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LARGE-SCALE PRODUCTION OF POTTERY AT GORDION : COMPARISON OF THE LATE BRONZE AND EARLY PHRYGIAN INDUSTRIES

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Abstract : *Analysis of the pottery production technology has suggested large-scale production of pottery in both the Late Bronze Age (1400-1200 BC) and Early Phrygian (ca 950-700 BC) periods at Gordion (Turkey). Chemical characterization of both pottery and local clay samples has defined markedly different patterns of resource use in the two periods, suggesting a different geographic scale in the economy as Gordion's socio-political and economic roles changed from local center to royal capital city.*

Résumé : *L'analyse des moyens de production de la poterie suggère qu'à Gordion (Turquie) la poterie était produite à grande échelle aussi bien au Bronze Récent (1400-1200 av. J.C.) qu'au Phrygien ancien (env. 960-700 av. J.C.). La caractérisation chimique de la poterie et des échantillons d'argile locale a permis de définir clairement différents modes d'utilisation des ressources lors des deux périodes. Ceci serait l'indication que, sur le plan géographique, l'économie de Gordion s'exerce à une échelle différente au B.R. et au Phrygien ancien, ce qui correspondrait au changement que l'on constate sur les plans socio-politique et économique, Gordion laissant son rôle de centre local pour devenir capitale royale.*

Key-words : *Turkey, Gordion, Late Bronze Age, Early Phrygian, Pottery production, Chemical Characterization.*
Mots clefs : *Turquie, Gordion, Bronze Récent, Phrygien Ancien, Production de poterie, Caractérisation minérale.*

INTRODUCTION

Large-scale pottery production may be variously organized depending on the society and economy within which it occurs. Materials, technologies, and culture, each variable in itself, may interact in diverse combinations, yielding distinctive styles of technology for each ceramic industry. Patterns of resource exploitation and workshop distribution will vary. Analyses of pottery production technology (including forming and finishing methods and firing temperatures) and standardization (of vessel forms, sizes, forming and finishing methods) concluded that large-scale ceramic production characterized both the Late Bronze Age (ca 1400-1200 BC) and Early Phrygian period (ca 950-700 BC) at Gordion in central western Turkey[1]. Chemical characterization of ceramics from each industry and local clays has defined significant changes in patterns of resource utilization for pottery production between the Late Bronze Age and Early Phrygian period. These suggest differing geographical scales of economic organization which probably relate to the changing role of Gordion within the valley and region[2].

The ceramic samples chosen for analysis come from well-dated and stratigraphically sealed contexts in the 1988-89 excavations directed by M. M. Voigt. Although pottery samples from the Middle Bronze Age through Late Phrygian periods (1600-330 BC) have been run, only Late Bronze and Early Phrygian data will be discussed here. Clay samples have been collected from the banks of the Sakarya River, the surrounding flood plain, and clay fills within the site itself in order both to begin to define the local clay resources and to attempt to establish links with the ceramics. This sampling strategy allows not only study of ceramic pastes but also tests potential raw material sources and changes in resource exploitation.

1. HENRICKSON, 1993, 1994, 1995a-b, *in prep.*; HENRICKSON and BLACKMAN *in prep*. (a-b).

2. For details, see HENRICKSON, 1993, 1994, 1995a; VOIGT, 1994, *in press*.

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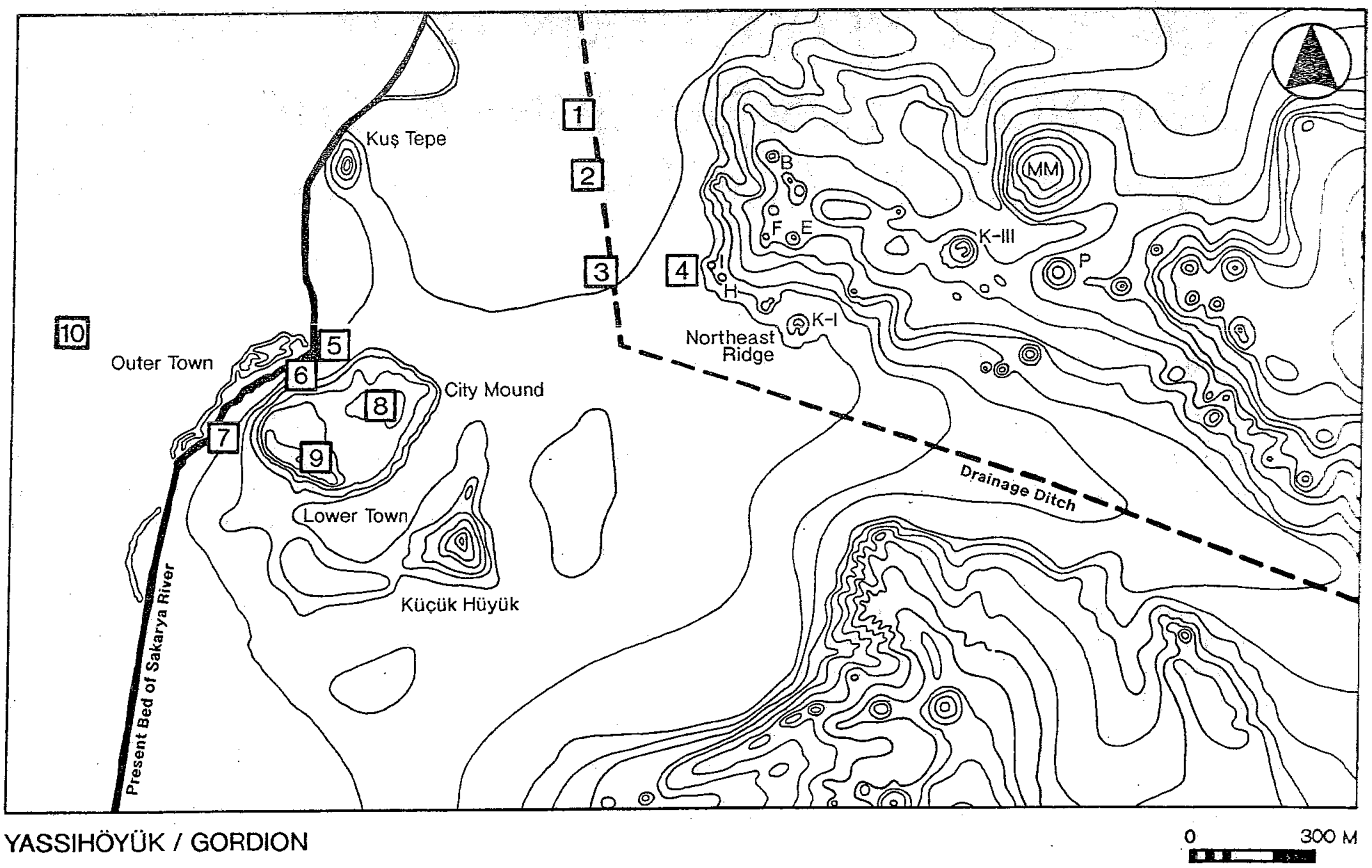

Fig. 1 : *Map of the Gordion area, with sources of pottery and clay samples marked.*
1-3 : Drainage ditch 2 m deep cut through floodplain.
4 : Well drilling, sample from 12-13 m depth.
5-7 : Banks of Sakarya River.
8 : Yassıhöyük Stratigraphic Sequence trenches and Early-Middle Phrygian clay fills in eastern half of City Mound.
9 : Middle Phrygian clay fills in western half of City Mound.
10 : Pottery samples from sounding (Op. 22) in Outer Town.

The following discussion consists of five sections : background on the site, the archaeological sequence, samples, analyses, and interpretation.

GORDION : THE SITE

The site of Yassıhöyük (literally "flat mound") lies on the right bank of the Sakarya River some 20 km west-southwest of the market town of Polatlı in west central Turkey, approximately 100 km southwest of Ankara. The site (fig. 1) consists of a 10-12 ha Citadel Mound, a 10-15 ha Lower Town enclosed by remnants of a fortification system, and a 40-60 ha Outer Town on the opposite bank of the Sakarya River. Identification of the site as Gordion, the capital of the Phrygian kingdom, is based on correlations between information from ancient authors and Yassıhöyük's archaeological sequence and geographical setting, as well as the wealth demonstrated by tumulus burials and the Early Phrygian palace quarter within the Citadel itself[3].

The settlement patterns in the valley exhibit long-term stability, although there is variation in the specific distribution of sites from period to period.

3. VOIGT in press; cf. KÖRTE and KÖRTE, 1904.

The general pattern of settlement location, established in Early Bronze times, remains in effect today. Settlements east of the Sakarya River are concentrated below the 800 m contour on the well-watered lower slopes of the Çile Dag and in the narrow side valleys formed by spring fed streams and torrents flowing westward toward the Sakarya from the mountain. Although water is less abundant, a similar pattern prevails along the Porsuk and its tributaries to the west[4].

ARCHAEOLOGICAL SEQUENCE

HISTORY OF RESEARCH

After the first excavation at Gordion by the Körte brothers in 1900[5], University Museum (University of Pennsylvania) has sponsored excavations and study since 1950, under the direction of R. S. Young (1950-1973), K. DeVries (1973-1987), and G. K. Sams (1987-present)[6]. Since 1988 M. M. Voigt has directed renewed excavations. In 1988-89 the goal was definition of a detailed stratigraphic sequence based on well-stratified artifactual, floral, and faunal samples from the Middle Bronze Age through the late Hellenistic period (ca 1500-150 B.C.). W. M. Sumner initiated an archaeological reconnaissance of regional settlement patterns[7]. Geomorphological survey has concentrated on reconstructing the ancient course of the Sakarya River and dating the alluviation on the valley floor around the site[8].

BASIC CHRONOLOGY

The Yassıhöyük Stratigraphic Sequence (hereafter YHSS) is based on the 1988-89 excavations and provides the foundation for the following discussion. Voigt has divided the archaeological sequence into ten phases, numbered downward from the present mound surface (YHSS 1-10)[9].

Detailed discussions are available elsewhere[10]. Only Late Bronze Age (YHSS 9-8) and Early Phrygian (YHSS 6) periods will be discussed here.

Table 1 : *The Yassıhöyük Stratigraphic Sequence (YHSS).*

YHSS Phase	Period Name	Approximate Dates
1	Medieval	10-12th century AD ?
2	Roman	1st century BC – 3rd century AD
3	Hellenistic	330-180 BC
4	Late Phrygian	550-330 BC
5	Middle Phrygian	700-550 BC
6	Early Phrygian	950-700 BC
7	Early Iron Age	1100-950 BC
8-9	Late Bronze Age	1400-1200 BC
10	Middle Bronze Age	1600(?)-1400 BC

YHSS 9-8 : Late Bronze Age (1400-1200 BC)

Archaeological Contexts. Two major phases were distinguished within the Late Bronze Age (LBA). The earlier, *YHSS 9*, consists of thick sloping trash strata very rich in pottery and bones, covered by an accumulation of more than a meter of clay from the decay of mudbrick structures outside the excavated area. The major features of the later phase, *YHSS 8*, consist of a single structure and pits. A 4 × 7 m rectilinear cellar more than a meter deep had sides lined with drystone walls which probably supported a wooden superstructure. Two large cylindrical pits were cut from a contemporary surface[11].

Pottery. The LBA (YHSS 9-8) assemblages consist of oxidation-fired buff wares, made using calcareous clays (see below). Levigation or crushing was probably used to prepare the clay for the finer fabrics, since common and fine wares are chemically similar (see below).

Table 2 : *Late Bronze Age (YHSS 9-8) Ware Frequencies.*

Ware	YHSS 9 N = 8791	YHSS 8 N = 6365
Buff Common	90 %	87 %
Buff Fine	1	5
Cooking	5	5
Red-Slipped Buff	4	3

4. SAMS and VOIGT, 1989 : 83.
5. KÖRTE and KÖRTE, 1904.
6. YOUNG, 1981; DEVRIES, 1990; GUNTER, 1991; SAMS, 1994.
7. VOIGT, 1994, *in press*; SAMS and VOIGT, 1989 : 82-83, fig. 21; 1994. Excavation and survey since 1993 has concentrated on the form and organization of the city after ca 700 B.C.
8. WILKINSON, 1992; MARSH, 1993, 1994, 1995.
9. VOIGT, 1994, *in press.*
10. VOIGT, 1994, *in press*; HENRICKSON, 1993, 1994, 1995a-b; DEVRIES, 1990; GUNTER, 1991; SAMS, 1994.

11. VOIGT, 1994 : 266-267, Pl. 25.1.2-3, fig. 25.2.1.

Although YHSS 9 pastes tend to be somewhat lighter in color than those of YHSS 8, the assemblages are technologically and typologically very similar. Both were mass-produced, judging from the standardization and homogeneity of wares, methods of manufacture, shapes, vessel sizes within single types, and general simplicity of finish. Small vessels (maximum dimension < 20-25 cm) were often thrown on a potter's wheel, while larger vessels were handformed using a variety of methods and wheel-finished; the largest (maximum dimension > 50-60 cm) were generally coiled. Refiring tests on YHSS 8 sherds indicated an original firing temperature of 800-1000 °C. Potters were probably specialists [12].The pottery from YHSS 9-8 is closely related in both technology and typology to the Hittite assemblage known from the imperial capital at Bogazköy and other Hittite sites [13].

YHSS 7 : Early Iron Age (1100-950 BC)

The transition to the Early Iron Age involved the collapse of the Hittite and other Anatolian states in the late second millennium B.C. and the probable immigration of new peoples, including the Phrygians, into the area [14].

YHSS 6 : Early Phrygian (950-700 BC)

Archaeological Contexts. R. S. Young excavated more than 2 hectares of the royal quarter on the Citadel Mound (YHSS 6A), small areas of the underlying initial Early Phrygian phase (YHSS 6B), and large tumuli [15]. In the smaller YHSS excavations (ca. 250 m^2), the initial phase of the Early Phrygian period, YHSS 6B, consists of a series of courtyard surfaces, intervening fills, and remains of structure within an area of monumental buildings, presumably predecessors of the royal quarter best known from the Destruction Level [16].

The second phase of the Early Phrygian period, YHSS 6A, comprises the architecture, construction fills, and associated artifacts of the Destruction Level, when much of the Citadel Mound architecture burned ca. 700 BC [17]. The YHSS excavations cleared much of the floor of an anteroom (TB2a, 75 m.2) in a row of service buildings associated with the royal quarter [18]. Among the artifacts recovered from the floor of TB2a were approximately 100 vessels, some badly burned, vitrified, or even bloated by intense heat. The vessels range from drinking cups to large storage jars [19]. Other rooms in the same line of buildings had as many as 300 or more vessels on their floors [20].

Pottery. The Early Phrygian assemblage [21] was produced on a large scale, judging from the standardization of shapes, vessel sizes within single types, methods of manufacture, and general simplicity of finish [22]. Clays used tended to be low- or non-calcareous (see below). Grey wares began to dominate as reduction-firing began to replace oxidation-firing during the Early Phrygian period. These YHSS 6B courtyard surfaces and intervening fills yielded typical Early Phrygian grey and painted buff ware sherds, mixed with numerous LBA and EIA sherds. Precise ware frequencies are thus unavailable, but the frequency of grey wares seems to have increased. Fine wares constitute perhaps 5-10 % of the assemblage; painted buff wares are rare [23]. Although none of the forming sequences or shapes are related to those of the Late Bronze assemblage, many small vessels (maximum dimension < 20-25 cm) were thrown, medium-sized ones handformed and usually wheel-finished, and the largest coiled [24].

ANALYTICAL SAMPLES

Both pottery and local clays have been sampled.

POTTERY SAMPLES

All pottery samples have been chosen from clearly defined, sealed, and securely dated stratigraphic contexts which represent relatively brief depositional episodes; most derive from discrete trash deposits on floors or in pits. Usually only general vessel types may be identified since most sherds exported for analysis were body sherds. Sampling concentra-

12. HENRICKSON, 1993 : 103-110, Table 1; 1994 : 104-106; 1995a; *in prep.*; cf. GUNTER, 1991; see VAN DER LEEUW, 1977, PEACOCK, 1982, and COSTIN, 1991 on organization of production.
13. HENRICKSON, 1993 : 103-110, Table 1; 1994 : 104-106; 1995a; cf. MÜLLER-KARPE, 1988.
14. VOIGT, 1994 : 267-268, fig. 25.2.2, 25.3.1, Pl. 25.2.1-4, 25.3.1-4, 25.4.1-2; SAMS, 1994; HENRICKSON, 1993 : 111-122; 1994 : 106-110; HENRICKSON and BLACKMAN, *in prep*(a).
15. For an overview, see SAMS, 1994 : 7-17; DeVRIES, 1990; YOUNG, 1981; KÖRTE and KÖRTE, 1904.
16. VOIGT, 1994 : 268-272, fig. 25.4.3-4; SAMS and VOIGT, 1994 : 370-374, figures 2-7; cf. DeVRIES, 1990 : 372-391.
17. SAMS, 1994 : 2-7, 17-18; DeVRIES, 1990 : 377-391; VOIGT, 1994 : 272-273, fig. 25.4, Pl. 25.5.
18. VOIGT, 1994 : figure 25.1 (area 1).
19. HENRICKSON, 1993; *in prep* (b). Vessels which were severely burned or vitrified were not sampled.
20. DeVRIES, 1990 : 385, 387.
21. Cf. SAMS, 1994.
22. HENRICKSON, 1993, 1994, *in prep.*
23. SAMS, 1994, *passim.*
24. HENRICKSON, 1993 : 123-130; 1995b; *in prep.*

Table 3 : *Numbers of Samples, by Ware and YHSS Phase.*

Phase	No of Samples	Medium-Coarse	Common	Medium-Fine	Fine	Cooking	Other
EARLY PHRYGIAN							
YHSS 6A	57		48	6	3		
YHSS 6B	80	3	45	10	12	1	9
LATE BRONZE							
YHSS 8	71		53		8	10	
YHSS 9	36		36				
Total Samples	244	3	182	16	23	11	9

ted on the predominant ware from each period (Buff Common ware in the Late Bronze Age [YHSS 9-8] and Grey Common ware in the Early Phrygian period [YHSS 6]); running limited numbers of samples from minor wares (Buff Fine and Cooking wares in the LBA and finer grey wares in Early Phrygian levels) have begun to explore the variability among wares within single periods. All samples were prepared by grinding away all surfaces and edges before crushing in a mortar.

CLAY SAMPLES (fig.1)

Both stratigraphically ancient and modern clays were sampled to define the nature of clay resources available and to determine whether changes might have occurred over time. Shrinkage and workability tests confirmed that almost all of the clays sampled were potentially usable for pottery production, even without preparation[25].

River and Flood Plain Samples (fig. 1, areas 1-7). The preliminary findings from geomorphological survey in the area surrounding the site in 1992-1995 indicate that extensive and deep (4 m or more) alluviation has buried the ancient valley floor. Alluvium 1-2 m deep covers *in situ* Phrygian and Hellenistic deposits visible in the present riverbank[26]. The deposits on the floodplain along the river are primarily calcareous grey silts and clays derived from Sakarya River overbank flooding. Between the site and the eastern side of the valley at least 4-6 meters of alluviation consist of reddish fine silty clays which have washed out of the Çekerdeksis side valley from the east. These derive from the weathering of volcanic deposits and tend to be less calcareous.

Given that regional drainage patterns and hard-rock geology have remained unchanged, recently deposited sediments should be similar to those available in antiquity. Samples were therefore collected from the Sakarya River banks and from several localities on the plain (fig. 1). Four samples, however, come from clay deposits probably already *in situ* by the Phrygian era[27].

Clay Samples from Phrygian Construction Fills (fig. 1, areas 7-8). Most clay samples used in this study come from sealed massive construction fills used to create terraces on the City Mound which date to the eighth and seventh centuries BC. They thus provide samples of material available in antiquity. The relatively clean clays and silts making up these fills contain little or no cultural material. They range in color from off-white through greys to brown to red-brown and in texture from clayey to silty.

Two distinct episodes of filling were sampled. The earlier fill was laid to raise and extend a large courtyard as part of an major rebuilding in the Royal Quarter which was cut short by the destruction ending the Early Phrygian period ca. 700 BC[28]. The second fill, far more extensive, marks the beginning of the Middle Phrygian (YHSS 5) rebuilding program, with 1-5 m of clay and silts laid over much of the

25. See also JOHNSTON, 1970 : 35-180.
26. WILKINSON, 1992; MARSH, 1993, 1994, 1995; see also GUNTER, 1991 : 1-3, 109-110, Plan 11.
27. MARSH (personal communication). YHC051 and YHC052 came from just above water level in the Sakarya bank in 1993. Auger boring on the riverbank to a 4 m depth below the 1993 river surface yielded YHC082. A well drilled in 1993 at the eastern edge of the floodplain yielded YHC083 from a depth of 12-13 m below the surface of the plain (figure 1, locus 4).
28. VOIGT, 1994 : 272; SAMS, 1994 : 2-17.

8-10 ha area of the Citadel mound[29]. The remarkable volume, perhaps 100,000-200,000 m^3 or even more, suggests that the material came from near the city. Wilkinson and Marsh have suggested that much is spoil from channelization of the river and related irrigation projects[30].

These clay samples from fills provide critical data on potential 'local' raw materials, available near the settlement, during the Phrygian florescence in the second quarter of the first millennium BC. Adding samples from more recently deposited sediments tests the degree of change in Sakarya River sediments from the first millennium BC to the present day.

Clay Sample Preparation. Preparation and firing temperature have crucial effects on the long-term durability of a ceramic fabric made using calcareous clays. Decomposition of calcium carbonate ($CaCO_3$: limestone, calcite, or shell) into lime (CaO) occurs over a range of temperature, beginning at ± 800 °C and accelerating at 870-900 °C; its pace depends on grain size, purity, and the partial pressure of CO_2. Rehydration of the lime causes expansion, producing cracking, spalling, or disintegration of the ceramic fabric[31].

In order to improve comparability between the clay samples and ceramics, two unaltered lumps (1-2 cm in diameter) of each clay sample were fired for one hour at 650 °C and 850 °C in an oxidizing atmosphere. These bracket the temperature at which carbonate decomposition occurs and represent the range of original firing temperatures for common wares as estimated from refiring experiments[32]. Clay samples were numbered in the form "YHC0nn" when collected; YHC6nn designates the sample after firing at 650 °C, and YHC8nn for 850 °C.

CHEMICAL CHARACTERIZATION OF CLAYS AND CERAMICS

Chemical analysis was carried out by instrumental neutron activation analysis (INAA) in the Smithsonian Institution Conservation Analytical Laboratory's INAA facility, using the

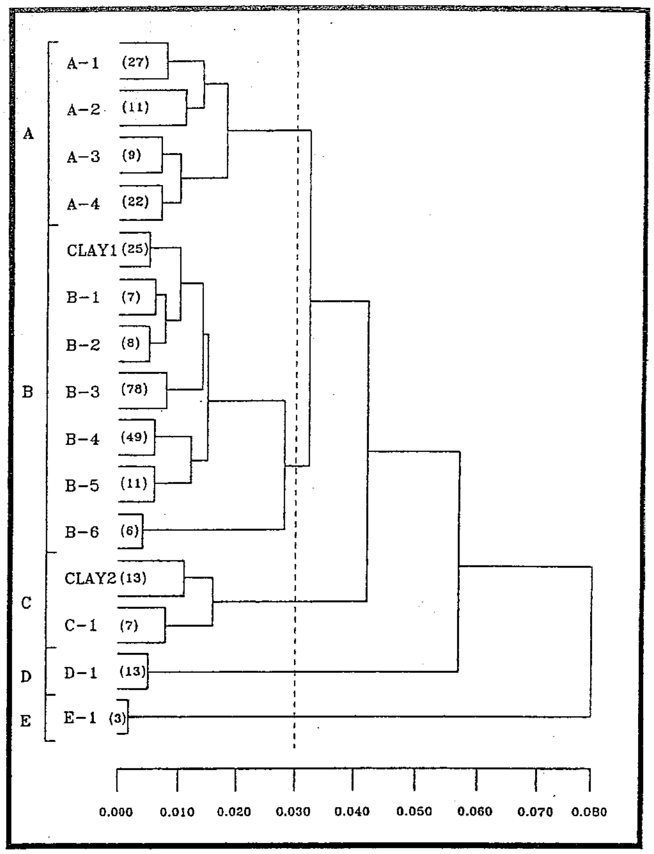

Fig. 2 : *Dendrogram, in skeletal form with outliers omitted, based on nearest neighbor clustering algorithm on a squared mean euclidean distance matrix of 15 elements (K, Sc, Cr, Fe, Co, Rb, Cs, La, Ce, Sm, Eu, Yb, Hf, Ta, Th [see Appendix 1]).*

20 MW NBS Research Reactor at the National Institute of Standards and Technology. The analytical protocol was a modification of that outlined by Blackman[33]. Appendix 1 shows the elements sought and the analytical parameters.

The chemical data for 244 ceramic samples (107 LBA, 137 Early Phrygian), and 62 clay source samples (62 fired at 850 °C and 38 of those also fired at 650 °C) were first processed by cluster analysis using a nearest neighbor clustering algorithm on a squared mean euclidean distance matrix of 15 elements (see Appendix 1). The resulting dendrogram (fig. 2), shown in skeletal form with outliers omitted, consisted of five major clusters, three of which had two or more sub-clusters. The means and coefficients of variation for these

29. DEVRIES, 1990 : 391; VOIGT, 1994 : 273-275, Pl. 25.6.2.
30. WILKINSON, 1992; MARSH, 1994, 1995.
31. RYE, 1976, 1981; BUTTERWORTH, 1956; LAIRD and WORCESTER, 1956. Indeed, carbonate decomposition in a few clay samples and sherds (not LBA) fired in the laboratory at ± 800°C and above was severe enough that they disintegrated in the weeks following firing; for other testing of Gordion clays, see JOHNSTON, 1970 : 35-180.
32. HENRICKSON, 1993 : 103, Table 1; 1994 : 105; cf. TITE and MANIATIS, 1975; TITE *et al.*, 1982; HEIMANN, 1989.
33. BLACKMAN, 1984 : 23-25.

Table 4 : *Summary of Basic Contrasting Characteristics of Chemical Clusters.*

A cluster :	low to undetectable Ca (< 5 %) moderate Cr (150-300 ppm) high REE (La > 45 ppm)
B cluster :	moderate Ca (5-15 %) high Cr (> 200 ppm) low REE (La < 35 ppm)
C cluster :	high Ca (> 15 %) high Cr (> 200 ppm) low REE (La < 25 ppm)
D cluster :	moderate Ca (5-10 %) low Cr (< 70 ppm) high REE (La > 45 ppm)
E cluster :	low Ca (< 3 %) high Cr (> 300 ppm) moderate REE (La 33 ppm)

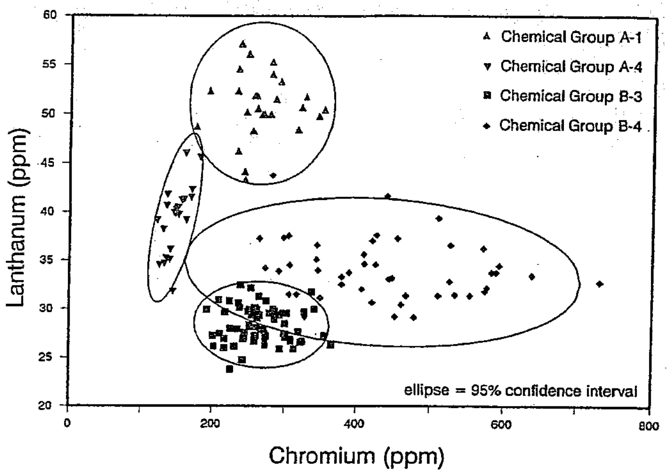

Fig. 3 : *Chromium vs Lanthanum plot illustrating the separation of four major chemical groups (A-1, A-4, B-3, B-4).*

clusters and their associated sub-clusters are presented in Appendix 2. The chemical differences among the clusters are summarized in Table 4.

The statistical validity of the sub-clusters (hereafter "groups") was examined by multivariate statistical analysis using Mahalanobis distance and Hotellings T2 statistic[34]. Using this type of analysis, the groups to be tested must contain at least one more sample than the number of variates (elements) used in the calculation. To avoid inflated probabilities of group membership[35], the number of samples should exceed the number of variables by at least three times. Fourteen elements (cf Appendix 3) were used in the analysis, so only four sub-clusters (A-1, A-4, B-3 and B-4) were directly tested. The results, presented in Appendix 3, verify that the four groups tested are chemically distinct. Bivariate plots of Cr vs La (fig. 3) for these four chemical groups illustrate their distinctiveness.

The remaining clusters and sub-clusters contained too few members to test internally. Each, however, could be compared with the four large chemical groups previously tested. Appendix 4 shows the probabilities of individual members of the smaller groups (A-2, A-3, B-1, B-2, B-5, B-6, and C-1) and clusters (D-1 and E-1) belonging to Groups A-1, A-4, B-3, or B-4. As can be seen, with the exception of group B-5 where most members have high probabilities of belonging to either Group B-3 or B-4, members of all of the other smaller chemical groups display low probabilities of membership in any of the large chemical groups.

Elemental bivariate plots can be used to display the distinctiveness of chemical groups within clusters A-E, while principal components analysis is necessary to show the separation among chemical groups within the clusters. The bivariate plot of La vs Sc (fig. 4) shows the separation of groups C-1, D-1 and E-1 from groups A-1 and B-4. Plots of principal components can be used to illustrate the separation of groups within the two major clusters (A and B) (see Appendix 5 for the principal components upon which the following bivariate plots are based). Figure 5, a plot of principal components 2 and 6, shows the separation of Group A-3, a LBA pottery group, from the two major Early Phrygian groups in this cluster. Figure 6 plots principal components 2 and 9 to show the separation of LBA pottery group B-1 from the two large LBA groups (B-3 and B-4) in the B cluster.

In summary, the statistical analysis confirms the validity of the chemical groups formed in the cluster analysis. These will be used in the following interpretation. Appendix 2 presents the means and coefficients of variation for all elements for each of the groups.

The locations of fired clay samples in the overall clustering provide further data on the interrelationships of the groups

34. SAYRE, 1975.
35. We use the term "probability of group membership" for simplicity. The probabilities cited are, more precisely, the probability that a sample selected at random from a single population will have a Mahalanobis distance from the centroid of that population that is equal to or greater than that calculated. This is the logical equivalent of the likelihood of the sample having been drawn from that population.

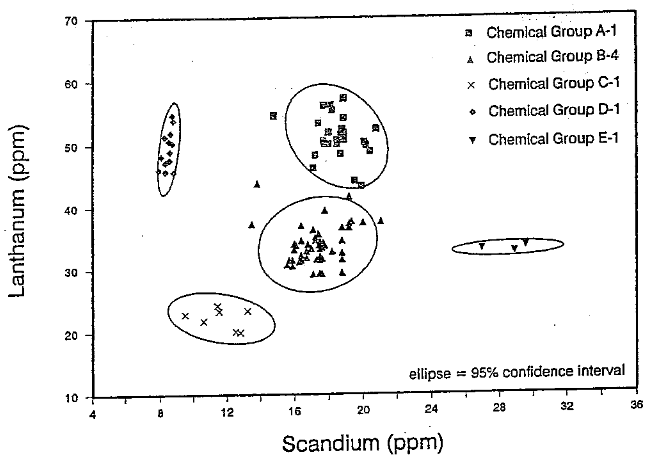

Fig. 4 : *Lanthanum vs Scandium plot illustrating the separation of representative groups belonging to minor clusters (C-1, D-1 and E-1) from groups (A-1 and B-4) in major clusters (A and B).*

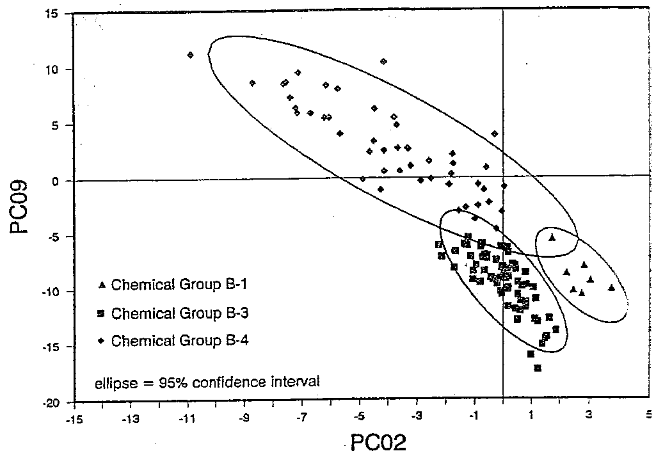

Fig. 6 : *Separation of B-1 (LBA pottery group) from B-3 and B-4 (two large LBA groups) in the B cluster, using principal components 2 and 9 (see Appendix 5); LBA pottery group B-1 is clearly distinguished from the two other large LBA groups (B-3 and B-4).*

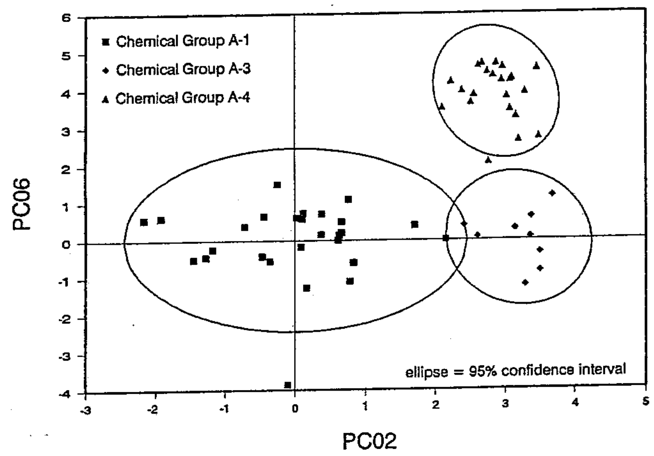

Fig. 5 : *Separation of Group A-3 (LBA pottery group) from the A-1 and A-4 (two major Early Phrygian groups) in the A cluster, using principal components 2 and 6 (see Appendix 5); LBA Group A-3 is clearly distinguished from the two major Early Phrygian groups in Cluster A.*

and clusters. All of the fired clay samples which are not outliers belong to either the B or C cluster. Two groups, one within the B cluster (Clay-1) and one in the C cluster (Clay-2) consist exclusively of fired clays. Other clay samples belong to three groups which also contain ceramic paste samples (Table 5).

Most pairs of low- and high-fired clay samples cluster together within the same group. Sometimes, however, the different firing temperatures had a significant effect on chemical composition. In the case of eight samples, the two firing temperatures split pairs into separate chemical groups.

For example (Table 6), Group B-1 contains six LBA cooking ware and one low-fired clay sample (YHC610). The technological distinctiveness of cooking ware, in clay preparation, forming methods, and low firing temperature, is thus repeated in the clay composition. The related higher-fired clay sample (YHC810) belongs to group B-3, showing the same clay is used for both, with preparation and firing temperature leading to differences in final chemical composition. Clearly all of the groups in clusters B and C which contain members

Table 5 : *Chemical Groups Containing Clay Samples.*

Group	Total Samples (N=)	Clay Samples (N=)	Date of Ceramics
B1	7	1	Only Late Bronze
B3	78	50	Predominantly Late Bronze
C1	7	4	Only Late Bronze
Clay-1	13	13	[None]
Clay-2	11	11	[None]

Table 6 : *High- and Low-Fired Pairs of Clay Samples Split between Chemical Groups.*

Group	YHCnnn Sample		Group
Clay-2	864	864	B3
Clay-2	607	807	B3
Clay-2	608	808	B3
Clay-2	619	819	B3
Clay-2	672	872	B3
Clay-2	678	878	B3
C1	683	883	B3
B1	610	810	B3
Clay-2	656	856	Clay-1

Clay-1 : All samples are clays.
Clay-2 : All samples are clays.
B1 : All ceramic samples are Late Bronze Cooking ware.
B3 : All samples are LBA Buff Common and Fine wares.
C1 : samples are Late Bronze Buff Common ware.

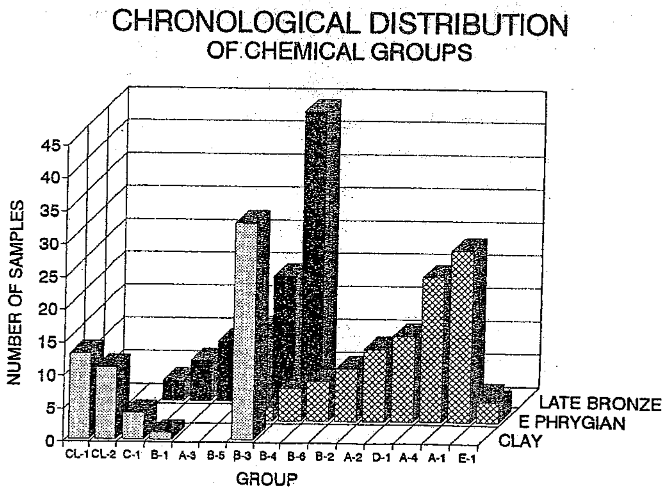

Fig. 7 : *Chronological Distribution of Samples in Chemical Groups.*

of split pairs of fired clay samples are interrelated; their apparent chemical differences are due to differences in firing temperature since all other variables are held constant (Tables 4-6, Appendix 2).

Looking next at the groups from the viewpoint of chronological homogeneity, in most, regardless of size, individual groups tend to be predominantly or exclusively either Late Bronze or Early Phrygian (see fig. 7). Late Bronze dominates in six subclusters (A-3, B-1, B-3, B-4, B-5, C-1). Early Phrygian dominates in seven subclusters (A-1, A-2, A-4, B-2, B-6, D-1, E-1).

Cluster A contains four groups, two exclusively Early Phrygian pottery (A-2 and A-4), one (A-1) almost entirely Early Phrygian (26 of 27, 96 %), and one Late Bronze pottery only (A-3).

Cluster B contains seven groups. Group B-1 consists of Late Bronze pottery and a single fired clay sample. Groups B-2 and B-6 are both Early Phrygian, while B-5 is only Late Bronze. The two largest groups are B-3 and B-4. B-3 is a mixture of fired clays and Late Bronze pottery with a single Early Phrygian sample. B-4 is 90 % Late Bronze pottery and 10 % Early Phrygian pottery. Group Clay-1 consists entirely of fired clay samples.

Cluster C consists of two groups, one exclusively fired clays (Clay-2) and the other (C-1) a mixture of Late Bronze Age pottery and fired clays.

Cluster D (13 samples) and *Cluster E* (3 samples), each contain only Early Phrygian pottery.

These disjunctions indicate that there was relatively little continuity in use of clay resources (fig. 7).

EFFECTS OF TEMPER ON CHEMICAL CHARACTERIZATION OF CLAYS

Although the common wares constituting the core of these analyses by definition have some visible aplastic inclusions, statistical simulations and real world tests indicate that addition of common "tempering" materials, even in large proportions, may but need not substantially affect the compositional data determined by neutron activation analysis[36]. Quartz, for example, simply dilutes chemical concentrations since its composition does not include those elements used for statistical analysis[37].

Our analytical data suggest that aplastic inclusions, whether naturally occurring or intentionally added, had no great impact on chemical compositions. Workability and firing tests of the local clays showed that the clays yield durable fabrics without processing. Various grain sizes seem to be similar

36. NEFF, BISHOP and SAYRE, 1988, 1989.
37. BLACKMAN, 1992; NEFF, BISHOP, and ARNOLD, 1988; BISHOP and NEFF, 1989; ARNOLD, NEFF and BISHOP, 1991.

mineralogically; grain size variation within pastes seems to be related to the degree of natural weathering of the parent material. At least some of the inclusions may be naturally occurring rather than human additions. Fine ware samples included in the analyses show no difference in chemical composition from contemporary common and even coarser wares, falling within clusters defined by the common wares.

ARCHAEOLOGICAL AND CULTURAL INTERPRETATION

BASES FOR INFERENCE OF LOCAL PRODUCTION

Several patterns in clustering of samples provide a basis for inferring local production. In an analytically isolated study such as the present one, it is impossible to *prove* that a given paste is 'imported', since we do not have chemical 'fingerprints' for likely imports. Relatively few chemical characterization studies of pottery have been undertaken in Turkey; none provide data useful to the present study for identification of imports. PIXE analysis of pastes from imported Greek Black Glazed vessels and typical contemporary fine wares assumed to be local demonstrated that the two groups were absolutely distinct[38].

Apparent uniqueness may simply result from having too few comparable samples available to form a statistical cluster. Indeed, successive additions of samples to our database, whether from other periods or simply more from one previously sampled, have tended to integrate some of the former outlier samples into newly formed clusters.

A case for local production may be made in several circumstances. First, when clay and pottery samples both belong within a statistically significant cluster, local production is a reasonable inference. Second, if large clusters emerge, the paste probably represents local production; this inference has more force if the samples in the cluster represent a wide variety of vessel types or common wares rather than just one. Third, in a land-locked setting such as that of Gordion, difficulty of transportation suggests that large and heavy vessels such as large storage jars[39] and large roof tiles (pan tiles > 50 × 50 cm) and terra cotta architectural fittings[40] would likely have been made relatively near to where they were used[41]. Finally, if a statistically significant cluster includes samples from a number of different periods, the paste is likely local. Sustained 'importing' from a non-local source becomes more unlikely with increasing time, cultural diversity, and cultural and economic breaks spanned.

38. WILLIAMS *et al.*, 1987.
39. Unpublished NAA data; HENRICKSON, 1995b; EDWARDS, 1963 : fig. 27-28.
40. E.g., KÖRTE and KÖRTE, 1904 : Abb. 138-149; YOUNG, 1951 : fig. 2; 1953 : fig. 8, 15-16.

ANALYSES OF ANCIENT AND RECENT CLAYS

Chemical analysis by neutron activation, together with geomorphological study, demonstrate that the predominantly buff to grey calcareous clays used in construction fills on the City Mound came from Sakarya River sediments. Given the presence of both archaeological and modern clays within both the Clay-1 and Clay-2 groups, the parent material for the modern sediment load of the Sakarya River has not changed appreciably in the past several thousand years (see below). Thus use of river clays from the area of Gordion, at least downstream to the confluence with the Porsuk Çay (and below that with the Ankara Çay) should be identifiable from before the LBA down to modern times.

The calcareous clays characteristic of the Sakarya (essentially clusters B and C with Clay-1 and Clay-2) reflect the geology upstream along the Sakarya from Gordion[42]. The marked differences in pastes of clusters A, D, and E indicate that other geological backgrounds must be sought. The geological diversity of the region offers several possibilities. The mountains just east of the Sakarya River include extensive volcanic deposits. The red-brown clays washing out of the eastern side-valley derive in part from volcanic strata in the area of Çekerdeksis (see fig. 1). The red-brown clays of the floodplain east of the site, and some of the brown clays of the fills in the site, appear to be a mixture of the volcanic deposits from the eastern side valley and the calcareous river clays. The Porsuk Çay, which flows into the Sakarya from the west ca 4 km downstream from Gordion, and the Ankara Çay, which joins the Sakarya from the east ca 20 km downstream, each flow geologically distinctive regions[43]. In addition, the extensive alluviation may have buried clay sources used in antiquity. Further survey and sampling in the rest of the valley and local region should yield a more complete picture of resources.

41. Samples of terra cotta roof tiles and architectural decorative elements (e.g., gutters and spouts) and oversize storage jars have been run from later periods (essentially all Middle and Late Phrygian [700-330 B.C.]). Since they are neither closely related to the chemical groups discussed here nor contemporary, they have been left aside and will be discussed elsewhere.
42. ERENTÖZ, 1975 : Geological Map of Turkey (Ankara Sheet [1 : 500 000]).
43. WILKINSON, 1992; MARSH, 1993, 1994, 1995; ERENTÖZ, 1975 : Geological Map of Turkey (Ankara Sheet [1 : 500 000]).

YHSS 9-8 : Late Bronze Age (1400-1200 BC)

Almost all LBA ceramics were produced in the area of Gordion, using locally available calcareous clays, given the close statistical similarity of clay and pottery samples. Three of six LBA pottery clusters (B-1, B-3, C-1) contain clay samples; two (B-3, C-1) contain *both* recent river *and* archaeological clays. More than 85 % of all LBA pottery samples fall into just six chemical groups, with most of those belonging to the three largest groups in cluster B (B3, B4, B5); few remain as outliers (fig. 7, Table 7).

Table 7 : *Percentages of Samples Assigned to Chemical Groups, by Period.*

	Late Bronze N = 107	Early Phrygian N = 137
In Chemical Groups	87 %	70 %
Outliers / unassigned	13 %	30 %

The presence of few and large clusters in itself would suggest large-scale local production. The relative homogeneity of the pastes and the standardization of vessels within these large groups also strongly suggests the inference of specialist potters working in a limited number of 'workshops'. Both fine and common ware samples are intermingled within individual clusters. This dovetails with inferences about the organization of production based on typology, metrology, and technology[44].

LBA potters mitigated or circumvented problems due to carbonate decomposition in several ways. Cooking ware, which used a low calcium clay (Group B-1; mean concentration of Ca, 6 %), was fired at a low enough temperature (perhaps < 700 °C) to simply avoid the problem altogether[45]. LBA fine and common wares seem to have been fired at 800-1000 °C. The higher part of the range is sufficient to produce enough vitrification to stabilize the fabric[46]. At these temperatures, reducing the calcium carbonate particle size and achieving an even distribution mitigates or eliminates problems from lime rehydration and expansion. LBA fine ware, by its nature, thus avoided problems. Although limited lime spalling occurs on a small number of LBA common ware sherds but it does not represent a threat to long-term durability[47].

YHSS 6B-A : Early Phrygian (950-700 BC)

The Early Phrygian ceramic pastes yield a pattern markedly different from that of the LBA. First, most Early Phrygian pottery used low- to no-calcium clays (Appendix 2, Groups A-1, A-2, A-4, B-2, B-6, D-1, E-1). The shift to predominantly low- or non-calcareous clays for ceramic production marks a major change in resource exploitation, perhaps due to technological changes such shifting from oxidizing to reducing firing atmospheres (i.e., buff to grey wares). The Early Phrygian pastes samples form more and smaller sub-clusters, leaving many additional triplet, paired, and single outliers (Table 7). Some of the Early Phrygian groups have a relatively tight chronological focus within the period. For example, A-1 consists almost entirely of samples from the YHSS 6B courtyard fills. Most of group A-4 is from the Destruction Level (YHSS 6A). Other groups contain equal proportions of YHSS 6B and 6A.

Table 8 : *Types and Sizes of Vessels From Early Phrygian (YHSS 6A) Terrace Building 2 Anteroom (TB2a) in Chemical Groups.*

Groups	Bowls			Jars			Pots			Totals
Size	S	M	L	S	M	L	S	M	L	
A-1		1			2					3
A-2		1			2			1	1	5
A-4		4	2		9			3	2	20
A					2			1	1	4
B-2					1				1	2
B-4				1				1		2
B-6					3					3
B					2			1	1	4
D					1				1	2
E1							1	1	1	3
E									1	1
NONE				1		1	1		3	6
TOTALS		6	2	2	22	1	2	8	12	55

S : Small (maximum dimension < 20-25 cm).
M : Medium (maximum dimension ± 20-35 cm).
L : Large (maximum dimension > 35 cm).

44. HENRICKSON, 1993, 1994; cf. COSTIN, 1991; STEIN and BLACKMAN, 1993.
45. RYE, 1976; cf. JOHNSTON, 1970.
46. MANIATIS and TITE, 1981; TITE and MANIATIS, 1975a-b; TITE *et al.*, 1982.

47. Some sherds from the YHSS 9 trash deposit have small rounded voids, both at the surface and within the fabric, which seem to result from lime having dissolved away; the acidic nature of the deposit is clear from partially dissolved alabaster artifacts (M. VOIGT and W. MCLAIN : personal communications).

The 55 vessels sampled from the anteroom floor of Terrace Building 2 in YHSS 6A offer a particularly well-controlled corpus. Since none of the vessels has any obvious 'heirloom' value and most are types which would tend to have use-lives measured in years rather than decades[48], essential contemporaneity in date of manufacture is a reasonable assumption. Most of group A-4 (20 of 22 samples) consists of vessels from the YHSS 6A floor, including a variety of sizes and types of vessels, but with a appreciable number of medium-size jugs. The majority of samples, however, scatter into other groups (20 vessels) or remain outliers (13 samples; see Table 8). The heterogeneity of pastes reflects a diversity of raw materials at a 'point in time', with clays ranging from non- to highly calcareous (Table 4, Appendix 2). This suggests at least several sources of raw materials, if not also multiple workshops, within an industry clearly geared toward large-scale production.

LATE BRONZE VS EARLY PHRYGIAN POTTERY PRODUCTION

The Late Bronze Age (1400-1200 BC) regional settlement pattern is clear, although the nature of settlement at Gordion itself remains uncertain since only ca 300 m^2 has been exposed[49].

By the Middle-Late Bronze Age period, some settlements, including Gordion, had evolved into small regional centers. As the settlements increased in both size and number, the regional population, estimated at around 9000, would have approached modern levels[50].

The largest settlements known from surface survey seem to have been no more than 2-3 ha[51]. Stamp seal impressed jar rims and shoulders and stamp seals suggest that Gordion may have been a local center. One sealing includes an unreadable personal name written in Hittite hieroglyphics[52]. Combined with the evidence of the strong typological and technological links to the Hittite heartland ceramic tradition, Gordion seems to have been part of a minor polity within the periphery of the Hittite empire in the third quarter of the second millennium BC[53]. The predominant use of local river clays, available right beside the site, suggests a strongly localized production economy.

After the upheavals of the Early Iron Age (1100-950 BC), the Early Phrygian socioeconomic and political structure of the region differed dramatically from that of the LBA. Gordion became the royal capital of the Phrygian state in the Early Phrygian period (ca 950-700 BC)[54]. During the Phrygian era, settlement patterns within the valley, and region changed markedly : "In Phrygian times there may have been a slight decrease in the village population, but the urban population at Gordion increased dramatically, perhaps reaching 5,000. The regional population is estimated at 13,000, greater than at present. Gordion's large population, and the fact that it served as the king's residence, suggest that it had a rural sustaining area extending well beyond the boundaries of the survey area"[55].

A major Phrygian town/city lies approximately 20 km to the northeast across a single ridge at Haci Tuğrul; at least one large and a number of small tumuli lie along the route between the two sites[56]. The entire regional political and economic organization had changed. This, and technological factors, may contribute to the shift in resource selection.

The limited overlaps between Early Phrygian and LBA ceramic groups (fig. 7) indicate a sharp break with the LBA patterns of resource exploitation and production. Phrygian ceramics were predominantly low to lacking in calcium (detection threshold ± 1 %). Relatively few of the Early Phrygian samples are even outliers in clusters B and C which are derived from the Sakarya. The clay samples from construction fills on the Citadel Mound demonstrate that almost all clays found adjacent to the site in the first millennium BC were calcareous to some degree (> 5 %). The low- to no-calcium clays therefore must come from farther afield. The source of such clays is not clear at present, but clay sampling so far has tested only the area immediately around the site.

Overall, the pattern of resource exploitation demonstrated by the chemical characterization of pottery suggests movement toward a larger regional economy in the Early Phrygian period. The Early Phrygian pottery assemblage need not have been made exclusively at Gordion itself, but likely instead at a number of places elsewhere in the surrounding region, perhaps closer to sources of non-calcareous clays and/or more abundant fuel, given the greatly increased size of the city and

48. Cf. DeBoer, 1974; Longacre, 1985; Nelson, 1991.
49. Voigt, 1994 : 266-267.
50. Sams and Voigt, 1989 : 83.
51. *Ibid.*
52. Güterbock, 1980 : fig. 1-4 and 10, and personal communication to M. Voigt; Henrickson, 1995a : 83; Sams and Voigt, 1990 : fig. 19; cf. Gunter, 1991 : Pl. 24.381 and 29.532.
53. Voigt, 1994; Henrickson, 1993a : 98-111; 1994, 1995a.
54. Voigt, 1994 : 271-273.
55. Sams and Voigt, 1990 : 83; cf. Sumner, 1992.
56. Sumner, 1992; Marsh, 1994.

local population. Since there is no evidence to suggest state control of potters, relative independence similar to that in other regions of the ancient Near East is reasonable[57]. As a royal capital, Gordion would likely have drawn heavily on the surrounding region to support the increased population and central government. The adjacent Sakarya and nearby Porsuk rivers could have facilitated movement of goods.

With the Phrygian shift to an emphasis on grey (reduction fired) wares, technological considerations may also have led to the use of non-calcareous clays. Firing temperatures also seem to have been somewhat lower, since crushing and grinding samples for neutron activation analysis made it abundantly clear that LBA pottery is usually harder than Phrygian.

CONCLUDING REMARKS

The analyses presented here demonstrate marked differences in resource exploitation between two periods which were characterized by similar scales of pottery production. The relatively minor changes in river sediments over the millennia indicate that use of local riverine clays should be identifiable in any period, providing a baseline for ongoing studies of pottery from other periods. Late Bronze Age potters primarily used calcareous river clays, available adjacent to the site. Since the scale of production is disproportionate to the apparent small size of Gordion itself and the other known LBA sites in the region, the potters working around Gordion were likely supplying a number of settlements. This ceramic evidence suggests a modest regional economy whose possible nature and scale ought to be examined using other lines of data[58].

Far more extensive use of low-/non-calcareous clays, which apparently were not available in the immediate vicinity of Gordion, marks the beginning of the Early Phrygian period, accompanying the introduction of new ceramic technologies. The sources of most clays, and the locations of workshops, remain uncertain. In contrast to the more locally circumscribed economy in the LBA, with most pottery produced nearby, the ceramic evidence suggests that the basic economy of Gordion depended on the exploitation of a much wider region during the Early Phrygian period, seen here in the apparently more widespread sources of pottery, as the city became a royal capital and then remained a regional economic center through most of the first millennium BC. Ongoing analyses of other data from the excavations at Gordion should test the social and economic patterns suggested by the ceramic data.

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57. Cf. COSTIN, 1991; STEIN and BLACKMAN, 1993.
58. ZEDER and ARTER, 1994.

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Appendix 1 : *INAA Analytical Parameters.*

Element	Nuclide	Gamma Ray Energy (Kev)	Conc. in Standard SRM 1633[1]	Count[2]	Analytical Precision SRM 679[3]
Na	Na-24	1369	0.32 %	1	2.4 %
K*	K-42	1525	1.61 %	1	5.6 %
Ca	Ca-47	1297	4.70 %	1	n.d.
Sc*	Sc-46	889	27.0 ppm	2	1.9 %
Cr*	Cr-51	320	131. ppm	2	3.0 %
Fe*	Fe-58	1099 & 1292	6.20 %	2	3.1 %
Co*	Co-60	1173 & 1333	41.5 ppm	2	2.1 %
Zn	Zn-65	1115	213. ppm	2	3.7 %
As	As-76	559	61.0 ppm	1	5.8 %
Br	Br-82	554	8.6 ppm	1	27.0 %
Rb*	Rb-86	1077	125. ppm	2	7.3 %
Sr	Sr-85	514	1700. ppm	2	n.d
Zr	Zr-95	757	301. ppm	2	n.d
Sb	Sb-124	1691	6.9 ppm	2	9.9 %
Cs*	Cs-134	796	8.6 ppm	2	2.7 %
Ba	Ba-131	496	2700. ppm	1	12.9 %
La*	La-140	1596	82.0 ppm	1	1.7 %
Ce*	Ce-141	145	146. ppm	2	2.1 %
Nd	Nd-147	91	64.0 ppm	2	11.0 %
Sm*	Sm-153	103	12.9 ppm	1	2.5 %
Eu*	Eu-152	1408	2.5 ppm	2	2.4 %
Tb	Tb-160	879	1.9 ppm	2	13.7 %
Yb*	Yb-169	197	6.4 ppm	2	5.1 %
Lu	Lu-177	208	1.0 ppm	1	6.5 %
Hf*	Hf-181	482	7.9 ppm	2	3.2 %
Ta*	Ta-182	1221	1.8 ppm	2	6.7 %
Th*	Pa-233	312	24.8 ppm	2	2.4 %
U	Np-239	106	11.6 ppm	1	15.7 %
W	W-187	686	5.5 ppm	1	n.d.

n.d. : not determined.
* Elements used in the cluster analysis.
[1] ONDOV *et al.*, 1975, and Certificate of analysis SRMs 1632 and 1633, National Bureau of Standards.
[2] Count 1 : 1 hour after a 5/day decay; count 2 : 2 hours after a 30/day decay.
[3] BLACKMAN, 1986.

Appendix 2 : *Chemical Groups Means and Coefficients of Variations.*

	Na %	K %	Ca %	Sc ppm	Cr ppm	Fe %	Co ppm	Zn ppm	Rb ppm	Cs ppm	Ba ppm	La ppm	Ce ppm	Nd ppm	Sm ppm	Eu ppm	Tb ppm	Yb ppm	Lu ppm	Hf ppm	Ta ppm	Th ppm
Chemical Group A-1 (n = 27)																						
Mean	1.11	2.50	n.d.	18.5	266.	5.24	26.0	101.	156.	9.91	477.	51.1	95.4	36.3	7.22	1.43	0.945	3.40	0.457	6.17	1.36	14.9
c. v.	19.3	9.5		6.7	15.7	5.5	9.0	10.2	11.5	22.0	24.5	6.6	8.2	8.9	6.8	8.6	10.5	10.4	12.2	7.4	10.7	11.2
Chemical Group A-2 (n = 11)																						
Mean	0.694	2.16	n.d.	17.6	148.	5.16	22.1	90.9	122.	6.69	490.	49.8	90.2	36.8	7.21	1.42	0.990	3.49	0.508	6.70	1.46	16.7
c. v.	47.4	9.0		9.3	11.6	8.7	18.3	16.7	22.0	17.0	21.5	13.5	13.9	17.2	13.1	11.5	22.9	26.5	24.3	12.7	10.3	11.8
Chemical Group A-3 (n = 9)																						
Mean	0.827	2.60	6.16	16.6	128.	4.34	20.5	103.	145.	9.71	600.	45.4	79.9	34.3	6.39	1.31	0.910	2.82	0.410	5.28	1.13	14.6
c. v.	27.3	14.0	38.4	14.9	15.6	10.8	18.3	10.2	10.5	12.8	22.0	8.7	8.8	9.4	11.4	12.9	13.8	8.1	11.4	9.8	6.5	6.7
Chemical Group A-4 (n = 22)																						
Mean	0.928	2.51	6.05	14.8	146.	4.40	15.2	78.9	125.	7.33	458.	39.3	70.6	29.6	5.66	1.23	0.751	2.30	0.322	5.07	1.29	10.4
c. v.	33.9	12.4	23.0	11.9	10.4	7.8	11.8	19.7	10.4	14.1	27.3	9.0	10.7	14.6	10.0	8.1	14.3	14.0	13.2	8.6	8.9	9.4
Chemical Group B-1 (n = 7)																						
Mean	1.33	2.57	6.12	12.8	155.	4.17	19.4	91.3	107.	7.12	536.	31.5	55.5	24.0	4.35	1.07	0.635	1.76	0.260	4.32	0.861	9.41
c. v.	15.9	12.4	25.0	7.9	17.8	5.7	12.1	7.5	12.7	9.5	21.3	5.8	7.9	10.5	8.9	7.1	12.0	14.6	24.1	16.2	12.3	9.0
Chemical Group B-2 (n = 8)																						
Mean	1.52	2.21	7.70	13.7	200.	4.19	20.6	94.5	91.7	5.57	595.	38.4	64.2	26.1	4.79	1.13	0.602	1.92	0.257	4.05	1.03	11.7
c. v.	14.6	12.6	22.7	5.2	8.2	4.8	5.5	12.0	4.1	6.3	15.9	9.3	7.2	7.5	5.2	6.0	15.5	15.0	16.6	19.3	14.0	4.9
Chemical Group B-3 (n = 78)																						
Mean	0.838	2.20	13.9	14.2	272.	4.03	22.3	83.7	98.0	11.6	367.	28.5	49.9	20.8	4.19	0.970	0.610	1.95	0.281	3.67	0.936	8.27
c. v.	28.4	17.7	24.2	18.0	17.5	16.3	16.3	19.2	13.4	21.8	21.8	7.2	7.7	17.1	8.7	10.3	14.5	10.1	15.0	12.2	10.4	11.9
Chemical Group B-4 (n = 49)																						
Mean	0.966	2.36	7.46	17.3	429.	4.89	27.9	101.	114.	7.38	371.	33.8	58.5	24.3	4.73	1.11	0.685	2.13	0.303	3.99	1.07	11.3
c. v.	12.5	10.1	22.7	8.6	26.1	7.3	8.6	10.7	11.6	11.3	31.0	8.2	7.7	12.4	8.5	7.5	13.8	10.6	16.4	9.1	13.0	10.8
Chemical Group B-5 (n = 11)																						
Mean	0.890	2.32	9.34	15.0	357.	4.36	24.6	88.3	97.1	5.88	371.	26.5	46.7	20.0	3.94	0.950	0.622	1.75	0.238	3.30	0.962	8.13
c. v.	18.1	8.4	13.4	9.9	27.4	10.9	11.6	6.8	11.2	17.8	26.4	5.3	5.2	7.7	4.7	5.8	21.6	3.7	10.4	5.0	8.9	6.1
Chemical Group B-6 (n = 6)																						
Mean	1.28	1.54	9.67	13.1	322.	4.14	26.6	73.4	64.6	3.36	454.	31.8	58.4	23.1	4.31	1.03	0.622	1.83	0.230	3.52	0.881	7.69
c. v.	11.6	6.7	18.5	6.9	12.0	5.7	6.3	17.4	19.4	7.7	25.2	8.2	5.6	17.3	6.1	7.5	11.9	7.1	9.1	4.5	8.1	6.0
Chemical Group C-1 (n = 7)																						
Mean	0.635	1.93	15.8	11.6	281.	3.30	19.3	75.5	81.2	8.91	380.	22.3	39.1	15.9	3.27	0.740	0.492	1.71	0.235	2.67	0.735	7.25
c. v.	20.7	16.9	16.7	11.2	25.5	11.0	11.9	10.3	12.1	12.2	17.6	7.6	8.0	15.9	5.0	7.6	15.9	20.5	28.7	11.4	11.3	7.9
Chemical Group D-1 (n = 13)																						
Mean	2.01	2.38	5.75	8.50	62.0	2.89	9.60	91.0	118.	6.64	698.	49.4	83.5	33.3	5.89	1.26	0.699	2.23	0.286	6.04	0.888	15.8
c. v.	10.1	9.2	34.4	3.3	8.9	4.2	8.4	39.7	9.1	7.4	24.7	6.0	5.7	7.6	5.1	7.3	8.1	13.8	13.8	7.2	7.4	6.4
Chemical Group E-1 (n = 3)																						
Mean	2.01	1.76	2.22	28.5	324.	8.80	47.9	135.	66.8	3.25	n.d.	33.1	64.0	27.8	6.46	1.89	0.853	2.06	0.274	5.58	2.39	5.55
c. v.	8.2	4.7	42.0	4.7	10.7	3.3	6.2	17.1	5.5	6.8		1.5	4.1	8.5	4.9	3.2	7.1	10.8	11.4	2.6	4.4	4.8
Clay 1 (n = 25)																						
Mean	1.14	2.45	8.59	16.5	192.	5.12	27.0	85.1	93.5	8.36	411.	33.5	59.2	24.8	5.05	1.26	0.724	2.25	0.323	3.89	1.10	9.10
c. v.	33.0	21.4	20.6	6.8	9.3	6.2	6.0	10.2	15.0	15.7	16.2	4.7	5.1	16.1	5.1	5.2	13.0	5.0	13.7	6.3	7.9	8.3
Clay 2 (n = 13)																						
Mean	0.742	1.81	21.2	11.1	230.	3.11	17.5	67.1	99.3	18.3	370.	25.1	43.6	18.5	3.71	0.810	0.521	1.74	0.265	3.24	0.865	8.80
c. v.	30.3	22.5	34.5	10.8	22.8	11.5	13.7	15.9	13.6	13.3	15.2	9.4	9.0	17.3	11.4	9.5	20.3	13.2	10.6	16.7	12.7	12.0

Appendix 3 : *Multivariate Probabilities of Group Membership for the Four Core Groups Variables used are : K, Sc, Cr, Fe, Co, Rb, Cs, La, Ce, Sm, Yb, Hf, Ta, Th.*

GROUP B-3 Group Membership Probabilities				
Id. No.	A-1	A-4	B-3	B-4
YHC604	0.088	0.000	74.407	0.152
YHC804	0.006	0.000	56.960	0.008
YHC807	0.000	0.005	96.543	0.000
YHC808	0.000	0.009	40.635	0.000
YHC810	0.000	0.004	94.105	0.000
YHC611	0.000	0.009	76.491	0.000
YHC811	0.000	0.008	53.429	0.000
YHC615	0.003	0.000	46.308	0.003
YHC614	0.002	0.000	38.969	0.000
YHC814	0.000	0.000	26.462	0.000
YHC815	0.004	0.000	57.860	0.000
YHC616	0.017	0.000	73.980	0.000
YHC816	0.017	0.000	0.188	0.000
YHC617	0.004	0.000	70.745	0.000
YHC817	0.002	0.000	6.294	0.000
YHC819	0.005	0.000	30.013	0.000
YHC654	0.001	0.000	97.146	0.000
YHC854	0.002	0.005	49.727	0.005
YHC655	0.001	0.000	90.439	0.000
YHC855	0.007	0.001	94.813	0.029
YHC658	0.000	0.006	60.552	0.012
YHC858	0.003	0.001	79.235	0.000
YHC660	0.000	0.001	50.197	0.000
YHC860	0.003	0.000	63.360	0.000
YHC661	0.016	0.000	40.385	0.023
YHC861	0.006	0.000	81.290	0.000
YHC662	0.000	0.003	94.930	0.000
YHC862	0.000	0.000	77.676	0.000
YHC663	0.001	0.000	90.832	0.000
YHC863	0.001	0.000	79.371	0.000
YHC664	0.006	0.000	26.267	0.000
YHC667	0.000	0.003	91.908	0.000
YHC867	0.001	0.001	5.873	0.000
YHC668	0.001	0.000	78.487	0.000
YHC868	0.003	0.000	65.966	0.000
YHC669	0.004	0.000	6.044	0.000
YHC869	0.003	0.000	93.723	0.000
YHC670	0.055	0.000	78.598	0.101
YHC870	0.029	0.000	35.587	0.000
YHC872	0.001	0.001	96.596	0.001
YHC673	0.001	0.000	95.691	0.001
YHC873	0.007	0.000	90.634	0.015
YHC674	0.000	0.159	70.198	0.000
YHC874	0.000	0.050	54.222	0.000
YHC675	0.001	0.000	90.571	0.021
YHC875	0.026	0.000	94.296	0.000
YHC676	0.000	0.001	63.252	0.000
YHC876	0.000	0.001	52.237	0.000
YHC677	0.001	0.000	67.268	0.000
YHC878	0.000	0.007	88.067	0.000
YHC679	0.000	0.001	68.187	0.000
YHC879	0.047	0.000	58.859	2.310
YHC680	0.000	0.000	86.981	0.003

GROUP B-3 Group Membership Probabilities				
Id. No.	A-1	A-4	B-3	B-4
YHC880	0.002	0.000	97.191	0.151
YHC682	0.018	0.000	64.255	0.057
YHC882	0.079	0.000	37.295	0.229
YHC883	0.004	0.001	96.953	0.603
YHP062	0.106	0.000	96.340	28.721
YHP112	0.000	0.001	29.852	0.001
YHP114	0.017	0.000	70.526	2.125
YHP119	0.086	0.000	89.301	12.530
YHP120	0.002	0.000	19.874	0.000
YHP122	0.043	0.000	81.372	20.302
YHP124	0.238	0.000	77.118	0.551
YHP126	0.002	0.000	69.211	0.010
YHP127	0.038	0.000	97.879	6.672
YHP130	0.014	0.000	99.947	1.564
YHP134	0.115	0.000	94.804	2.111
YHP136	0.153	0.000	98.785	0.615
YHP138	0.032	0.000	67.607	0.003
YHP140	0.007	0.000	88.657	0.139
YHP147	0.122	0.001	73.075	5.460
YHP150	0.024	0.001	88.767	0.230

GROUP A-1 Group Membership Probabilities				
Id. No.	A-1	A-4	B-3	B-4
YHP129	85.135	0.005	0.000	0.000
YHP224	68.371	0.003	0.000	0.000
YHP257	92.236	0.000	0.000	0.000
YHP261	92.583	0.011	0.000	0.000
YHP262	97.636	0.001	0.000	0.000
YHP264	99.647	0.000	0.000	0.000
YHP267	98.292	0.000	0.000	0.000
YHP269	98.851	0.001	0.000	0.000
YHP274	93.029	0.000	0.000	0.000
YHP284	78.321	0.000	0.000	0.000
YHP285	68.593	0.001	0.000	0.000
YHP287	93.707	0.000	0.000	0.000
YHP291	93.106	0.004	0.000	0.000
YHP294	98.115	0.000	0.000	0.000
YHP295	67.815	0.000	0.000	0.000
YHP296	98.330	0.000	0.000	0.000
YHP299	89.321	0.000	0.000	0.000
YHP300	85.797	0.110	0.000	0.000
YHP302	98.730	0.005	0.000	0.000
YHP306	85.197	0.004	0.000	0.000
YHP307	90.486	0.000	0.000	0.000
YHP308	97.340	0.001	0.000	0.000
YHP309	93.664	0.001	0.000	0.000
YHP310	99.984	0.001	0.000	0.000
YHP327	84.227	0.002	0.000	0.000
YHP346	76.905	8.542	0.000	0.000
YHP369	84.296	0.001	0.000	0.000

GROUP A-4
Group Membership Probabilities

Id. No.	A-1	A-4	B-3	B-4
YHP215	0.179	94.562	0.000	0.000
YHP216	0.142	99.851	0.000	0.000
YHP217	0.004	93.851	0.000	0.000
YHP218	0.227	93.895	0.000	0.000
YHP222	0.369	96.636	0.000	0.000
YHP226	0.028	98.674	0.000	0.000
YHP227	0.858	97.771	0.000	0.000
YHP228	0.432	94.246	0.000	0.000
YHP229	0.042	95.589	0.000	0.000
YHP259	0.120	93.706	0.000	0.000
YHP265	0.305	97.998	0.000	0.000
YHP345	1.604	96.153	0.000	0.000
YHP350	1.225	90.175	0.000	0.000
YHP351	0.326	94.331	0.000	0.000
YHP354	0.002	93.096	0.000	0.000
YHP355	0.074	96.127	0.000	0.000
YHP356	0.501	99.675	0.000	0.000
YHP358	0.163	95.268	0.000	0.000
YHP362	0.464	95.695	0.000	0.000
YHP363	2.042	98.116	0.000	0.000
YHP371	2.723	92.672	0.000	0.000
YHP379	0.050	90.165	0.000	0.000

GROUP B-4
Group Membership Probabilities

Id. No.	A-1	A-4	B-3	B-4
YHP020	0.001	0.000	0.000	27.147
YHP021	0.001	0.000	0.000	65.220
YHP022	0.000	0.000	0.000	71.746
YHP023	0.002	0.000	0.000	69.587
YHP024	0.014	0.000	0.000	95.726
YHP025	0.000	0.000	0.000	60.829
YHP026	0.004	0.000	0.000	73.314
YHP028	0.281	0.000	0.069	70.623
YHP029	0.000	0.000	0.000	96.951
YHP030	0.000	0.000	0.000	90.026
YHP031	0.000	0.000	0.000	92.385
YHP033	0.500	0.000	0.055	76.862
YHP035	0.001	0.000	0.000	94.971
YHP036	0.073	0.000	0.055	98.533
YHP039	0.000	0.000	0.000	66.804
YHP042	0.369	0.000	2.739	99.904
YHP043	0.015	0.000	0.188	84.782
YHP044	0.963	0.000	1.235	92.053
YHP046	0.001	0.000	0.008	99.653
YHP047	0.008	0.000	0.166	99.447
YHP048	0.031	0.000	0.164	96.445
YHP050	0.596	0.000	7.598	93.504
YHP052	0.009	0.000	0.051	93.636
YHP054	0.054	0.000	0.457	71.743
YHP055	0.001	0.000	0.000	95.504
YHP057	0.002	0.000	0.000	23.476
YHP059	0.001	0.000	0.000	81.902
YHP060	0.016	0.000	5.379	97.261
YHP061	0.308	0.000	2.923	78.130

GROUP B-4
Group Membership Probabilities

Id. No.	A-1	A-4	B-3	B-4
YHP063	1.025	0.000	19.932	60.814
YHP067	0.001	0.000	0.000	96.767
YHP069	0.004	0.000	0.003	78.573
YHP070	0.144	0.000	0.000	28.474
YHP071	0.306	0.000	33.690	73.780
YHP113	0.000	0.000	0.000	96.535
YHP117	0.377	0.000	0.262	36.181
YHP123	0.093	0.000	0.834	64.887
YHP128	0.825	0.000	27.310	55.567
YHP133	0.084	0.000	0.206	56.569
YHP135	0.120	0.000	0.002	48.050
YHP148	3.652	0.000	0.007	61.095
YHP149	2.308	0.000	0.556	76.464
YHP151	12.383	0.000	1.230	87.485
YHP155	0.001	0.000	0.000	10.525
YHP225	13.160	0.000	0.768	39.566
YHP311	3.622	0.000	18.354	74.616
YHP339	0.129	0.000	1.042	99.489
YHP352	1.691	0.000	0.385	43.288

Appendix 4 : *Multivariate Probabilities of Group Membership for the Four Core Groups Variables used are : K, Sc, Cr, Fe, Co, Rb, Cs, La, Ce, Sm, Yb, Hf, Ta, Th.*

GROUP A-2 — Group Membership Probabilities

Id. No.	A-1	A-4	B-3	B-4
YHP223	3.521	0.042	0.000	0.000
YHP263	0.024	1.037	0.000	0.000
YHP286	0.097	0.012	0.000	0.000
YHP289	38.991	0.516	0.000	0.000
YHP297	2.242	0.019	0.000	0.000
YHP312	0.111	0.154	0.000	0.000
YHP314	4.932	1.078	0.000	0.000
YHP344	0.000	0.109	0.000	0.000
YHP360	13.210	0.813	0.000	0.000
YHP376	2.332	0.084	0.000	0.000
YHP377	0.576	0.064	0.000	0.000

GROUP A-3 — Group Membership Probabilities

Id. No.	A-1	A-4	B-3	B-4
YHP019	7.729	2.445	0.000	0.000
YHP032	2.920	0.997	0.000	0.000
YHP037	0.165	0.682	0.000	0.000
YHP038	0.501	0.653	0.000	0.000
YHP064	0.982	0.194	0.000	0.000
YHP066	23.795	1.420	0.000	0.000
YHP109	45.800	2.470	0.000	0.000
YHP121	0.374	0.232	0.000	0.000
YHP152	0.757	12.580	0.000	0.000

GROUP B-1 — Group Membership Probabilities

Id. No.	A-1	A-4	B-3	B-4
YHC610	0.000	4.140	0.872	0.000
YHP154	0.025	0.003	0.001	14.759
YHP156	0.055	2.283	0.000	0.001
YHP159	0.003	45.242	0.000	0.000
YHP160	0.008	1.649	0.000	0.000
YHP161	0.009	0.059	0.001	0.188
YHP162	0.007	0.643	0.000	0.006

GROUP B-2 — Group Membership Probabilities

Id. No.	A-1	A-4	B-3	B-4
YHP282	0.001	0.001	0.000	0.004
YHP326	0.649	0.011	0.039	0.007
YHP337	1.659	0.100	0.000	0.000
YHP338	0.574	0.041	0.240	0.150
YHP357	0.001	0.000	0.000	0.001
YHP364	0.028	0.001	0.005	0.574

GROUP B-5 — Group Membership Probabilities

Id. No.	A-1	A-4	B-3	B-4
YHP027	0.038	0.003	2.370	0.002
YHP041	0.034	0.000	16.679	31.979
YHP051	0.025	0.000	71.870	14.979
YHP072	0.033	0.000	8.584	39.662
YHP110	0.044	0.000	16.404	3.288
YHP116	0.004	0.000	0.000	44.555
YHP131	0.009	0.000	0.000	4.701
YHP137	0.003	0.000	0.004	20.518
YHP144	0.005	0.000	0.009	0.180
YHP145	0.033	0.000	73.053	26.333
YHP157	0.013	0.000	0.001	0.775

GROUP B-6 — Group Membership Probabilities

Id. No.	A-1	A-4	B-3	B-4
YHP271	0.005	0.000	0.006	0.000
YHP278	0.011	0.000	0.002	0.000
YHP298	0.015	0.000	0.000	0.000
YHP343	0.005	0.000	0.000	0.000
YHP347	0.020	0.000	0.002	0.000
YHP359	0.010	0.000	0.016	0.000

GROUP C-1 — Group Membership Probabilities

Id. No.	A-1	A-4	B-3	B-4
YHC683	0.005	0.001	4.670	0.006
YHC801	0.001	0.001	0.403	0.055
YHC802	0.001	0.001	0.162	0.002
YHC809	0.000	0.000	0.310	0.000
YHP132	0.001	0.000	1.697	0.001
YHP142	0.005	0.000	8.049	4.130
YHP143	0.002	0.000	29.798	0.179

GROUP E-1 — Group Membership Probabilities

Id. No.	A-1	A-4	B-3	B-4
YHP220	0.000	0.000	0.000	0.000
YHP230	0.000	0.001	0.000	0.000
YHP370	0.000	0.000	0.000	0.000

GROUP D-2 Group Membership Probabilities				
Id. No.	A-1	A-4	B-3	B-4
YHP258	0.012	0.053	0.000	0.000
YHP266	0.013	0.026	0.000	0.000
YHP270	0.008	0.012	0.000	0.000
YHP273	0.002	0.030	0.000	0.000
YHP279	0.019	0.007	0.000	0.000
YHP280	0.004	0.012	0.000	0.000
YHP283	0.032	0.014	0.000	0.000
YHP301	0.013	0.012	0.000	0.000
YHP304	0.014	0.008	0.000	0.000
YHP305	0.007	0.006	0.000	0.000
YHP313	0.003	0.004	0.000	0.000
YHP332	0.010	0.061	0.000	0.000
YHP336	0.016	0.192	0.000	0.000

Appendix 5 : *Principal Components Analysis, Based on Group A-1. Analysis Based on Variance-Covariance Matrix.*

Eigenvalues	Percentage of Variance Explained
8.176E+006	99.97
1755.	0.02146
319.5	0.003907
46.74	0.0005715
4.506	5.509E–005
3.101	3.792E–005
0.9229	1.128E–005
0.3919	4.791E–006
0.3142	3.842E–006
0.1113	1.361E–006
0.05565	6.804E–007
0.01784	2.181E–007
0.006288	7.689E–008

Principal Components (largest to smallest)													
Sc	0.0003	0.0025	0.0014	–0.0501	–0.1459	0.0684	0.4823	–0.7983	0.0371	–0.2845	0.1372	–0.0181	0.0144
Cr	0.0006	–0.9904	0.1342	0.0101	0.0155	0.0085	–0.0125	–0.0148	0.0192	0.0058	–0.0025	0.0026	0.0007
Fe	1.0000	0.0005	–0.0009	–0.0002	0.0003	0.0002	–0.0001	0.0003	0.0000	0.0001	–0.0000	0.0000	0.0000
Co	0.0003	–0.0177	0.0306	0.0237	–0.7108	–0.6611	0.1462	0.1768	–0.0240	–0.0463	0.0049	–0.0224	0.0053
Rb	–0.0009	–0.1304	–0.9438	–0.2898	–0.0659	0.0046	–0.0533	–0.0070	0.0277	0.0075	–0.0101	0.0103	0.0031
Cs	–0.0001	–0.0207	–0.0611	–0.0670	0.5902	–0.4726	0.4500	0.1652	–0.4025	–0.1014	0.1192	–0.0233	–0.0533
La	–0.0001	–0.0034	–0.1221	0.3567	0.1656	–0.0612	0.4286	0.1835	0.7631	0.0989	–0.1104	–0.0212	0.0681
Ce	–0.0001	–0.0.29	–0.2674	0.8777	–0.0599	0.0639	–0.0775	–0.0808	–0.3628	–0.0464	0.0265	–0.0482	–0.0093
Sm	0.0000	0.0014	–0.0104	0.0624	–0.0080	–0.0171	–0.0131	0.0221	0.0671	–0.0556	0.2133	0.8995	–0.3644
Yb	–0.0000	–0.0002	–0.0074	0.0196	–0.0130	0.0144	–0.1012	0.0766	0.1503	0.1083	0.9422	–0.2451	–0.0310
Hf	0.0000	–0.0035	–0.0021	0.0122	0.0360	0.0518	–0.1690	0.2403	0.1521	–0.9354	0.0184	–0.0974	–0.0394
Ta	–0.0000	0.0006	0.0011	0.0069	0.0291	–0.0305	–0.0360	0.0198	–0.0420	–0.0678	0.1291	0.3416	0.9256
Th	0.0001	0.0185	–0.0073	0.0795	0.2953	–0.5683	–0.5573	–0.4463	0.2626	0.0111	–0.0613	–0.0201	–0.0119