng group members (P16 and P28, discussed above) into that group, and placed the expected three P'ungnap T'osŏng sherds (L09, L25, L41) into Kwangju. The remaining sherds were simply placed in the group corresponding to their site of origin by LDA. The reduction of variables necessary for LDA caused problems as with MD, and so within-group variation was visualized using Parallel Coordinate Plots. PCPs visualize multivariate data by plotting each observation along n parallel lines, making patterns readily apparent (Fig. 4). This technique is well-suited for data with variables at different scales, since PCPs can be generated from parts-per-million values without transformation. The use of PCP visualization to create a compositional profile of each sherd is adapted from the “spider diagram” routinely employed by geologists for evaluating chemical data (Rollinson 2014; see also Minc 2016 and Minc et al. 2016 for their use in archaeological ceramics). As in these studies, elements are ordered and plotted by geochemical group (i.e., major elements, transition metals, alkali elements, rare earth elements, and high field-strength incompatibles).

When visualized in this way, the distinctions between the Hansŏng and Kwangju groups across all 29 elements are easy to detect, and the limitations of PCA, MD, and LDA are mitigated. As shown in Figure 4, the placement of three P'ungnap T'osŏng sherds in the Kwangju group and two Palsan sherds in Hansŏng was confirmed. Importantly, five sherds from P'ungnap T'osŏng and two from Palsan showed little resemblance to other sherds in the dataset and were therefore considered exotic material. Most of these sherds had been placed into a composition group by MD, but with relatively low probabilities of group membership. (The highest, sherd L13, had a $p = 0.154$ association with Hansŏng and $p = 0.015$ with Kwangju, but shows peaks in chromium and cobalt inconsistent with either group.) All other sherds could be made non-core members of Hansŏng or Kwangju, as chemical variations that had excluded them in PCA or MD were relatively minor when viewed in PCP. For example, one P'ungnap T'osŏng sherd, which landed far outside the 95% density ellipse in PCA (see the empty square on the extreme upper right of the graph in Fig. 2), had an extremely high quantity of manganese, an element which tends to occur in discrete concretions, but was an otherwise entirely typical Hansŏng sherd.

The relatively small sample sizes in the current study proved advantageous in PCP analysis, making further distinctions possible within the major composition groups. Three sherds from Palsan showed nearly identical chemical signatures, forming a clear subgroup within the range of Kwangju compositional variation. A group of 16 sherds from P'ungnap T'osŏng showed a strongly cohesive signal, one that matches the PCP of a sample of 32 sherds taken from the contemporaneous kiln complex site of Sansu-ri/Samnyong-ni (Walsh 2017). Discussion of the Sansu-ri assemblage is outside the realm of the current article, but no other multivariate method was able to consistently make this distinction, though the pattern is clear when viewed as compositional profiles in PCP.

The reliability of these tests as applied to Korean ceramic data will only increase as the comparative dataset expands, but at present the use of methods employing either the full or reduced set of variables support each other to enable the formation of geochemical groups.

APPENDIX A. INAA DATA, ALUMINUM THROUGH RUBIDIUM

INAA ID	AL	CA	K	NA	FE	TI	SC	V	CR	MN	CO	ZN	AS	SB	RB
KOR_L01	105774	3603	25555	6342	22701	6223.3	16.61	117.26	126.1	138.48	10.57	93.91	4.24	0.8	161.94
KOR_L02	95512	5511	27147	9501	26456	5318.03	13.52	106.06	85.43	169.37	11.03	70.8	5.47	0.69	136.49
KOR_L03	102849	4157	21031	5915	42311	5920.7	15.58	130.18	90.51	509.15	14.33	64.64	3.7	1.09	133.46
KOR_L04	115886	3885	28279	6420	37888	5532.08	14.45	113.65	78.57	232.75	11.22	108.04	9.26	1.14	169.41
KOR_L05	115983	4836	23751	9827	24945	5955.01	16.46	137.92	95.04	145.86	9.35	60.22	0.88	1.27	144.77
KOR_L06	98448	2971	23880	5766	39529	6015.93	15.34	125.87	107.37	345.31	16.02	78.54	10.11	1.04	135.06
KOR_L07	101596	3942	23468	7207	43814	5697.4	14.13	115.34	76.58	260.28	18.58	67.96	11.79	0.95	138.84
KOR_L08	110016	2251	25800	4114	29385	6374.61	17.09	133.71	133.34	198.34	14.32	115.25	7.38	1.07	156.2
KOR_L09	95089	2718	25346	5421	39774	5890.67	12.65	94.1	75.54	176.88	11.29	73.51	7.65	0.84	151.09
KOR_L10	104989	2879	23813	4470	17985	5943	15.67	104.01	94.65	140.12	6.57	58.63	1.72	0.93	150.62
KOR_L11	102971	8431	23529	10207	31078	5203.81	13.91	101.52	75.49	281.82	8.65	101.01	6.01	0.79	131.51
KOR_L12	100641	5254	23505	7629	51228	5300.77	17.29	137.02	108.75	1224.66	29.44	120.18	9.67	0.88	134.33
KOR_L13	94529	5406	24257	7485	36281	5401.09	15.7	113.08	155.4	292.29	16.42	91.63	12.03	0.69	140.13
KOR_L14	98432	4389	21437	6500	30086	5812.08	17.3	126.88	119.33	272.85	16.83	83.36	5.18	0.94	113.52
KOR_L15	119336	3591	22018	5910	36353	5886.48	18.41	146.58	99.89	175.01	9.66	62.54	3.92	1.45	150.06
KOR_L16	107307	5614	22226	8692	27647	5424.34	15.85	110.4	96.42	327.81	7.73	76.49	5.43	0.65	132.19
KOR_L17	110148	6643	30465	5076	34809	5705.87	16.74	108.07	100.11	314.58	8.87	80.26	6.89	0.41	172.83
KOR_L18	87140	3581	26294	7448	28735	4969.54	13.77	97.34	115.32	165.72	11.87	76.4	3.34	0.73	127.3
KOR_L19	93108	5308	27652	11378	28054	6296.44	15.74	116.91	87.41	294.15	10.44	79.57	4.9	0.73	131.41
KOR_L20	106699	3451	21839	5173	18199	6099.58	17.48	137.19	107.28	143.77	6.82	52.38	3.41	1.21	162.32
KOR_L21	99038	3802	23166	6797	36458	6001	14.39	114.02	84.57	290.52	14.03	74.76	9.25	1.03	134.72
KOR_L22	98018	3717	23415	7984	34364	5463.49	15.54	125.87	88.34	167.69	11.86	62.13	8.54	1.24	140.74
KOR_L23	122918	3846	17761	5598	35099	6166.71	16.65	121.71	81.83	279.28	13.54	84.81	4.09	0.77	128.52
KOR_L24	115299	7604	20950	7766	44135	5209.51	16.32	107.63	74.43	314.76	16.87	141.03	3.62	0.43	135.33
KOR_L25	114139	3196	28554	5759	32483	3518.71	11.21	70.37	55.6	283.43	9.31	100.51	6.04	0.8	201.75

(Continued)

APPENDIX A. (Continued)

INAA ID	AL	CA	K	NA	FE	TI	SC	V	CR	MN	CO	ZN	AS	SB	RB
KOR_L26	130704	2579	16341	5374	27097	6270.9	15.08	114.27	69.26	86.75	8.24	60.92	8.24	0.94	129.51
KOR_L27	98468	3496	18783	7979	22335	5980.18	16.28	134.19	95.81	143.1	7.9	69.75	4.71	1.3	138.34
KOR_L28	94059	3280	23466	6327	32213	5272.48	14.62	118.96	82.79	259.79	13.36	64.75	7.72	1.16	153.81
KOR_L29	104603	3717	22193	6825	35315	4727.06	15.39	102.02	118.64	251.21	11	86.05	4.64	0.75	148.14
KOR_L30	101087	2924	24042	4924	23734	5372.89	14.26	99.32	80.67	133.03	7.44	62.9	5.06	1.08	167.58
KOR_L31	103083	2639	25713	7392	29571	4761.94	14.07	112.27	84.82	133.29	6.92	57.85	9.84	1.16	143.94
KOR_L32	114880	3114	21003	8756	30301	5669.5	15.58	117.71	85.24	197.24	6.72	59.21	6.26	1.14	140.17
KOR_L33	102526	3051	24050	7302	32780	5050.92	15.49	107.73	96.19	138.92	7.77	71.5	10.07	1.14	151.29
KOR_L34	88582	3958	20218	7058	28649	5172.61	14.85	113.29	82.69	127.02	9.72	57.61	7.16	1.09	127.95
KOR_L35	95657	3887	20092	7868	22764	5505.54	16.48	128.68	94.48	135.79	8.17	53.18	4.38	1.16	141.62
KOR_L36	107285	3723	18968	7352	49419	5586.25	15.92	114.03	81.3	655.46	25.3	86.95	10.29	1.06	147.58
KOR_L37	94793	2479	18711	5905	28303	5723.75	15.15	115.81	85.83	143.65	9.29	61.23	6	1.15	130.2
KOR_L38	127064	2966	17823	5481	26569	6476.51	14.71	109.73	67.15	85.7	8.28	58.95	8.05	0.87	124.35
KOR_L39	109466	3863	23166	7620	31793	5567.47	17.12	118.31	107.8	224.97	10.86	69.05	6.27	1.14	150.44
KOR_L40	107150	2235	23834	7745	31340	4873.08	14.81	112.98	91.32	146.96	7.52	61.73	10.48	1.11	153.3
KOR_L41	106269	2867	22249	4534	34826	6655.65	10.26	93.5	52.64	158.19	8.1	76.47	5.58	0.87	145.78
KOR_L42	120678	3885	18756	4807	45312	5565.41	19.41	139.81	105.38	147.05	8.85	62.01	10.51	1.42	156.4
KOR_P01	91752	3026	20407	4886	28063	5295.4	11.25	91.76	73.69	192.77	8.31	66.92	7.05	0.78	103.05
KOR_P02	78727	2120	22833	3548	28161	3950.2	9.45	56.41	81.1	99.77	5.85	51.49	5.9	0.82	117.33
KOR_P03	87645	2793	24275	4107	30597	4515.5	7.84	70.19	64.56	264.2	7.18	75.72	7.69	0.49	122.3
KOR_P04	111310	2579	19040	3819	59350	5783.3	14.85	114.82	146.93	130.38	11.65	77.07	7.72	0.94	139.2
KOR_P05	81769	1437	26883	5212	23218	4689.2	10.62	69.17	70.67	123.25	6.64	58.32	5.4	0.8	134.86
KOR_P06	86256	3049	22394	4476	40723	5073	11.5	91.49	80.94	105.13	5.52	51.56	9.08	0.77	109.85
KOR_P07	89158	1029	18292	2265	37063	5041	10.4	80.9	66.48	132.61	8.45	56.17	5.5	0.89	112.71

(Continued)

APPENDIX A. (Continued)

INAA ID	AL	CA	K	NA	FE	TI	SC	V	CR	MN	CO	ZN	AS	SB	RB
KOR_P08	84670	2370	27355	4595	19670	4768.3	9.74	60.13	77.09	83.5	8.18	80.99	1.79	0.78	115.54
KOR_P09	95844	3062	21793	4133	29646	4780.9	10.1	56.82	44.32	133.66	10.32	78.84	6.26	0.63	117.69
KOR_P10	86092	1715	16695	3163	26069	5024	9.28	76.5	66.98	97.96	6.37	64.55	7.83	0.71	83.82
KOR_P11	95014	1956	24009	4305	27487	4633.8	10.82	104.29	84.34	109.16	3.87	42.84	11.37	0.62	109.07
KOR_P12	92725	1881	16268	4982	29343	5446.9	12.72	100.35	98.41	125.37	8	91.68	6.83	0.75	120.71
KOR_P13	86441	2288	22448	4104	27759	4977.8	9.93	56.4	54.66	73.38	4.91	72.8	7.16	0.64	104.82
KOR_P14	95368	1394	21531	3777	32286	4818.6	9.98	79.61	49.83	96.35	7.42	69.95	7.03	0.72	108.07
KOR_P15	98589	2367	26775	6805	25652	3526.3	10.75	65.38	53.78	152.28	6.91	89.36	5.62	0.66	156.54
KOR_P16	104080	2954	18218	5602	50579	5202.1	15.84	105.03	105.87	255.19	16.86	87.6	8.37	0.67	125.98
KOR_P17	87995	1853	22108	4803	34666	4646.7	9.19	54.1	57.35	137.84	5.71	80.81	9.45	0.71	126.64
KOR_P18	89192	2438	24758	3961	30153	4519.9	7.77	66.9	65.86	238.05	7.13	87.3	6.34	0.57	114.89
KOR_P19	89790	1302	22520	3586	31366	4918.3	10.79	74.33	66.53	291.8	6.59	78.14	5.77	0.84	113.04
KOR_P20	85469	875	25221	4819	38056	4734.2	9.11	70.47	54.4	94.57	5.21	66.57	11.46	0.65	136.71
KOR_P21	86041	2545	19797	3531	36470	4354	8.31	72.12	51.85	151.34	4.36	57.04	8.91	0.82	121.68
KOR_P22	97609	1799	20208	3820	30444	5102.5	11.47	79.39	63.33	146.25	12.92	73.86	2.56	0.77	142.81
KOR_P23	108610	2061	19201	4961	31498	5884.4	14.21	97.51	94.21	106.98	9.24	155.72	7.5	0.84	92.91
KOR_P24	88668	2002	22361	4526	21956	4965	9.42	67.27	94.39	72.47	5.04	62.74	6.49	0.6	116.43
KOR_P25	94788	1176	16101	2923	18747	5061.7	10.34	82.8	67.44	111.4	5.46	50.73	7.77	0.71	100.89
KOR_P26	83347	2263	21200	3751	32703	4959.4	9.63	82.03	80.35	74.16	4.13	41.84	8.27	0.46	110.71
KOR_P27	98561	2063	19419	3539	30808	5244.9	11.1	86.45	68.35	133.38	9.99	81.48	1.45	0.83	143.38
KOR_P28	107050	3169	19233	7854	32292	5953.7	15.54	124.78	97.04	101.08	8.55	61.08	9.12	0.97	112.49
KOR_P29	84858	2159	16444	4154	45760	6124.9	11.85	91.7	80.57	240.46	8.08	69.89	11.76	1	116.56
KOR_P30	100110	2338	20128	3618	29577	4937.8	10.76	85.14	64.87	131.56	9.28	63.9	1.26	0.73	141.25
Normalization Standard	101140	7949	19519	8148	38656	6802.4	15.59	118.25	101.22	271.88	12.05	84.21	7.22	0.81	116.35

APPENDIX B. INAA DATA, CESIUM THROUGH URANIUM

INAA ID	CS	BA	LA	CE	ND	SM	EU	TB	DY	YB	LU	HF	TA	TH	U
KOR_L01	11.25	896.28	73.91	145.17	54.34	10.44	1.88	1.13	6.55	2.94	0.4	9.78	1.48	21.39	5.37
KOR_L02	7.93	1276.87	66.71	127.31	58.31	8.28	1.63	1.04	5.71	2.7	0.42	7.1	1.75	21.64	4.99
KOR_L03	10.98	712.06	48.61	98.15	37.04	8	1.46	1.06	6.4	3.17	0.43	7.17	1.36	17.34	4.32
KOR_L04	10.87	760.15	52.7	104.08	50.62	7.58	1.64	0.93	5.53	2.37	0.37	7.1	1.41	22.07	4.88
KOR_L05	10.66	680.3	63.6	122.76	59.15	10.68	2.13	1.39	8.68	3.98	0.54	6.38	1.37	18.35	4.95
KOR_L06	8.2	673.37	60.44	116.61	55.82	9.67	1.7	1.27	7.24	3.43	0.45	7.89	1.34	19.98	3.94
KOR_L07	9.15	677.71	46.2	94.83	41.19	7.38	1.47	0.95	6.07	3.07	0.42	7.13	1.46	17.86	4.82
KOR_L08	9.36	788.45	53.89	109.93	35.62	8.94	1.71	1.12	7.18	3.52	0.47	7.53	1.53	19.56	4.2
KOR_L09	9.29	656.95	47.17	98.84	41.43	7.31	1.27	1.01	5.02	2.44	0.34	8.2	1.5	18.51	3.97
KOR_L10	10.45	645.9	45.52	95.4	42.76	8.13	1.56	1.02	6.72	3.27	0.46	8.68	1.52	18.91	5.37
KOR_L11	7.08	1289.33	56.26	107.37	43.92	9.1	1.66	1.11	7	3.25	0.52	8.24	1.5	18.76	6.67
KOR_L12	8.23	721.59	60.19	116.07	39.48	9.7	1.72	1.03	6.54	3.5	0.54	6.46	1.18	19.71	3.95
KOR_L13	6.72	1426.27	57.53	114.91	45.7	8.68	1.78	1.01	6.38	2.81	0.44	8.31	1.29	18.87	6.46
KOR_L14	7.92	763.21	51.94	107.54	34.64	8.25	1.58	0.96	6.2	3.06	0.47	7.97	1.23	16.98	3.51
KOR_L15	12.77	572.25	52.34	106.87	41.82	8.92	1.72	1.1	6.82	3.4	0.48	5.79	1.45	19.7	5.08
KOR_L16	8.25	1284.73	47.64	97.12	34.55	7.97	1.59	1.07	6.7	3.26	0.58	5.88	1.39	16.13	4.14
KOR_L17	7.44	1240.22	64.53	119.24	54.88	9.58	1.56	1.07	6.04	2.71	0.41	5.5	1.26	28.12	3.72
KOR_L18	5.95	979.29	49.91	99.13	38.89	7.66	1.42	1.05	6.18	3.41	0.5	7.7	1.3	17.16	3.94
KOR_L19	7.39	884.79	48.45	95.72	34.48	7.2	1.38	1.06	5.43	2.99	0.45	9.72	1.53	18.2	4.52
KOR_L20	11.81	634.66	51.21	108.86	35.36	8.44	1.7	1.19	7.03	3.31	0.56	7.98	1.7	19.05	5.24
KOR_L21	10.22	751.02	49.8	100.58	29.59	8.05	1.58	1.12	6.2	3.3	0.45	8.45	1.49	17.96	4.67
KOR_L22	10.95	651.76	45.67	97.3	28.61	7.75	1.6	0.99	6.17	3.19	0.43	7.74	1.46	17.22	4.63
KOR_L23	11.86	654.29	64.56	124.83	40.16	9.51	2.18	1.26	7.03	3.21	0.45	6.65	1.77	17.71	7.11
KOR_L24	7.84	735.82	65.83	132.33	43.33	9.18	1.93	1.17	6.12	3.06	0.44	8.12	1.24	19.73	6.26
KOR_L25	9.01	711.46	51.4	100.36	44.49	8.52	1.34	0.89	4.77	2.65	0.31	7.29	1.99	19.87	6.01

(Continued)

APPENDIX B. (Continued)

INAA ID	CS	BA	LA	CE	ND	SM	EU	TB	DY	YB	LU	HF	TA	TH	U
KOR_L26	10.48	500.45	67.73	141.68	61.84	10.55	2.14	1.25	7.21	3.21	0.37	5.65	1.47	21.85	5.07
KOR_L27	10.5	621.19	72.14	137.62	56.58	10.65	2.12	1.39	8.42	4.18	0.61	7.89	2.16	18.39	4.97
KOR_L28	9.94	686.3	54.61	102.21	48.65	8.64	1.54	1.05	6.22	3.5	0.55	8.22	1.49	17.62	4.99
KOR_L29	8.35	632.48	47.37	95.33	44.84	7.73	1.55	0.92	5.51	3.01	0.43	6.92	1.12	16.16	3.82
KOR_L30	10.77	707.94	53.07	106.58	34.6	8.41	1.62	0.92	5.61	3.01	0.46	8.21	1.55	18.91	4.66
KOR_L31	9.82	728.53	56.05	98.35	41.11	9.89	1.86	1.09	6.38	3.29	0.48	6.62	1.26	18.88	4.31
KOR_L32	10.75	615.45	56.76	116.86	48.52	9.35	1.76	1.07	6.19	3.32	0.4	8.6	1.44	20.55	5.24
KOR_L33	10.82	699.44	54.06	106.91	61.92	9.61	1.98	1.22	6.31	3.18	0.45	6.99	1.33	20.48	4.1
KOR_L34	10.03	567.84	61.42	116.41	51.69	9.62	1.8	1.12	6.92	3.8	0.56	8.17	1.4	16.89	4.91
KOR_L35	10.64	591.96	72.46	139.32	52.82	10.91	2.12	1.41	8.01	4.04	0.57	7.5	1.46	18.24	4.69
KOR_L36	10.26	597.58	62.62	139.43	54.64	9.48	1.71	1.07	5.92	3.29	0.52	7.57	1.8	20.85	6.19
KOR_L37	10.09	694.55	63.62	117.69	58.19	10.22	1.92	1.25	7.22	3.76	0.55	8.45	1.68	17.61	5.28
KOR_L38	10.75	505.34	68.75	136.12	54.91	10.56	2.14	1.14	6.7	3.28	0.47	5.79	1.44	19.74	5.35
KOR_L39	11.37	658	59.91	120.15	54.32	9.86	1.77	1.31	7.42	3.63	0.51	8	1.65	21.08	4.82
KOR_L40	10.33	736.37	50.36	94.29	49.25	9.2	1.89	1.2	6.67	3.23	0.44	6.76	1.38	17.92	4.19
KOR_L41	8.79	518.94	63.14	113.41	56.56	8.17	1.51	0.94	4.42	2.28	0.32	9.86	1.68	20.73	5.45
KOR_L42	13.32	453.33	49.7	104.42	40.63	8.71	1.65	1.13	5.97	3.34	0.47	5.91	1.45	22.14	5.32
KOR_P01	5.15	808.86	37.91	76.23	24.83	6.1	1.18	0.8	4.32	2.46	0.33	10.33	1.45	14.41	4.55
KOR_P02	5.29	869.65	34.21	68.53	36.46	5.31	1.1	0.61	3.44	1.93	0.25	8.97	1.31	13.65	3.63
KOR_P03	5.06	1292.2	37.04	75.31	25.42	4.7	1.04	0.44	2.79	1.71	0.23	8	0.99	12.53	3.32
KOR_P04	8.98	517.09	45.73	86.58	44.04	6.44	1.21	0.81	4.73	2.62	0.3	8.09	1.47	18.67	4.66
KOR_P05	5.96	1057	35.65	73	31.06	5.58	1.07	0.63	3.78	2.11	0.26	7.27	1.42	16.44	3.71
KOR_P06	4.33	882.35	29.49	64.51	33.25	5.03	1.06	0.73	3.45	2.28	0.26	8.84	1.52	15.36	4.36
KOR_P07	6.6	653.03	27.73	53.77	20.49	4.11	0.72	0.53	2.78	1.78	0.23	8	1.72	14.22	3.93

(Continued)

APPENDIX B. (Continued)

INAA ID	CS	BA	LA	CE	ND	SM	EU	TB	DY	YB	LU	HF	TA	TH	U
KOR_P08	5.43	894.73	32.83	66.36	35.24	4.69	1.12	0.56	3.24	1.96	0.25	8.58	1.34	15.04	3.44
KOR_P09	6.24	876.66	38.69	99.61	37.38	6.15	1.28	0.75	3.76	2.22	0.29	9.68	1.71	16.28	4.87
KOR_P10	2.56	610.32	40.3	81.06	34.54	5.88	1.08	0.66	3.96	2.22	0.3	9.7	1.72	17.3	4.38
KOR_P11	4.8	800.39	42.25	78.73	44.32	6.54	1.24	0.73	4.23	2.48	0.29	7.99	1.37	17.42	4.53
KOR_P12	7.91	820.22	42.4	83.03	35.74	6.23	1.23	0.76	4.25	2.32	0.32	8.02	1.44	16.91	3.92
KOR_P13	5.18	817.54	26.47	60.45	23.23	4.46	0.95	0.53	3.14	1.9	0.2	7.42	1.82	15.24	4.61
KOR_P14	5.31	895.98	27.71	57.84	21.07	4.12	0.89	0.57	3.26	1.77	0.24	7.79	1.45	16.55	3.86
KOR_P15	6.81	783.48	40.67	76.78	33.97	6.03	1.12	0.76	5.17	2.69	0.37	6.23	1.42	16.67	4.46
KOR_P16	7.58	645.98	51.77	101.71	45.9	7.87	1.78	0.97	5.11	2.98	0.37	7.6	1.44	18.09	4.36
KOR_P17	5.44	1014.8	32.91	64.39	28.5	4.28	0.94	0.63	2.94	1.65	0.26	7.8	1.2	12.26	2.69
KOR_P18	5.19	1272.8	40.05	78.46	19.36	4.83	1.08	0.51	3.02	1.75	0.21	7.74	1.03	11.64	3.27
KOR_P19	5.64	1164.6	46.94	84.12	49.01	6.69	1.15	0.73	4.43	2.22	0.35	8.3	1.45	18.71	4.38
KOR_P20	5.16	945.31	49.65	94.41	41.5	6.88	1.23	0.84	4.7	2.37	0.3	8.46	1.69	17.84	3.47
KOR_P21	6.58	718.17	47.66	81.52	32.38	4.82	0.86	0.45	3.15	1.95	0.26	8.23	1.45	15.64	3.26
KOR_P22	8.49	713.75	58.13	131.67	47.41	8.12	1.55	0.93	5.06	2.68	0.33	9.92	1.65	19.22	4.5
KOR_P23	3.12	625.46	38.88	78.04	34.98	6.36	1.15	0.95	4.95	3.08	0.41	10.88	1.67	21.02	4.71
KOR_P24	6.16	970.66	33.67	67.56	26.05	4.8	1.02	0.62	3.31	1.84	0.24	8.89	1.32	15.19	3.25
KOR_P25	5.4	877.83	36.67	88.06	27.04	5.28	0.95	0.6	3.64	2.36	0.34	8.66	1.1	16.74	3.95
KOR_P26	4.62	766.48	26.62	53.86	21.05	4.36	0.89	0.49	2.91	1.98	0.28	8.37	1.36	12.45	3.94
KOR_P27	8.39	543.19	56.8	117.59	42.59	7.91	1.5	0.9	4.69	2.79	0.39	8.37	1.54	19.44	3.98
KOR_P28	6.39	639.46	47.24	97.48	38.88	7.62	1.38	1.09	6.05	3.29	0.48	7.15	1.53	18.88	4.37
KOR_P29	6.62	723.58	30.75	60.68	19.15	4.6	0.89	0.65	3.12	2.18	0.35	8.36	1.4	14.65	4.02
KOR_P30	8.72	640.71	56.61	99.27	37.84	7.92	1.47	0.86	4.71	2.71	0.38	7.95	1.54	19.09	4.19
Normalization Standard	7.07	781.27	48.39	94.60	40.20	7.76	1.66	0.96	5.53	2.92	0.43	7.61	1.70	17.32	4.21

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