# A STUDY OF THE MINERAL COMPOSITION OF POTTERY SHERDS FROM, MALYAN, IRAN.

A THESIS

PRESENTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE BACHELOR OF SCIENCE.

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# ABSTRACT

From 1971 through 1978 William M. Sumner , of the Ohio State University Department of Anthropology, conducted a five season preliminary excavation at Tal-e-Malyan, Iran. A result of his work was the discovery of a new phase of occupation, which is now known as the Banesh Phase ( c. 3400-2600 B.C. ). Two broad catagories of Banesh ware have been identified; one is a coarse, low fired straw tempered ware and the second is a hard grit tempered ware which occurs in several varieties, ( Sumner 1980 ).

Younger, Islamic wares ( c. 800-1900 A.D. ) are very similar in appearance to the older Banesh wares. Consequently the two different pottery wares can be confused. By conducting a mineral analysis on the two different wares it can now be shown that some distinguishing characteristics do exist.

Twenty five Malyan sherds, ranging in size from one inch to two inches were donated for this study. In order to eliminate bias all information regarding the archaeological context of the sherds was withheld until the mineral analysis and catagorization of each sherd was completed. Only Mr. Sumner, knew that the sherds represented Banesh and Islamic pottery types. The purpose of this study was to see if textural mineral analysis of the sherds would permit catagorization. After the catagorizations were completed they were matched to Mr. Sumner's archaeological catagorizations. The results showed that the Islamic sherds characteristically contained micrite, carbonate grains, quartz, feldspar, and a low percentage of iron oxides. The Banesh sherds contained, either large percentages of iron oxides, or else differed in composition from the characteristic Islamic sherd constituents. The polarizing microscope, Vreland Spectroscope, and x-ray analyzer were utilized in the analysis.

# INTRODUCTION

The identification of the mineralogical composition of a ceramic pottery sherd, as well as the relationship of these minerals within the sherd, can reveal information regarding the production technique, source area, and possible trade connections associated with the ceramic industry that the sherd represents. For years the analysis of ceramics, in an archaeological context, was based primarily upon morphology and style. Stylistic seriation ( both intrasite and intersite ) of production attributes helped to distinguish ceramic production between different sites both chronologically and within the same time period. Archaeologists now realize that surface attributes are not revealing the entire picture. In fact, the surface attributes which were used to control classification schemes were themselves controlled by the composition of the material used in the production. As stated by Shepard ( 1976, p. 95 ): The physical properties are directly effected by materials and by the potters technique, also the nature of the material often limits the choice of technique, and both the material and technique in turn influence style.

The latter mode of inquiry, that is from composition to end product, led to a very easy means by which pottery ceramics could be classified on the basis of their paste and temper composition. Classification based on such parameters could separate locally produced wares from younger wares, or even classify wares on the basis of production techniques ( as indicated by materials used ). For instance by analyzing the mineral composition of a particular sherd, the results can be matched to a geologic survey of the immediate area in which the sherd was found. If the sherd's temper consisted of biotite or chlorite and the geologic survey of the area indicated no metamorphic outcrops, then either the sherd itself or the temper used in the sherd was imported from another region. If a local material will work in ceramic production there is no need for importation of raw material. Therefore, if a material not found in the immediate area is used in ceramic production chances are very good that the ceramic itself is an import, not the material used in it's production.

Several different techniques can and have been utilized for the analysis of the temper and paste found in pottery sherds. One method involves differential thermal analysis. This procedure utilizes the principle that a substance will undergo changes when it is heated. Such changes may include, destruction of the crystalline phases, decomposition or oxidation, and loss of water of recrystallization. The procedure involves heating an unknown and then comparing the rate of heating of the unknown to that of an inert reference material. The temperature difference between the two materials is then plotted on a graph. This is not a new method and in fact according to Shepard, differential thermal analysis dates back to Le Chatelier in 1887. It's main advantage is in the analysis of submicroscopic materials.

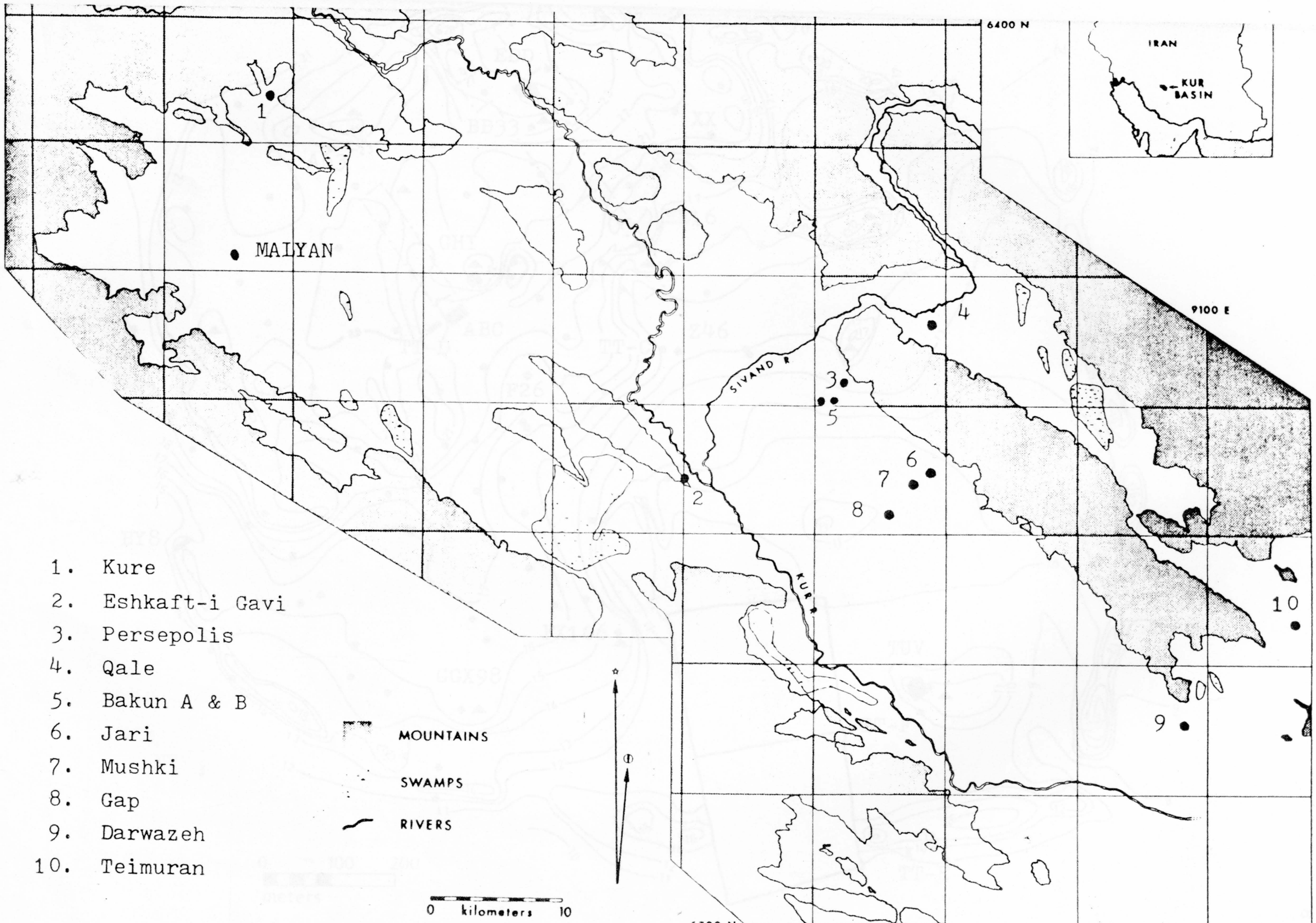
As mentioned earlier, mineral relationships, or texture of the sherd can also yield vital clues. In a study done by Mararíu, Bogden, and Ardelean ( 1977, pp. 187-221 ), it was theorized that ancient pottery could be classified into four main catagories of pore structure, regardless of it's origin or age. The size distribution of mineral grains controls the porosity, which is defined as the ratio of the void space to the total volume of an object. Volume of the void spaces and the size and shape of the pores affect density, strength, permeability, degree of resistance to weathering and abrasion, extent of discoloration by fluids, and resistance to thermal shock ( Shepard 1976 ). Morariu, Bogden, and Ardelean ( 1977 ) conclude that a relationship appears to exist between pore structure and firing techniques. The higher the temperature the narrower the pore size distribution, and the average pore size is smaller for better fired ceramics.

Thin section analysis using a polarizing microscope was chosen for this study on the basis of ease and equipment availability. Not only can rapid identification of constituents be acheived but textural relationships can also be observed. A permanent record of the sherd in the form of a thin section can also be saved for future study.

The early urban site of Malyan, Iran roughly dates from, ( 3400 - 500 B.C. ). In a paper done by James M. Blackman of the Conservation Analytical Laboratory of the Smithsonian Institution in Washington D.C. , a good description on the location of the Malyan site is given. Malyan is located is a drainage basin in the lower Kur River Valley in the highlands of the Fars Province in southwest Iran. The lower part of the Kur River basin is synclinal, and is surrounded by high, massive, folded, limestone mountains and bisected by anticlinal ridges. The Kur River flows on the northeast side of the ridges while Malyan is located in a small internal drainage basin to the southwest of the ridges and well out of the alluvial valley fill ( Blackman, 1979 ). See map 1.

The site itself is a large mound. An ancient wall surrounded the perimeter of the site and enclosed 200 hectares ( 1 hectare equals 10,000 square meters ) but the main mound within the walls only had an area of 130 hectares ( Sumner, 1980 ). There are 35 positively identified Banesh sites in the Kur River Basin. It was during the Banesh phase ( c. 3400-2600 B.C. ) that Malyan acheived urban status ( Sumner, 1980 ). The Banesh sherds used in this study came from two different operations being: BY8 and GHI ( see map 2 and table 1.

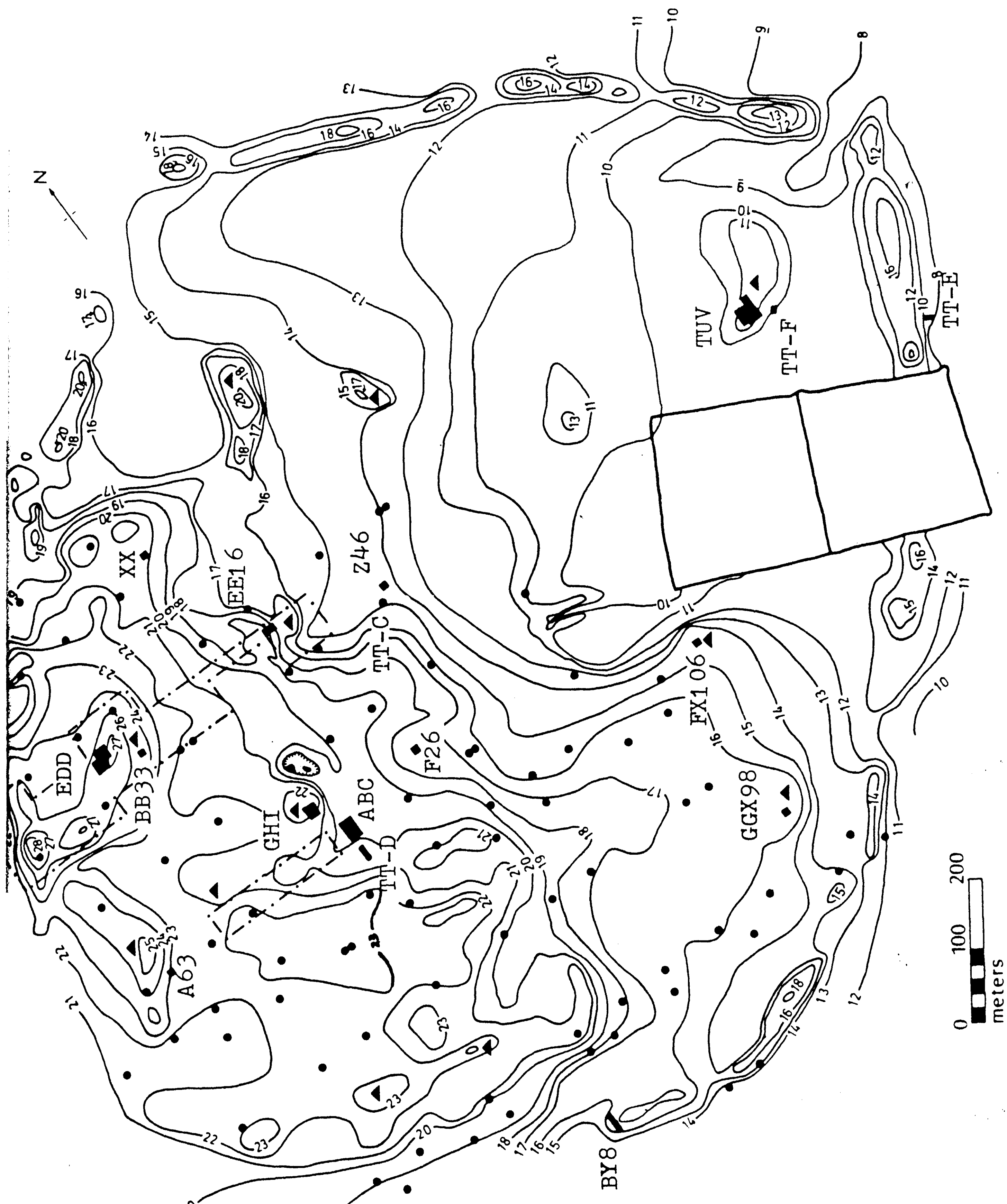
Operation GHI constisted of four 10 X 10 meter squares which investigated a slight rise in one of the mounds of the site. Five building levels were uncovered exhibiting elaborate hearths, wells, socketed doors and thick walls. Operation BY8 was an excavation done on the city wall. The wall was originally constructed in late Banesh times ( Sumner, 1980 ).




Selected Sites in the Kur River Basin

( Summer, 1980 )

MAP 2




Tal-e Malyan: Operations, Pick-up Squares, Magnetometer Survey ( Summer, 1980 )

TABLE NUMBER ONE

ARCHAEOLOGICAL CONTEXT OF SHERDS

| BANESH 3400 B.C. - 3600 B.C. | | | | ISLAMIC 800 A.D. - 1900 A.D. | | | |
|---|---|---|---|---|---|---|---|
| SHERD | LOT | OP. | DESCRIPTION | SHERD | LOT. | OP. | DESCRIPTION |
| 4 | H-5 | 208 | SURFACE PICKUPS | 6 | BAT | | SURFACE SURVEYED LATE ISLAMIC SITES |
| 2 | H-5 | 208 | | 7 | BAU | | |
| 19 | H-5 | 198 | MAYLAN EXCAVATED BANESH OR BANESH KAFTARI TRANSITION | 9 | BAU | | |
| 20 | H-5 | 194 | | 12 | BAS | | |
| 21 | H-5 | 198 | | 13 | BAH | | |
| 22 | H-5 | 199 | | 14 | BAH | | |
| 8 | 8 E5 | | MAYLAN SITE, SURVEYED BANESH LAPUI, (RED WARE) | 17 | BAG | | |
| 10 | BY 8 | 125 | MAYLAN EXCAVATED LATE BANESH | 18 | BAG | | |
| 11 | BY 8 | 125 | | 1 | | | SURFACE PICKUP OF ISLAMIC PAINTED WARE, BAU SITE |
| 23 | BY 8 | 110 | MAYLAN EXCAVATED LATE BANESH | | | | |
| 25 | BY 8 | 110 | | | | | |
| | | | | | | | |

## CERAMIC ATTRIBUTES

A brief discussion of several of the attributes associated with ceramics should be kept in mind when performing a ceramic study. Sherd color can lead to several conflicting conclusions. In a pottery sherd not only does the composition of the material present control the color, but the atmosphere, duration and temperature of firing are also controlling factors ( Shepard, 1976 ). Clay is colored chiefly by the impurities which are present, such as iron compounds and carbonate materials. Upon firing the iron compounds convert to oxides and become permanent colorant for the clay ( Shepard, 1976 ). An oxidizing environment will produce red colors and a reducing environment will produce gray colors. Shepard also states that a fire that oxidizes one clay may only partially oxidize another. Therefore it is quite possible that two mineralogically identical sherds may vary in color due to the way in which they were fired.

Hardness can be used to judge the serviceability of pottery ( Shepard, 1976 ). Hardness refers to the resistance of the ceramic to penetration, abrasion, crushing, and elasticity. Hardness according to Shepard can be effected by firing temperature and also by impurities found within the clay and temper that render the clay more fusible. If the pottery is hard, it could have been produced from a low-fusing dense-firing clay, or it may have been produced at a relatively high temperature or in an atmosphere that promotes vitrification ( Shepard, 1976 ). Shepard brings out an excellent point, namely that primitive pottery, due to it's porous and heterogeneous nature makes hardness an unsuitable method for classification or analysis.

Texture of the paste is influenced by the nonplastic inclusions of the clay, grain size, and porosity of the clay ( Shepard, 1976 ). The paste should contain a sufficient amount of nonplastic material to counteract excessive shrinkage and to insure uniform drying, but if too much is added the body of the ceramic is weakened ( Shepard, 1976 ). The grain size of course depends upon the material being used, and the potters technique of material preparation.

# PROCEDURE

A standard thin section was made of each sherd by using the following steps:

1. Each sherd was cut down to a size small enough to comfortably fit on a thin section slide. The thickness was left at about one quarter of an inch. Impregnation of the sherd with bakelite prior to cutting was not necessary.

2. A flat smooth surface was ground down on one side of each of the sherds using a rotary lap and #200, #400 & #600 grinding grits respectivly.

3. Chips were placed in an oven at a low temperature for 30 minutes to insure dryness.

4. Using balsam each sherd was glued, smooth side down, to a standard thin section slide. The slide was then placed on a hot plate for one hour while the balsam set. Chips were allowed to set over night to insure adhesion.

5. The chips, now attached to a slide, were cut down to a thickness of one-thirtysecond of an inch using a lapidary saw equipped with a pre-set guide arm.

6. Each chip was placed on a thin section grinder and slowly brought to a thickness of 0.03mm. This thickness was obtained by looking for first order red or blue interference colors from the grains present in the chips using a polarizing microscope. Many of the grains were void of quartz, which made thickness determination difficult. Many sections had to be finished by hand using a glass plate and #1000 grinding grit.

7. Using balsam, a cover slip was glued over each chip to protect the surface.

Each slide was then examined using a polarizing microscope. Texture, composition, relative constituent percentages and grain sizes were noted.

## SHERD DISCRIPTIONS

Each sherd description is divided into two parts. First a brief description is given, indicating color, texture, noticeable constituents, and any peculiar features. Hopefully this will aid recognization in the field. Second, a thin section description of the sherd is given. This consists of a brief description of the overall matrix followed by a list of the constituents found within the sherd. Each constituent listed gives material, grain size, and percent composition, in that order. For instance; quartz - 1mm - 40%, means quartz grains that are 1mm in size and costitute 40% of the thin section. Finally, when pertinent, any additional information,which should be stated about the sherd,is presented.

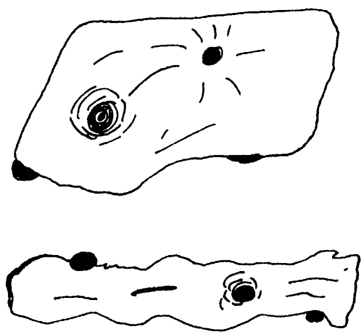
SHERD 1. An orange buff sherd with traces of a reddish brown surface design. The sherd appears to be composed of a sandy carbonaceous clay that contains medium to coarse grain temper.

Surface design not to scale

Some porosity is evident, but the pores are very small. The sherd is easily scratched by a knife and gives no reaction to dilute HCL.

THIN SECTION: Brownish yellow fine-grain matrix that contains; micrite - 40%, subhedral to anhedral grains of k-spar - 0.03mm to 0.05mm - 30%, anhedral grains of hematite - 1mm - 20%,anhedral grains of quartz - 0.03mm to 0.05mm - 10%, trace of plagioclase, microcline, and biotite.

SHERD 2. A reddish dark brown to black " sherd " with a very irregular surface texture. The sherd contains spherical nodules of hematite which display exfoliation. The color of the nodules range from brownish red to black and may represent different firing conditions. The average size of the exfoliated nodules is 1mm.



not to scale

THIN SECTION: Reddish orange fine-grain matrix that contains exfoliated nodules of hematite - 1mm - 70%, irregular, semi-nodular opaques which are believed to be either hematite or magnetite - 1mm - 20%, anhedral to subhedral grains of feldspar - 0.02mm - 10%, and a trace of quartz.

This sherd may not be a ceramic. The spherical nodules could be either hematite or magnetite. Hematite upon heating in a reducing flame becomes black and strongly magnetic, resembling the nodules found in this sherd ( Dana, 1977: 269-270 ). Analysis of these nodules using the Vreland Spectrometer indicated large amounts of Fe, and small amounts of Li, Na, No, and Ti. This sherd could possibly represent a smelting material. It is in any case unique and does not conform with the other sherds.

SHERD 4. A dull gray sherd containing 20% to 30% euhedral calcite grains on the surface. The sherd is easily scratched by a knife and reacts to dilute HCL.
THIN SECTION: Reddish brown coarse-grain matrix containing euhedral to anhedral calcits grains, some showing polysynthetic twinning, - 1mm - 80%, micrite, concentrated around the pores and calcite grains which may represent secondary precipitated material - 10%, trace of hematite - 0.04mm, and a trace of fossil material.
Not all of the calcite crystals show cleavage rhombs, which may be related to a production technique in which the calcite was pre-crushed before being included in the paste. The fact that the crystals are still intact indicates a low firing temperature. Calcite undergoes calcination at 750 - 800 degrees celcius ( Shepard, 1976 ).

SHERD 6. A reddish brown sherd with a fine-grain matrix that contains a heterogeneous coarse-grain temper. The sherd also contains a few very small spherical hematite nodules. The surface can be easily scratched by a knife.
THIN SECTION: Orange yellow fine-grain carbonate rich matrix that contains: micrite - 90%, hematite and opaques - 1mm - 5%, quartz or feldspar grains - 1mm -5%.
( The possibility exists that in this one sherd some of the hematite and opaques were dislodged during preparation. The sherd did not appear porous, but the thin section has several open pores. )

SHERD 7. A greenish white sherd with a fine grain carbonaceous clay matrix and a coarse grain temper. The sherd

appears to be slightly porous, and is easily scratched by a knife.
THIN SECTION: Yellowish buff homogeneous matrix with a creamy texture indication partial fusing of the grains. Constituents include: a large amount of micrite mixed with a small amount of iron oxide - 70%, quartz or feldspar grains - 0.02mm - 15%, opaques - 1mm- 5% to 10%, and hematite grains - 0.03mm - 3% to 5%.

SHERD 8. An orange red brick-colored sherd with a fine grain matrix containing sparsely dispersed medium to coarse-grain temper. The sherd is layered with darker material on one edge, possible indicating a varied firing atmosphere. The sherd can be easily scratched by a knife and offers a weak reaction to dilute HCL.
THIN SECTION: Blood red homogeneous matrix exhibiting a creamy texture, which indicates a partial fusing of grains. Constituents include: hematite grains - 0.5mm - 80%, quartz or feldspar grains - 0.01mm - 5% to 10%, and micrite - 5% to 10%.

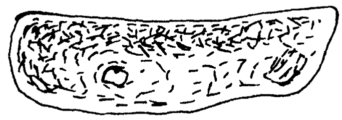
SHERD 9. A red buff, fine grain sherd containing coarse hematitic sandstone grains. The sherd can be easily scratched by a knife, and offers a weak reaction to dilute HCL.
THIN SECTION: Brownish yellow homogeneous matrix exhibiting a creamy texture which indicates partial fusing of grains. Constituents include: carbonate ( partially fused in the paste ) - 45%, micrite - 20%, hematite grains - 0.5mm - 20%, feldspar grains - 0.02mm - 10%, and a linear fiberous unknown mineral with parallel extinction - 2% to 3%.

SHERD 10. An orange gray sherd that exhibits a fine grain porous matrix containing a coarse grain temper. The sherd is difficult to scratch with a knife and reacts weakly to dilut HCL.
THIN SECTION: Light yellowish tan fine grain matrix containing: large gray ( somewhat altered ) carbonate grains - 20%, opaques ( believed to be magnetite or hematite ) - 20%, hematite grains - 0.001mm - 15%, feldspar grains - 0.001mm - 10%, and micrite - 5%.

SHERD 11. A brownish gray sherd with a fine grain matrix and a coarse grain temper. The surface of the sherd can not be scratched by a knife. It appears to have an irregular texture which may be due to the one time presence of organic material which was burnt off when the piece was fired.

THIN SECTION: Light yellowish tan creamy matrix containing: grains of anhedral carbonate which display a cracked surface texture - 30%, opaques ( probably iron oxide ) - 20%, subhedral hematite grains - 0.02mm - 20%, feldspar grains - 0.001mm - 5% to 10%, quartz grains - 0.001mm - 5% to 10%, and amorphous material - 3% to 5%.

SHERD 12. A reddish brown sherd displaying a distinct zonation of platy, somewhat acicular, grains of hematite or magnetite. The grains are magnetic and exhibit a black streak. Spectrometer analysis of the grains indicates that they contain large amounts of Fe, and small amounts of Ti, and Mn. Attempts to isolate and subject the grains to x-ray analysis were not successful. X-ray analysis indicated the presence of quartz and dolomite, which probably represents paste material. The sherd gives no reaction to dilute HCL, but can be scratched by a knife. It is thicker than the other sherds, being 13mm thick. It is a possibility that this sherd is not a ceramic, but a smelting container or other such item.



Profile, not to scale

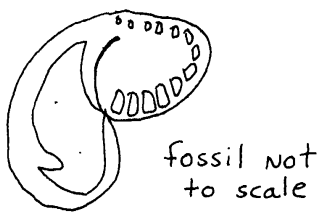
THIN SECTION: Orange red homogeneous matrix displaying a creamy slightly fused matrix. Constituents include: platy to acicular hematite and opaque grains - 1mm - 70%, micrite - 3%, and a trace of very fine-grain feldspar.

SHERD 13. An orange buff sherd with a fine grain matrix and dispersed medium-grain temper. Gives a weak reaction to HCL, and can be easily scratched by a knife. The sherd is slightly porous with a few isolated cavities which may have once held organic debris.

THIN SECTION: Orange tan heterogeneous fine grain matrix containing: subhedral carbonate grains which display good cleavage - 0.3mm - 25%, micrite - 25%, hematite grains - 0.2mm - 20%, subhedral feldspar grains - 0.001mm - 15%, amorphous material - 15%, and a trace of fossil material.

SHERD 14. A brownish red sherd with a fine grain heterogeneous temper composed predominately of platy to acicular magnetite or hematite grains. The sherd gives a weak reaction to dilute HCL, and can be easily scratched by a knife.
THIN SECTION: Reddish brown matrix displaying a creamy homogeneous slightly fused matrix. Constituents include: anhedral carbonate grains - 0.04mm - 30%, hematite grains - 0.01mm - 30%, micrite - 20%, amorphous material - 20%, and a trace of feldspar.

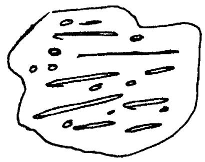
SHERD 17. A dark reddish brown sherd with a fine-grain matrix and a coarse grain temper. The surface is easily scratched with a knife and it offers a weak reaction to dilute HCL. The sherd contains hematite or magnetite which is concentrated near the surface.
THIN SECTION: Orange brown homogeneous matrix displaying a creamy slightly fused texture. Constituents include: Carbonate grains which display a cracked surface texture - 0.05mm - 60%, micrite - 10%, hematite grains - 0.01mm - 10%, scattered amorphous material - 5% to 10%, trace of feldspar, and a few fossils.




SHERD 18. An orange buff sherd with a fine-grain matrix and a coarse-grain temper. The sherd reacts very weakly to HCL and is easily scratched with a knife.
THIN SECTION: Orange brown homogeneous matrix displaying a creamy slightly fused texture. Constituents include: micrite - 30%, carbonate grains with a cracked surface texture - 0.02mm to 0.03mm - 20%, amorphous material - 5% to 10%, feldspar grains - 0.001mm -5%, and a very small amount of scattered opaques.

SHERD 19. A whitish cream colored sherd with a fine grain matrix and a coarse grain temper. The sherd is slighly porous and may have once contained organic debris. It gives no reaction to dilute HCL, and is easily scratched by a knife.
THIN SECTION:Yellowish tan homogeneous sherd displaying a creamy slightly fused texture. Constituents include: micrite - 30%, hematite grains - 0.01mm to 0.02mm - 25%, grayish white carbonate grains with a cracked surface texture - 0.03mm - 20%, amorphous material ( including a very small fraction of glass grains ) - .02mm - 10%, trace of feldspar and scattered fossils.

SHERD 20. A dark brown sherd with a fine grain matrix and a linear pore structure.
The sherd may have once contained some kind of chaff material which burned away during firing, leaving the linear pores. It gives a weak reaction to HCL, and can be scratched easily by a knife.



not to scale

THIN SECTION: Reddish brown homogeneous matrix displaying a slightly fused texture. Linear cavities dominate the slide. Constituents include: very fine quartz or feldspar grains - 0.001mm - 45%, amorphous material - 20% to 25%, hematite grains - 0.001mm - 10%, and micrite - 5%.

SHERD 21. A reddish orange sherd with a very coarse, predominately hematite or magnetite temper. The sherd gives no reaction to dilute HCL, and can not be scratched by a knife.
THIN SECTION: Reddish orange homogeneous matrix displaying a creamy partially fused texture. Constituents include: euhedral to anhedral tannish gray carbonate grains which exhibit a smooth surface texture - 0.4mm - 40%, micrite - 25%, feldspar grains - 0.001mm - 15%, and hematite grains - 0.02mm - 15%.

SHERD 23. An orange buff sherd, slightly porous, with a coarse-grain temper. It gives a weak reaction to dilute HCL, and the surface cannot be scratched by a knife. The middle of the sherd is soft, but the outside surface is very durable.

THIN SECTION: Orange tan homogeneous matrix displaying a creamy slightly fused texture. Constituents include: subhedral to anhedral carbonate grains with a cracked surface texture - 50%, micrite - 15%, hematite and opaque grains - 0.01mm - 15%, amorphous material - 10%, and feldspar grains - 0.01mm - 5%.

SHERD 25. A yellowish white sherd which resembles chalk. It has a fine grain matrix which contains a sparse amount of medium-grain to fine-grain temper material. It gives a strong reaction to dilute HCL and can be easily scratched by a knife.

THIN SECTION: Yellowish tan homogeneous matrix displaying a creamy partially fused texture. Constituents include: micrite - 60%, amorphous material - 20%, feldspar grains - 10% to 15%, hematite grains - 0.001mm - 5%, and a small amount of opaques ( probably iron oxide ) - 0.005mm - 3% to 5%.

## RESULTS

Analysis showed that most of the sherds contained the same constituents ( micrite, carbonate, feldspar, quartz, and iron oxides ). Percentages were used to determine similarities among the sherds, and five groupings were differentiated. Group 1 ( sherds #2, #4, #8, #12, and #20 ) all exhibit unique characteristics. Their uniqueness served as a similarity for which they could be grouped. Sherd #2, which was discussed in the sherd descriptions, contains spherical exfoliated hematite nodules. Sherd #4, contains sparite crystals. Sherd #8 contains a high percentage of hematite which is blood red and blends in well with the matrix of the sherd. Sherd #12, contains very distinct platy to linear iron oxide grains which are concentrated near the surface of the sherd. Sherd #12 is also very thick, when compared to the other sherds. Sherd #20 exhibits an unusual texture which may be caused by the burning away of once present organic material. ( See table 2).

Four other groups were differentiated, mostly upon the basis of the percentage of constituents present. All of the sherds contained more or less the same basic constituents ( micrite, carbonate, feldspar, quartz, and iron oxides ). ( See table 3 ) Group two contains sherds #6, #7, #22, and #25. All four of these sherds contain at least 60% micrite or more. In all the sherds the micrite appeared to be primary, that is contained in the original clay used to make the sherd and not precipitated into the sherd after production. The fact that the carbonate still exists indicates that the sherds were fired below 750 °c, which is the approximate temperature at which carbonates break down, ( Shepard 1976 ). Each sherd contains less than 15% fine grain feldspar and little to no quartz. The iron oxide percentage does not exceed 10%. The average feldspar and quartz grain size is 0.005mm and the average hematite grain size is 0.3mm. Sherd #6 is the only reddish brown sherd. Sherd #7 is greenish white, sherd #22 is yellowish tan, and sherd #25 is yellowish white. In thin section sherds #7, #22 and #25 appear yellowish tan or buff colored and sherd #6 is an orange yellow color.

Group three contains sherds #1, #9, #13, and #21. These sherds contain from 25% to 45% carbonate grains. The grains have a smooth surface texture. The micrite percentage ranges from 20% to 40%. The feldspar percentage ranges from 10% to 15% and the hematite percentage ranges from 15% to 20%. Sherd #1 also contains 10% quartz and 30% k-spar. It was included in this grouping based upon it's micrite and iron oxide percentages. The average grain size is as follows: carbonates 0.3mm, quartz 0.04mm, feldspar 0.02mm and hematite 0.4mm. All of these sherds were either orange-buff or red-buff in color. In thin section sherds #1 and #13 display a fine grain matrix and sherds #9 and #21 display a homogeneous partially fused matrix.

Group four consists of sherds #17, #18, #19, and #14. All of these sherds contain between 10% and 30% micrite and between 20% and 60% carbonate ( which exhibits a cracked surface texture of high releif under orthoscopic light ). This feature is probably due to the loss of $CO_2$ upon heating. Each sherd contains 5% to just a trace of feldspar. The hematite percentage ranges from 10% to 30% and the percentage of amorphous material ranges from 10% to 20%. The average grain size is as follows: carbonate 0.24mm and hematite 0.35mm. Sherds #14 and #17 are dark reddish-brown in color. Sherd #18 is orange-brown and sherd #19 is whitish-cream colored. In thin section sherds #17, #18, and #14 are all either reddish or orange-brown. Sherd #19 is yellowish-tan in thin section.

Group five contains sherds #10, #11, and #23. All contain from 5% to 20% micrite and 20% to 50% carbonate grains ( which display a cracked surface texture of high relief ). This group is similar to group four, but contains a higher percentage of feldspar ( 5% to 10% ). The hematite percentage ranges from 15% to 20%. The average grain size is as follows: carbonate 0.5mm, quartz 0.001mm, feldspar 0.007mm and hematite 0.01mm. Sherds #10 and #11 are a shade of gray and sherd #23 is orange-buff in color. In thin section sherds #23 and #11 display a yellow or orange-tan, slightly fused matrix and sherd #10 displays a fine grain, whitish-gray matrix. Appendices ( pages 30 - 34 ) show groupings with both percent composition and grain sizes.

# TABLE NUMBER TWO

## KEY TO TABLES USED IN REPORT

CARB(CR) ---Stands for carbonate grains with a cracked surface texture.
CARB(SM) ---Stands for carbonate grains with a smooth surface texture.
FELD--------Stands for feldspar grains.
QTZ---------Stands for quartz grains.
FELD/QTZ----Stands for quartz and or feldspar in which the grains were too small or stressed ( making positive identification impossible )
AMOR--------Stands for amorphous material.
Fos---------Stands for fossil material.
CAL/CRYS----Stands for calcite crystals.

## GROUP NUMBER ONE

| SHERD | MICRITE | CARB(CR) | CARB(SM) | FELD | QTZ | FELD/QTZ | IRON OXIDES | OPAQUES | AMOR | K-SPAR | CAL/CRYS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2. | | | | 10% | TR. | | 70% | 20% | | | |
| 8. | 5-10% | | | 5-10% | | | 80% | | | | |
| 4. | 10% | | | | | | TR. | | | | 80% |
| 12. | 3% | | | TR. | | | 70% | | | | |
| 20. | 5% | | | 45% | 5% | | 10% | | 20% | | |

# TABLE THREE

## GROUP NUMBER TWO

| SHERD | MICRITE | CARB (CR) | CARB (SM) | FELD | QTZ | FELD/QTZ | IRON OXIDES | OPAQUES | AMOR | K-SPAR | FOS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6. | 90% | | | | | 5% | 5% | | | | |
| 7. | 70% | | | | | 15% | 3-5% | 5-10% | | | |
| 22. | 90% | | | TR. | | 5-10% | | | | | |
| 25. | 60% | | | 10-15% | | | 5% | 3-5% | | | |

## GROUP NUMBER THREE

| SHERD | MICRITE | CARB (CR) | CARB (SM) | FELD | QTZ | FELD/QTZ | IRON OXIDES | OPAQUES | AMOR | K-SPAR | FOS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 40% | | | | 10% | | 20% | | | 30% | |
| 9. | 20% | | 45% | 10% | | | 20% | | | | |
| 13. | 25% | | 25% | 15% | | | 20% | | 15% | | TR. |
| 21. | 30% | | 30% | 10% | | | 15% | | | | |

## GROUP NUMBER FOUR

| SHERD | MICRITE | CARB (CR) | CARB (SM) | FELD | QTZ | FELD/QTZ | IRON OXIDES | OPAQUES | AMOR | K-SPAR | FOS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 17. | 10% | 60% | | TR. | | | 10% | | | | TR. |
| 18. | 30% | 20% | | 5% | | | 30% | | 10% | | |
| 19. | 30% | 20% | | TR. | | | 25% | | 10% | | TR. |
| 14. | 20% | 30% | | TR. | | | 30% | | 20% | | |

## GROUP NUMBER FIVE

| SHERD | MICRITE | CARB (CR) | CARB (SM) | FELD | QTZ | FELD/QTZ | IRON OXIDES | OPAQUES | AMOR | K-SPAR | FOS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10. | 5% | 20% | | 10% | | | 15% | 20% | | | |
| 11. | 15% | 30% | | 5-10% | 5-10% | | 20% | TR. | 3-5% | | |
| 23. | 20% | 50% | | 10% | | | 15% | TR. | 10% | | |

## SPECIAL QUESTIONS OF INTEREST

Several of the sherds contained long linear and platy iron oxide grains. The grains are black and magnetic, both properties of magnetite. They may have originally been hematite. Upon heating in a reducing flame hematite becomes black and strongly magnetic and is converted to magnetite, ( Dana, 1977 : 269-270 ). Sherd #2 contained small spherical exfoliated hematite nodules. Such constituents were not initially expected. A possibility exists, as previously mentioned, that these materials may be connected to smelting operations, or they may just reflect an iron oxide rich source material.

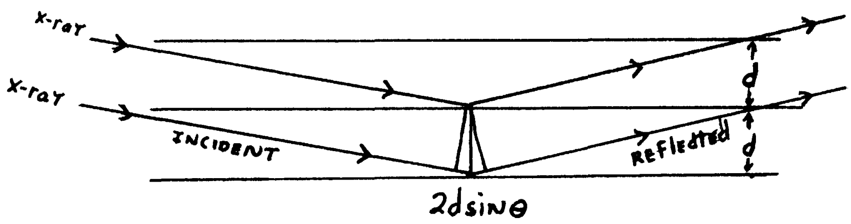
Both types of iron oxide grains ( linear platy, exfoliated spherical ) were analyzed using the Vreland Spectroscope. The theory behind it's operation is that atoms in an excited state will emit energy of a definate wavelength. If this light is dispersed, a spectrum is created. The light is emitted from electrons as they adjust from high energy levels down to lower energy levels. The energy difference between these two levels determines the wavelength of light emitted, ( Dana, 1977 ). Each element emits a characteristic spectrum. The Vreland Spectroscope is equipped with a rotating filmstrip which displays the spectrum for every element except silica. By matching the spectrum emitted against the defined spectrum on the filmstrip, an identification can be achieved. The spherical exfoliated nodules within sherd #2 were found to contain Fe, Li, Na, Mo and Ti. The linear platy inclusions in sherd #12 contained Fe, Ti, and Mn. The spectroscope is a qualitative instrument, therefore any quantitative assertions would be unjustified. In both cases though, the strongest show was for iron.

Tepe Yahya is a Near-Eastern site located on the Iranian Plateau approximately 250 kilometers south-east of Kerman, Iran. In an article describing the site it was reported that iron oxides were incorporated in the local ceramics. The paste used to produce the ceramics contained hematite and magnetite. The ceramics were dated to 4000B.C., (Kamilli, Lamberg, and Karlousky, 1979 ).

X-ray diffraction was used in an attempt to determine whether or not the iron oxide grains consisted more of iron or of quartz. As mentioned earlier, the Vreland Spectroscope will not analyze for quartz. X-ray diffraction is commonly used on very fine grain material that is impossible to analyze using the microscope. The theory behind x-ray analysis is centered on Bragg's equation.

$$n\lambda = 2d \sin\theta$$

Minerals are composed of orderly three dimensional structures. When an x-ray beam strikes an electron, it causes the electron to vibrate with the same frequency as the incident x-ray beam. These x-ray induced radiation waves will either cancel or reinforce. When they reinforce, the reflection can be recorded. Each mineral has it's characteristic reflection pattern, relating to it's characteristic lattice structure. Bragg's equation satisfies the proper conditions for reinforcement. Under the proper conditions x-ray energy will be reflected and reinforced from successive planes of atoms within a mineral lattice, ( Lipson, 1970 : 47 ) ( See illustration below ).




Representation of planes in mica crystal.
( Lipson, 1970, pg-47 )

n represents the number of wavelengths of separation of reflected x-rays. d represents the interplaner spacing of the atomic layers within the crystal lattice (which is unique for every crystal species). $\theta$ represents the incident angle of the x-ray beam. n must be a multiple of one in order for reinforcement to take place. By fixing $\lambda$ and varying $\theta$ , d the interplaner separation can be determined, ( Dana, 1977 ). $\theta$ can be varied by rotating the sample while a fixed x-ray beam is being shot. Iron oxide grains from sherd #12 were analyzed. The specimen was ground to a fine powder, placed in the specimen chamber and rotated through an angle ($2\theta$) of 70°.

Analysis indicated characteristic peaks of quartz, with a few peaks of dolomite. No peaks for magnetite or hematite were found. Since no iron rich phases were indicated, paste material must have contaminated the specimen. It is known that the specimen is iron rich and yet no show for iron occurred. The separation of the grains in question must have been at fault. Not enough pure grains were isolated. An involved separation process is called for. It was decided that unless future work dictated a positive answer, not to pursue the question. A positive answer is not vital to this report.

## INTERPRETATIONS

After grouping the samples, the archaeological context of the sherds was obtained from Dr. Sumner. The sherds represent two periods of ceramic production. The oldest sherds are Banesh ( 3400-2600 B.C. ), and the younger sherds are Islamic and date anywhere from 800 A.D. to 1900 A.D., ( see table 1 ). In outward appearance these two sherd types are very similar. Both of the ceramic types were produced in the same area, so both are composed, more or less, of the same local materials.

The fact that both ceramic types are local in nature explains the more or less similar mineral compositions. The only real clear cut parameter which can help distinguish between the two types is the iron oxide content. With the exception of sherd #12, the Banesh sherds contained iron oxide in amounts greater than 70%, ( see table 4 ). Any drastic deviation from the common micrite, feldspar, carbonate, and iron oxide constituents also represents a Banesh sherd. For example sherd #4 is composed of 80% calcite crystals and is a Banesh sherd. Sherd #20 has an unusual texture and contains a large amount of k-spar and is a Banesh sherd.

In summary, this study shows that the Islamic sherds contain micrite, carbonate, feldspar, quartz and low percentages of iron oxides. If a sherd is found in the area and a mineral analysis shows it to contain either a large amount of iron oxide, ( greater than 30% ), or a constituent ( of sizeable amount ) of something other than the ones just listed as being characteristic, then chances are good that it is a Banesh sherd. This is the fastest and the most practicle way of mineralogically differentiating between the two types.
Of course this method may not always work, and it should be kept in mind that it was never meant to be full proof. If combined with archaeological and other types of evidence, it could prove very helpful.

## TABLE NUMBER FOUR

### BANESH SHERDS

| SHERD. | MICRITE | CARB (CR) | CARB (SM) | FELD | QTZ | FELD/QTZ | IRON OXIDES | OPAQUES | AMOR | K-SPAR | CAL/CRYS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10. | 5% | 20% | | | | | 15% | 20% | | | |
| 11. | 15% | 30% | | 5-10% | 5-10% | | 20% | TR | 3-% | | |
| 23. | 20% | 50% | | 5% | | | 15% | TR | 10 | | |
| 21. | 30% | | 30% | 10% | | | 15% | | | | |
| 19. | | 20% | | TR | | | 25% | | 10 | | |
| 22. | 90% | | | TR | | | 5-10% | | | | |
| 25. | 60% | | | 10-15% | | | 5% | 3-5% | | | |
| 8. | 5-10% | | | 5-10% | | | 80% | | | | |
| 2. | | | | 10% | | | 70% | 20% | | | |
| 4. | 10% | | | | | | TR | | | | 80% |
| 20. | | | | | 5% | | 10% | | 20 | 45% | |

### ISLAMIC SHERDS

| SHERD. | MICRITE | CARB (CR) | CARB (SM) | FELD | QTZ | FELD/QTZ | IRON OXIDES | OPAQUES | AMOR | K-SPAR | CAL/CRYS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 17. | 10% | 60% | | TR | | | 10% | | | | |
| 18. | 30% | 20% | | 5% | | | 30% | | 10 | | |
| 14. | 20% | 30% | | TR | | | 30% | | 20 | | |
| 1. | 40% | | | 30% | 10% | | 20% | | | | |
| 9. | 20% | | 45% | 10% | | | 20% | | | | |
| 13. | 25% | | 25% | 15% | | | 20% | | | | |
| 6. | 90% | | | | | 5% | 5% | | | | |
| 7. | 70% | | | | | 15% | 3-5% | | | | |
| 12. | 3% | | | TR. | | | 70% | | | | |

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APPENDIX NUMBER ONE

GROUP ONE

| SHERD | | MICRITE | FELDSPAR | QUARTZ and/or FELDSPAR | HEMATITE | OPAQUES | AMORPHOUS | FOSSILS | AVERAGE GRAIN SIZE FOR THE GROUP |
|---|---|---|---|---|---|---|---|---|---|
| 6 | % | 90% | | 5% | 5% | | | | HEMATITE .3 mm |
| | GRAIN SIZE | | | .001 mm | 1 mm | | | | FELDSPAR .005 mm |
| 7 | % | 70% | | 15% | 3%-5% | 5%-10% | | | |
| | GRAIN SIZE | | | .02 mm | .3 mm | | | | |
| 22 | % | 90% | TRACE | | 5%-10% | | | TRACE | |
| | GRAIN SIZE | | .001 mm | | .03 mm | | | | |
| 25 | % | 60% | 10% - 15% | | 5% | 3%-5% | | | |
| | GRAIN SIZE | | .001 mm | | .001 mm | | | | |

APPENDIX NUMBER TWO

GROUP TWO

| SHERD | | MICRITE | CARBONATE CRACKED SURFACE TEXTURE | FELDSPAR | HEMATITE and or MAGNETITE | AMORPHOUS | FOSSILS | | AVERAGE GRAIN SIZE FOR THE GROUP |
|---|---|---|---|---|---|---|---|---|---|
| 17 | % | 10% | 60% | TRACE | 10% | | TRACE | | HEMATITE .035 mm |
| | GRAIN SIZE | | .5 mm | | .01mm | | | | CARBONATE .24 mm |
| 18 | % | 30% | 20% | 5% | 30% | 10% | | | |
| | GRAIN SIZE | | .03 mm | | .01 mm | | | | |
| 19 | % | 30% | 20% | TRACE | 25% | 10% | TRACE | | |
| | GRAIN SIZE | | .03 mm | | ·02 mm | | | | |
| 14 | % | 20% | 30% | TRACE | 30% | 20% | | | |
| | GRAIN SIZE | | .4 mm | | .1mm | | | | |

APPENDIX NUMBER FIVE

GROUP FIVE

| SHERD | | MICRITE | QUARTZ | FELDSPAR | OPAQUES | HEMATITE | AMORPHOUS | FOSSILS | CALCITE CRYSTALS |
|---|---|---|---|---|---|---|---|---|---|
| 2 | % | | TRACE | 10% | 20% | 70% | | | |
| | GRAIN SIZE | | | .02 mm | 1 mm | 1 mm | | | |
| 8 | % | 5% - 10% | | 5% - 10%÷ | | 80% | | TRACE | |
| | GRAIN SIZE | | | .01 mm | | .5 mm | | | |
| 4 | % | 10% | | | | TRACE | | | 80% |
| | GRAIN SIZE | | | | | .04 mm | | | 1 mm |
| 12 | % | 3% | | TRACE | | 70% | | | |
| | GRAIN SIZE | | | | | 1 mm | | | |
| 20 | % | 5% | 5% | 45% | | 10% | 20% | | |
| | GRAIN SIZE | | | .001 mm | | .001 mm | | | |

APPENDIX NUMBER THREE

GROUP THREE

| SHERD | | MICRITE | CARBONATE SMOOTHLY TEXTURED | QUARTZ | FELDSPAR | HAMATITE | AMORPHOUS | FOSSILS | AVERAGE GRAIN SIZE FOR THE GROUP |
|---|---|---|---|---|---|---|---|---|---|
| 1 | % | 40% | | 10% | 30% | 20% | | | HEMATITE .4 MM |
| | GRAIN SIZE | | | .04 mm | .04 mm | 1 mm | | | FELDSPAR .02 mm |
| 9 | % | 20% | 45% | | 10% | 20% | | | QUARTZ .04 mm |
| | GRAIN SIZE | | | | .02 mm | .5 mm | | | CARBONATE .3 mm |
| 13 | % | 25% | 25% | | 15% | 20% | 15% | TRACE | |
| | GRAIN SIZE | | .3 mm | | .001 mm | .2 mm | | | |
| 21 | % | 30% | 30% | | 10% | 15% | | | |
| | GRAIN SIZE | | .4 mm | | .001 mm | .02 mm | | | |

APPENDIX NUMBER FOUR

GROUP FOUR

| SHERD | | MICRITE | CARBONATE CRACKED SURFACE TEXTURE | QUARTZ | FELDSPAR | OPAQUES | HEMATITE | AMORPHOUS | AVERAGE GRAIN SIZE FOR THE GROUP |
|---|---|---|---|---|---|---|---|---|---|
| 10 | % | 5% | 20% | | 10& | 20% | 15% | | HEMATITE .01 mm |
| | GRAIN SIZE | | .5 mm | | .001 mm | 1 mm | .001 mm | | FELDSPAR .007 mm |
| 11 | % | 15% | 30% | 5% - 10% | 5%-10% | YES | 20% | 3% - 5% | QUARTZ .001 mm |
| | GRAIN SIZE | | .5 mm | .001 mm | .001 mm | | .02 mm | | CARBONATE .5 mm |
| 23 | % | 20% | 50% | | 5% | TRACE | 15% | 10% | |
| | GRAIN SIZE | | .5 mm | | .01 mm | | .02 mm | | |
| | % | | | | | | | | |
| | GRAIN SIZE | | | | | | | | |