PETROGRAPHIC, X-RAY DIFFRACTION, AND CHEMICAL ANALYSIS OF POTTERY FROM ANYANG, CHINA

A THESIS
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ABSTRACT

The Shang site at Anyang, China, was occupied from the 14th century to the 11th century BC. Excavations of this site have provided a wealth of information about the life of the people living there at the time. Grey, wheel-thrown, unglazed pottery was one of the many artifact types found. Previous to this study, there had been no petrographic work done on the ceramics found at Anyang. In this study, thirty-three sherds from Anyang were studied petrographically in order to determine the raw materials used in the manufacture of the pottery, whether the materials have changed over the length of time the pottery was being made, and whether different vessel types had distinct mineralogies. X-ray diffraction was used to determine the mineralogy of the sherds and local loessic soils, and thus, help to determine the provenance of the materials used in pottery manufacture. Chemical analysis was also used to further study the chemistry of the sherds and soils. The results indicate the pottery represented by the sherds was made of similar raw materials, and the raw materials differed throughout pottery types and phases, but with no real cultural pattern. Petrographically, the sherds were made of similar materials, and only grain size seemed to be a factor that set some sherds apart from the rest. XRD indicated the material in the sherds matches the local soils. Using a factor analysis for the chemical analysis data, two distinct chemical populations are indicated, but apparently mean little from a social or cultural standpoint. From 1275-1045 BC, the materials and local sources for the pottery manufacture did not vary greatly.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

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INTRODUCTION

An important archaeological problem in understanding ancient Chinese ceramics is the lack of any petrography. Shang Dynasty potsherds from the Anyang site are investigated in this study. The provenance of these sherds is addressed, and then used to interpret technological aspects of the culture at the time of the Shang dynasty.

Anyang is located in Henan province about 120 km north of the Yellow River (Figure 1). The archaeological site at Anyang was occupied from the 14^{th} century BC until 11^{th} century BC. The site has been excavated from 1928 until present (Li Chi, 1977). Figure 2 shows the distribution of sites. The pottery under investigation is composed of four different pottery types: jue, a drinking vessel; li, a cooking vessel; gu, another drinking vessel; and gui, an eating vessel (Figure 3). The pottery analyzed is from three different phases; phase II, III, and IV. Phase II is the earliest, from about 1275 BC to 1205 BC, phase III from 1205 BC to 1135 BC, and phase IV from 1135 BC to 1045 BC (personal communication from G. Rapp). The pottery is grey stoneware that is wheel-thrown, unglazed, and has some geometric decoration made by cord impressions and incising with a tool. The firing temperature of this pottery was about 1000° -1050° C. (Wenjie, 1996, p. 82).

The main focus of the investigation is to characterize the materials used in the making of the pottery, and to determine the provenance of these materials. Did the source for the pottery from phase II, III, and IV differ over time? Were different materials used for li, gui, gu, or jue? Were local sources used for the pottery, or does the pottery consist of exotic materials? Petrographic analysis, X-ray diffraction (XRD), and chemical analysis are employed in order to answer these questions.

This investigation is exploratory in nature. No previous petrographic work has been done on any ceramics from this region. Petrographic analysis of the sherds from each pottery type and phase has been done in order to determine the kinds of mineral inclusions (natural or added as temper) in the pottery. XRD analysis of the sherds and alluvial and loessic soils from the site has been undertaken in order to compare materials used in temper and to determine what sort of clays in the local soils would have been available as clay matrix in the pottery. Chemical analysis has been done for further comparison among the sherds and with local soils.

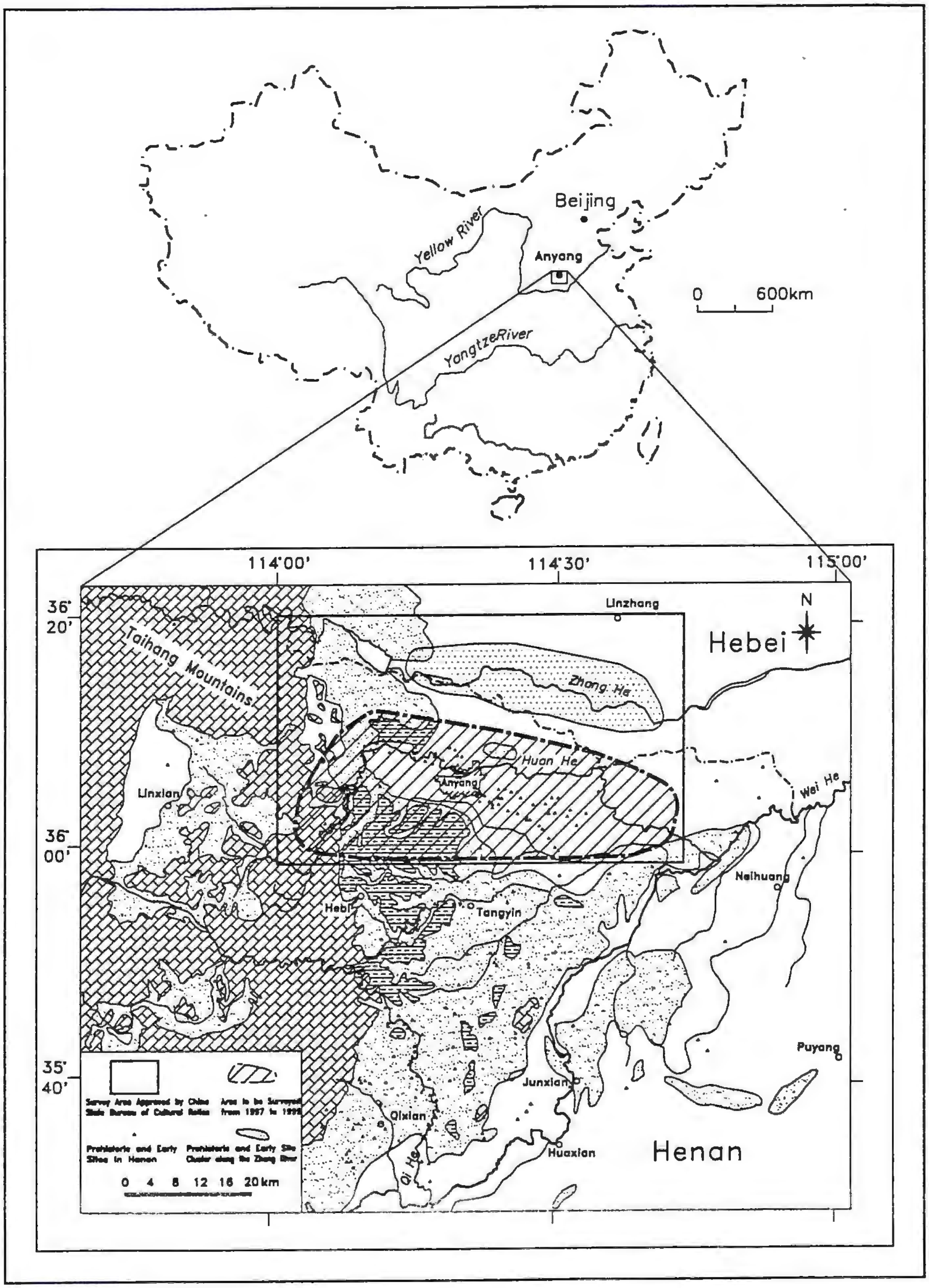

Figure 1: Map of China with location of Anyang. (From Z. Jing, 1999).

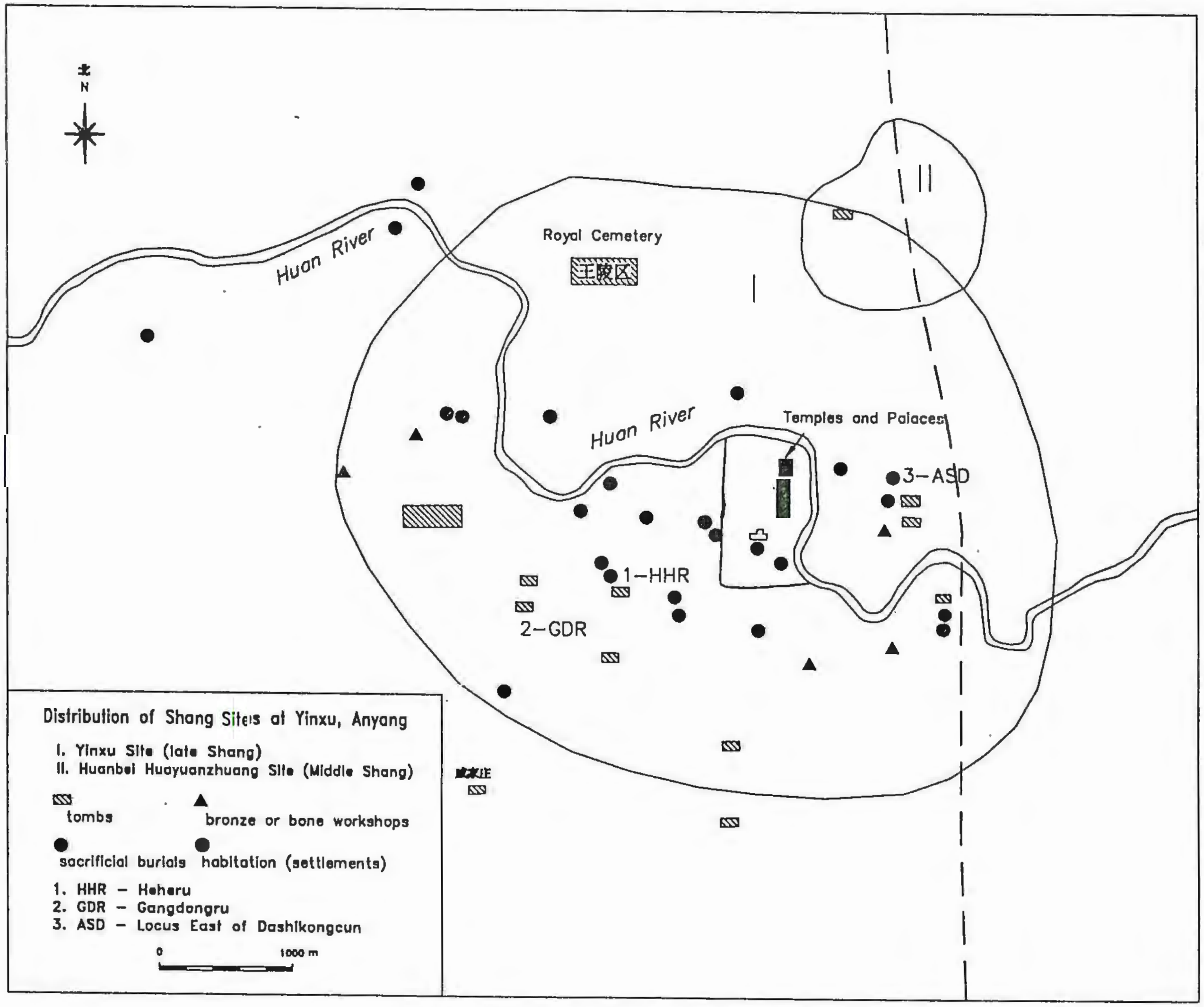

Figure 2: Distribution of Shang sites at Anyang. (From Z. Jing, 1999).

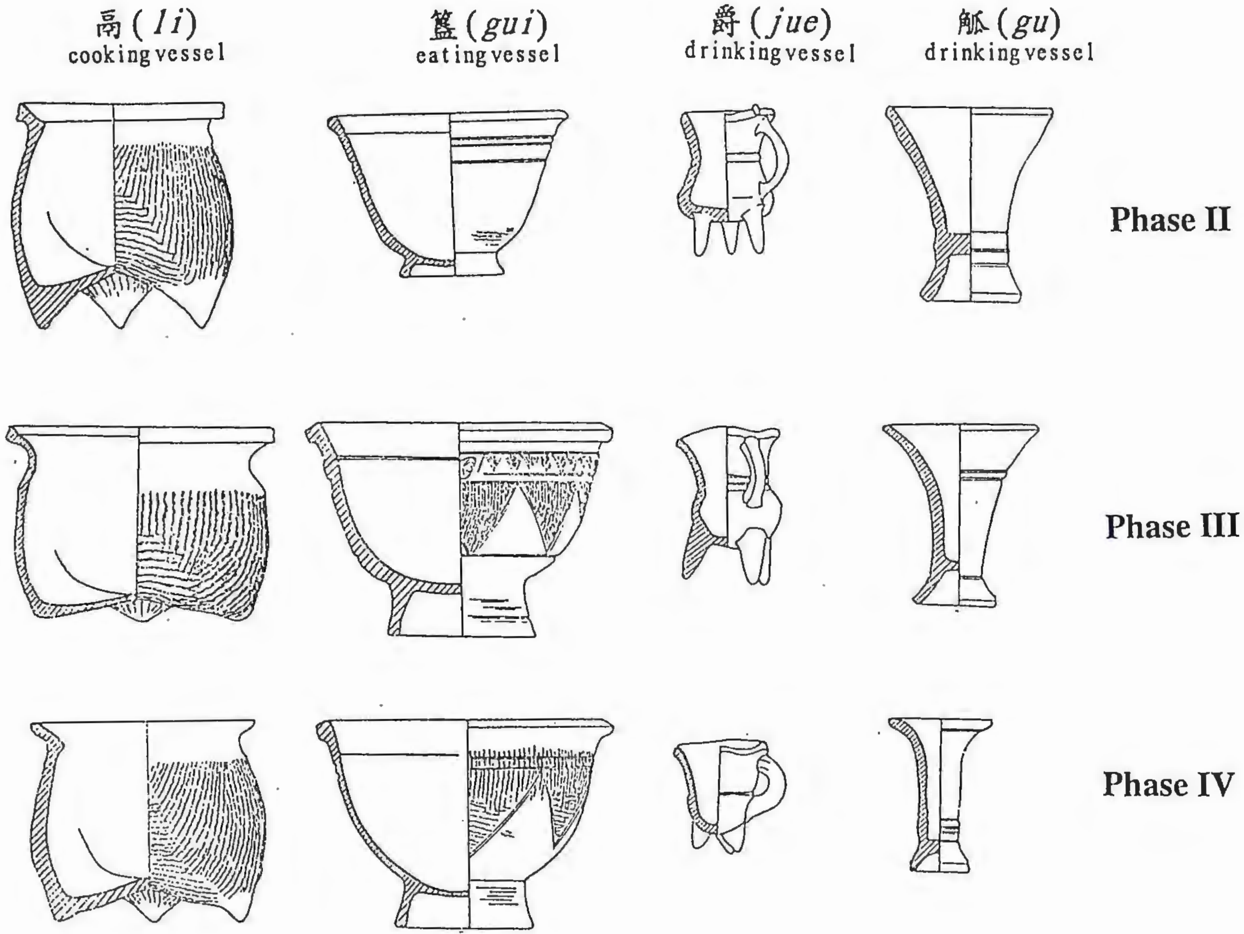

Figure 3: Phases and typology of Shang pottery. (From Z. Jing, 1999).

A BRIEF HISTORY OF THE SHANG AND THEIR CULTURE

The Shang are the first Chinese known to history; preceding the Shang are the Neolithic culture and the "black pottery Neolithic culture" (Creel, 1937). It is thought that the Shang moved to Anyang on the banks of the Huan River in the 14^{th} century B.C. Anyang was an ideal location for farming. The yellow loessic soil was fertile, and few trees grew on the plains so clearing the land was unnecessary. Invaders would be easy to detect coming over the plains, so the city could be defended easily. The Taihang Mountains to the west provided more protections from invaders, and were also a source of wood for the Shang. The Huan River was the water source, and yet another barrier to invaders.

The Shang were farmers and hunters, using the plains to pasture their cows and sheep, and using the Taihang Mountains to hunt for wild animals such as deer, boar, rabbit, and pheasant. Domesticated animals used by the Shang for food include cattle, sheep, pig, dog, and chicken. Oxen, water buffalo, and elephants may have been used to do heavy lifting and hauling for the Shang. Millet was an important crop for the Shang, wheat and rice less so. Unlike their Neolithic predecessors, the Shang manufactured chariots, pulled by horses, and had a complex system of writing (Creel, 1937). Houses built by the Shang were similar to houses built by the preceding black-earth Neolithic culture and are still built in the same fashion in parts of China today: a foundation was made of earth pounded into a compact, brick-like surface. Pillars were erected on top of the foundation, and stones were used as a base for the pillar to protect the foundation. A gabled, thatched roof was erected above pounded-earth walls.

Some of the pottery found at Anyang is similar to the pottery types found in excavations of the black-earth Neolithics: the vessel known as li is a tripod-shaped cooking vessel, and is only found in this part of China (Creel, 1937). Bronzes and ceramics were closely related; at times, ceramics seemed to mimic the shapes of bronze vessels, and ceramics were used as molds for casting bronze vessels (Vainker, 1991). These bronze molds were made from aeolian loess, which has a low clay content and therefore shrinkage would be minimal, and fine decorations would be possible (Vainker, 1991). The majority of Shang ceramics include grey, buff, or red clay vessels for everyday usage, such as the li tripod for cooking, the bowl-like gui eating vessel, mug-like jue wine vessel, and the beaker-like gu drinking vessel. There are two other types of Shang ceramics that are unlike the ones in this study, but are important to mention. The white wares and glazed wares served a ceremonial, rather than utilitarian, purpose (Vainker, 1991). The white wares were made of kaolin, and were deeply incised with intricate patterns, resembling bronze vessels. The glazed wares had a thin, greenish-yellow glaze inside and out, and were shaped similar to bronze vessels.

STUDY AREA

The archaeological site at Anyang lies at 36° N latitude and 114° E longitude. The Huan River runs through the site, which is approximately 120 km north of the Yellow River. The site is set on the North China plains, bordered by the Taihang Mountains to the west, and the Yellow River alluvium and marshland to the east (Figure 4). The Taihang Mountains are approximately 1500 meters above sea level (Personal communication from Z. Jing, 1999). The center of the site is approximately 15 kilometers east of the Taihang foothills, and in contrast, is approximately 70 meters above sea level (Personal communication from Z. Jing, 1999). The alluvial plains (at the time of Shang occupation) were created by the drainage of the rivers Ch'i, Chang, and Ch'ing, which flowed to the Yellow River (Chang, 1980, p. 24).

The Taihang mountains are mostly composed of Paleozoic sedimentary rocks, mainly marine carbonates from the early Cambrian to middle Ordovician in age, (limestone, dolomite, and interbedded argillaceous rocks); middle Carboniferous to Permian rocks such as quartzose and clayey sandstone, sandy mudstone, siltstone, ferruginous claystone, shale, bioclastic limestone, micritic limestone, and coal beds; and some Neogene and Pleistocene terrestrial clastics (sand, calcareous silt, and clay). Mesozoic diorite, syenite, and porphyritic diorite are intruded into the aforementioned sedimentary rocks (Z. Jing, translation of Chinese maps).

During the Quaternary period, both fluvial and aeolian processes were predominant geomorphic influences. The site rests on an old terrace surface of the Huan

River. This terrace is covered with a brown loessic paleosol that is most likely Holocene in age. Locally, this brown paleosol is overlain by a 50-110 cm thick veneer of wind-deposited loessic sediment. The loess consists mainly of quartz, feldspar, and mica blown onto the North China plains, from igneous rocks in the Tibetian plateau (Vainker, 1991). The lower Huan River valley is underlain by alluvial sediments, and contains a paleosol beneath the present floodplain. This paleosol has a dark A horizon underlain by a Bk horizon containing carbonate filaments and nodules. This paleosol may have formed at the same time as the strong brown paleosol on the terrace, and both may have been sources of clay for pottery manufacture during the Shang period (Personal communication from Z. Jing, 1999). This study will help to determine whether the paleosols were indeed sources.

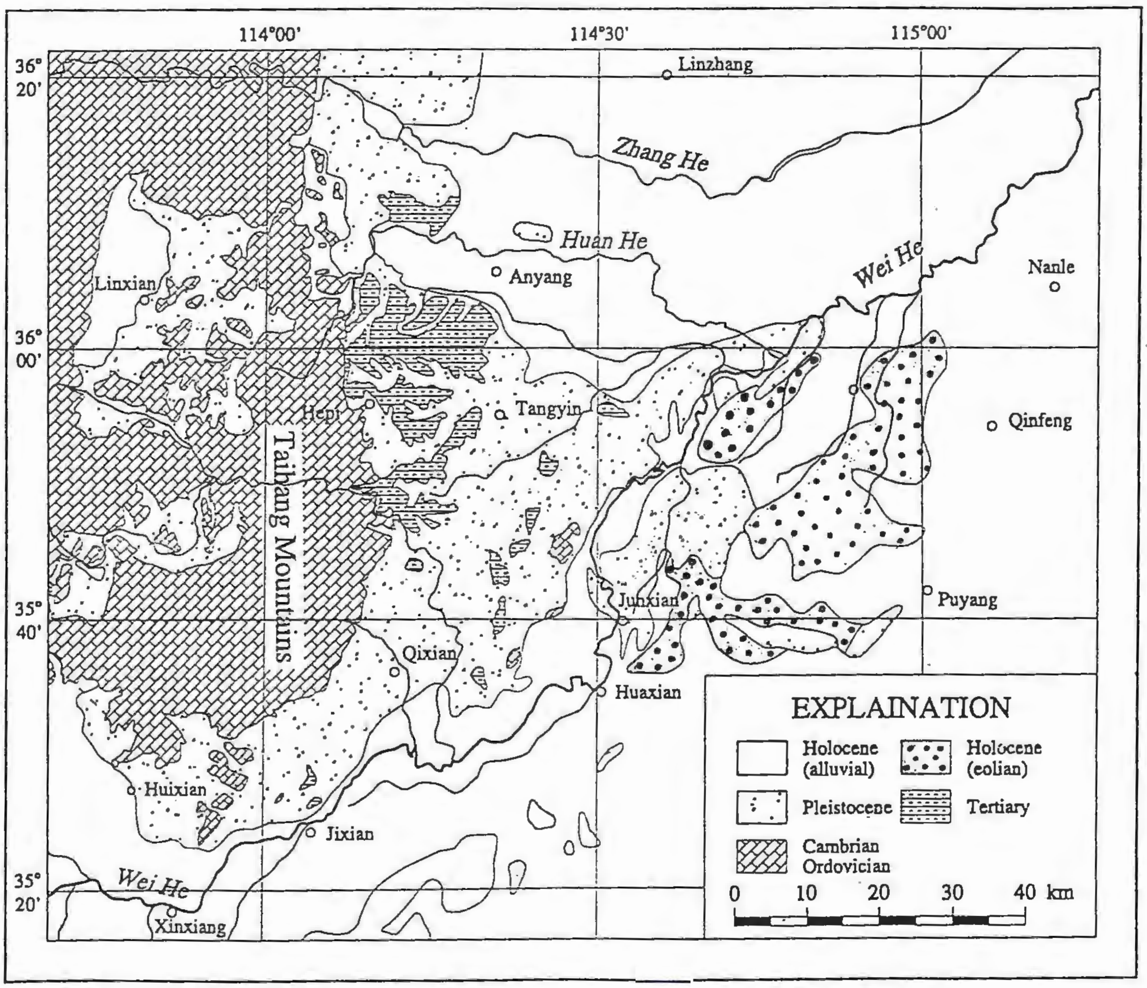

Figure 4: Geologic map of area surrounding Anyang. (From Z. Jing, 1999).

ANALYTICAL METHODS

A great many different kinds of analytical methods have been used in the technical analysis of ceramics, including, but not limited to, petrography, microchemical analysis, spectrographic analysis, differential thermal analysis, and X-ray diffraction (Shepard, 1954; Matson, 1952, Stoltman, 1989; 1991, Wilson, 1978). A combination of petrographic analysis, X-ray diffraction (XRD), and chemical analysis was used in this investigation. Petrographic analysis often proves to be of a greater benefit in provenance studies than data from only the elemental analysis of sherds because of the tendency of potters to add temper to the clay during the manufacture of the pottery (Stoltman, 1989; 1991). Paste is the clay body of the sherd that may also include mineral clasts from the source area (Arnold et al. 1978; Rice 1978; Wilson 1978; Bishop et al. 1982). Temper is material that is added to clay to counteract shrinkage and uneven drying during the firing of pottery, thus reducing the risk of cracking due to strain. Potters use many different materials as temper: sand, shell, ground rock or sherd fragments (known as grog), organics such as burnt bark, plants, or feathers (Shepard, 1954, p. 58). Elemental analysis cannot discern between temper and the paste of the sample, thus at times yielding a mixed signal as to the source of the clay.

Petrographic Analysis

This study began with petrographic analysis of the pottery sherds. From thirty-three sherds, forty-two thin sections were made (some sherds were so small, two thin sections were needed of each to be able to acquire enough data during point counting). Of these sherds, thirteen were from phase II, eleven were from phase III, and nine were from phase IV. For each phase, the rim, body, and foot of each pottery type li, gui, gu, or jue, was represented (Figure 3). The sherds were cut perpendicular to the wall surface, so as to analyze the fabric of the pottery. The fabric, or body, of the sherd is meant in this case to include the clays, natural inclusions that are silt, sand or gravel sized, and the temper material (Shepard, 1936, 1954; Rye 1976, 1981; Peacock 1970). Impregnation and vacuum embedding were required in the manufacture of the thin sections. No staining for pore spaces or feldspars was utilized, but in retrospect, would have been quite useful.

Before point counting, a preliminary inspection of each thin section was made in order to become familiar with the mineralogy of the paste and temper used in the pottery. Porosity, fabric of mineral grains, and grain size were also noted during this examination. Plates 1 and 2 show representative thin sections.

Due to the irregular shapes of sherds, thin sections varied in shape and area available for point counting. Thin sections used for point counting were determined by the area of the sherd on the section. The largest possible sherd was used in order to insure a count of at least 500 grains per sherd. Therefore, the parts of the pottery represented in the data include the rim, body, and foot. A li, gui, gu, and jue from phases II, III, and IV were counted, for a total of 24 thin sections. The 24 thin sections were point counted using a standard polarizing microscope and mechanical stage in order to derive the percentages of each material present in the thin section. A total of 500 grains was counted on each sherd, in order to provide a statistically sound basis for comparison (Bishop et al. 1982). Using an eyepiece micrometer, maximum, minimum, and mean grain sizes were also measured.

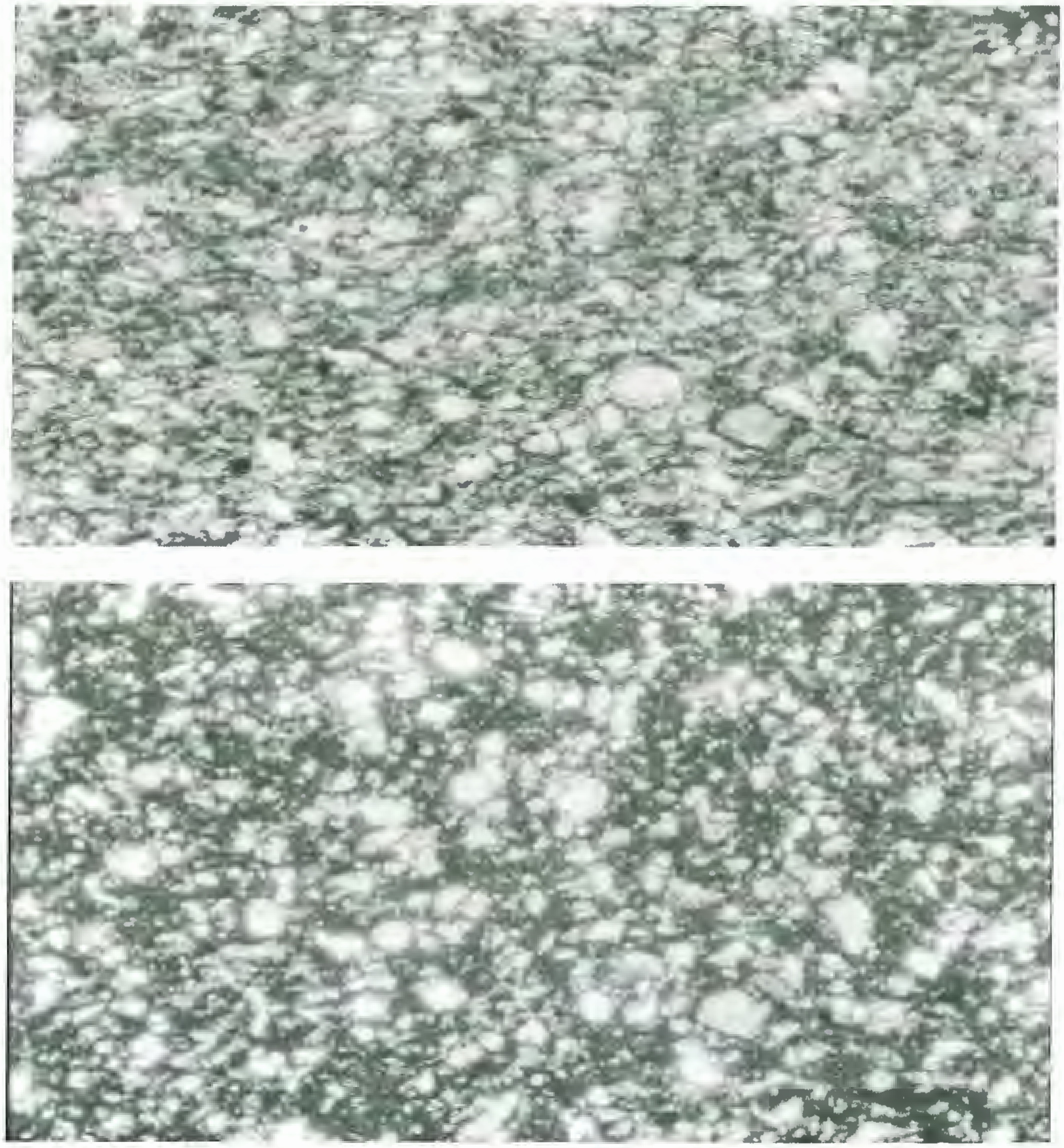

Plate 1. Phase II Gui, Rim uncrossed nicols, 10x; 2 mm long (top)

Phase II Gui, Rim crossed nicols, 10x; 2 mm long (bottom, same view)

These plates show the typical view of a fine-grained sherd, the most common sherd texture in the study.

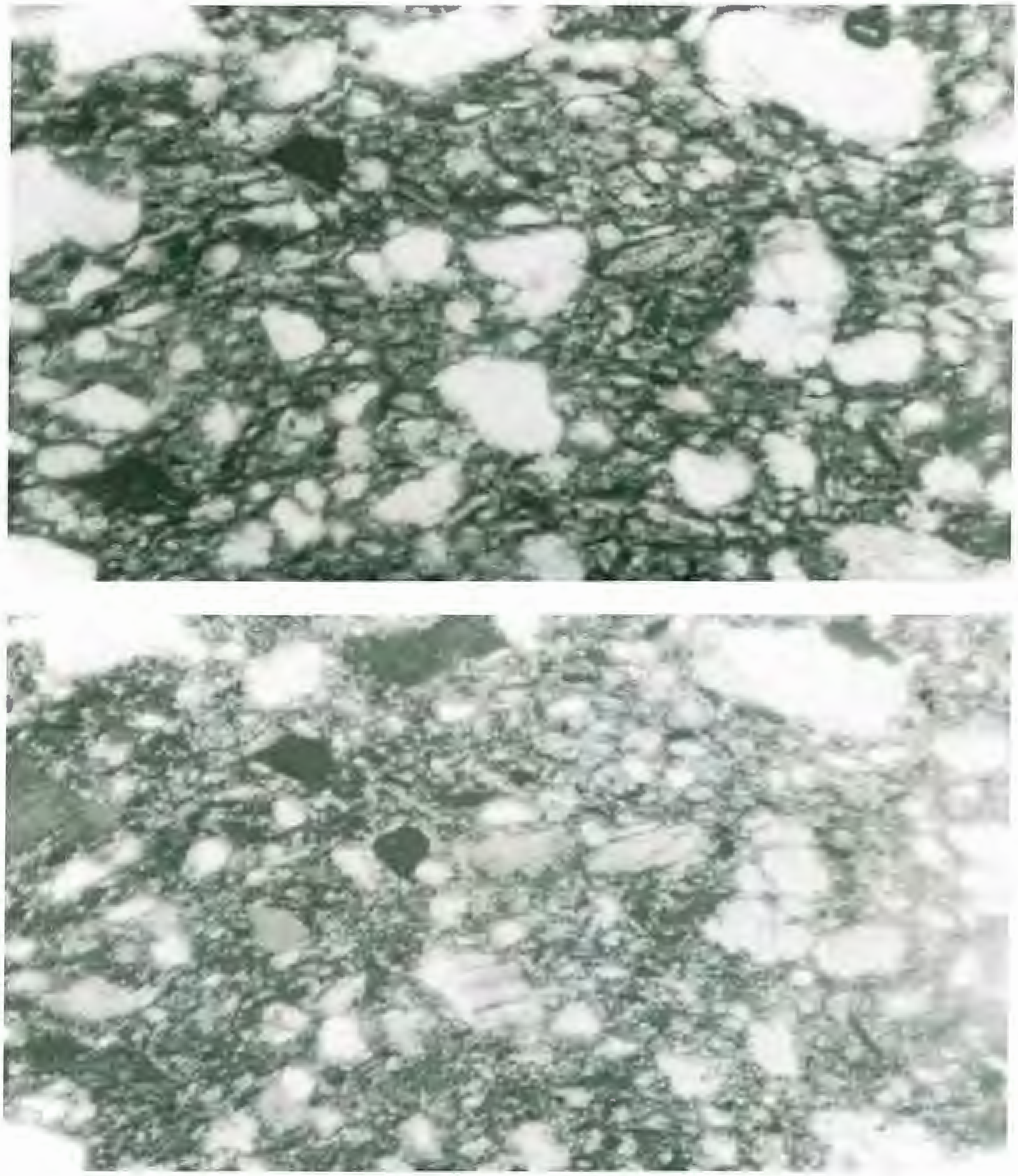

Plate 2. Phase II Li Rim uncrossed nicols, 10x; 2mm long (top)

Phase II Li Rim crossed nicols, 10x; 2mm long (bottom, same view)

These plates show the larger grained sherds- note how it is much easier to identify feldspars, mica, and quartz clasts.

X-Ray Diffraction

Both the sherds and the soil samples were analyzed by XRD in order to determine what minerals were present to help determine the provenance of the sherds. In some cases, XRD can be useful in determining the clay minerals used to make the pottery (Shepard 1971). Because the high firing temperatures (1000°-1050° C) would have altered the clay minerals, the sherds were not used to determine the clays. Since it is not possible to determine the mineralogy of the clays used for the pottery from the thin section, soil samples were tested for the identification of clay minerals present. If the sherds can be shown to be from a local source, soils developed on the alluvial sediments would be the most probable sources available for pottery production.

The XRD methods used were based on Carroll, (1970). The soils used for identification of clay minerals were first ground in an agate mortar and pestle until passable through a 400-mesh sieve (38 μm). The sample was then suspended in distilled water and the clay and water mixture pipetted onto glass plates, and desiccated. For some samples, Calgon was used as a dispersant. Two to three layers of water and clay were pipetted onto the glass plate until there was a large enough sample for an XRD scan. The samples were scanned from $2^{\circ} - 40^{\circ}$ 2 theta, for twenty-five minutes each. A 10 cm beam mask and ¼ inch divergence and scatter slits were used. The solor slit was set at 0.04. In order to detect expandable clays, the samples were placed in a dessicator containing ethylene glycol, and heated to 90° C for one hour, then scanned immediately after being taken from the dessicator, using the same parameters and program as the untreated clay samples. The last step in determining the clay minerals present was to heat the samples to 575° C for one hour in a muffle furnace, and then scan them as soon as the samples were cool enough to handle.

Several sherd samples and another set of soil samples were then packed, after grinding, into 1 cm x 2 cm x 1 mm aluminum holders. This was done in order to determine if the same minerals were present in both the sherds and the soils. If so, this would support the theory that the pottery is of a local, and not exotic source. These samples were then scanned from 2°- 70° 2 theta, for approximately two hours and twenty minutes, using a 10 cm beam mask and ¼ inch divergence and scatter slits and a 0.04 solor slit. Figures 5 and 6 show the locations of the soil samples used.

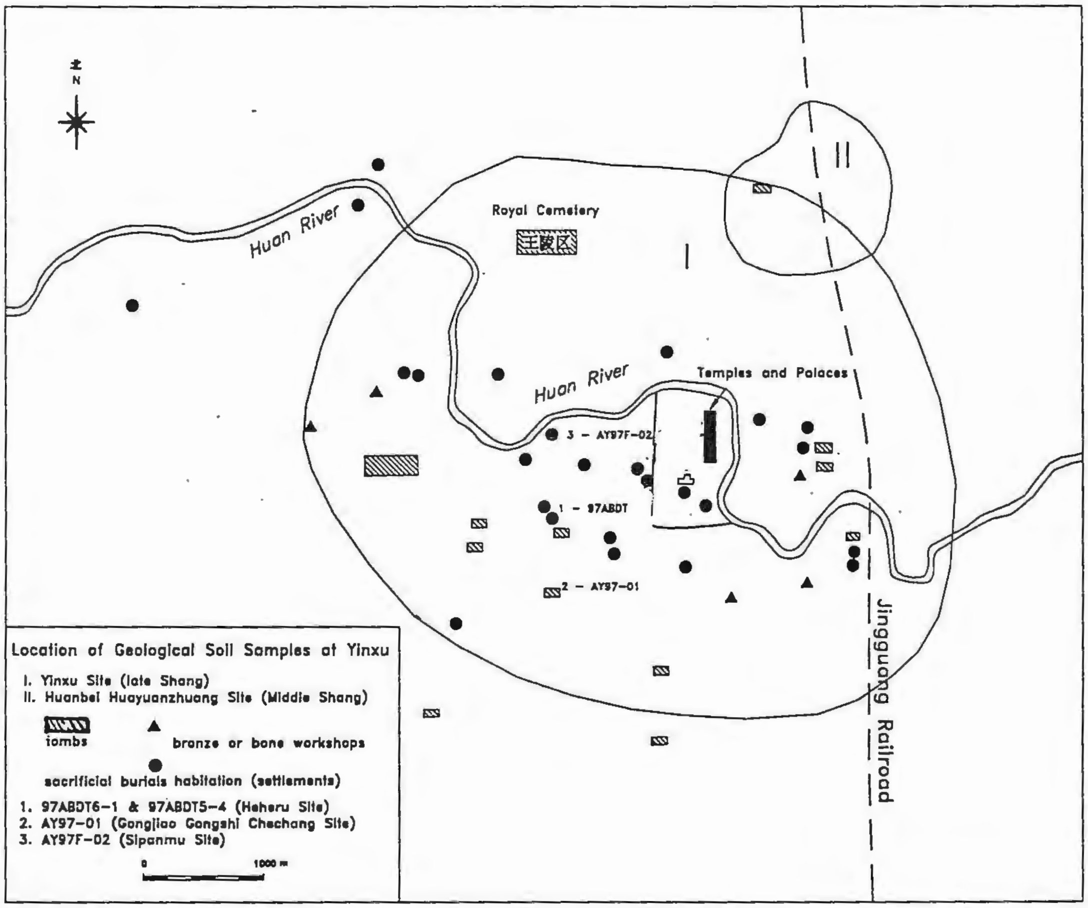

Figure 5: Location of soil samples at Yinxu. (From Z. Jing, 1999).

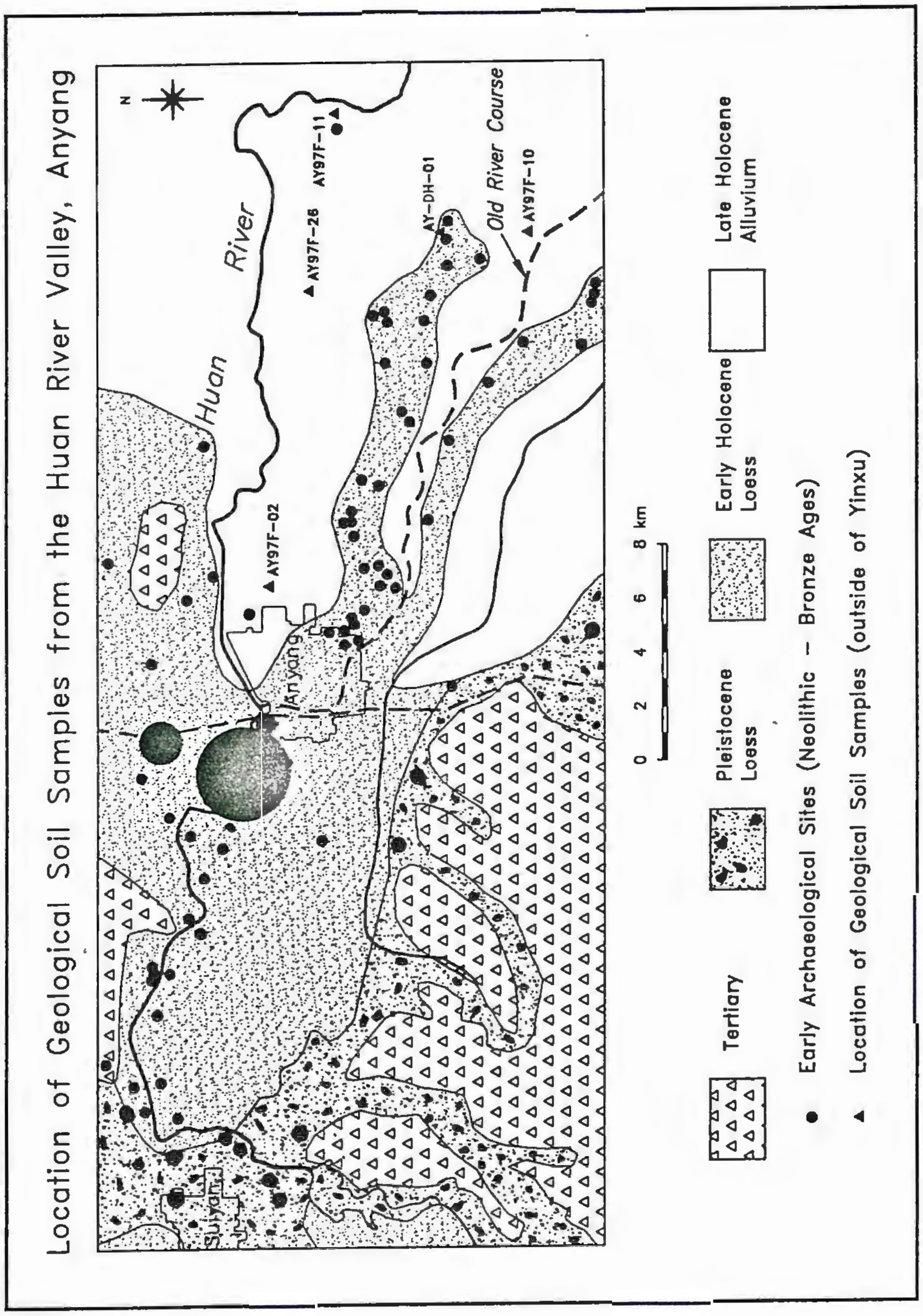

Figure 6: Location of soil samples from the Huan River Valley, Anyang. (From Z. Jing, 1999).

Chemical Analysis

Seventeen samples were sent to the University of Minnesota Twin Cities Department of Geology and Geophysics for chemical analysis by Inductive by Coupled Plasma Mass Spectometry (ICP-MS) using a Perkin Elmer/Sciex Elan 5000. Thirteen of the samples were from the remaining sherds that had not been consumed during thin sectioning, and the other four samples were soil samples. Two of the sherd samples were duplicates from the same sherd. The samples were prepared by the lithium metaborate fusion method, after which they were further diluted 200 times into 0.2 N HCl to which Rh and Sc were added as internal standard elements. Element concentrations were calibrated using an artificial standard prepared from NIST traceable single element standards and USGS rock standards (Personal communication, R. Knurr, 1999).

RESULTS AND DISCUSSION

After reviewing the data from the petrographic, XRD, and chemical analyses, there was not enough evidence to support the hypothesis of any pottery coming from an exotic source. All investigated pottery was from a similar local source.

Petrographic Analysis

Careful review of each thin section showed the same materials throughout. The only variable parameter in the thin sections was the grain size. Table 1 shows the maximum, minimum, and mean grain sizes for each sherd measured. See Plates 1 and 2 for representative thin sections of the coarse-grained and fine-grained thin sections. Six thin sections were coarse-grained, those of phase II li and phase IV gui, which together had an average grain size of 0.53 mm, maximum grain size of 3.6 mm, and minimum grain size of 0.02 mm for measurable grains (Table 1). The remaining thirty-six sections were very fine-grained, with an average grain size of 0.16 mm, maximum grain size of 1.26 mm, and minimum grain size of 0.02 mm for measurable grains (Table 1). Point-counting data on a ternary diagram were plotted (Figure 7). Table 2 shows the categories used during point counting. For purposes of easier diagramming, the point-count categories were condensed into three groups: the quartz, plagioclase, microcline, orthoclase, hornblende, biotite, muscovite, and rock fragment values for each sherd were combined at one corner (a "granite") in the same fashion as Skokan, (1993). Rock fragments in this case were typically granitic in composition- for example, a piece of quartz combined with a piece of feldspar was typical. An occasional non-granitic rock fragment was found, and was included with the "other" category. Clay matrix was shown in another corner, and the remaining values of pore space, grog, and other materials (non-granitic rock fragments) were combined on the third corner and labeled as "PGO".

Previous research by other ceramic petrographers shows different ways to plot point-counting data. Stoltman (1991) suggests using the terms "matrix", "temper", and "sand" on the ternary diagram; these distinguish the materials according to grain size and identification of temper material. Since this study was of a more exploratory nature, more information than just the grain size and temper distinctions was wanted on the diagram in order to more fully describe all the materials present in the sherds. When plotted on the "granite", "clay matrix" and "PGO" axes, the samples show little variance in any of the thin sections (Figure 8). This supports the hypothesis that all the material used in the pottery was from a similar source. In order to determine if the source was local or exotic, XRD analysis of both the sherds and local soils was employed, as well as a chemical analysis of the sherds and local soils. Although it was very important to employ petrography, other methods must also be used in order to support what is tentatively suggested by the observation of the thin sections.

Sample #	Minimum (mm)	Maximum (mm)	Mean (mm)
L2M511GR	0.02	0.62	0.19
L3M2503GR	0.02	0.58	0.13
L3M1261LR	0.04	0.64	0.16
L4M882LFA	0.02	0.5	0.13
L2M2892JF	0.03	0.68	0.16
L4M1484URB	0.02	1.26	0.2
L4M1156GBB	0.02	3.6	0.51
L4M1156GF	0.02	1.02	0.44
L2M131LB	0.03	3	0.64
L2M131LR	0.04	1.5	0.56
L2M131LF	0.04	2.3	0.68
L4M1156GR	0.02	0.94	0.35

Table 1: Maximum, minimum, and mean grain sizes of grains in the sherds.

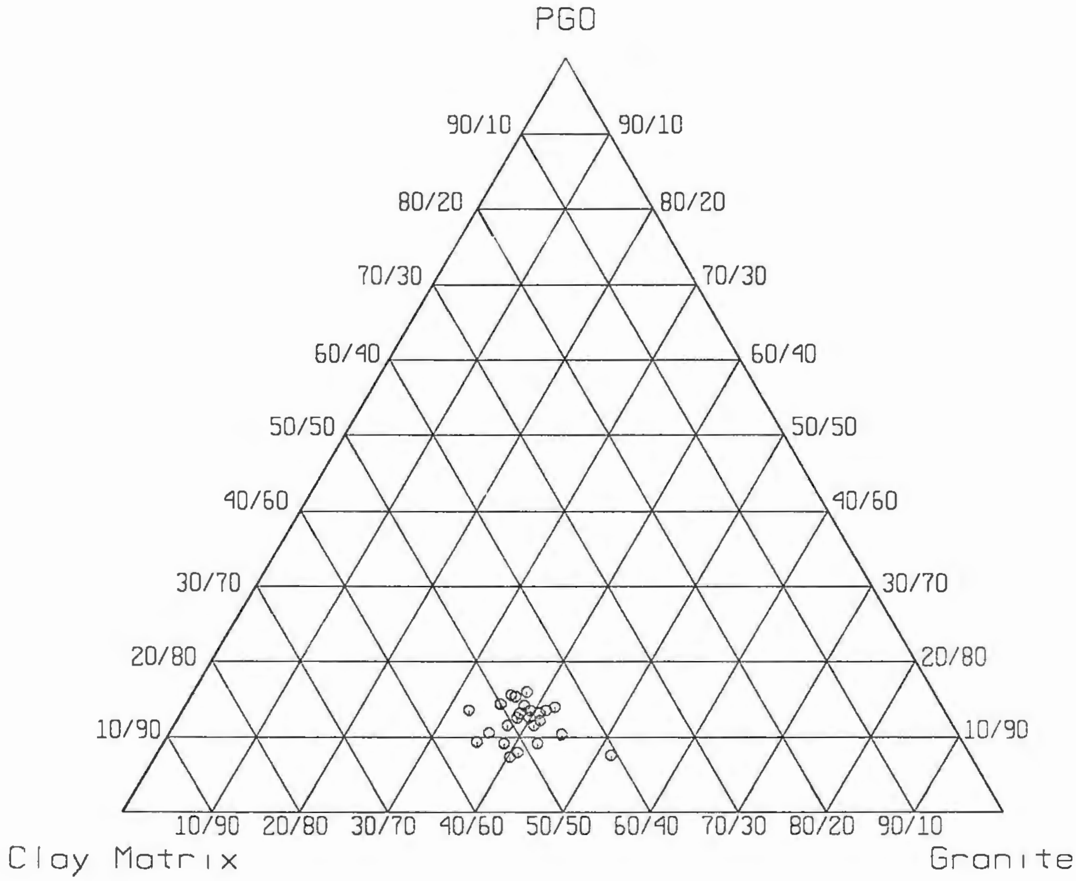

Figure 7: Ternary diagram of point counting data

Granite = quartz, plagioclase, microcline, orthoclase, hornblende, biotite, muscovite, and rock fragment values.

PGO = pore space, grog, and other materials (non-granitic rock fragments).

Clay Matrix = clay matrix of sherd.

Table 2: Point counting data for sherds. Rock fragments are granite and rock fragments composed of quartz and feldspar.

Sample #	Quartz	Plagioclase	Microcline	Orthoclase	Hornblende	Mica	Rock Frag	Clay Matrix	Pore	Grog	Other	Total	Granite	PGO
L2M131LB	99	50	20	30	9	13	37	204	32	0	6	500	258	38
L2M511GF	103	16	1	12	2	48	7	253	46	9	3	500	189	58
L2M2892JBB	98	12	0	20	7	44	11	245	53	3	7	500	192	63
L2M514UF	108	20	1	24	7	29	3	237	45	23	3	500	192	71
L2M131LR	108	31	13	23	11	11	26	225	41	4	7	500	223	52
L2M511GR	102	27	4	28	4	42	3	220	42	17	11	500	210	70
L2M2892JRA	91	7	2	34	15	33	7	231	62	6	12	500	189	80
L2M514UR	110	24	2	37	8	21	4	226	44	17	7	500	206	68
L3M2503GB	98	20	2	41	10	23	12	233	40	9	12	500	206	61
L3M1261LF	132	12	0	37	6	21	4	242	39	3	4	500	212	46
L3M1264JBA	112	10	0	28	3	19	12	239	52	8	17	500	184	77
L3M2502UB	109	18	2	21	7	31	9	235	57	2	9	500	197	68
L3M2503GR	112	17	3	38	8	18	7	231	50	10	6	500	203	66
L3M1261LBB	135	14	2	27	3	17	6	238	41	8	9	500	204	58
L3M1264JRA	105	21	2	18	10	16	9	241	41	24	13	500	181	78
L3M2502URB	107	17	1	27	5	27	15	238	46	4	13	500	199	63
L4M1156GR	98	18	0	17	2	14	13	270	47	8	13	500	162	68
L4M882LFA	131	11	2	24	6	7	11	242	52	10	4	500	192	66
L4M1485JRB	124	23	1	25	13	6	1	261	44	0	2	500	193	46
L4M1484URB	108	19	1	32	12	24	8	256	29	2	9	500	204	40
L4M1156GBA	127	11	1	26	3	5	28	262	27	10	0	500	201	37
L4M882LRA	122	16	0	20	3	10	7	250	45	21	6	500	178	72
L4M1485JRA	106	17	3	15	10	26	4	266	31	7	15	500	181	53
L4M1484URA	126	24	0	15	2	8	2	276	42	2	3	500	177	47

X-Ray Diffraction

The analysis of the soil samples and the clay samples also support the theory of a local source. It is not the intention of this study to determine precisely which soil or sediment locations would match the ceramics. What was sought was a general comparison between local soils and sediments and the materials used to make the pottery. Petrographic analysis of the sherds indicates the pottery from all phases is derived from similar materials. The XRD comparisons of local materials and the sherds were designed to assist in establishing whether the materials used for the pottery were from a local or exotic source.

XRD analyses of the soils sampled show the following minerals: predominantly clinochlore and illite, some montmorillonite, and tosudite (a mixed layer chlorite-smectite) (Table 3; Appendix pp. 47-51). One cannot say for certain that all of these minerals were used in the manufacture of the pottery being studied. Firing at temperatures of 1000^{o} C and up alters or destroys the clay minerals present in the raw material. If further analysis of the soils and sherds show the temper and other mineral inclusions in the pottery body to be similar, chances are that the clay minerals identified in the local soils were the main constituents of the pottery's paste.

The soils and the sherd samples analyzed in a packed mount showed the following minerals most commonly: quartz, orthoclase, anorthite, albite, and muscovite (Table 4; Appendix pp. 40-46). In the soil samples, clinochlore, illite, montmorillonite, tosudite, and carbonate are also present (Table 4; Appendix pp. 40-46). The suite of minerals detected in the XRD analyses is similar to that seen in the thin sections of the sherds, and is also similar to that expected in the soils and their parent sediments based on the local geology. Quartz sandstone from the Carboniferous to the Permian would be the source rocks for the quartz. The Mesozoic diorites and syenites from the Taihang Mountains would be the source rocks for the feldspar and biotite clasts in the clayey sediments, rather than regional sedimentary rocks, which are mostly carbonates, siltstones, and claystones.

Soil Sample #	Quartz	Illite	Montmorillonite	Clinoclore	Tosudite	Biotite
54210	x	x	x	x		
54200	x	x		x		
61470	x	x		x		
61440	x	x		x		
61420	x	x		x		
61310	x	x		x		
26360	x	x	x	x	x	
26380	x	x		x		x
26320	x	x	x	x	x	
AYF2			x	x		
AYF4		x		x		
AYF10	x	x		x		
AYF11		x		x		
AY971	x	x		x		
AYDH1	x	x		x		

Table 3: XRD results of clay analysis, prepared by suspending clay particles and settling on glass slide.

X= present

Soil Sample #	Quartz	Albite	Sodian Anorthite	Clinoclore	Muscovite	Illite	Montmorillonite	Tosudite	Other
AYDH1	x	x	x	x	x	x			
AY971	x	x	x	x		x	x	x	Orthoclase
AYF2	x	x	x	x	x	x		x	
AYF4	x	x	x	x	x	x	x	x	
AYF10	x	x	x	x	x	x	x		
AYF11	x	x	x	x	x	x	x	x	Microcline
26320	x	x		x	x	x			
26380	x	x		x	x	x	x	x	
26360	x	x		x	x	x		x	
61310	x	x	x	x		x			Calcite, Orthoclase
61420	x	x	x	x	x	x	x	x	
61440	x	x	x	x		x			
61470	x	x		x	x	x	x		
54200	x	x	x	x	x	x			
54210	x	x	x	x		x	x	x	

Sherd Sample #	Quartz	Albite	Anorthite	Sodian Anorthite	Clinoclore	Muscovite	Orthoclase	Microcline
4GUIRP	x	x	x	x				
4LIBP	x	x	x	x	x			
3LIFP	x	x	x	x		x		
4GUBFP	x	x	x	x		x		
2GUFP	x	x	x	x		x		
2LIRP	x	x	x	x			x	
2GUIRP	x	x	x	x			x	x
2JUEBP	x	x	x	x		x		
4GUIBP	x	x	x	x		x		
3GUBP	x	x	x	x		x		

Table 4: XRD results of packed mount samples, sherds (top) and soils (bottom).

Chemical Analysis

In order to get a chemical "fingerprint" of the sherds and soils, sherd and soil samples were submitted for chemical analyses of the major, minor, and trace elements present. Chemical attributes of these materials provide an additional parameter for judging whether the pottery was made from local materials or exotic sources. Principal component factor analysis was used in an attempt to group the samples into separate types. Prior to analysis, the data were normalized to a mean of zero and unit standard deviation. The number of factors retained was determined by the 75 percent variance rule. Factor loadings are on pages 56-57 of the appendix and factor scores are tabulated on page 58. By plotting these factors against each other (Figure 8), one can judge which samples group together. If the same samples group together in each of the plots, a chemical difference is signified, indicating that the sherds and/or soils in that group are a distinct population. This is the case for the Factor 1 scores in this study, but not the other Factors, 2-7. Looking at Figure 8, note that the group of samples on the right side of the graph, the Factor 1 scores, is the same each time. These samples are the soil samples 61-470 and 61-310, and the sherd samples of Phase III Gui, Phase II Jue and Phase II Li. However, since this is an exploratory study and the sample base was small, these results may not be conclusive. Hence we cannot conclude that the soils in the Factor 1 group are the raw materials for the sherds found in the same group. Furthermore, the pottery samples that differ from the rest are all of different phases, and different pottery types. The factor analysis shows a separate population, one that is composed of sherds of differing phases and pottery types, not one particular phase, or type. This does not support the idea that source areas were changed over time, or different sources were used for a given pottery type. Although the factor analysis shows chemically similar samples that may represent a single population, that population does not signify any cultural phenomenon.

The Factor 2-7 charts show that none of the samples consistently group together. Therefore, it cannot be said that any of these samples vary significantly from each other, and all belong to the same general population, which is variable. The factor analysis did not indicate separable populations.

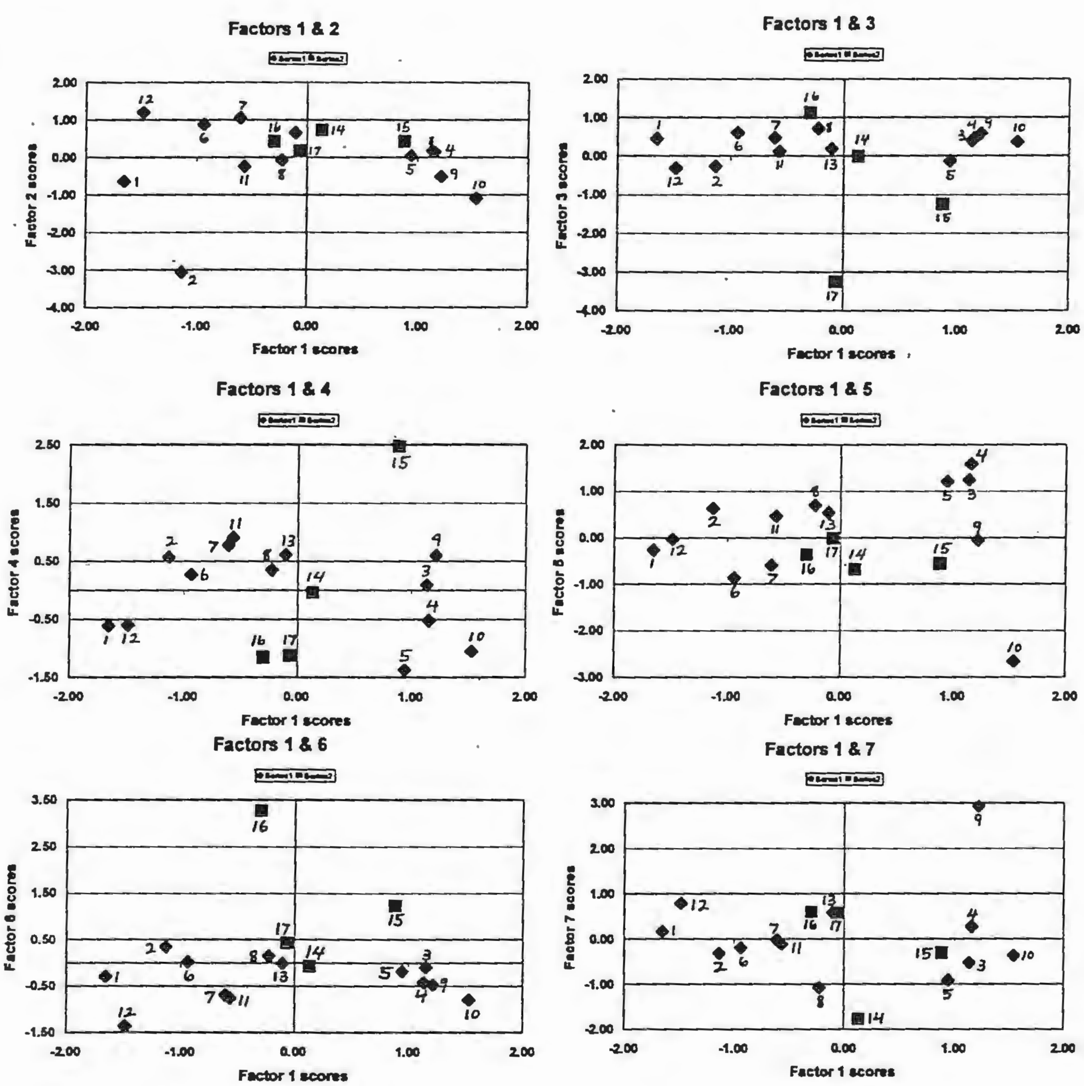

Figure 8: Factor plots of the chemical data.

CONCLUSIONS

This exploratory project on pottery sherds from Anyang, China, helps give a clearer view of what raw materials were used in the manufacture of Yinxu pottery, and the provenance of these materials. The petrographic study characterized the sherds, characterized materials present, and then established that the use of materials did not change throughout the different cultural phases of manufacture. This led to the hypothesis that the pottery was all made of the same material from a similar source. To judge whether the raw material used in the pottery manufacture was from a local or exotic source, X-ray diffraction was used to compare the mineralogy of the local soils with that of the sherds. Since the sherds and soils matched mineralogically, and no exotic materials were identified, local sources are implied. The final step was to compare soil versus sherd chemical "fingerprints". Using multivariate statistics, principal component factor analysis showed that one group can be distinguished as a separate population. However, the samples from the distinct population were of different phases and pottery types. Although some of the samples stand out as a separate chemical population, none of the sample grouping implies any cultural phenomena. In conclusion, these sherds are all very similar; they are made of the same materials from a local source, and the source of materials did not change significantly over time. Differences in grain size are not correlated with differences in chemistry; the samples found to be chemically dissimilar from the rest are a mix of coarse-grained and fine-grained sherds. A study of a larger suite of sherds is now recommended for a more thorough understanding of Anyang ceramics.

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APPENDIX

List of Sherds and Thin Sections

Original Potsherd Label	Thin Section Label
Phase 2 M51:1 Gui, Rim 96 Gangdongru	L2M511GR
Phase 2 M51:1 Gui, Body 96 Gangdongru	L2M511GB
Phase 2 M51:1 Gui, Foot 96 Gangdongru	L2M511GF
Phase 2 M13:1 Li, Rim 96 Heheru	L2M131LR
Phase 2 M13:1 Li, Body 96 Heheru	L2M131LB
Phase 2 M13:1 Li, Foot 96 Heheru	L2M131LF
Phase 2 M289:2 Jue, Rim 97 Heheru	L2M2892JRA, B, C, D
Phase 2 M289:2 Jue, Body 97 Heheru	L2M2892JBA, B
Phase 2 M289:2 Jue, Foot 97 Heheru	L2M2892JF
Phase 2 M51:4 Gu, Rim 96 Gangdongru	L2M514UR
Phase 2 M51:4 Gu, Foot 96 Gangdongru	L2M514UF
Phase 2 M289:1 Gu, Body 97 Heheru	L22891UB
Phase 3 M126:1 Li, Rim 94 ASD	L3M1261LR
Phase 3 M126:1 Li, Body 94 ASD	L3M1261LBA, B
Phase 3 M126:1 Li, Foot 94 ASD	L3M1261LF
Phase 3 M250:3 Gui, Rim 94 ASD	L3M2503GR
Phase 3 M250:3 Gui, Body 94 ASD	L3M2503GB
Phase 3 M241:1 Gui, Foot 94 ASD	L3M2411GF
Phase 3 M126:4 Jue, Rim 94 ASD	L3M1264JRA,B
Phase 3 M126:4 Jue, Body, Foot 94 ASD	L3M1264JBA,B
Phase 3 M250:2 Gu, Rim 94 ASD	L3M2502URA,B
Phase 3 M121:3 Gu, Body 94 ASD	L3M1213UB
Phase 3 M126:3 Gu, Foot 94 ASD	L3M1263UFA,B
Phase 4 M88:2 Li, Rim 94 ASD	L4M882LRA, B
Phase 4 M88:2 Li, Body 94 ASD	L4M882LB
Phase 4 M88:2 Li, Foot 94 ASD	L4M882LFA,B
Phase 4 M115:6 Gui, Rim 94 ASD	L4M1156GR
Phase 4 M115:6 Gui, Body 94 ASD	L4M1156GBA,B
Phase 4 M115:6 Gui, Foot 94 ASD	L4M1156GF
Phase 4 M148:4 Gu, Rim 97 ASD	L4M1484URA,B
Phase 4 M48:3 Gu, Body, Foot 94 ASD	L4M483UBF
Phase 4 M148:5 Jue, Rim 94 ASD	L4M1485JRA,B

List of Soil Samples

Soil Sample	Date	Explanations
97ABDT6-1 (310-312 CM)	12 APR 97	culturally modified clay loam, Shang
97ABDT6-1 (420-422 CM)	12 APR 97	culturally modified clay loam, Shang
97ABDT6-1 (440-442 CM)	12 APR 97	culturally modified clay loam, Shang
97ABDT6-1 (470-472 CM)	12 APR 97	clay loam (sterile soil) loessic,pre-Shang
97ABDT5-4 (200-202 CM)	13 APR 97	clay loam (sterile soil) loessic,pre-Shang
97ABDT5-4 (210-212 CM)	13 APR 97	clay loam (sterile soil) loessic,pre-Shang
AY-DH-01	30 SEP 97	clay loam (sterile soil) loessic,pre-Shang
AY97-01 (200-205 CM)	1 OCT 97	clay loam (sterile soil) loessic,pre-Shang
AY07F-02 (350-360 CM)	6 OCT 97	clay loam (sterile soil) loessic,pre-Shang
AY97F-04 (415-435 CM)	6 OCT 97	silty clay (sterile soil) alluvial, Shang?
AY97F-10 (320-350 CM)	30 OCT 97	clay, silty clay, alluvial Lacustrine
AY97F-11 (140-150 CM)	31 OCT 97	clay, silty clay, alluvial Late historic
AY97F-26 (320-330 CM)	10 NOV 97	silty clay alluvial (Ab) Shang?
AY97F-26 (360-370 CM)	10 NOV 97	silty clay alluvial (ABb) Shang?
AY97F-26 (380-390 CM)	10 NOV 97	Clayey silt, alluvial (Bkb) Shang?

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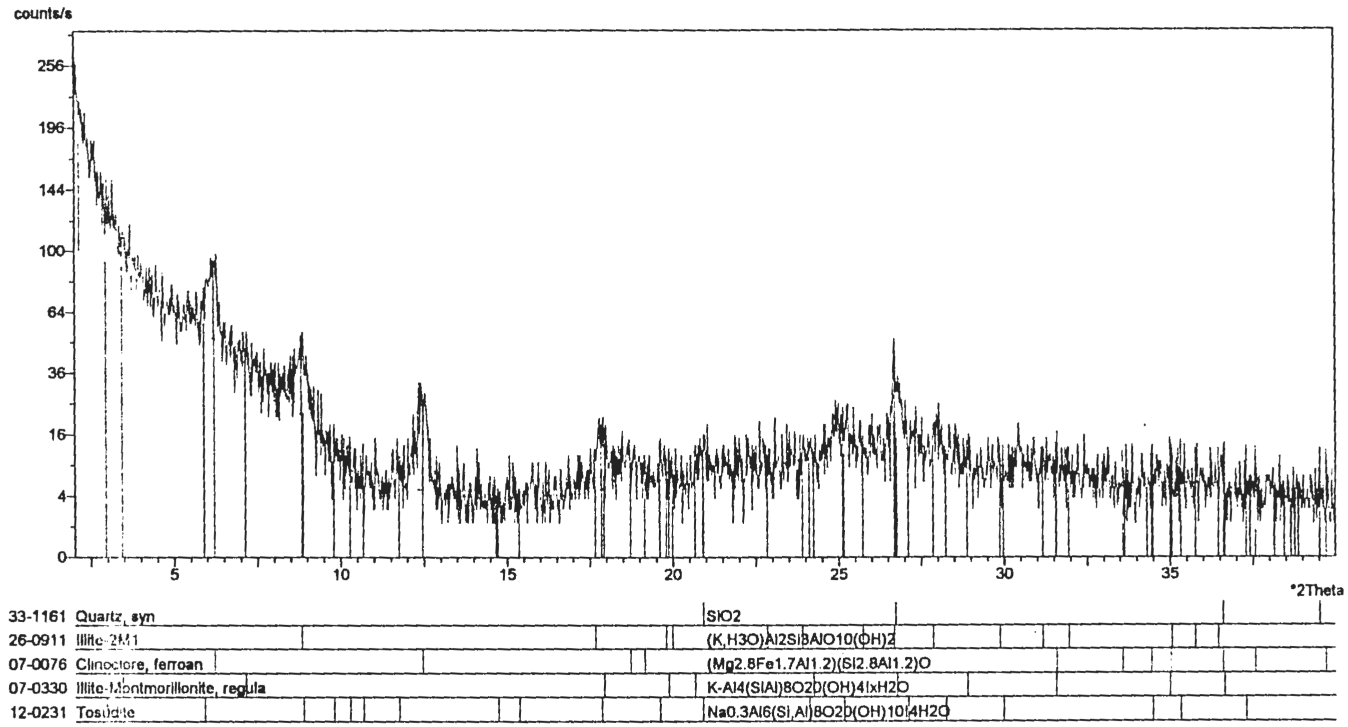

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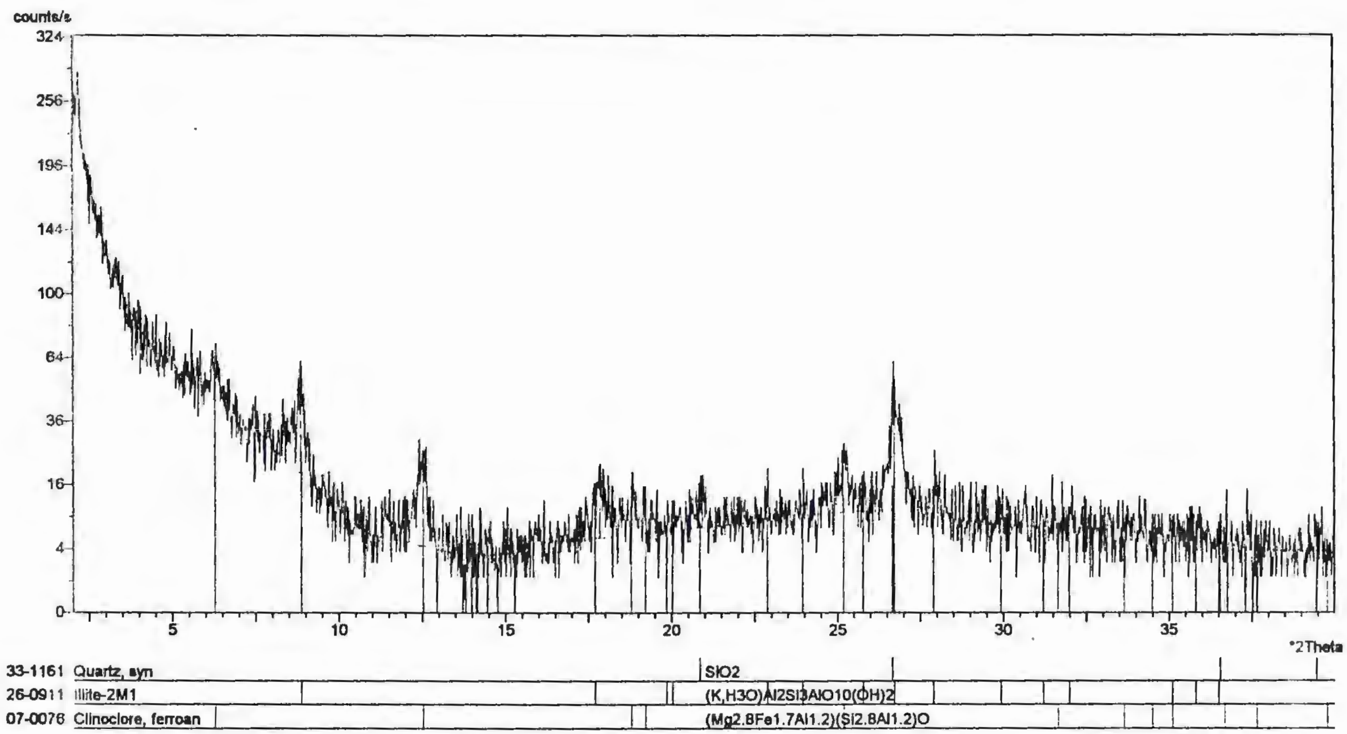
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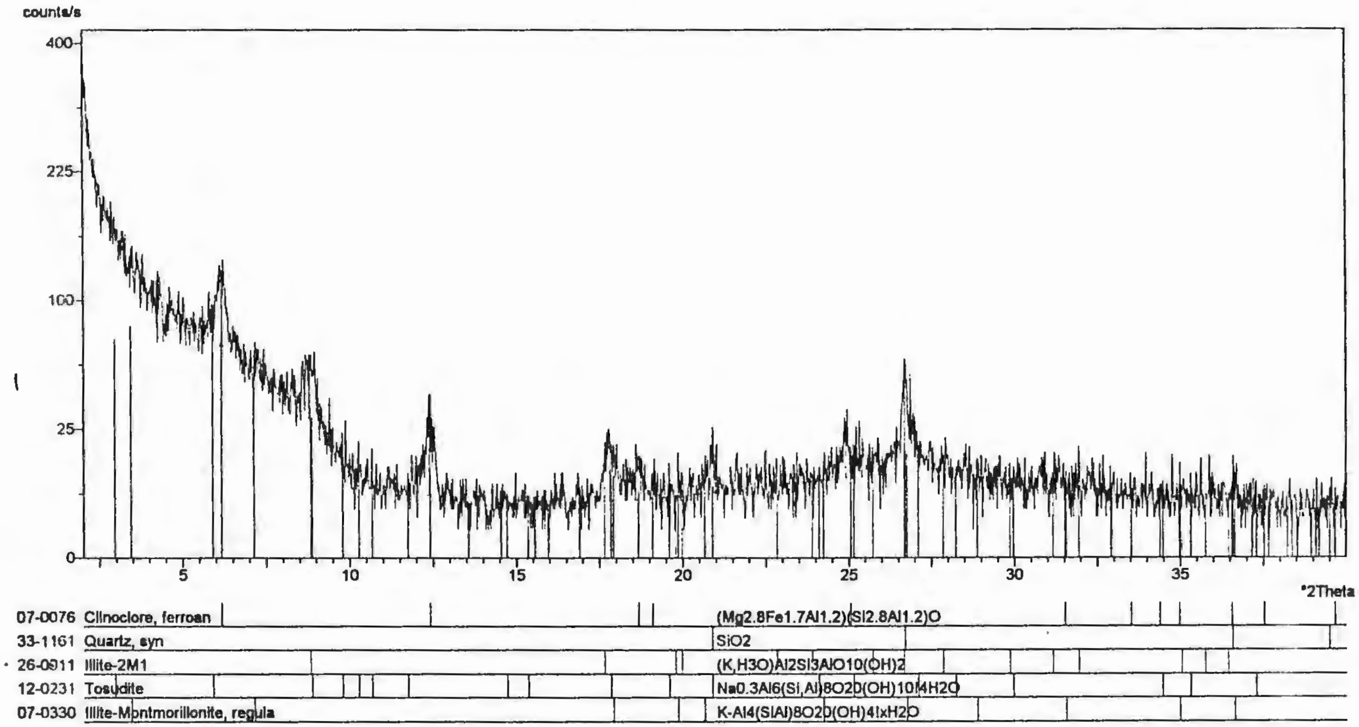

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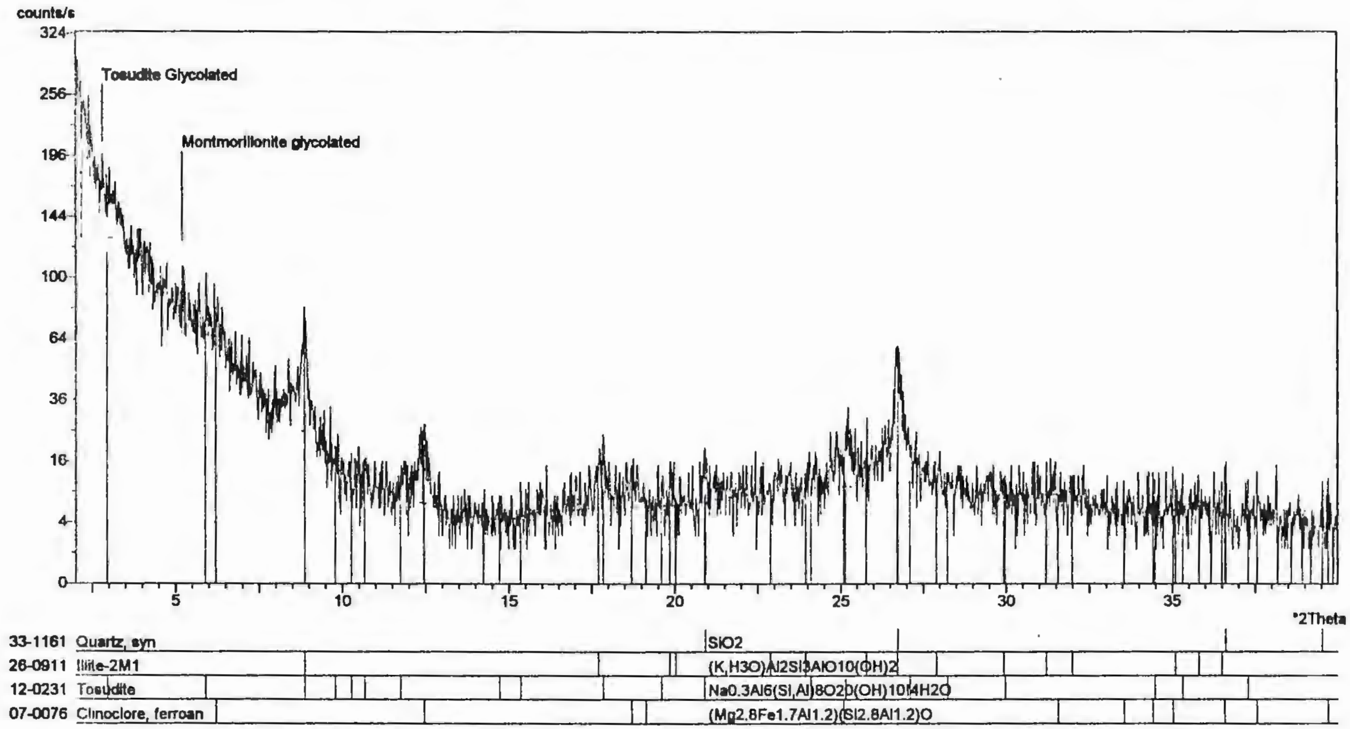

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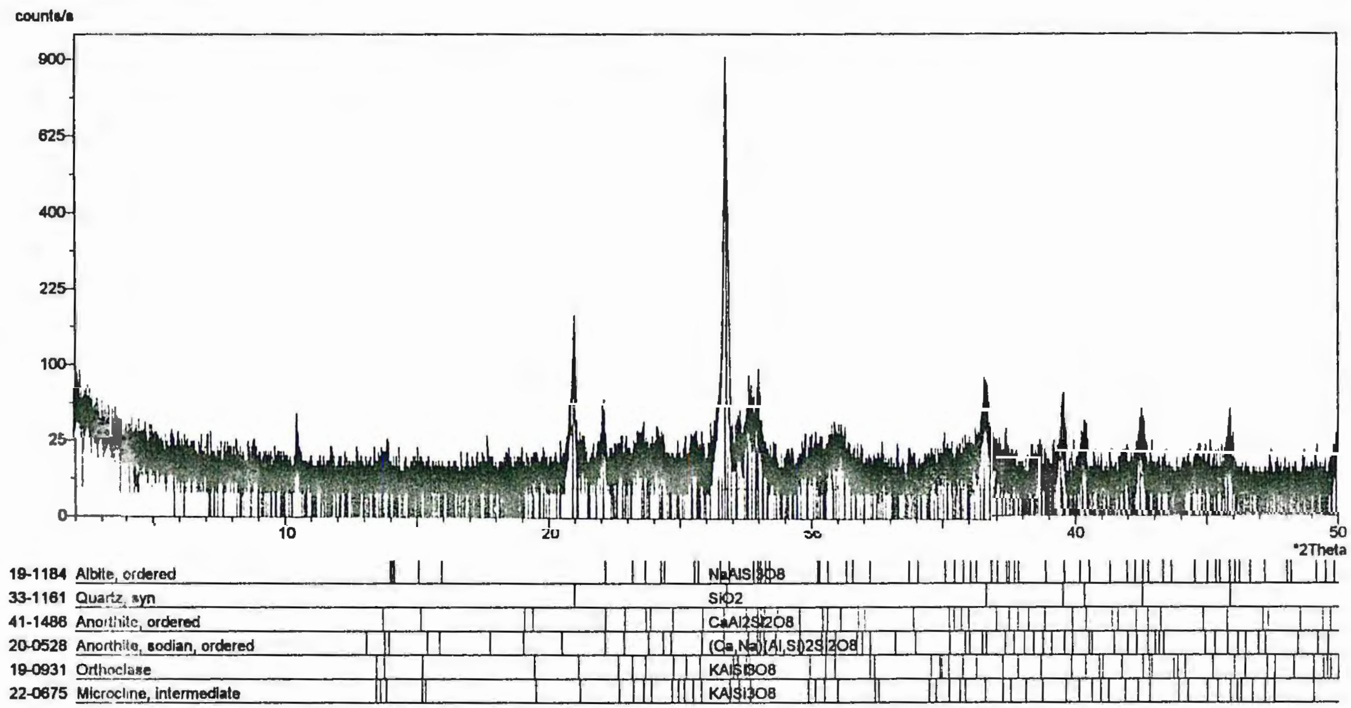

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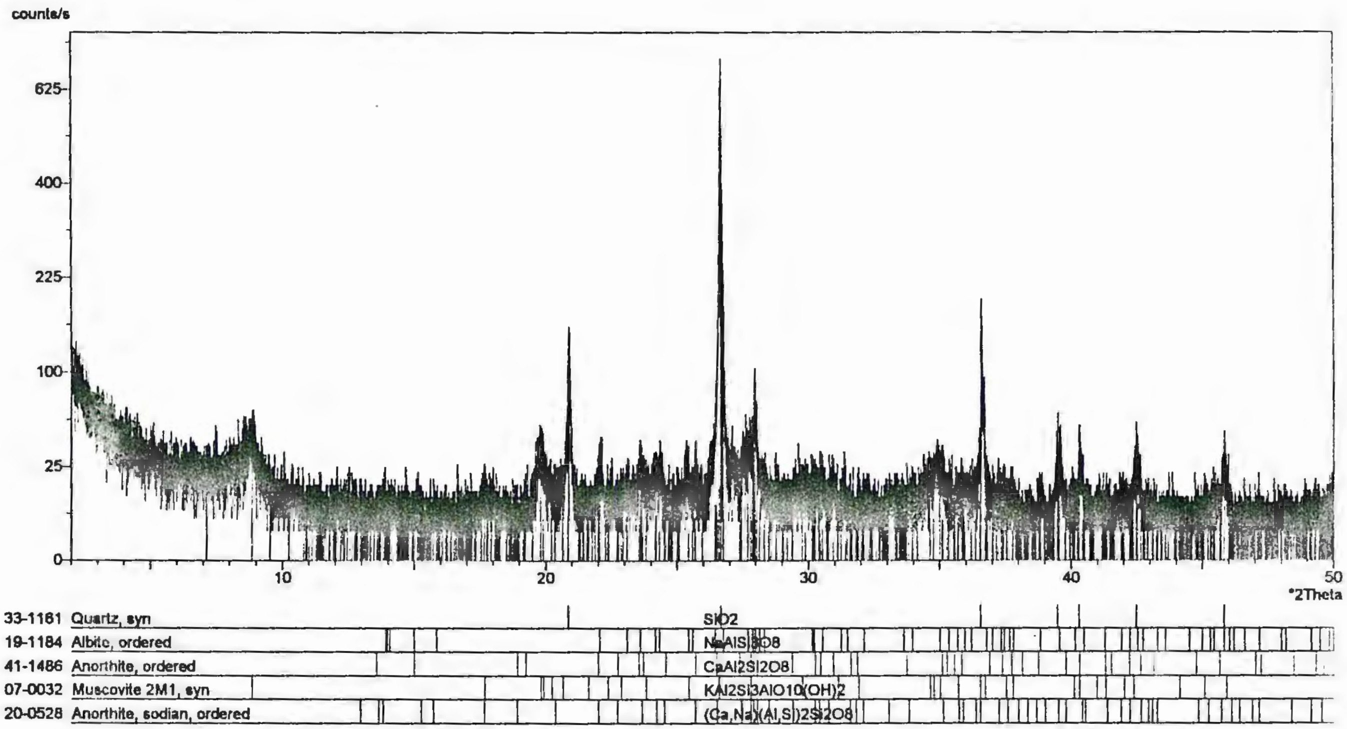

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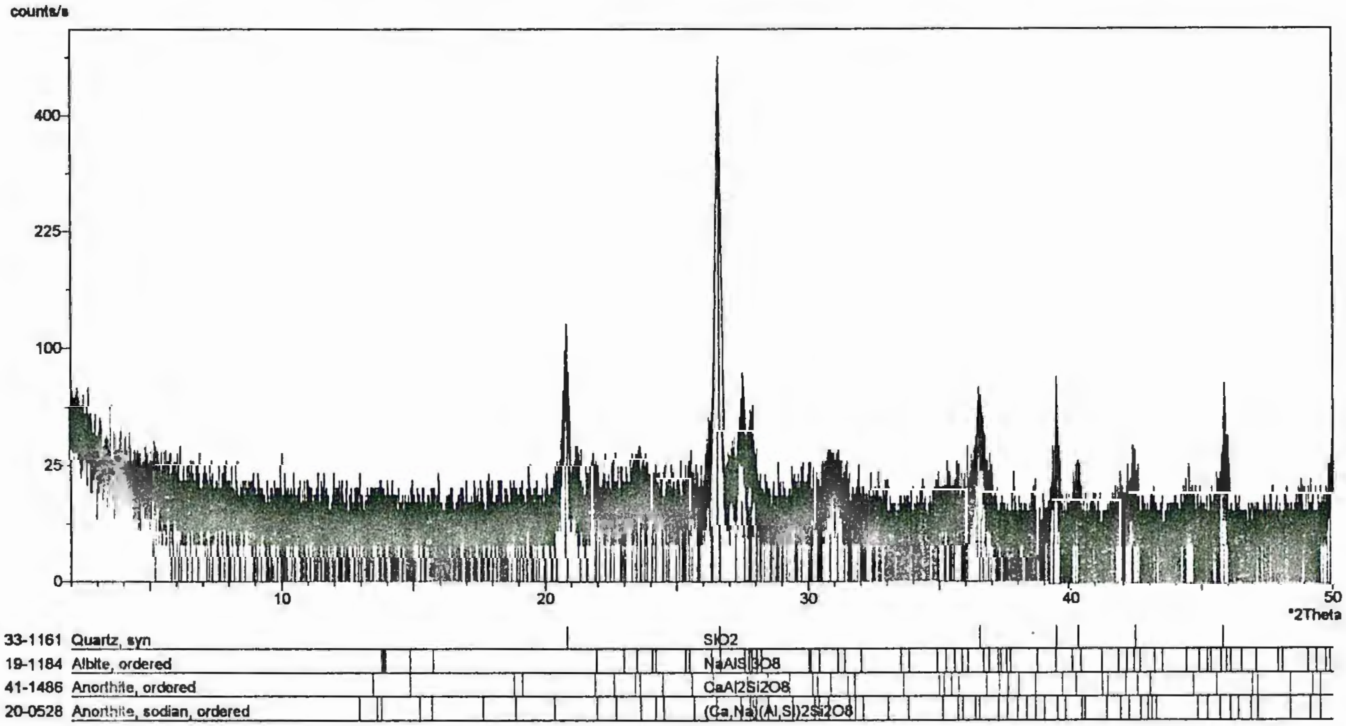

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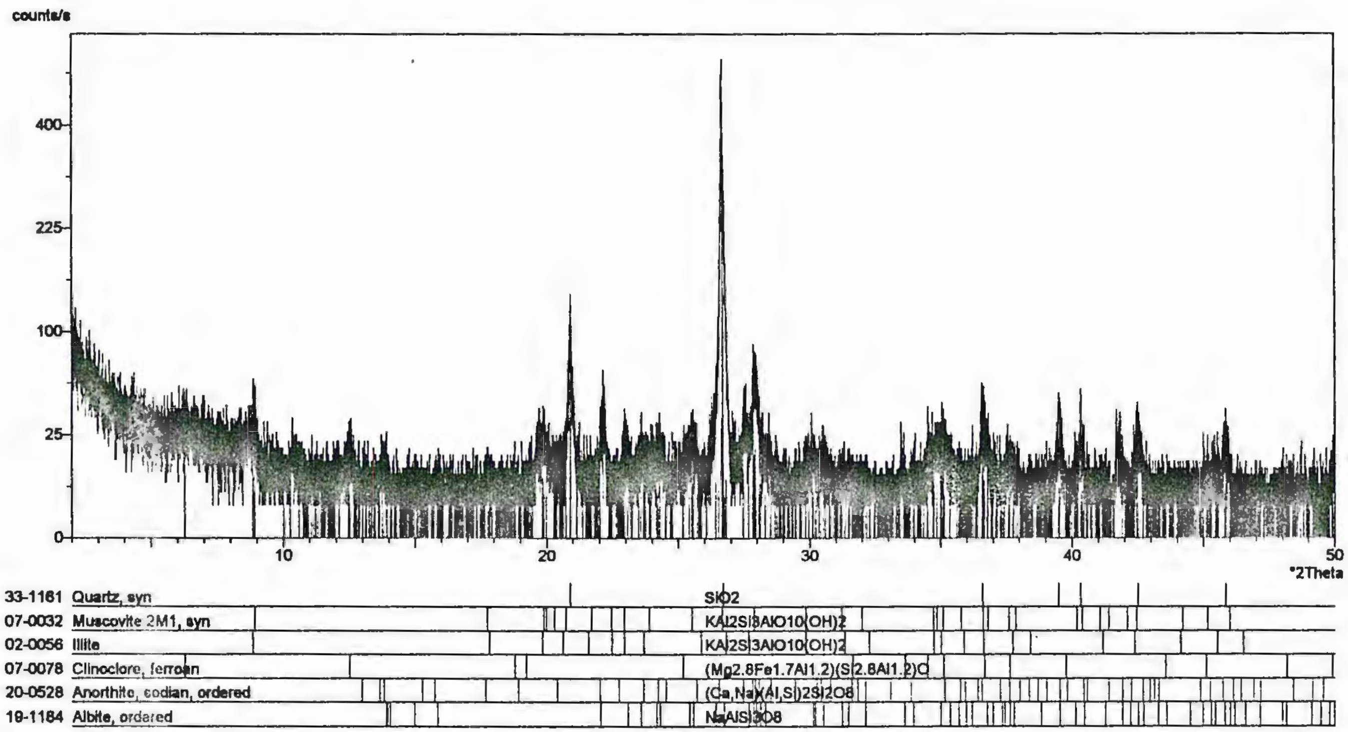

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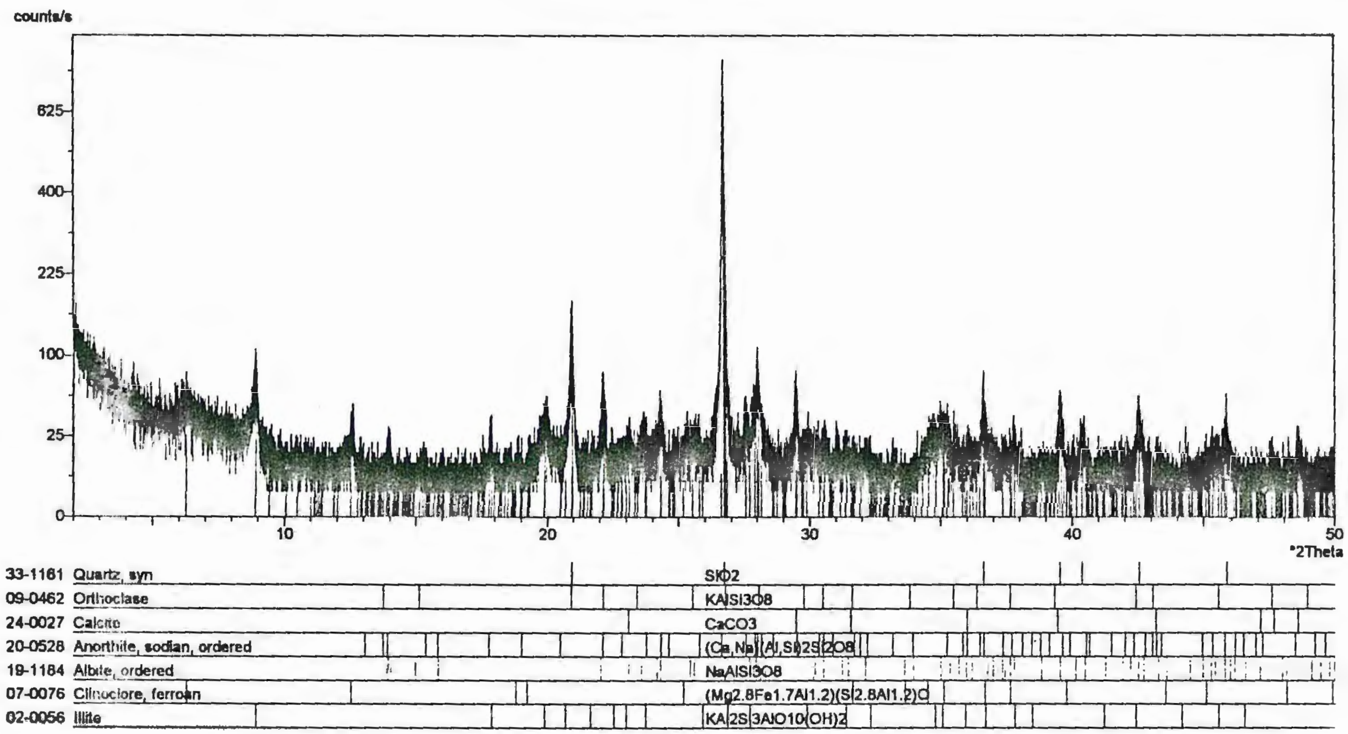

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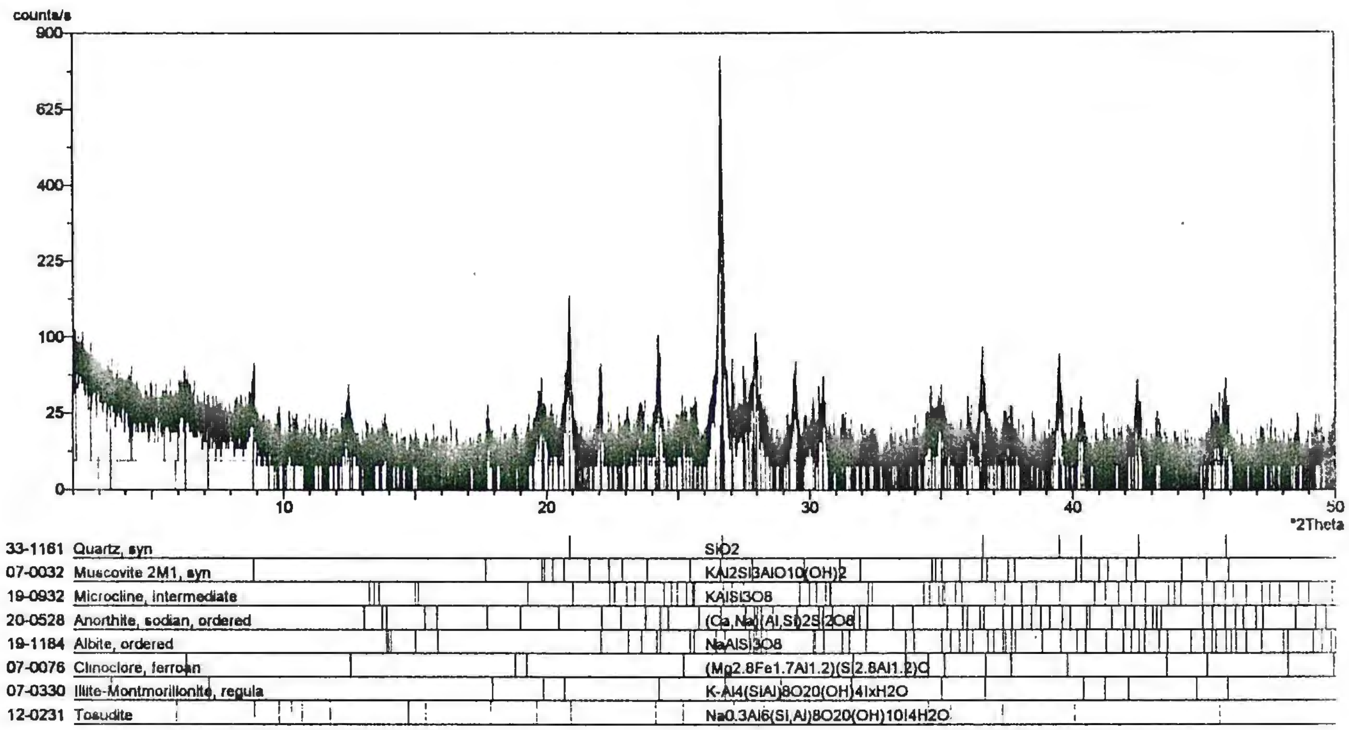

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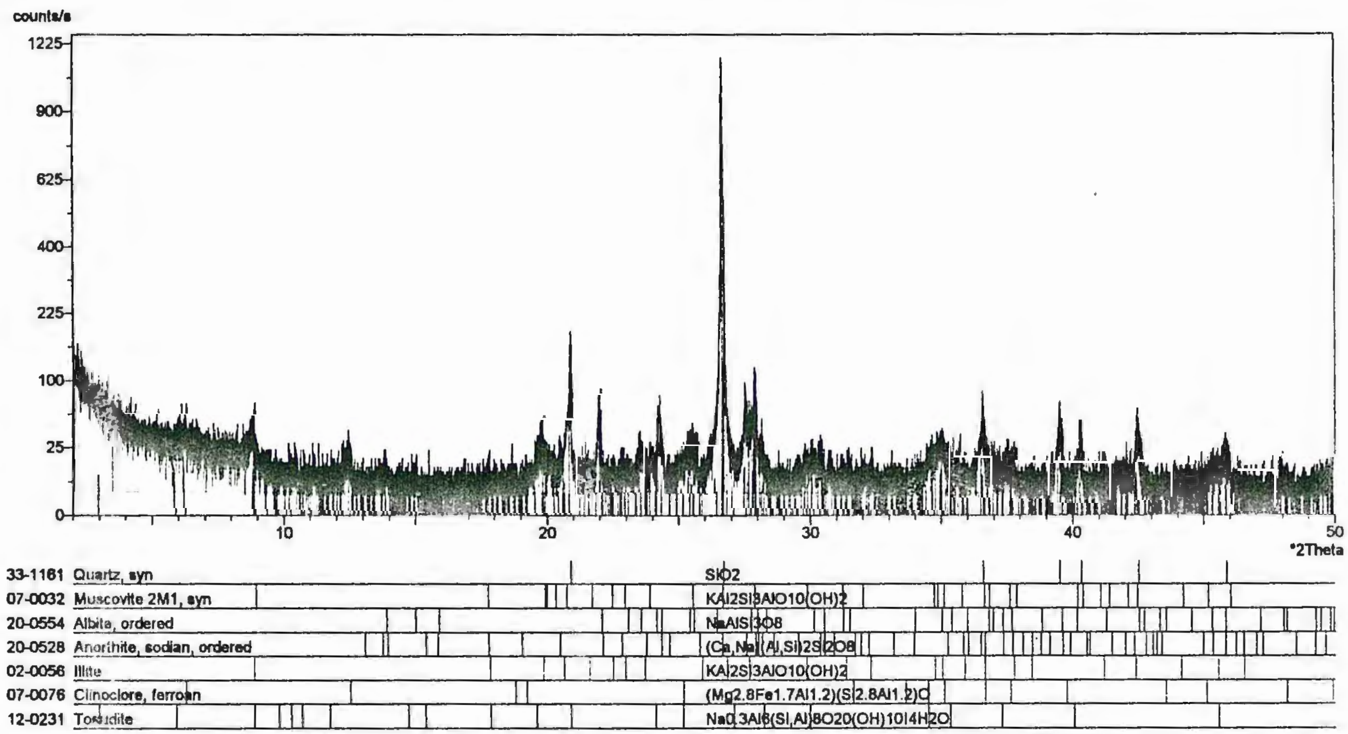

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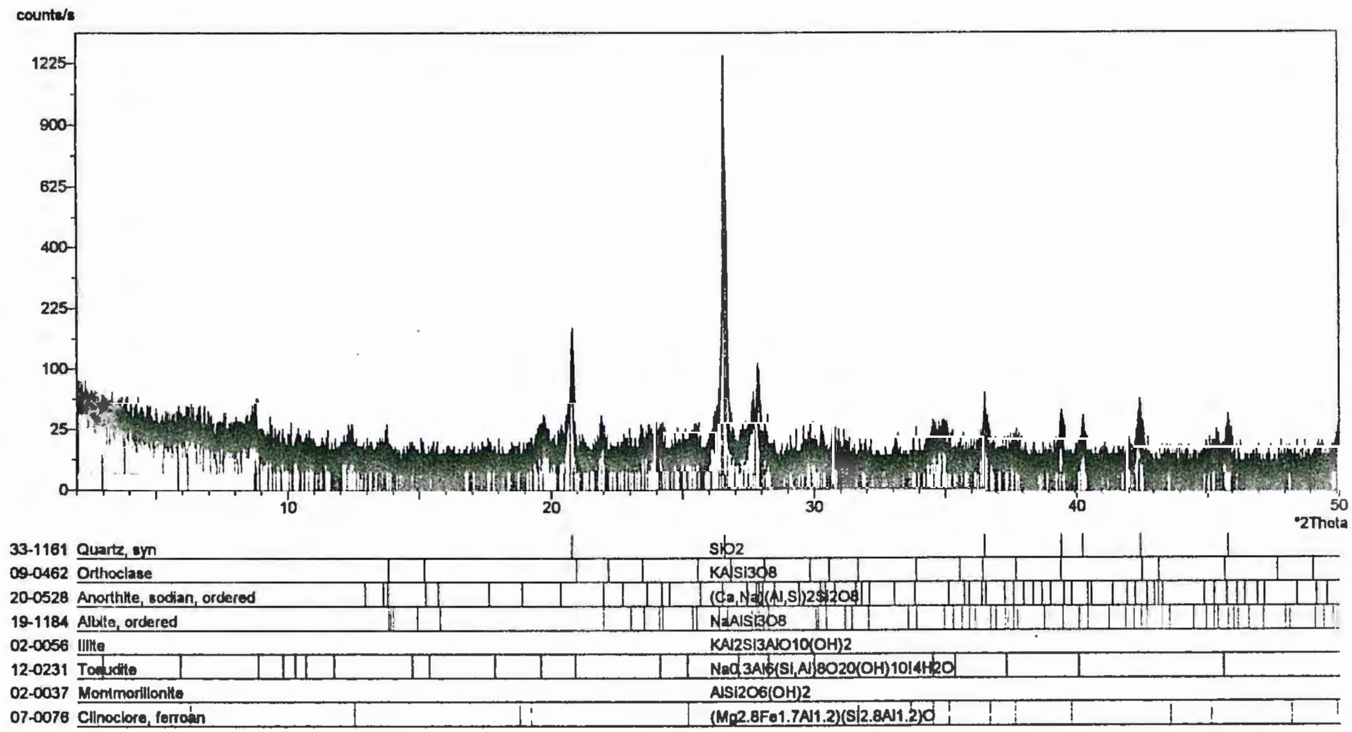

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51

Sherd and Soil Samples: Major Elements [* = duplicate samples]

Sample	Na	Mg	Al	Si	P	K	Ca	Ti	Fe	Mn	Sr	Ba
L2M511GB	1.39	1.92	14.95	67.87	0.803	2.43	1.65	0.81	5.77	0.093	169.07	763.37
L2M511GF	1.32	1.88	14.85	63.84	2.27	2.14	2.37	0.81	5.71	0.092	255.39	932.75
L3M2503GR	1.39	1.67	14.49	65.67	0.38	2.63	1.26	0.77	5.22	0.041	130.31	662.81
L3M2503GB1*	1.37	1.67	14.67	64.88	0.35	2.53	1.34	0.76	5.43	0.043	128.81	660.36
L3M2503GB2*	1.36	1.68	14.59	62.44	0.34	2.48	1.38	0.76	5.38	0.042	128.38	655.36
L4M1156GB	1.46	1.8	13.98	69.03	0.24	2.82	1.6	0.77	5.41	0.1	136.77	577.16
L4M1156GF	1.26	1.77	14.25	70.13	0.24	2.91	1.1	0.77	5.39	0.1	123.95	581.17
L2M514UR	1.51	1.62	13.84	66.28	0.14	2.52	1.13	0.79	5.2	0.05	135.21	685.65
L3M2502UR	1.41	1.46	13.92	63.44	0.58	2.45	1.32	0.74	5.39	0.07	146.91	781.75
L2M131LB	1.47	1.28	13.37	66.66	0.23	2.21	1.7	0.59	4.67	0.055	170.19	731.46
L3M1261LR	1.37	1.69	14.51	65.15	0.41	2.77	1.46	0.78	5.65	0.099	151.63	832.79
L4M882LR	1.29	2.06	16.24	66.19	0.14	2.75	1.39	0.81	6.27	0.1	130.22	615.08
L3M1264JR	1.3	1.84	14.42	65.3	0.18	2.64	0.91	0.77	5.63	0.073	129.77	604.37
Soils												
61-470	1.55	1.81	13.12	66.06	0.22	2.67	1.46	0.74	4.76	0.047	137.54	520.07
61-310	1.36	1.99	12.73	62.86	0.58	2.73	3.56	0.69	4.8	0.091	155.17	541.77
26-360	1.4	1.56	12.8	68.16	0.08	2.53	1.21	0.71	4.56	0.059	124.85	513.21
AYF4	0.98	2.42	14.66	53.64	0.17	2.56	4.31	0.7	6.3	0.084	172.25	593.23

Sherd and Soil Samples: Trace Elements [* = duplicate samples]

Sample	Be	V	Cr	Co	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Cs	Ba	Hf	Pb	Th	U
L2M511GB	1.63	91.41	89.65	16.3	44.66	27.13	80.28	20	103.36	171.22	30.12	256.53	7.45	743.13	6.81	25.97	13.47	3.07
L2M511GF	3	107.79	92.15	16.1	44	27.31	80.52	19.81	80.47	255.93	29.77	249.87	4.99	904.07	6.62	25.05	13.86	3.2
L3M2503GR	2.35	104.36	93.5	13.25	42.91	27.93	62.88	18.45	103.3	131.14	23.28	249.19	7.87	643.17	7.41	24.22	20.85	2.67
L3M2503GB1*	2.01	105.1	97.23	12.44	46.55	29.92	60.21	18.65	103.44	130.02	23.03	256.26	7.78	643.29	7.76	24.94	23.21	2.77
L3M2503GB2*	1.58	102.98	89.43	12.87	42.29	30.79	59.73	18.58	104.78	131.22	23.72	236.6	7.58	648.5	6.49	25	16.48	2.72
L4M1156GB	1.6	89.63	80.03	15.39	40.24	36.02	84.29	18.69	117.81	135.73	27.59	258.07	8.77	561.7	6.93	24.99	14.48	2.62
L4M1156GF	2.27	100.42	86.3	15.63	42.27	25.49	75.2	19.13	123.51	125.45	26.84	246.29	9.34	574.47	6.6	23.14	13.85	2.63
L2M514UR	2.89	102.89	90.57	13.85	42.5	31.29	74.52	18.12	103.48	138.21	27.79	250.14	7.62	675.45	6.71	24.41	16.16	2.64
L3M2502UR	2.16	98.85	109.37	15.08	57.67	29.64	72.5	17.89	97.25	144.85	22.05	250.73	7.02	750.15	7.49	24.1	20.25	2.67
L2M131LB	1.43	71.93	101.14	13.2	40.8	28.79	49.27	15.5	81.39	168.14	20.46	252.3	4.17	705.17	6.56	20.75	11.29	1.92
L3M1261LR	2.91	116.19	88.52	16.12	44.59	27.97	73.17	19.46	114.53	154.79	29.01	229.77	8.04	811.17	5.98	25.59	13.69	3.06
L4M882LR	1.5	104	89.29	18.05	46.1	30.6	89.16	21.6	131	131.23	29.32	232.72	10.71	600	6.22	28.9	14.7	2.8
L3M1264JR	2.87	99.19	89.89	14.86	46.57	33.59	75.28	19.81	113.96	132.64	26.6	235.82	9.55	598.28	7.09	25.07	21.23	2.64
Soils																		
61-470	1.67	87.89	81.72	14.77	40.2	30.76	73.26	18.1	116.87	138.2	26.87	210.03	8.76	513.53	5.76	22.45	14.02	2.24
61-310	3.12	92.48	75.69	13.73	43.33	44.67	107.06	17.68	117.66	154.29	23.67	167.02	9.41	522.79	5.47	21.07	19.16	2.1
26-360	1.73	88.31	75.66	12.45	45.49	61.03	54.6	17.1	108.43	126.67	27.57	301.18	7.62	513.68	7.85	21.21	13.65	2.8
AYF4	2.05	106.36	86.62	17.05	47.62	38.27	84.5	19.82	134.86	174.89	26.77	155.24	10.66	587.76	4.11	24.82	13.24	2.38

Sherd and Soil Samples: Rare Earth Elements [* = duplicate samples]

Sample	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
L2M511GB	30.21	43.28	82.59	9.77	35.72	7.41	1.57	7.55	1.13	6.01	1.24	3.52	0.5	3.43	0.55
L2M511GF	29.13	42.37	78.27	9.54	33.99	7.01	1.6	7.49	1.07	5.9	1.2	3.47	0.49	3.14	0.53
L3M2503GR	23.17	31.33	57.05	7.28	26.05	5.37	1.21	5.7	0.85	4.67	0.96	2.7	0.41	2.81	0.43
L3M2503GB1*	22.95	30.38	58.48	7.17	25.92	5.46	1.12	5.12	0.93	4.67	0.99	2.87	0.42	2.8	0.45
L3M2503GB2*	23.41	30.53	58.75	7.26	26.48	5.54	1.15	5.55	0.92	4.65	0.99	2.74	0.43	2.89	0.46
L4M1156GB	27.53	41.55	76.56	9.22	33.61	6.66	1.46	6.74	1.07	5.51	1.11	3.14	0.48	3.05	0.49
L4M1156GF	26.65	40.4	75.71	9.19	33.12	6.34	1.44	6.59	1.01	5.31	1.06	3.13	0.48	3.04	0.48
L2M514UR	26.85	37.28	66.63	8.71	32.25	6.54	1.35	6.81	1.05	5.33	1.11	3.27	0.48	2.96	0.48
L3M2502UR	22.49	30.37	59.3	7.27	25.3	5.26	1.2	5.2	0.84	4.73	0.91	2.62	0.39	2.74	0.48
L2M131LB	20.48	31.22	63.36	7.06	25.56	5.24	1.15	5.46	0.81	4.03	0.78	2.49	0.33	2.32	0.37
L3M1261LR	27.93	39.55	78.65	9.17	32.57	6.43	1.36	6.78	0.98	5.27	1.09	3.17	0.49	3.21	0.48
L4M882LR	28.98	42.24	84.95	9.72	35.09	7.21	1.63	7.31	1.2	5.65	1.2	3.31	0.51	3.25	0.52
L3M1264JR	25.85	38.39	74.74	8.86	31.83	6.38	1.36	6.62	1.03	5.03	1.04	3.11	0.44	2.94	0.46
Soils															
61-470	26.25	36.43	69.42	8.44	30.17	5.89	1.34	6.22	0.94	4.82	0.99	3	0.43	2.95	0.42
61-310	22.77	34.56	64.7	7.72	28.53	5.52	1.3	5.88	0.88	4.52	0.94	2.66	0.4	2.58	0.4
26-360	27.47	36.91	72.03	8.63	30.43	6.22	1.25	6.29	0.95	5.13	0.97	3.03	0.45	2.85	0.49
AYF4	26.7	39.3	73.75	8.85	31.81	6.7	1.32	6.56	0.99	5.42	1.04	2.86	0.42	2.86	0.46

List of Soil and Sherd Samples with Corresponding Factor Analysis Numbers

Soil Sample Label	Factor Analysis Number
26-360	15
61-310	16
61-470	11
AYF 4	12

Sherd Sample Label	Factor Analysis Number
L2M131LB	21
L2M511GB	23
L2M511GF	19
L2M514UR	8
L3M1261LR	2
L3M1264JR	9
L3M2502UR	10
L3M2503GB1	13
L3M2504GB2	14
L3M2503GR	3
L4M1156GB	5
L4M1156GF	4
L4M882LR	1

		VA1	VA2	VA3	VA4	VA5	VA6	VA7
1	Na	0.18	-0.05	0.77	0.14	-0.19	0	-0.34
2	Mg	-0.49	0.2	-0.8	0	0.16	0	0
3	Al	-0.46	-0.05	-0.17	-0.3	0.45	-0.57	0.23
4	Si	-0.22	0.17	0.88	0.11	-0.26	-0.06	-0.16
5	P	-0.25	-0.85	-0.06	0.25	0.16	0	0
6	K	-0.21	0.85	0	0.36	0.05	-0.09	0
7	Ca	0	-0.18	-0.89	0.16	-0.18	0.23	0
8	Ti	-0.64	0	0.21	0.15	0.65	-0.23	0
9	Fe	-0.52	0	-0.46	-0.15	0.38	-0.46	0.35
10	Mn	-0.7	0	-0.26	0.4	-0.27	-0.12	0.3
11	Sr	-0.23	-0.89	-0.31	0.13	-0.13	0	0
12	Ba	-0.12	-0.86	0.13	0.08	0.15	-0.36	0.15
13	Y	-0.97	0	0	-0.06	0.1	0.07	0
14	La	-0.96	0	-0.15	0.12	-0.11	0	0
15	Ce	-0.94	0	-0.13	0	-0.21	-0.06	0.06
16	Pr	-0.98	0	-0.09	0.1	0	0	0
17	Nd	-0.98	0	-0.12	0.07	0	0	-0.09
18	Sm	-0.97	-0.07	-0.14	-0.07	0	0	0
19	Eu	-0.91	-0.1	-0.13	0.22	-0.07	-0.15	0
20	Gd	-0.96	-0.11	-0.12	0.07	0	0	-0.08
21	Tb	-0.93	0.06	0	-0.06	0.14	-0.16	0
22	Dy	-0.95	-0.13	-0.09	0	0.18	0	0.09
23	Ho	-0.91	-0.08	-0.05	0	0.34	-0.13	0
24	Er	-0.93	-0.13	0.14	0	0.2	0	-0.11
25	Tm	-0.91	0.12	0.1	0.08	0.32	0	-0.08
26	Yb	-0.88	0	0.08	0	0.34	-0.19	0
27	Lu	-0.83	-0.16	0.15	-0.13	0.32	0	0.32
28	Be	0	-0.28	-0.13	0.78	0.33	0.13	-0.05
29	V	-0.23	0	-0.25	0.18	0.81	-0.21	0.13
30	Cr	0.39	-0.42	0.19	-0.18	0.1	-0.58	0.45
31	Co	-0.72	0	-0.43	0.09	-0.14	-0.4	0.25
32	Ni	0.12	-0.09	-0.08	0	0.22	0	0.91
33	Cu	0	0.26	-0.07	-0.06	-0.14	0.91	0.13
34	Zn	-0.43	0.15	-0.51	0.63	0	0	0.06
35	Ga	-0.7	0.12	-0.31	0	0.48	-0.3	0.17
36	Rb	-0.32	0.8	-0.48	0.06	0.07	0	0
37	Sr	-0.25	-0.88	-0.33	0.12	-0.09	0	-0.05
38	Y	-0.96	0	0	0	0.15	0.09	-0.12
39	Zr	-0.13	-0.15	0.89	-0.31	0.05	0.13	0.13
40	Cs	-0.27	0.77	-0.49	0.14	0.22	0	0.07
41	Ba	-0.14	-0.86	0.12	0	0.19	-0.34	0.11
42	Hf	0.13	-0.06	0.88	-0.09	0.23	0.12	0.24
43	Pb	-0.56	0.08	-0.08	-0.2	0.52	-0.49	0.23
44	Th	0.48	0.22	0.14	0.31	0.61	0	0.26
45	U	-0.6	-0.3	0.28	-0.06	0.61	0	0.21
	%:	44.51	16.02	12.53	10.01	4.62	3.52	2.75

93.95%

VA1 VA2 VA3 VA4 VA5 VA6 VA7

16	Pr	-0.98	0	0	0	0	0	0
17	Nd	-0.98	0	0	0	0	0	0
13	Y	-0.97	0	0	0	0	0	0
18	Sm	-0.97	0	0	0	0	0	0
14	La	-0.96	0	0	0	0	0	0
38	Y	-0.96	0	0	0	0	0	0
20	Gd	-0.96	0	0	0	0	0	0
22	Dy	-0.95	0	0	0	0	0	0
15	Ce	-0.94	0	0	0	0	0	0
24	Er	-0.93	0	0	0	0	0	0
21	Tb	-0.93	0	0	0	0	0	0
19	Eu	-0.91	0	0	0	0	0	0
23	Ho	-0.91	0	0	0	0.34	0	0
25	Tm	-0.91	0	0	0	0.32	0	0
26	Yb	-0.88	0	0	0	0.34	0	0
27	Lu	-0.83	0	0	0	0.32	0	0.32
31	Co	-0.72	0	-0.43	0	0	-0.4	0.25
35	Ga	-0.7	0	-0.31	0	0.48	-0.3	0
10	Mn	-0.7	0	-0.26	0.4	-0.27	0	0.3
43	Pb	-0.56	0	0	0	0.52	-0.49	0
9	Fe	-0.52	0	-0.46	0	0.38	-0.46	0.35
11	Sr	0	-0.89	-0.31	0	0	0	0
37	Sr	-0.25	-0.88	-0.33	0	0	0	0
41	Ba	0	-0.86	0	0	0	-0.34	0
12	Ba	0	-0.86	0	0	0	-0.36	0
6	K	0	0.85	0	0.36	0	0	0
5	P	-0.25	-0.85	0	0.25	0	0	0
36	Rb	-0.32	0.8	-0.48	0	0	0	0
40	Cs	-0.27	0.77	-0.49	0	0	0	0
39	Zr	0	0	0.89	-0.31	0	0	0
7	Ca	0	0	-0.89	0	0	0	0
42	Hf	0	0	0.88	0	0	0	0
4	Si	0	0	0.88	0	-0.26	0	0
2	Mg	-0.49	0	-0.8	0	0	0	0
1	Na	0	0	0.77	0	0	0	-0.34
28	Be	0	-0.28	0	0.78	0.33	0	0
34	Zn	-0.43	0	-0.51	0.63	0	0	0
29	V	0	0	-0.25	0	0.81	0	0
8	Ti	-0.64	0	0	0	0.65	0	0
44	Th	0.48	0	0	0.31	0.61	0	0.26
45	U	-0.6	-0.3	0.28	0	0.61	0	0
33	Cu	0	0.26	0	0	0	0.91	0
30	Cr	0.39	-0.42	0	0	0	-0.58	0.45
3	Al	-0.46	0	0	-0.3	0.45	-0.57	0
32	Ni	0	0	0	0	0	0	0.91

	Sample	VF1	VF2	VF3	VF4	VF5	VF6	VF7
1	Sample 1	-1.65	-0.65	0.44	-0.62	-0.28	-0.31	0.15
2	Sample 2	-1.13	-3.08	-0.28	0.56	0.61	0.33	-0.34
3	Sample 3	1.14	0.16	0.39	0.08	1.22	-0.43	-0.54
4	Sample 4	1.16	0.13	0.44	-0.53	1.57	-0.11	0.26
5	Sample 5	0.95	0.03	-0.15	-1.38	1.19	-0.2	-0.93
6	Sample 6	-0.93	0.86	0.59	0.26	-0.88	0.01	-0.21
7	Sample 7	-0.6	1.04	0.46	0.77	-0.61	-0.71	-0.03
8	Sample 8	-0.22	-0.09	0.71	0.34	0.69	0.13	-1.09
9	Sample 9	1.22	-0.52	0.57	0.59	-0.07	-0.49	2.91
10	Sampe 10	1.54	-1.11	0.36	-1.06	-2.68	-0.81	-0.38
11	Sample 1	-0.56	-0.25	0.11	0.9	0.45	-0.77	-0.13
12	Sample 1	-1.48	1.18	-0.33	-0.61	-0.05	-1.38	0.77
13	Sample 1	-0.1	0.64	0.18	0.6	0.53	-0.03	0.57
14	Sample 1	0.14	0.71	-0.03	-0.05	-0.71	-0.09	-1.79
15	Sample 1	0.89	0.4	-1.27	2.46	-0.58	1.21	-0.33
16	Sample 1	-0.29	0.4	1.1	-1.17	-0.38	3.25	0.57
17	Sample 1	-0.06	0.15	-3.28	-1.14	-0.04	0.41	0.55

	Na	Mg	Al	Si	P	K	Ca
Na	1						
Mg	-0.72	1					
Al	-0.44	0.4	1				
Si	0.67	-0.54	-0.13	1			
P	-0.04	0.1	0.19	-0.09	1		
K	-0.1	0.3	0.02	0.22	-0.56	1	
Ca	-0.6	0.67	-0.09	-0.76	0.22	-0.11	1
Ti	-0.02	0.3	0.63	0.22	0.31	0.25	-0.34
Fe	-0.68	0.66	0.89	-0.41	0.17	0.1	0.23
Mn	-0.39	0.49	0.31	0.07	0.27	0.34	0.3
Sr	-0.19	0.2	0.13	-0.31	0.88	-0.66	0.49
Ba	0.05	-0.23	0.38	-0.06	0.71	-0.6	-0.06
Y	-0.18	0.5	0.42	0.18	0.26	0.18	-0.02
La	-0.27	0.57	0.37	0.18	0.25	0.24	0.13
Ce	-0.27	0.51	0.41	0.19	0.18	0.23	0.07
Pr	-0.25	0.54	0.41	0.2	0.22	0.25	0.04
Nd	-0.23	0.55	0.4	0.2	0.2	0.26	0.06
Sm	-0.3	0.58	0.53	0.09	0.25	0.1	0.09
Eu	-0.16	0.52	0.49	0.23	0.4	0.15	0.06
Gd	-0.2	0.52	0.43	0.16	0.33	0.09	0.07
Tb	-0.21	0.54	0.62	0.19	0.15	0.21	-0.07
Dy	-0.29	0.55	0.54	0.08	0.38	0.09	0.06
Ho	-0.2	0.54	0.64	0.13	0.37	0.15	-0.03
Er	-0.03	0.36	0.46	0.32	0.36	0.08	-0.18
Tm	-0.09	0.4	0.52	0.31	0.21	0.34	-0.21
Yb	-0.12	0.43	0.62	0.22	0.25	0.25	-0.2
Lu	-0.19	0.3	0.59	0.17	0.38	-0.01	-0.18
Be	-0.12	0.12	-0.11	-0.17	0.38	0.06	0.19
V	-0.45	0.38	0.59	-0.36	0.23	0.22	0.05
Cr	0.06	-0.44	0.33	-0.11	0.17	-0.5	-0.26
Co	-0.47	0.64	0.61	-0.18	0.21	0.22	0.27
Ni	-0.3	0	0.19	-0.36	0.07	-0.15	0.04
Cu	-0.07	0.08	-0.55	-0.08	-0.26	0.09	0.25
Zn	-0.3	0.72	0.14	-0.22	0.21	0.4	0.54
Ga	-0.51	0.71	0.84	-0.16	0.2	0.3	0.06
Rb	-0.49	0.69	0.18	-0.21	-0.56	0.82	0.26
Sr	-0.21	0.22	0.15	-0.32	0.88	-0.66	0.48
Y	-0.16	0.51	0.39	0.17	0.26	0.2	-0.01
Zr	0.51	-0.69	0.01	0.73	0.05	-0.23	-0.79
Cs	-0.48	0.71	0.23	-0.23	-0.5	0.8	0.22
Ba	0.03	-0.22	0.39	-0.07	0.71	-0.6	-0.07
Hf	0.52	-0.7	-0.05	0.65	0.03	-0.16	-0.78
Pb	-0.29	0.43	0.93	-0.1	0.12	0.15	-0.15
Th	0.05	-0.1	0.04	-0.1	-0.07	0.12	-0.19
U	-0.1	0.09	0.58	0.18	0.47	-0.08	-0.32

	Ti	Fe	Mn	Sr	Ba	Y	La
Ti	1						
Fe	0.55	1					
Mn	0.28	0.5	1				

Sr	0.01	0.22	0.32	1			
Ba	0.26	0.3	0.16	0.68	1		
Y	0.68	0.5	0.59	0.24	0.12	1	
La	0.51	0.5	0.78	0.31	0.07	0.92	1
Ce	0.43	0.52	0.8	0.27	0.09	0.88	0.96
Pr	0.58	0.52	0.74	0.26	0.09	0.96	0.99
Nd	0.58	0.51	0.73	0.24	0.06	0.94	0.99
Sm	0.6	0.62	0.66	0.31	0.15	0.95	0.95
Eu	0.61	0.53	0.76	0.38	0.19	0.86	0.93
Gd	0.58	0.5	0.67	0.38	0.2	0.93	0.96
Tb	0.7	0.64	0.58	0.13	0.06	0.88	0.87
Dy	0.73	0.64	0.64	0.34	0.24	0.95	0.9
Ho	0.85	0.66	0.57	0.26	0.26	0.91	0.84
Er	0.76	0.46	0.51	0.27	0.25	0.94	0.87
Tm	0.85	0.51	0.55	0.06	0.13	0.91	0.82
Yb	0.87	0.61	0.51	0.1	0.23	0.9	0.77
Lu	0.79	0.6	0.5	0.23	0.35	0.83	0.69
Be	0.23	0.04	0.19	0.29	0.3	0.04	0.1
V	0.66	0.64	0.18	0.07	0.35	0.32	0.17
Cr	-0.05	0.2	-0.27	0.16	0.62	-0.42	-0.45
Co	0.42	0.78	0.78	0.33	0.23	0.67	0.77
Ni	0.07	0.33	0.07	0.02	0.26	-0.12	-0.2
Cu	-0.35	-0.39	-0.05	-0.2	-0.56	0.03	-0.02
Zn	0.3	0.39	0.69	0.21	-0.12	0.37	0.53
Ga	0.78	0.88	0.54	0.11	0.14	0.69	0.65
Rb	0.17	0.39	0.38	-0.49	-0.65	0.32	0.37
Sr	0.04	0.24	0.32	1	0.69	0.27	0.33
Y	0.68	0.47	0.58	0.24	0.12	0.99	0.92
Zr	0.21	-0.29	-0.22	-0.16	0.21	0.12	-0.04
Cs	0.27	0.43	0.32	-0.5	-0.65	0.29	0.32
Ba	0.28	0.32	0.15	0.68	1	0.15	0.09
Hf	0.21	-0.34	-0.35	-0.27	0.13	-0.14	-0.29
Pb	0.76	0.87	0.34	0.02	0.31	0.54	0.44
Th	0.18	-0.02	-0.38	-0.34	-0.09	-0.46	-0.54
U	0.82	0.49	0.28	0.22	0.54	0.65	0.44

	Ce	Pr	Nd	Sm	Eu	Gd	Tb
Ce	1						
Pr	0.96	1					
Nd	0.95	0.99	1				
Sm	0.92	0.96	0.97	1			
Eu	0.89	0.92	0.92	0.9	1		
Gd	0.91	0.96	0.97	0.96	0.93	1	
Tb	0.85	0.9	0.92	0.94	0.88	0.88	1
Dy	0.82	0.92	0.91	0.95	0.87	0.91	0.89
Ho	0.77	0.87	0.88	0.91	0.87	0.88	0.93
Er	0.81	0.91	0.91	0.91	0.86	0.91	0.91
Tm	0.76	0.87	0.87	0.85	0.8	0.83	0.89
Yb	0.75	0.83	0.82	0.83	0.78	0.8	0.85
Lu	0.66	0.75	0.72	0.8	0.72	0.72	0.79
Be	-0.01	0.1	0.1	0.02	0.1	0.16	-0.03

V	0.12	0.24	0.21	0.26	0.19	0.23	0.29
Cr	-0.38	-0.41	-0.45	-0.33	-0.29	-0.37	-0.29
Co	0.79	0.76	0.74	0.75	0.8	0.72	0.69
Ni	-0.13	-0.14	-0.21	-0.11	-0.14	-0.23	-0.12
Cu	-0.01	-0.02	-0.04	-0.04	-0.19	-0.08	-0.12
Zn	0.45	0.48	0.52	0.45	0.6	0.48	0.45
Ga	0.65	0.69	0.68	0.73	0.71	0.66	0.8
Rb	0.38	0.38	0.39	0.32	0.25	0.23	0.37
Sr	0.28	0.28	0.26	0.34	0.4	0.4	0.15
Y	0.88	0.96	0.95	0.93	0.85	0.94	0.88
Zr	-0.01	0.02	-0.02	0.02	-0.02	0	0.08
Cs	0.31	0.34	0.35	0.29	0.25	0.21	0.38
Ba	0.1	0.11	0.08	0.17	0.2	0.22	0.08
Hf	-0.28	-0.24	-0.26	-0.24	-0.21	-0.25	-0.12
Pb	0.47	0.49	0.49	0.6	0.54	0.49	0.72
Th	-0.57	-0.51	-0.5	-0.48	-0.42	-0.52	-0.3
U	0.42	0.51	0.47	0.55	0.47	0.51	0.55

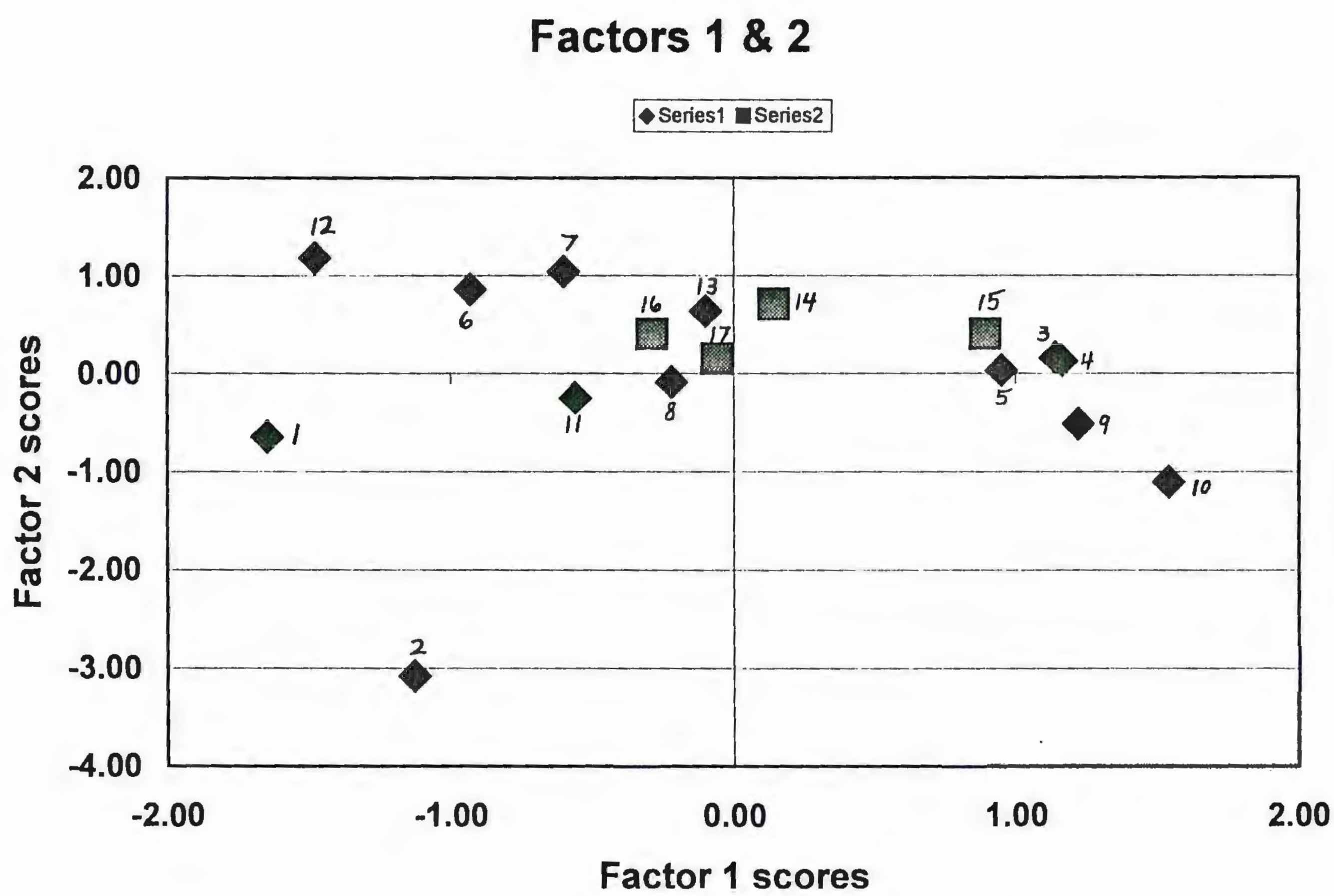
	Dy	Ho	Er	Tm	Yb	Lu	Be
Dy	1						
Ho	0.95	1					
Er	0.92	0.94	1				
Tm	0.89	0.94	0.92	1			
Yb	0.89	0.94	0.89	0.94	1		
Lu	0.91	0.87	0.83	0.85	0.87	1	
Be	0.08	0.13	0.14	0.13	0.02	-0.01	1
V	0.4	0.48	0.32	0.49	0.49	0.43	0.51
Cr	-0.25	-0.24	-0.27	-0.36	-0.21	-0.04	-0.06
Co	0.72	0.67	0.56	0.57	0.65	0.56	0.02
Ni	0.02	-0.08	-0.16	-0.14	-0.03	0.25	0.11
Cu	-0.09	-0.22	-0.15	-0.11	-0.26	-0.09	-0.04
Zn	0.44	0.48	0.32	0.38	0.32	0.24	0.4
Ga	0.75	0.83	0.67	0.75	0.81	0.7	0.12
Rb	0.26	0.26	0.13	0.33	0.3	0.09	-0.08
Sr	0.37	0.29	0.3	0.09	0.13	0.25	0.31
Y	0.92	0.9	0.94	0.92	0.89	0.78	0.14
Zr	0.09	0.06	0.24	0.2	0.15	0.35	-0.27
Cs	0.25	0.29	0.14	0.33	0.3	0.11	0.03
Ba	0.27	0.28	0.28	0.16	0.26	0.37	0.3
Hf	-0.12	-0.1	0.03	0.01	-0.02	0.19	-0.11
Pb	0.62	0.74	0.56	0.65	0.74	0.68	-0.05
Th	-0.36	-0.22	-0.33	-0.25	-0.23	-0.19	0.34
U	0.71	0.73	0.71	0.75	0.79	0.86	0.18

	V	Cr	Co	Ni	Cu	Zn	Ga
V	1						
Cr	0.1	1					
Co	0.34	-0.02	1				
Ni	0.29	0.54	0.19	1			
Cu	-0.28	-0.61	-0.33	0.04	1		
Zn	0.23	-0.4	0.6	0.05	0.03	1	

Ga	0.67	-0.09	0.77	0.16	-0.31	0.51	1
Rb	0.26	-0.54	0.45	-0.01	0.23	0.51	0.5
Sr	0.11	0.15	0.34	0.01	-0.2	0.21	0.14
Y	0.35	-0.46	0.64	-0.17	0.03	0.41	0.69
Zr	-0.19	0.22	-0.34	0	0.04	-0.63	-0.21
Cs	0.33	-0.48	0.41	0.07	0.2	0.57	0.56
Ba	0.37	0.61	0.23	0.25	-0.55	-0.13	0.16
Hf	-0.13	0.31	-0.51	0.17	0.03	-0.54	-0.24
Pb	0.63	0.21	0.64	0.22	-0.45	0.27	0.88
Th	0.3	0.29	-0.4	0.41	-0.05	0.02	0.03
U	0.63	0.08	0.3	0.23	-0.18	-0.01	0.61

	Rb	Sr	Y	Zr	Cs	Ba	Hf
Rb	1						
Sr	-0.48	1					
Y	0.33	0.27	1				
Zr	-0.51	-0.16	0.07	1			
Cs	0.97	-0.49	0.3	-0.51	1		
Ba	-0.65	0.69	0.15	0.22	-0.64	1	
Hf	-0.51	-0.28	-0.18	0.89	-0.42	0.13	1
Pb	0.29	0.04	0.52	0.01	0.35	0.32	-0.03
Th	-0.04	-0.35	-0.44	-0.01	0.17	-0.1	0.42
U	-0.12	0.25	0.63	0.46	-0.07	0.56	0.36

	Pb	Th	U
Pb	1		
Th	0.09	1	
U	0.64	0.03	1


Factors 1 & 2
Series1
Series2
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
Factor 2 scores
-2.00
-1.00
0.00
1.00
2.00
Factor 1 scores
1
2
3
4
5
6
7
8
9
10
11
12
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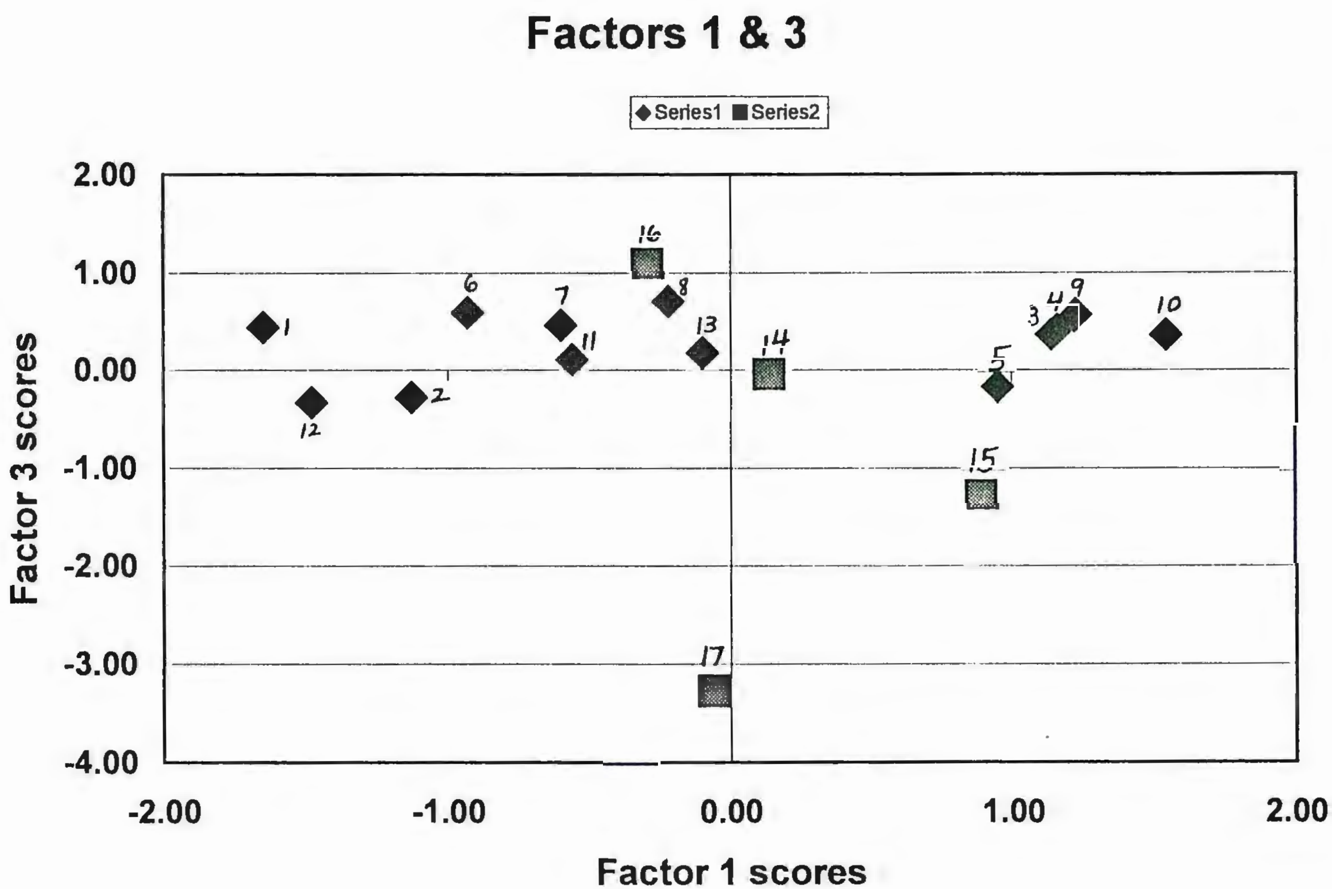
14
15
16
17


Factors 1 & 3
Series1
Series2
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1.00
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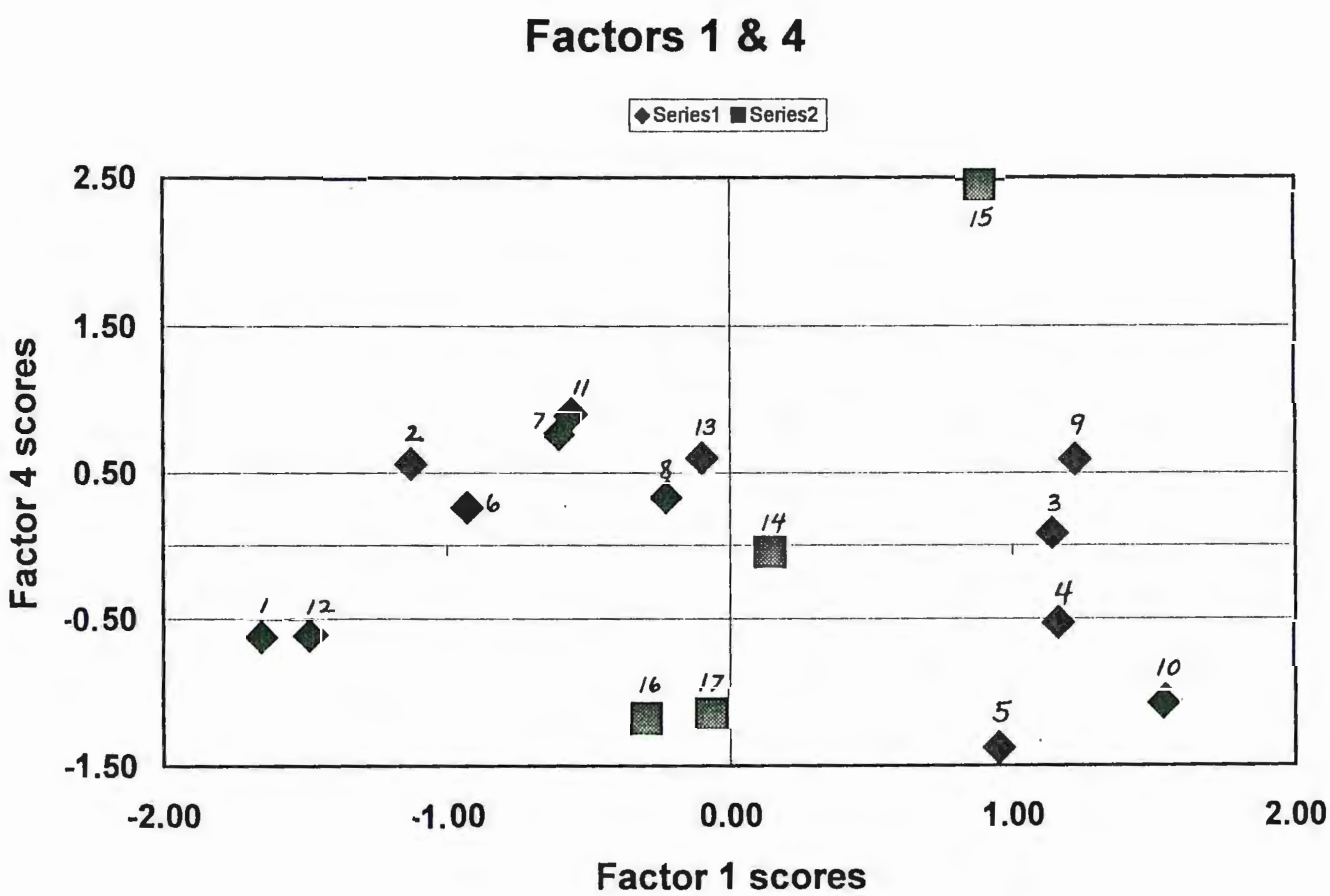
0.00
1.00
2.00
Factor 3 scores
Factor 1 scores
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17


Factors 1 & 4
Series1
Series2
Factor 4 scores
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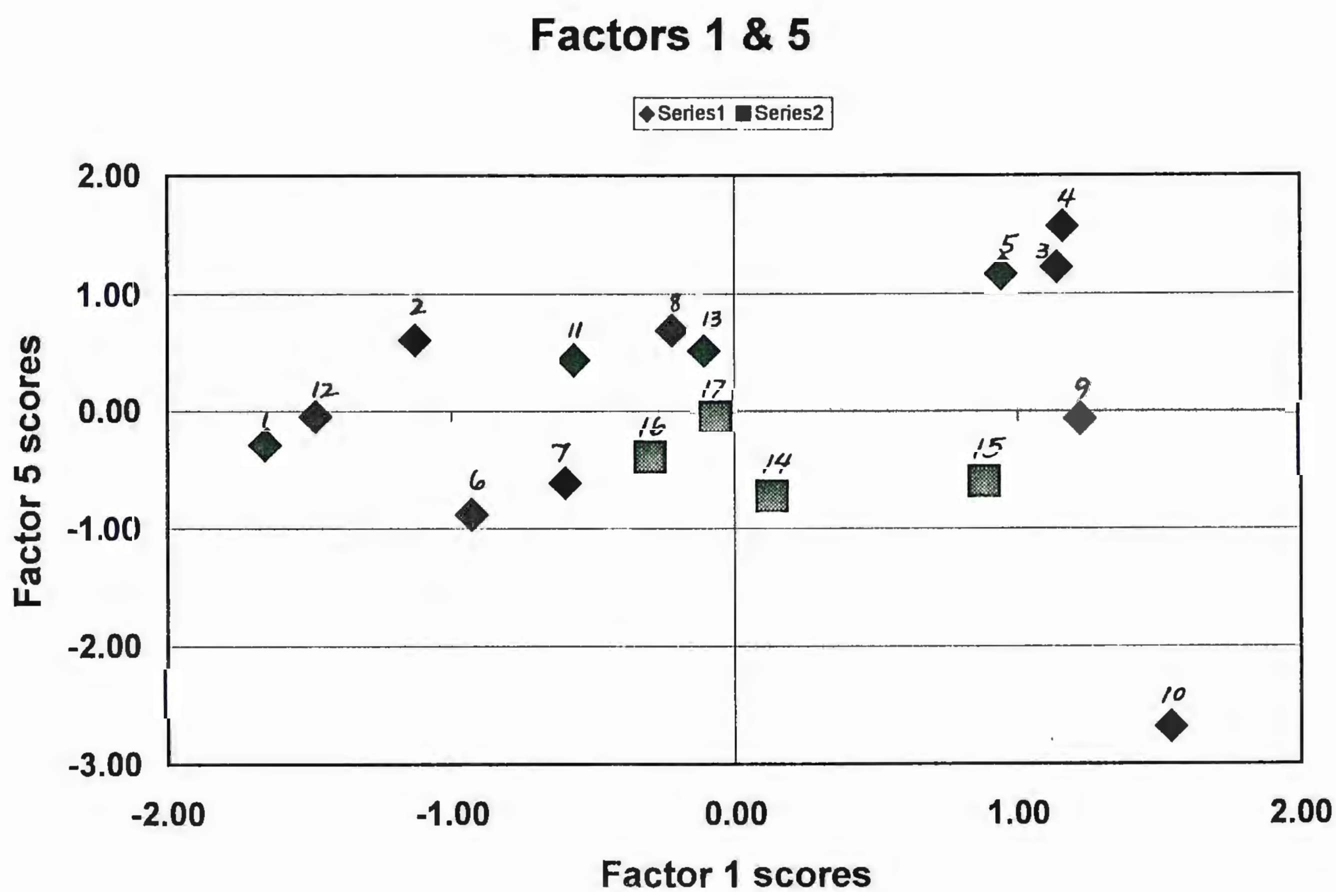
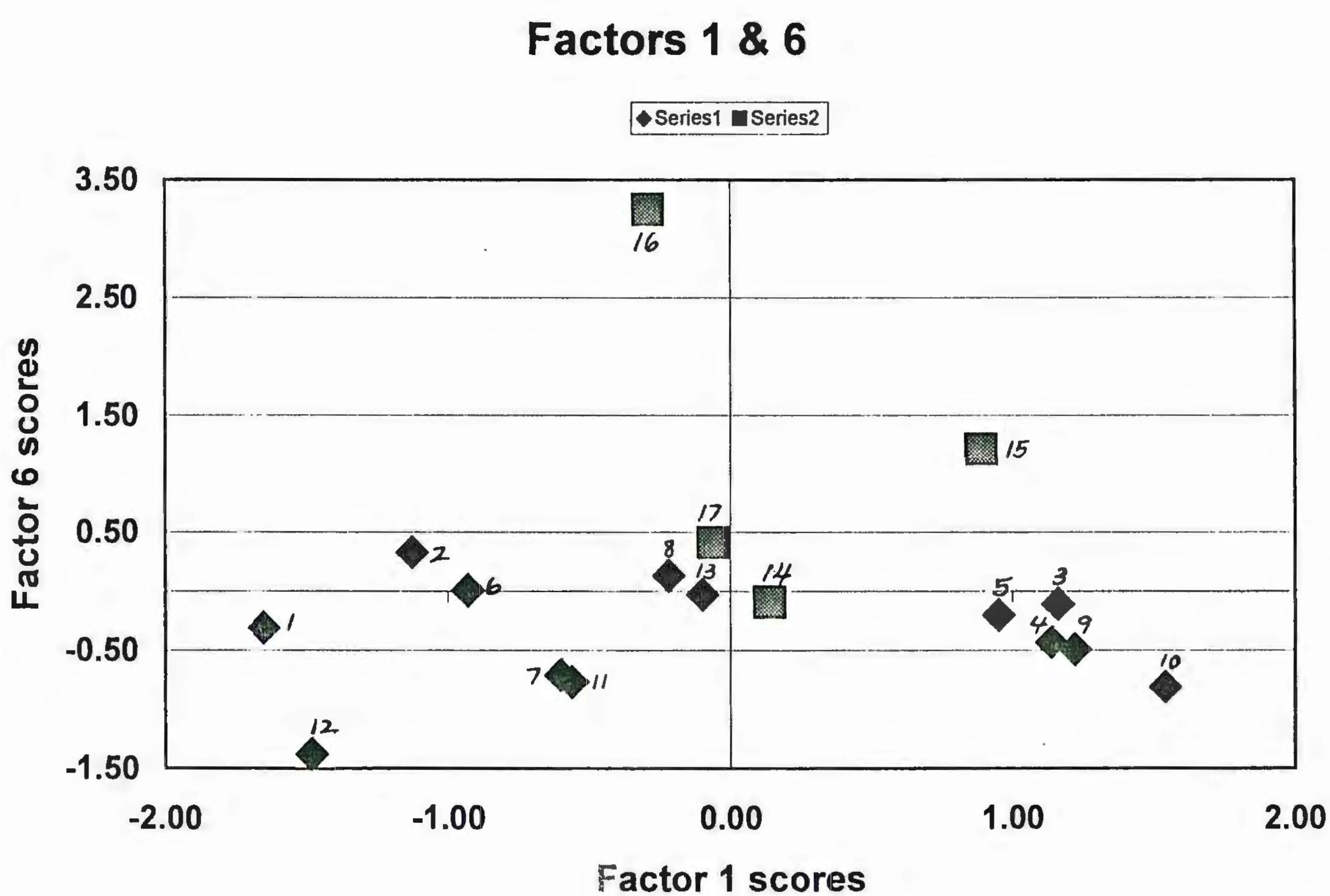
1.50
0.50
-0.50
-1.50
-2.00
-1.00
0.00
1.00
2.00
Factor 1 scores
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17


Factors 1 & 5
Series1
Series2
2.00
1.00
0.00
-1.00
-2.00
-3.00
Factor 5 scores
-2.00
-1.00
0.00
1.00
2.00
Factor 1 scores
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17


Factors 1 & 6
Series1
Series2
3.50
2.50
1.50
0.50
-0.50
-1.50
-2.00
-1.00
0.00
1.00
2.00
Factor 6 scores
Factor 1 scores
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2
3
4
5
6
7
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9
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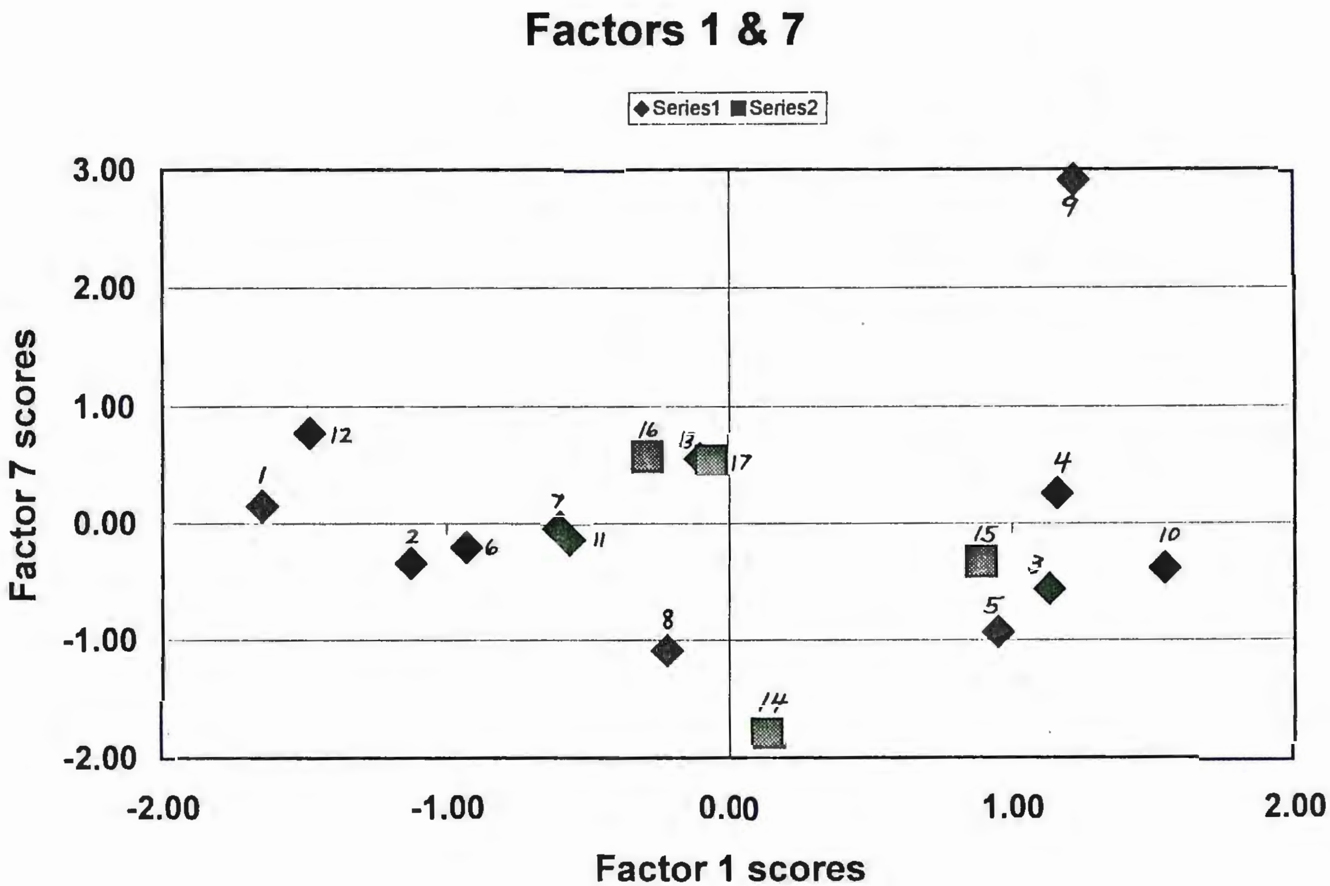
11
12
13
14
15
16
17


Factors 1 & 7
Series1
Series2
Factor 7 scores
3.00
2.00
1.00
0.00
-1.00
-2.00
-2.00
-1.00
0.00
1.00
2.00
Factor 1 scores
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17