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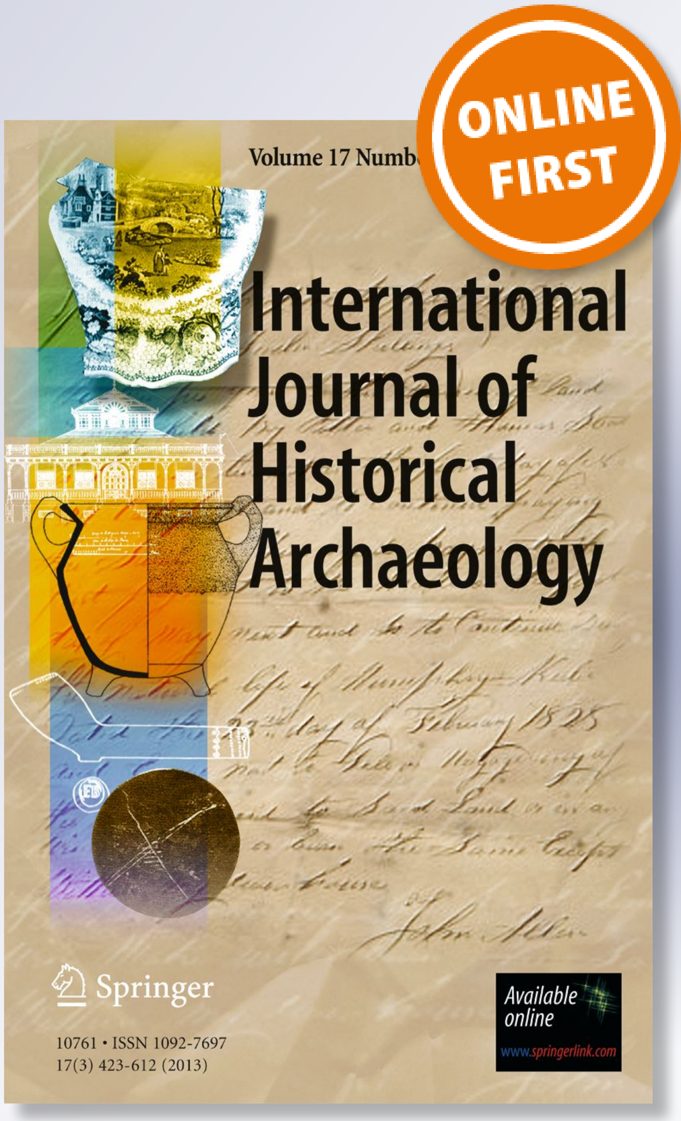

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Seriation Based on Agglomerative Clustering: An Example Using Ceramics Imported to Sulawesi, Indonesia

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Abstract
Similarity coefficients between artifact samples can be used for constructing larger groupings or for seriating the artifact samples. Indeed, these two approaches work well together, because the construction of groupings assists the seriation of the samples within and across groups. Sequentially grouping the samples into a single total sample, through hierarchical analysis of their coefficients, enables the use of these coefficients to seriate the artifact samples in the reverse order of their grouping. If the main point of interest is the composition of the groupings (for instance, as a summary of attribute similarities between artifact samples), seriation is still valuable in providing the hierarchical structure with an overall orientation that would otherwise be lacking. Alternatively, if the main point of interest is the seriated order (for instance, based on patterns of co-occurrences between the artifact samples), grouping analysis provides a structure to the seriation that would otherwise be lacking. Moreover, because we are dealing with samples, these can be subjected to stepwise agglomeration (rather than hierarchical clustering as commonly understood) during the grouping process, and then subjected to reverse-order sequential partitioning during the seriation process. The advantage of using agglomerated samples is that the coefficients between them can be calculated directly rather than derived indirectly from the constituent sample coefficients. How this approach can be applied to the seriation of artifact types is illustrated through a revisited analysis of high-fired ceramics imported to Sulawesi, Indonesia.

Keywords Seriation · Statistical implementation · Indonesia · Trade ceramics · Shipwreck ceramics · Sulawesi archaeology

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Introduction

Seriation Including Grouping

Seriation involves the ordering of items along a single dimension whereby the position of any item relative to the other items reflects its similarity respective to the other items. In archaeology, the dominant interest in seriation has been to order items from earliest to most recent, even if other topics may also be amenable to unidimensional ordering. Chronological seriation works on the principle that, for any artifact type or style, there was a period before it became available, followed by a period of availability with peak popularity at around the middle of this period, followed by a period of disuse (Marquardt 1978).

Graphical implementation of this principle produces the "battleship diagrams" in which artifact types (for instance, pottery types or gravestone styles) successively replaced each other in relative frequency at a group of related sites. Chronological information, which may be relative (for instance, archaeological stratigraphy) and/or absolute (for instance, inscription dates or radiometric determinations), orders the site components from those associated with artifact types whose popularity peaked earliest, continuing through to the site components associated with artifact types whose popularity peaked latest in time (Fagan 1994:89–94).

As a formal improvement over battleship diagrams, numerous approaches have been developed to document statistically the site components that are most dissimilar from each other and the transitional position of the other analyzed site components between the polar extremes (Marquardt 1978). The seriated order is represented by a matrix of coefficients in which the highest coefficients are placed close to the median diagonal of identity (where the item would be compared with itself), and with each step away from the median diagonal the coefficient decreases (Table 1). (If distances rather than coefficients are used, the same logic but turned around is employed, to produce a matrix with the greatest distances at the furthest remove from the median diagonal, and decreasing distance with each step closer to the median diagonal of identity.) In practice, irregularities emerge in the stepwise decrease of the coefficient values away from the median diagonal, and operative decisions need to be made in deciding on the seriated order that best accommodates these irregularities (Irwin 1985:122 ff.).

Cluster analysis can also be employed in seriation. Irwin (1985) employed dendrographs, which are similar to the hierarchical dendrograms customarily produced by within-group cluster analysis, but which additionally order the site components to better reflect their between-group statistical relationships. In practice, the pottery-based dendrographs developed for late prehistoric sites in Papua New Guinea found the correct high-level ordering but were less convincing in determining the lower-level ordering (compare Irwin 1985:Figs. 59 and 62). Marquardt (1978) describes the technique of de la Vega which combines average-linkage clustering with an ordering method derived from a statistically simple seriation algorithm.

In my work along these lines, I have seriated the Operative Taxonomic Units (OTUs, to borrow a term from biological taxonomy) in the reverse order of the sequence in which they were clustered, by availing the matrix of coefficients that had been generated at each clustering step (Fig. 1, left panel). For instance, take the situation in which clustering had arrived at three clusters—A, B1 and B2—and where B1 and B2

Table 1 Robinson coefficients[(a)], unstandardized (top right half-matrix) and standardized (bottom left half-matrix), between ceramic classes[(b)] arranged in their seriated order (Fig. 3)

	QCL	EUR	JPN	QWR	QSW	QBW	SWT	HEX	LBW	MSW	SWR	MBW	EMC	SWH	EFV
QCL	–	0.9	0.9	0.9	0.9	0.9	0.8	0.8	0.7	0.8	0.7	0.7	0.7	0.7	0.6
EUR	1.4	–	0.9	1.0	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7
JPN	1.4	1.4	–	0.9	0.9	0.9	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.6
QWR	1.3	1.4	**1.4**	–	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7
QSW	1.3	1.3	1.3	1.3	–	1.0	0.9	0.8	0.8	0.8	0.8	0.8	0.7	0.7	0.7
QBW	1.3	1.3	1.3	1.3	**1.3**	–	0.9	0.8	0.9	0.9	0.8	0.8	0.8	0.7	0.7
SWT	1.2	1.2	1.2	1.2	1.2	1.2	–	0.9	0.9	0.9	0.9	0.9	0.8	0.8	0.8
HEX	1.1	1.1	1.1	1.1	1.1	1.1	1.2	–	0.9	0.9	0.9	0.9	0.9	0.8	0.8
LBW	1.0	1.1	1.0	1.1	1.1	1.1	1.2	1.2	–	0.9	0.9	0.9	0.9	0.9	0.9
MSW	1.0	1.1	1.1	1.1	1.1	1.1	1.2	1.2	**1.2**	–	0.9	0.9	0.9	0.9	0.9
SWR	0.9	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.1	–	0.9	0.9	0.9	0.9
MBW	1.0	1.0	0.9	1.0	1.0	1.0	1.1	1.1	1.1	1.1	**1.2**	–	0.9	0.9	0.9
EMC	0.9	1.0	0.9	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.2	1.1	–	0.9	0.9
SWH	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.2	–	0.9
EFV	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	–
WNL	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.1	1.1	1.1	1.1	1.2	1.1	1.1	1.1
BLU	0.8	0.8	0.7	0.8	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.1
SUK	0.7	0.7	0.7	0.7	0.8	0.8	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.0
MFV	0.7	0.7	0.6	0.7	0.7	0.7	0.8	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.0
MWH	0.8	0.8	0.8	0.8	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0
VBW	0.9	0.9	0.8	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.1
YMC	0.8	0.9	0.8	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.1
MCL	0.9	0.9	0.8	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.1	1.1	1.0	1.1	1.0

Table 1 (continued)

	QCL	EUR	JPN	QWR	QSW	QBW	SWT	HEX	LBW	MSW	SWR	MBW	EMC	SWH	EFV
SWM	0.8	0.8	0.8	0.8	0.8	0.8	0.9	1.0	1.0	1.0	1.1	1.1	1.0	1.1	1.0
EWH	0.8	0.8	0.7	0.8	0.8	0.8	0.9	1.0	0.9	1.0	1.1	1.1	1.0	1.0	1.0
VMC	0.8	0.8	0.7	0.8	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0
VBL	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.0	0.9	1.0	0.9
EBW	0.8	0.8	0.8	0.8	0.8	0.8	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.1	1.0
SAN	0.7	0.7	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.9	1.0	1.0	0.9	1.0	1.0
JZH	0.6	0.6	0.5	0.6	0.6	0.6	0.7	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9

	WNL	BLU	SUK	MFV	MWH	VBW	YMC	MCL	SWM	EWH	VMC	VBL	EBW	SAN	JZH
QCL	0.7	0.6	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.4
EUR	0.7	0.6	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.4
JPN	0.6	0.5	0.5	0.4	0.5	0.6	0.6	0.6	0.5	0.5	0.5	0.6	0.5	0.4	0.3
QWR	0.7	0.6	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.4
QSW	0.7	0.6	0.5	0.5	0.6	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.4
QBW	0.7	0.6	0.6	0.5	0.6	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.4
SWT	0.8	0.7	0.6	0.6	0.7	0.8	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.6	0.5
HEX	0.8	0.7	0.7	0.6	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.6	0.5
LBW	0.9	0.7	0.7	0.6	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.6	0.5
MSW	0.9	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6
SWR	0.9	0.8	0.7	0.7	0.8	0.9	0.8	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6
MBW	0.9	0.8	0.8	0.7	0.8	0.9	0.8	0.9	0.8	0.8	0.8	0.7	0.8	0.7	0.6
EMC	0.9	0.8	0.8	0.7	0.8	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.8	0.8	0.7
SWH	0.9	0.8	0.8	0.7	0.8	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.7	0.6

Table 1 (continued)

	WNL	BLU	SUK	MFV	MWH	VBW	YMC	MCL	SWM	EWH	VMC	VBL	EBW	SAN	JZH
EFV	0.9	0.8	0.9	0.7	0.8	0.8	0.9	0.8	0.8	0.8	0.8	0.7	0.8	0.7	0.6
WNL	–	0.8	0.8	0.7	0.8	0.9	0.8	0.8	0.8	0.8	0.8	0.7	0.8	0.7	0.6
BLU	1.1	–	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.8	0.8	0.7
SUK	1.0	1.2	–	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.7	0.9	0.8	0.8
MFV	1.0	1.2	**1.2**	–	0.8	0.8	0.8	0.7	0.8	0.7	0.8	0.7	0.8	0.8	0.7
MWH	1.1	1.1	1.2	1.2	–	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.7
VBW	1.1	1.1	1.1	1.1	1.1	–	0.9	0.9	0.9	0.8	0.9	0.8	0.9	0.8	0.7
YMC	1.1	1.1	1.1	1.1	1.1	1.1	–	0.8	0.8	0.8	0.8	0.7	0.8	0.8	0.7
MCL	1.1	1.0	1.0	1.0	1.1	1.1	1.1	–	0.9	0.9	0.9	0.8	0.8	0.8	0.7
SWM	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.2	–	0.9	0.9	0.7	0.8	0.8	0.8
EWH	1.1	1.0	1.1	1.0	1.1	1.1	1.1	1.2	1.2	–	0.9	0.7	0.8	0.8	0.8
VMC	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	**1.2**	–	0.7	0.8	0.8	0.8
VBL	0.9	1.0	1.0	1.0	1.1	1.0	1.0	1.0	1.0	1.0	1.0	–	0.7	0.6	0.5
EBW	1.0	1.1	1.2	1.2	1.1	1.1	1.1	1.0	1.1	1.0	1.1	1.0	–	0.8	0.7
SAN	1.0	1.1	1.2	1.2	1.1	1.0	1.1	1.1	1.1	1.2	1.2	0.9	1.1	–	0.9
JZH	0.9	1.1	1.1	1.1	1.1	1.0	1.0	1.1	1.1	1.2	1.1	0.8	1.0	**1.4**	–

(a) Expressed to one decimal place (see Tables S1.xlsx for expression to three decimal places). Standardized coefficients in bold are those used to combine classes at the first step in the agglomeration exercise

(b) For acronyms, see Table 2

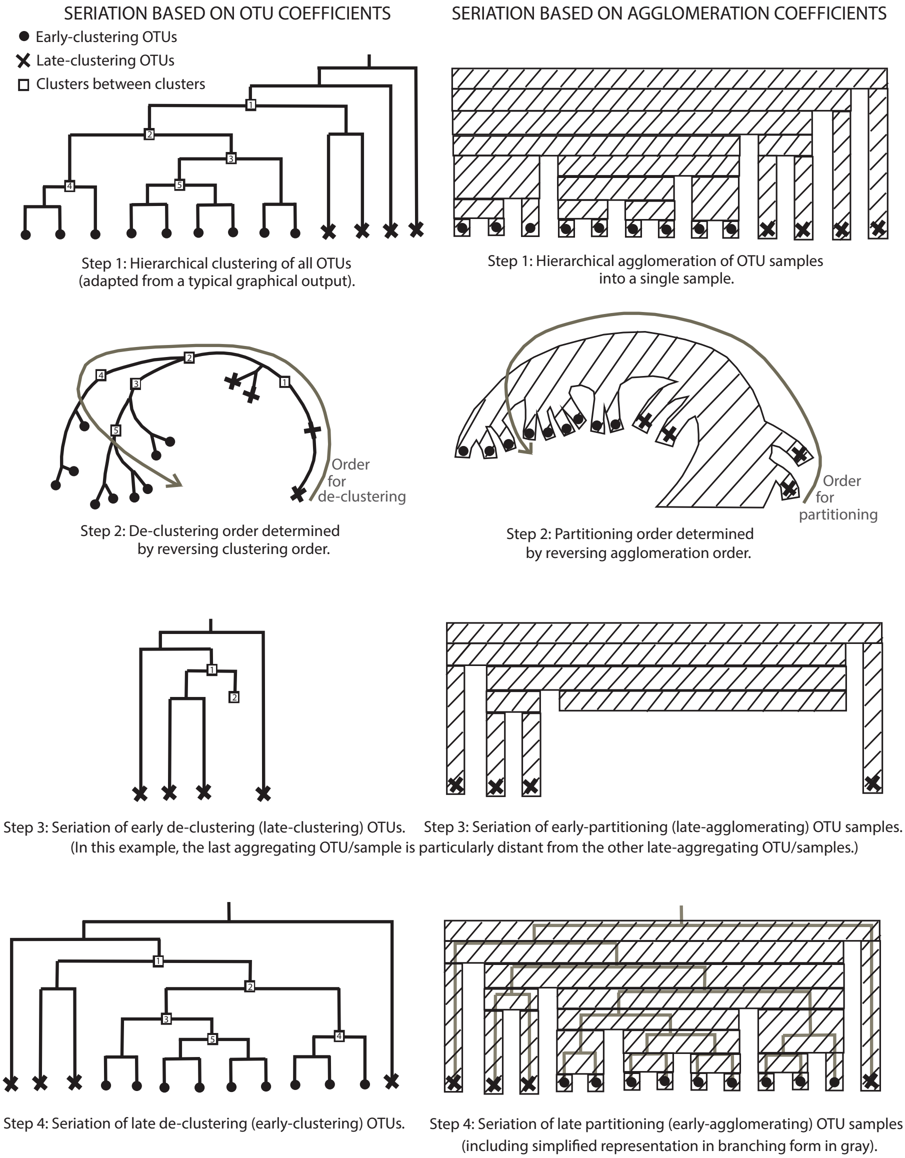


Fig. 1 Seriation based on OTU coefficients (left) compared with seriation based on agglomeration coefficients (right). Note: This hypothetical example shows the same seriated order obtained by both methods, so as to focus on their conceptual differences, but in most cases the two methods would produce different seriated orders

jointed into a B cluster, which then clustered with A. In the corresponding seriation exercise, A and B de-cluster first, followed by the de-clustering between B1 and B2. Now, based on the assumptions that underlie seriation, either B1 or B2 was closer to A in terms of its coefficients, and if it was B1 then the seriated order at this stage would be

A–B1–B2. This process continues until all of the OTUs have been ordered along a single seriation (e.g. Bulbeck 1992: Appendix 1, 2015; Bulbeck and Lauer 2006). While this solution does not guarantee optimization of the final seriation (however this optimization might be measured), it has several benefits. First, it sets the seriation in the context of a cluster-linked structure for the OTUs based on the coefficients between them, and complementarily, it provides an overall orientation to the hierarchical dendrogram. Secondly, even in cases where the primary interest is the composition of the clusters, seriation serves a complementary role in recognizing the ambiguous status of transitional OTUs in terms of their cluster membership. And thirdly, it makes the seriation exercise more tractable by dramatically limiting the number of possible orders in which the OTUs can be seriated, thus avoiding the "traveling salesman" problem discussed by Marquardt (1978).

The OTUs to be seriated can also be artifact types. Deetz's classic seriation of gravestone styles in Massachusetts included documentation of the simplification over time in the Death's Head style (Fagan 1994:Fig. 5.7). Marquardt (1978) presents a seriation analysis of seven automobile makes based on their coefficients for the presence/absence of five attributes, noting that a superior seriation would have been created through a better choice of attributes than those in his example. In my research on trade ceramics imported to Sulawesi, Indonesia, I have dealt with the situation where ceramics with very different attributes were imported at around the same time from distinct sources (Appendix 1), which makes dissimilarities between artifact types of no use as a guide for dissimilarity in age. Accordingly, my approach has been to create "assemblages" for each of the ceramic types by aggregating all of the site components in which that ceramic type was recorded (Bulbeck 1992: Appendix B; see below). While these OTUs correspond to artifact types, for the purpose of seriation analysis they resemble site components, in terms of consisting of co-occurrences of artifact types.

In hierarchical clustering, the coefficients for any cluster compared to other OTUs/clusters are derived from the original coefficients between the OTUs. Methods for deriving these coefficients include average linkage, minimum variance linkage, maximum distance linkage and minimum distance linkage (e.g., Orlóci 1978). A conceptually different approach (Bulbeck 1992: Appendix B), suitable for situations where the OTUs can in some sense be regarded as samples of overarching OTUs, is to treat any OTU grouping as a newly created sample whose coefficients with the other OTUs/samples may not be directly derivable from the initial coefficients (Fig. 1, right panel). For instance, based on Robinson coefficients, Irwin (1985:Fig. 76) found that Mailu period lots C2 and C3 are more similar to each other than any other pair of site components. This finding could be interpreted as suggesting that a Mailu period lot C2/C3 should be recognized, with a sample size that covers the sample sizes of the original C2 and C3 lots, and whose Robinson coefficients with the other lots should be calculated directly rather than indirectly derived. The advantages of this approach are to sequentially increase sample size during the agglomerative clustering process, and to avoid arbitrarily opting for any particular method (such as average linkage) for indirect derivation of coefficients for grouped OTUs. The process is similar to the construction of phylogenetic rather than phenetic trees in paleoanthropology (e.g., Cameron and Groves 2004) in that the trees are not directly derivable from the similarities/differences between the ungrouped taxa (OTUs).

Seriation Example

This contribution revisits the seriation of ceramics imported to Sulawesi, Indonesia (Bulbeck 1992: Appendix B) employing a number of enhancements (see below). Dating of imported ceramics is particularly important for Sulawesi's historical archaeology because they are conspicuous artifacts and a major source of chronological information for many Sulawesi sites. Notwithstanding the abundant literature on the chronology of the ceramic classes imported to Sulawesi in bulk quantities (Appendix 1), at least two confounding factors may complicate the application of general chronological information to dating Sulawesi archaeological sites where these ceramic classes have been identified:

- The ceramic identifications have predominantly been made on shards, sometimes small in size, which may diminish the reliability of the identifications;
- There may have been a lengthy period, even centuries, between when the ceramics were manufactured/shipped and when they were deposited as shards in archaeological sites (Fenner and Bulbeck 2013).

Materials and Methods

Materials

The materials for this study are the 65,498 identifications of high-fired ceramics (stoneware and porcelain) of East Asian, Southeast Asian and European manufacture in archaeological sites in South Sulawesi and northern Southeast Sulawesi (Fig. 2). The ceramics are from collections from the surface or excavated deposits of historical age (circa thirteenth century CE and later). The identifications follow the protocol (Appendix 1) developed by the author in conjunction with the late Karaeng Demmanari, a Makassar (South Sulawesi) expert in high-fired ceramics, and all of the identifications were made by the author and/or Karaeng Demmanari.

Methods

Initial analysis of ceramic data from Sulawesi (Bulbeck 1992:Appendix B) relied on surface collections from the "Makassar survey" and "Soppeng survey" (see Fig. 2) with similarity between ceramic classes measured using the Spearman's Rank Correlation Coefficient. The results can be treated as a "training exercise" for the current exercise, described below.

- The analyzed ceramic assemblages now include survey and excavated collections from the "Luwu project", "Cenrana project", and "Towuti-Routa project", along with various isolated collections reviewed by the author (Fig. 2).
- Collections identified by the author of looted ceramics from known sites are also included.
- As in the training exercise, an "assemblage" for each ceramic class is created by aggregating all of the collections for which that ceramic class is recorded (see Table 2 for examples).

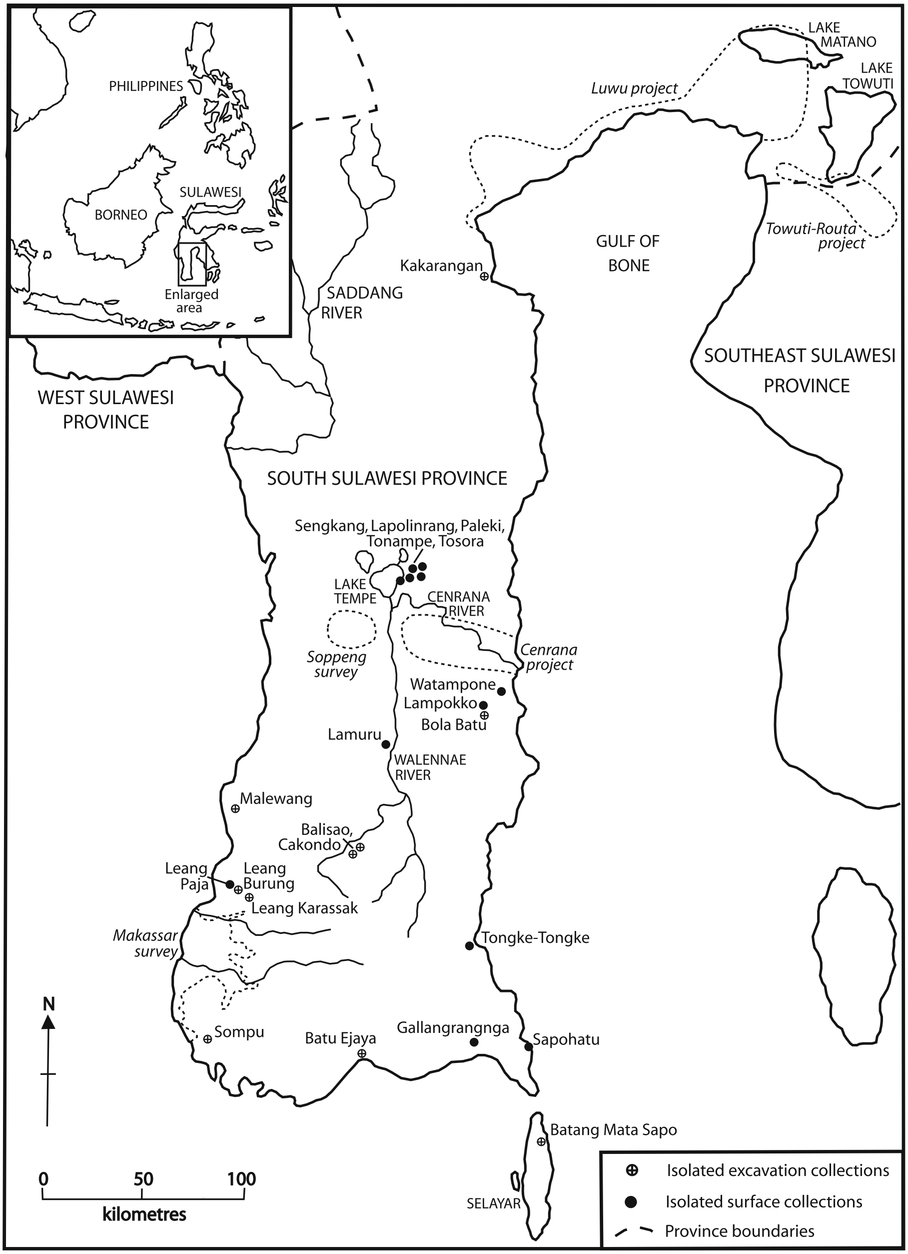


Fig. 2 Distribution of the southern Sulawesi surveys, projects and isolated collections that produced the assemblages of ceramic classes used in this study. Sources: Bulbeck (1992, 1996–7, 2006, unpublished laboratory data); Bulbeck and Caldwell (2000); O'Connor et al. (2014); Bulbeck et al. (2018)

- Developing from the training exercise, any collection with just one ceramic class is aggregated with the spatially closest collection that has at least one case of a different ceramic class (as the analysis is based on finding associations between ceramic classes).

Table 2 Examples of Robinson coefficients (unstandardized) between ceramic classes

Ceramic classes	The 2 classes that share the highest Robinson coefficient		The 2 classes that share the lowest Robinson coefficient	
	QPR assemblage[(a,b)]	EUR assemblage[(a,b)]	JPN assemblage[(a,b)]	JZH assemblage[(a,b)]
Qing celadon (QCL)	317 (0.8%)	345 (0.9%)	221 (1.1%)	4 (0.1%)
European (EUR)	6049 (14.7%)	**6474** (16.5%)	3648 (17.7%)	56 (1.3%)
Japanese (JPN)	649 (1.6%)	669 (1.7%)	**710 (3.4%)**	7 (0.2%)
Qing whiteware/Recent (QPR)	**14,567** (35.3%)	12,968 (33.0%)	7356 (35.6%)	161 (3.6%)
Qing Swatow (QSW)	3090 (7.5%)	2843 (7.2%)	1548 (7.5%)	161 (3.6%)
Qing blue-and-white (QBW)	8839 (21.4%)	8514 (21.7%)	4461 (21.6%)	468 (10.6%)
Swatow (SWT)	2941 (7.1%)	2657 (6.8%)	1106 (5.4%)	593 (13.4%)
Blue-and-white hexagonal (HEX)	59 (0.1%)	49 (0.1%)	22 (0.1%)	4 (0.1%)
Late Ming blue-and-white (LBW)	389 (0.9%)	321 (0.8%)	120 (0.6%)	44 (1.0%)
Ming Swatow (MSW)	1478 (3.6%)	1254 (3.2%)	421 (2.0%)	369 (8.3%)
Coarse stonewares (SWR)	676 (1.6%)	1036 (2.6%)	309 (1.5%)	1024 (23.2%)
Ming blue-and-white (MBW)	828 (2.0%)	785 (2.0%)	217 (1.1%)	619 (14.0%)
Early monochromes (EMC)	222 (0.5%)	183 (0.5%)	83 (0.4%)	63 (1.4%)
Sawankhalok black-and-white (SWH)	151 (0.4%)	133 (0.3%)	60 (0.3%)	27 (0.6%)
Early *famille verte* (EFV)	11 (<0.1%)	9 (<0.1%)	5 (<0.1%)	2 (<0.1%)
Wanli (WNL)	328 (0.8%)	275 (0.7%)	59 (0.3%)	109 (2.5%)
Blueware (BLU)	14 (<0.1%)	11 (<0.1%)	6 (<0.1%)	2 (<0.1%)
Sukothai (SUK)	21 (0.1%)	17 (<0.1%)	5 (<0.1%)	4 (0.1%)
Ming *famille verte* (MFV)	27 (0.1%)	24 (0.1%)	10 (<0.1%)	26 (0.6%)
Ming whiteware (MWH)	33 (0.1%)	38 (0.1%)	11 (0.1%)	38 (0.9%)
Vietnamese blue-and-white (VBW)	134 (0.3%)	139 (0.4%)	43 (0.2%)	140 (3.2%)
Yuan-Ming celadon (YMC)	55 (0.1%)	53 (0.1%)	21 (0.1%)	17 (0.4%)
Ming celadon (MCL)	79 (0.2%)	89 (0.2%)	31 (0.2%)	85 (1.9%)
Sawankhalok monochromes (SWM)	95 (0.2%)	154 (0.4%)	53 (0.3%)	169 (3.8%)
Early whiteware (EWH)	90 (0.2%)	100 (0.3%)	49 (0.2%)	86 (1.9%)
Vietnamese monochromes (VMC)	57 (0.1%)	66 (0.2%)	32 (0.2%)	41 (0.9%)
Vietnamese black-and-white (VBL)	7 (<0.1%)	6 (<0.1%)	4 (<0.1%)	0 (0.0%)
Early blue-and-white (EBW)	14 (<0.1%)	13 (<0.1%)	8 (<0.1%)	2 (<0.1%)
Sancai (SAN)	14 (<0.1%)	18 (<0.1%)	8 (<0.1%)	25 (0.6%)
Jizhou (JZH)	8 (<0.1%)	29 (0.1%)	8 (<0.1%)	**75 (1.7%)**
Total	41,242 (100%)	39,272 (100%)	20,635 (100%)	4421 (100%)
Robinson coefficient	192.6%		64.8%	
As a proportion of unity	0.963		0.324	

(a) QPR assemblage: summary of the ceramic classes found in the collections where QPR was recorded (analogously for EUR, JPN and JZH assemblages)

(b) Ceramic class sample sizes shown bold—the assemblages defined by including any given ceramic class (e.g., QPR) by definition include all of the identifications of that ceramic class

- Improving on the training exercise, the statistical similarity between each pair of ceramic assemblages is measured using Robinson (1951) coefficients, i.e., 200% minus the sum of the percentage differences between these two assemblages. Here the coefficients are divided by 200 so as to represent the coefficients along a scale from 1 (total similarity) to 0 (total dissimilarity). (See Table 2 for examples.)
- Improving on the training exercise, the coefficient between any two assemblages is standardized by dividing this coefficient by the square root of the average coefficients of the two compared assemblages. This produces coefficients where values above 1 indicate greater than average similarity, and values below 1 indicate less than average similarity (see Table 1), and accommodates the fact that the assemblages for better sampled classes have higher coefficients overall than for less well sampled classes. (The use of standardized coefficients is optional, and not intrinsic to the overarching methodology.)
- Akin to the training exercise, at each step in the analysis, any two assemblages (OTU/samples) that share a higher (standardized) coefficient with each other than either shares with any other OTU/sample are agglomerated, and treated as an agglomerated sample in the next step in the analysis.
- Akin to the training exercise, the samples (including agglomerated samples) are sequentially agglomerated until a single sample (here, at a standardized coefficient of 1) is created.
- Akin to the training exercise, the samples are then partitioned in the reverse order of their agglomeration (see Fig. 1, right panel).
- As in one implementation of the training exercise, the partitioned samples are ordered such that each is positioned closer to the other samples (at that partitioning level) with which it has a higher average (standardized) coefficient.

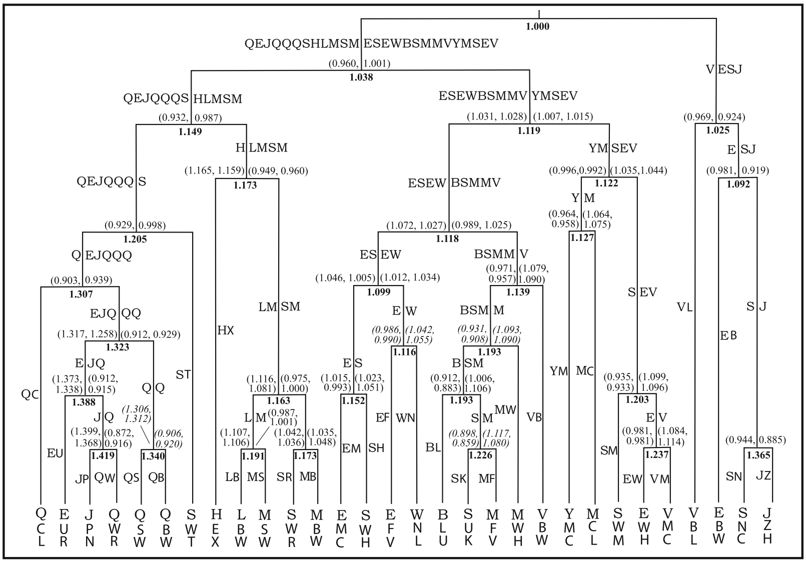
Calculations were undertaken in Excel spreadsheets, which are available from the author on request.

In a nutshell, (1) the ceramic assemblage associated with any ceramic class is found by aggregating all of the surface and excavation collections in which that ceramic class is represented. (2) The coefficient between each pair of classes is calculated from the Robinson coefficient between their ceramic assemblages, standardized by dividing this coefficient by the square root of the average coefficients of the two compared classes. (3) Whenever any two classes have a higher coefficient than either has with any other class, they are agglomerated. (1 reiterated) The ceramic assemblage for any agglomerated class is found by aggregating all of the surface and excavation collections in which any of the ceramic classes in the agglomerated class is represented. Steps 2, 3 and 1 are successively reiterated until all of the ceramic classes are agglomerated, at which point seriation proceeds through partitioning the ceramic classes in the reverse order of their agglomeration (Fig. 3).

Results

Calculation

To assist interpretation of Fig. 3, please note that the ceramic class acronyms along the bottom are represented by two-letter acronyms on the stalks that link them to their



QCL (QC) Qing celadon, C18-19. EUR (EU) European, C19. JPN (JP) Japanese, early C20. QWR (QW) Qing whiteware, C19-20. QSW (QS) Qing Swatow, C17-18. QBW (QB) Qing blue-&-white, C17-19. SWT (ST) Swatow, early C17. HEX (HX) Ming blue-&-white hexagonal ware, C16. LBW (LB) Late Ming blue-&-white, early C17. MSW (MS) Ming Swatow, C16. SWR (SW) Coarse stonewares, C12-19. MBW (MB) Ming blue-&-white, C16. EMC (EM) Early monochromes, C13-14. SWH (SH) Sawankhalok black-&-white, C16. EFV (EF) Early *famille verte*, C13-15. WNL (WN) Wanli, late C16. BLU (BL) Ming blueware, c. 1600. SUK (SK) Sukothai, late C14-15. MFV (MF) Ming *famille verte*, C16. MWH (MW) Ming whitewares, C15. VBW (VB) Vietnamese Ming blue-&-white, C14-15. YMC (YM) Yuan-Ming celadons, C14-15. MCL (MC) Ming celadons, circa 1500. SWM (SM) Sawankhalok monochromes, late C14-C15. EWH (EW) Early whitewares, C13-C14. VMC (VM) Vietnamese monochromes, C14-15. VBL (VI) Vietnamese black-&-white, circa 1400. EBW (EB) Early blue-&-white, circa 1400. SNC (SN) Sancai, C13-14. JZH (JZ) Jizhou, C13-14.

Fig. 3 Seriation of Ceramics imported to southern Sulawesi derived from Agglomerative Clustering

initial agglomeration, and by their first letter in the agglomerated samples. (The term "sample" can apply both to ceramic samples prior to their agglomeration and to agglomerated samples, whereas the term "agglomeration" applies only to the latter.) Also, that the standardized Robinson coefficients shown in bold are those at which the sequential agglomerations occurred.

The final agglomeration combined two high-level agglomerations, a large agglomeration of 26 ceramic classes (QEJQQQSHLMSMESEWBSMMVYMSEV) and a second, small agglomeration of four ceramic classes (VESJ). All of the classes in the second agglomeration are rare, represented by between 16 and 75 identifications. With the two rarest of these classes, VBL and EBW, their agglomerations with SAN and JZH would not have been predicted from the original Robinson coefficients (see Table 1). These agglomerations came to the fore only after all the ceramic classes in the large agglomeration had been agglomerated with at least one other class in that agglomeration. Most of the classes in the large agglomeration are represented by larger samples sizes, up to 14,567 (QPR), although some are represented only by small sample sizes, notably EFV and BLU (respectively, 17 and 21 identifications).

As for the seriation, the initial partition is between the large and the small high-level agglomerations (here, arbitrarily placed respectively to the left and the right). The large agglomeration had resulted from the agglomeration (with a standardized Robinson coefficient of 1.038) of QEJQQQSHLMSM and ESEWBSMMVYMSEV. Accordingly, these partition at the second step in the seriation. Their average standardized Robinson coefficients compared with the small (VESJ) agglomeration are respectively 0.960 and 1.001, and as the ESEWBSMMVYMSEV sample is closer to the small agglomeration it is placed adjacent to it.

At the next step in the seriation, the QEJQQQS and HLMSM agglomerations partition, as do the ESEWBSMMV and YMSEV agglomerations. So too do the VL sample and ESJ agglomeration. HLMSM seriates to the right of QEJQQQS because its average standardized Robinson coefficient (0.987) with ESEWBSMMV, YMSEV,VL and ESJ to the right is the higher. Similarly, VL seriates to the left of ESJ because of the higher, average standardized Robinson coefficient (0.969) of VL with QEJQQQS, HLMSM, ESEWBSMMV and YMSEV to the left. Seriation of the ESEWBSMMV and MSEV agglomerations is more complex because comparisons both to the left and the right should be considered. In this case, ESEWBSMMV is the closer to QEJQQQS and HLMSM to the left (average standardized Robinson coefficient of 1.031), while YMSEV is the closer to the VL and ESJ samples to the right (average standardized Robinson coefficient of 1.015), so the respective left and right seriation of ESEWBSMMV and YMSEV is unproblematic.

However, less straightforward cases may arise where one of the samples would potentially seriate both to the left or the right, as shown in italics in Fig. 3. To take the partitioning of BSMM as an example, compared with the MW sample, the BSM agglomeration has a higher, average standardized Robinson coefficient both with the 7 samples (at this level) to the left (0.931, compared with 0.908) and the 7 samples to the right (1.093, compared with 1.090). In this case, the BSM agglomeration is seriated to the left because the support for this ordering (7 samples * (0.931–0.908) = 0.161) is greater than the support for its seriation to the right (7 samples * (1.093–1.090) = 0.021).

Continuation of the procedures described above leads to the seriation of the 30 ceramic classes presented in Fig. 3.

Chronology

The legend to Fig. 3 includes the suspected datings of the tradeware classes based on the "manufacture central dating" and shipwreck evidence in Appendix 1. The datings reflect an overall transition between more recent classes at the left and older classes at the right, as would be expected of a seriated order. Specifically, from left to right, the QEJQQQS classes date between the seventeenth and twentieth centuries, the HLMSM classes focus on the sixteenth century, the ESEWBSMMV classes date between the thirteenth/fourteenth centuries and circa 1600, the YMSEV classes between the thirteenth/fourteenth centuries and circa 1500, and the VESJ classes between the thirteenth and fifteenth centuries.

However, on drilling down we observe dating anomalies in the seriated order. Notably, the EFV and EMC classes are placed at the left of the ESEWBSMMV agglomeration, and so should be amongst its most recent classes, contradicting their early dating in Appendix 1. In one case, Early *famille verte* (EFV), its small sample size (17 identifications) may be the reason why its supposed thirteenth–fifteenth century dating is not corroborated by the seriation exercise. But in the case of Early monochromes (EMC), lack of confirmation of its expected thirteenth–fourteenth century dating cannot be attributed to small sample size, because the class is represented by a healthy sample of 342 identifications. This particular result suggests that the mooted thirteenth–fourteenth century dating for the identified Early monochrome shards is unreliable. It may be because a substantial proportion of the identifications are incorrect, and/or because Early monochromes were durable ceramics that often remained in use well after their date of production (see Introduction).

As described under Methods, the author previously performed a seriation analysis (training exercise) of the ceramic classes analyzed here, based on a less extensive database and different methodological details. This previous analysis actually involved four variant applications (Bulbeck 1992: Figs. B-1 to B-4) in an attempt to iron out the apparent anomalies that each application produced. Appendix Table 5 compares those results with the results from the present analysis, in the context of the likely ages of the ceramic classes (Appendix 1). Table 3 summarizes these comparisons, which can be further summarized as follows:

- A predominance of confirmation of Bulbeck's (1992) results in the present study
- With respect to these confirmations, precise seriation was better in Bulbeck (1992) for "recent" classes (late seventeenth to twentieth centuries) but better in this study for "Ming" (fifteenth to early seventeenth century) and "early" (thirteenth to fourteenth century) classes
- Correction in the present study of two classes with a Ming seriated age and one class with an early seriated age in Bulbeck (1992)
- In the cases of the Early monochrome and Early *famille verte* classes, failure to confirm their early dating in Bulbeck (1992), but because their early dating may be unreliable (as noted above)
- An overall more satisfactory fit with the ceramic class datings in Appendix Table 4, achieved by the present study than by Bulbeck (1992), due to some combination of a larger database of ceramic collections and an improved seriation methodology.

Table 3 Summary of Appendix 2 comparison of seriated ages for ceramic classes in Bulbeck (1992) and in this study

Ceramic class(es)	Bulbeck 1992	This study	Comment
Six recent classes (late seventeenth to twentieth centuries)	Always most recent	Confirmed	Precise seriation often better in Bulbeck (1992) than in present study
Swatow	Always intermediate between recent and Ming classes	Confirmed	In agreement with ceramic class datings in Appendix Table 4
LBW, MSW, SWR, MBW, SWH, WNL, BLU, MFV, VBW, YMC, MCL, SWM	Always "Ming" (fifteenth to early seventeenth centuries)	Confirmed	Precise seriation often better in present study than in Bulbeck (1992)
Sancai, Jizhou	Always Ming	Early (thirteenth/ fourteenth centuries)	Present study corrects Bulbeck (1992)
Sukothai, Ming whiteware	Usually Ming	Ming status confirmed	Ming dating in present study is correct
Blue-and-white hexagonal	Early	Ming	Present study corrects Bulbeck (1992)
Early monochrome, Early *famille verte*	Early/usually early	Ming	Present study suggests early datings are unreliable
EWH, VMC, VBL, EBW	Early/usually early	Early status confirmed	Early dating in present study is correct

Discussion

Most of the data in this study come from surface collections, which are susceptible to producing noisy associations because there may have been multiple occupancy phases at any site. Ceramics of very different antiquity may be mixed together in a region such as southern Sulawesi where the ground is frequently churned over (for agriculture and construction, as well as grave digging and, regrettably, looting). Limiting the data to excavated collections may have helped reduce the noise but, unfortunately, disturbance of the deposit was often noted by excavators. Further, this would have been at the expense of reducing some of the ceramic classes to very small samples of identifications. Accordingly, the emphasis in this study was to maximize the available sample sizes through a methodology that sequentially agglomerates the samples during analysis, with the intention that the generated signal might overcome the noise.

The aim to maximize sample sizes is also a reason why bootstrapping was not considered. Bootstrapping would have involved drawing random samples for testing this study's solution in Fig. 3, but the results from each of these samples would be less reliable than the Fig. 3 solution. Instead, an appropriate test for the solution in Fig. 3 would be an enlarged database for analysis.

The author is aware of additional ceramic collections from southern Sulawesi excavations and surface surveys, some effectively unreported, and some ready for analysis with appropriate modifications. The latter include the ceramic identifications in Druce (2009), which indeed were made by Karaeng Demmanari, who (along with the author) made the identifications used in this study. Unfortunately, however, these identifications exclude the most frequently recorded class used in this study—Qing whiteware/Recent. Thus, for the present results to be tested by including the data in Druce (2009), and probably the data from some other collections, the seriated order of the Qing whiteware/Recent would not be amenable to testing (and other strategic modifications to the analytical classes would also need to be made).

Conclusions

In cases where the analytical classes can be considered as sub-samples of overarching classes, the samples' clustering can be implemented through reiterative, hierarchical agglomeration interpolated with re-calculation of the coefficients (or distances) between them. This approach maximizes the available sample sizes and also avoids arbitrary decisions on which clustering algorithm to follow. When all of the samples have been agglomerated, they can be seriated by partitioning them in the reverse order of their agglomeration, and positioning together samples that are as close to each other as the structure of the hierarchical agglomeration allows. Application of this approach is illustrated through seriation of classes of high-fired ceramics imported to southern Sulawesi, Indonesia.

Acknowledgments The author thanks the late Karaeng Demmanari for the tuition he provided during the many hours we spent together classifying ceramic sherds from South Sulawesi sites, and Campbell Macknight for his supervision of my PhD research and ongoing support for my interest in high-fired ceramics.

Appendices

Appendix 1 Classes employed in the ceramic analysis

Class	Main characteristics of Sulawesi/Indonesian examples						Shipwreck evidence		
	Fabric	Glaze color	Decorations	Distinguishing features	Manufacture central dating	Reference	Shipwrecks	Shipwreck dates	Reference
Qing celadon	Light gray stoneware	Gray to green	Scarce	Strong transparent glaze	18th–19th centuries	Bulbeck (1992)	Various, e.g. Desaru, Malaysia	c. 1700 to 1900 (Desaru 1830s)	Anon. (2012); Anon. (n.d.)
European	White to light gray stoneware	Clear to cream	Transferware and painted polychromes	Chalky fabric; designs and their production	Nineteenth century	Bulbeck (1992); Harrisson (1995)	Dutch; Scottish	19th–20th centuries	Sukkham (2016)
Japanese	White porcelain & fine stoneware	Clear to light gray	Underglaze blue flowers	Repetitively stamped petal & stamen elements	Early twentieth century	Bulbeck (1992); Fernando and Bulbeck (1992:247)	None documented?	N/A	N/A
Qing whiteware/ Recent	White porcelain	Clear	Rare sketchy overglaze	Featureless glaze clearly shows white body	19th–20th centuries	Bulbeck (1992)	Tuara, Labor, Cannon (Makassar)	Late 18th to early 19th centuries	Fletcher (1999)
Qing Swatow	White porcelain and fine stoneware	Clear or faint green tinge	Underglaze blue and rare overglaze enamels	Fine Qing rendering of "Kraak" ceramics	Late 17th–early 18th centuries	Bulbeck (1992); Rinaldi (1989)	Vung Tau, Vietnam	1680s	Koh (2015a)

Appendix 1 (continued)

Class	Main characteristics of Sulawesi/Indonesian examples						Shipwreck evidence		
	Fabric	Glaze color	Decorations	Distinguishing features	Manufacture central dating	Reference	Shipwrecks	Shipwreck dates	Reference
Qing Blue-and--white	White porcelain and fine stoneware	Clear or faint green tinge	Underglaze blue and rare overglaze enamels	Various distinctive decorative traditions	Late 17th–19th centuries	Bulbeck (1992); Harrisson (1995)	Numerous, e.g., Labor, Pinggang, Tuara, Cannon (Makassar)	Late 17th–19th centuries	Fletcher (1999); Harrisson (1995)
Swatow	Light gray stoneware	Green to gray tinge	Underglaze blue and overglaze enamels	Heavily potted; "composed" Swatow decorations	Seventeenth century	Bulbeck (1992); Crick (2010a)	San Diego, Philippines; Binh Thuan, Vietnam; Witte Leeuw; Batam, Riau	1600–1620	Crick (2010a); Koh (2015b)
Ming				Blue-and-white hexagonal	White and light gray fine stoneware	Faint green tinge	Underglaze blue	Honeycomb lattice of hexagons externally	Sixteenth century
Bulbeck (1992)	Lena, Philippines	Circa 1490	Crick (2010b)						
Late Ming Blue-and--white	White porcelain and light gray fine stoneware	Faint green tinge	Underglaze blue and occasional red overglaze enamels	Transitional Ming-Qing decorations in strong blue tones	Early seven-teenth century	Bulbeck (1992); Harrisson (1995)	Witte Leeuw, South Atlantic	1613	Ketel (2011)
Ming Swatow	Light gray to gray stoneware	Green to gray tinge	Underglaze blue (if not plain)	Crudely potted; "sketchy" Swatow decorations	Sixteenth century	Bulbeck (1992); Crick (2010a)	Belanakan, Java; San Isidro, San Diego, Philippines	Sixteenth century	Koh (2013); (Crick 2010a)

Appendix 1 (continued)

Class	Main characteristics of Sulawesi/Indonesian examples						Shipwreck evidence		
	Fabric	Glaze color	Decorations	Distinguishing features	Manufacture central dating	Reference	Shipwrecks	Shipwreck dates	Reference
Coarse stoneware	Pink, gray and brown stoneware	Brown, gray and black	Incisions and appliqué (if not plain)	Large stoneware jars not classified elsewhere	12th–19th centuries	Bulbeck (1992); Harrisson (1990)	Ubiquitous as accessory cargo component	10th–19th centuries	e.g., Harkantining-sih (2010); Anon. (n.d.)
Ming Blue-and--white	White porcelain and light gray fine stoneware	Faint green tinge	Underglaze blue	Distinctive designs documented in ceramics literature	Late 15th–16th centuries	Bulbeck (1992); Harrisson (1995)	Various, e.g., Ko Samui, Thailand; Lena, Belanakan	Late 15th–16th centuries	Brown (2004); Crick (2010b); Koh (2013)
Early mono--chromes	Light gray stoneware	Gray to green	Rare incisions and notched rims	Rich glazes, conical vessel forms	13th–14th centuries	Bulbeck 1992, 1996–7; Crick 2010c	Various, e.g., Java Sea shipwreck; Turiang (Malaysia)	12th–14th centuries	Sjostrand and Barnes 2001; Niziolek 2015
Sawan-khalok black and white	Light gray stoneware	Green to gray tinge	Underglaze black	Distinctive decorations and vessel forms, speckled fabric	Sixteenth century	Bulbeck 1992; Richards et al. 1984	Various, e.g., Ko Kradat, Thailand	Sixteenth century	Brown 2004
Early *famille verte*	Light gray fine stoneware	Light green to gray	Remnants of overglaze enamels	Rich glazes, underglaze slipping	13th–15th centuries	Bulbeck 1992	None documented?	N/A	N/A
Wanli	Whitish porcelainand	Faint green tinge	Underglaze blue (if not plain)	Silvery blue decorations;	Late 16th–early	Bulbeck 1992; Harrisson 1995	Wanli shipwreck, Malaysia	1620s	Brown and Sjostrand 2002

Appendix 1 (continued)

Class	Main characteristics of Sulawesi/Indonesian examples						Shipwreck evidence		
	Fabric	Glaze color	Decorations	Distinguishing features	Manufacture central dating	Reference	Shipwrecks	Shipwreck dates	Reference
	fine stoneware			small and/or slender vessels	17th centuries				
Blueware	Whitish porcelain	Blue	None	Blue exterior glaze	16th–18th centuries	Bulbeck 1992	Santa Cruz, Phillipines; Hatcher junk, Singapore	Late fifteenth century; 1643	Crick 2010d; Harrisson 1995
Sukothai	Reddish to gray coarse stoneware	Brown to gray tinge	Underglaze black fish & floral designs	Distinctive decorations on slip covering coarse fabric	15th–16th centuries	Bulbeck 1992; Richards et al. 1984	Varous, e.g., Pandanan (Philippines), Turiang	Late 14th–15th centuries	Brown 2004
Ming *famille verte*	Reddish gray stoneware	Faint green tinge	Overglaze red enamels	Standard overglaze floral motifs	Sixteenth century	Bulbeck 1992	Binh Thuan	c. 1608	Christie's Australia 2004
Ming whiteware	Whitish porcelain and fine stoneware	Green or pink tinge	None	Opaque *qingbai*-like glaze	14th–16th centuries	Bulbeck 1992; Crick 2010d	Longquan, Malaysia; Lena, Breaker, Philippines	Fifteenth century	Brown 2004; Crick 2010d, 2010e
Vietnam Blue-and--white	Fine light gray stoneware	Straw-colored tinge	Underglaze blue and/or overglaze enamels	"Proto-porcelain" fabric; Yuan-style de-signs	15th–16th centuries	Bulbeck 1992; Guy 1990	Varous, e.g., Pandanan, Turiang	14th–15th centuries	Brown 2004
Yuan-Ming celadons	Light gray stoneware	Brown to gray green			14th–15th centuries	Bulbeck 1992; Crick 2010c			Brown 2004

Appendix 1 (continued)

Class	Main characteristics of Sulawesi/Indonesian examples						Shipwreck evidence		
	Fabric	Glaze color	Decorations	Distinguishing features	Manufacture central dating	Reference	Shipwrecks	Shipwreck dates	Reference
			Rare molded floral designs and fluting	Fairly rich glazes, "crowded" decorations			Rang Kwien (Thailand), Turiang	Late 14th–early 15th centuries	
Ming celadons	Light gray stoneware	Light grayish green	Incised or molded fluting	Plates, fully glazed, with watery glaze	15th–16th centuries	Bulbeck 1992; Crick 2010c	Song Doc, Vietnam; Lena, Philippines	1490–1500	Brown 2004; Crick 2010f
Sawan-khalok mono--chromes	Light gray stoneware	Green	Vertical fluting, floral or curvilinear impressions	Strongly green transparent glaze, speckled fabric	15th–16th centuries	Bulbeck 1992; Richards et al. 1984	Varous, e.g., Song Doc, Turiang	Late 14th–15th centuries	Brown 2004
Early white wares	Porcelain to fine light gray stoneware	Light green to gray tinge	Curvilinear molding and incisions	Distinctive small vessel forms, rich whitish glaze	13th–14th centuries	Bulbeck 1992; Crick 2010d	Various, e.g. Java Sea shipwreck	12th/thirteenth century	Niziolek 2015; Niziolek et al. 2018
Vietnam mono--chromes	Light gray stoneware	Straw-colored to light gray/brown	Rare vertical fluting and curvilinear incisions	"Proto-porcelain" fabric; vitreous glaze	13th–15th centuries	Bulbeck 1992; Guy 1990	Various, e.g., Pandanan, Turiang	Late 14th–15th centuries	Sjostrand and Barnes 2001; Brown 2004
Vietnam black and white	Fine light gray stoneware	Straw-colored tinge	Underglaze black	Calligraphic designs, "proto--porcelain" fabric	Fourteenth century	Bulbeck 1992; Guy 1990	Rang Kwien, Song Doc, Turiang	Late 14th–early 15th centuries	Sjostrand and Barnes 2001; Brown 2004

Appendix 1 (continued)

Class	Main characteristics of Sulawesi/Indonesian examples						Shipwreck evidence		
	Fabric	Glaze color	Decorations	Distinguishing features	Manufacture central dating	Reference	Shipwrecks	Shipwreck dates	Reference
Early Blu-e--and-white	Fine white to light gray stoneware	Light green to gray tinge	Underglaze blue and/or red	Early white ware-type glaze, 'heaped and piled' dec-orations	14th–early 15th centuries	Bulbeck 1992; Crick 2010e, 2010g	Sinan, Korea (underglaze red); Rang Kwien (underglaze blue)	c. 1323 (Sinan); early fif-teenth centu-ry (Rang Kwien)	Crick 2010g; Miksic 2013
Sancai (late)	Light gray earthen-ware to stoneware	Green, yellow and brown	Glaze colors painted on slipped jars and vases	Vivid polychrome lead-based glazes	13th–14th centuries	Crick 2010f; Bulbeck 1992	None documented?	N/A	N/A
Jizhou (late)	Coarse gray stoneware	Light gray tinge	Underglaze black	Large jars, curvilinear and leaf designs on underglaze slip	13th–14th centuries	Crick 2010f; Bulbeck 1992	Java Sea shipwreck	12th/thirteenth century	Niziolek 2015; Niziolek et al. 2018

Appendix 2 Comparison of seriated ages for ceramic classes in this study and in Bulbeck (1992)

Ceramic classes	Seriated age in this study	Seriated age in Bulbeck (1992: Figs. B-1 to B-4)
Qing celadon (QCL)	Most recent class	Third/fourth most recent class[(a)]
European (EUR)	Second most recent class[(a)]	Second/third most recent class[(a)]
Japanese (JPN)	Third most recent class[(a)]	Second–fourth most recent class[(a)]
Qing whiteware/Recent (QPR)	Fourth most recent class	Most recent class[(a)]
Qing Swatow (QSW)	Fifth most recent class	Sixth most recent class[(a)]
Qing blue-and-white (QBW)	Sixth most recent class	Fifth most recent class[(a)]
Swatow (SWT)	Seventh most recent class[(a)]	Seventh most recent class[(a)]
Blue-and-white hexagonal (HEX)	Most recent of classes with sixteenth C. focus[(a)]	Early/earliest
Late Ming blue-and-white (LBW)	Second most recent of classes with sixteenth C. focus[(a)]	"Ming", otherwise variable
Ming Swatow (MSW)	Central within classes with sixteenth C. focus[(a)]	"Ming", otherwise variable
Coarse stonewares (SWR)	Second earliest of classes with sixteenth C. focus	"Ming", otherwise variable
Ming blue-and-white (MBW)	Earliest of classes with sixteenth C. focus[(a)]	"Ming", usually early Ming
Early monochromes (EMC)	Most recent of c. 1300–1600 classes	Usually early[(a)]
Sawankhalok black-and-white (SWH)	Second most recent of c. 1300–1600 classes[(a)]	"Ming", usually late Ming[(a)]
Early *famille verte* (EFV)	Third most recent of c. 1300–1600 classes	Early/earliest[(a)]
Wanli (WNL)	Central within c. 1300–1600 classes	"Ming", otherwise variable
Blueware (BLU)	Central within c. 1300–1600 classes	"Ming", otherwise highly variable
Sukothai (SUK)	Central within c. 1300–1600 classes[(a)]	Usually "Ming"
Ming *famille verte* (MFV)	Third earliest of c. 1300–1600 classes[(a)]	"Ming", otherwise highly variable
Ming whiteware MWH	Second earliest of c. 1300–1600 classes(a)	Usually "Ming"
Vietnamese blue-and-white (VBW)	Earliest of c. 1300–1600 classes[(a)]	"Ming", otherwise variable
Yuan-Ming celadon (YMC)	Most recent of c. 1300–1500 classes[(a)]	Middle "Ming"
Ming celadon (MCL)	Second most recent of c. 1300–1500 classes[(a)]	"Ming", otherwise variable
Sawankhalok monochromes (SWM)	Central within c. 1300–1500 classes	Middle "Ming""[(a)]
Early whiteware (EWH)	Second earliest of c. 1300–1500 classes[(a)]	Early[(a)]
Vietnamese monochromes (VMC)	Earliest of c. 1300–1500 classes[(a)]	Early/earliest
Vietnamese black-and-white (VBL)	Early[(a)]	Usually early
Early blue-and-white (EBW)	Early[(a)]	Usually early
Sancai (SAN)	Early[(a)]	"Ming", otherwise variable
Jizhou (JZH)	Early[(a)]	Early "Ming"

(a) Seriated age with (equally) best agreement with age indicated in Appendix Table 4 (where assessable)

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