

LOCATING OF SOIL MATERIAL FOR USE IN ADOBE STABILIZATION AT FORT
BOWIE NATIONAL HISTORIC SITE

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Preservation of adobe or earthen structures is a continuing problem. Various chemical amendments have been tried in the past, but they were often ineffective. A project at Fort Bowie was initiated to locate source areas of suitable soil that could be used successfully as unamended mud mortar or plaster material.

The senior author conducted a field analyses and prepared a soil map of the site, specifically identifying areas that had the greatest potential for use in the stabilization project. Samples were collected and laboratory analysis completed. This information was then used for comparative purposes with data available on the historic adobe material.

Three distinct adobe soils were used in the construction of Fort Bowie. These adobe materials were: a light gray, clay loam material; a reddish-yellowish brown sandy clay loam or sandy loam; and a grayish-brown sandy clay loam or sandy loam. Extensive field notes and observations plus laboratory analyses characterizing the particle size distribution, types of clay minerals, soluble salts, and various porosity-compression strength measurements were made.

The soil map showed that only limited source areas exist for two of the historic adobe materials, whereas the grayish-brown soil is widely distributed within the monument. Results using these identified soil sources for the stabilization project currently underway at Fort Bowie have been encouraging.

A secondary benefit gained from this study was the verification of the borrow pit locations for soil materials used in the original fort construction.

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INTRODUCTION

Stabilization and preservation of any adobe or earthen structure is a continuing problem. This is especially true of eroded structures and abandoned historic structures like Fort Bowie as a National Historic Site, where only remained eroded walls, foundations, and traces of buildings, all badly in need of preservation and stabilization. Between 1967 and 1969 an initial joint historic/archeology/stabilization program was completed by the Ruins Stabilization Unit of the National Park Service. This stabilization included the repair of basal and surface erosion on adobe and stone walls, grouting, or cracks, water channels and holes in the walls, and capping of adobe walls with a soil cement adobe. However, this effort has not been satisfactory because it sometimes enhanced the adobe deterioration, it discolored the ruins and made them appear unnatural, and it was expensive.

The specific objective of this research was to locate potential source areas of soil material that could be used as unamended mud mortar or plaster preservation material. This essentially involved "matching up" the historic adobe materials with the natural soils found on the Fort Bowie National Historic Site, (Abbreviated as "Site" in this report.)

The senior author is a soil scientist and he conducted an extensive in-field analysis and prepared a soil map of the site. Specific areas were identified which had the

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greatest potential for use in the stabilization project, samples were collected and the information was then used for comparative purposes with data available on the historic adobe material. The following discussion presents the data and methodology used in this research.

REVIEW OF LITERATURE

The National Bureau of Standards Technical Note 934 by J.R. Clifton (1) presents a current status report on the preservation of historic adobe structures. Particle size distribution is perhaps the most important characteristic in determining adobe stability. The particle size categories used by the U.S. Department of Agriculture will be used exclusively in this paper. These particle size categories are as follows:

Cobble and stones - greater than 3.0 inches in diameter X

Gravel - 2.00 millimeter to 3.0 inches in diameter

Sand - 2.00 to 0.05 millimeters in diameter

Silt - 0.05 to 0.002 millimeters in diameter

Clay - less than 0.002 millimeters in diameter

Fenn and Chambers (2) suggest the following optimum particle size distribution of a soil to be used as an unamended mortar or plaster: 20-25% clay, 60-70% sand, and 0-10% silt. Gravel of small diameter if present in limited volume is not a problem. This classification would be a sandy clay loam or gravelly sandy clay loam textural class notation.

The amount of clay should be high enough to provide good cementation, but not too high to cause reduced strength or potential shrink-swell and associated cracking problems. Silt sized particles in excess of 10% are undesirable because they neither provide good binding as does clay, nor good strength as does sand. The distribution of sand should be very coarse and medium sized particles. The fine and very fine sand size classes are close to silt in size and have many of the undesirable properties of silt. It is also beneficial if the sand and small gravel particles are angular in shape rather than rounded as this increases the strength of the adobe.

The type of clay mineral as evaluated by X-ray diffraction techniques is also important. A soil used for mud mortar or plaster should contain little or no montmorillonite or vermiculite. These two clay types swell considerably when moist and shrink upon drying causing serious cracking to occur.

The total concentration of soluble salts should be less than 1000 parts per million, and the lower the better. Excessive salts can attract hygroscopic moisture and form harmful salt efflorescence and subflorescence which tends to weaken the mortar. The pH of the soil material is another common chemical measurement that can sometimes add valuable data about the soil being studied.

Another important laboratory soil measurement is the liquid and plastic limit of the soil material. The liquid limit is the moisture percentage at which a soil passes from a plastic to a liquid stage. At this point the moisture films become so thick that cohesion is decreased and the soil mass "flows." The plastic limit is the moisture percentage at which a soil changes from a semisolid to a plastic state. The plasticity index is defined as the numerical difference between the liquid limit and plastic limit. These values are mostly determined by soil texture and type of clay mineral. However, the liquid limit measurement can also be used to determine the amount of water to add when mixing a mud mortar.

Other analyses which can be valuable are porosity and compression strength tests. These are soil engineering type analyses and are not within the scope of this project.

A final important attribute is the soil color. The color of soil is measured by comparison of the soil with standard Munsell soil color charts which note the hue, value, and chroma aspects of color. Although the color per se has minimal affect on adobe stability, the historic and unamended soil material must be matched for obvious reasons.

CHARACTERISTICS OF THE HISTORIC ADOBE WALLS

Three distinct soils were used in the construction of Fort Bowie and these are also described and characterized on the following pages. There were two different time

periods of adobe construction, and these are referred to as "Old" Fort Bowie and "New" Fort Bowie in this report. Construction dates for these two structures were respectively.

The "Old" Fort Bowie was constructed of a light gray adobe material, more clayey and silty in texture than the other adobes. The "New" Fort is constructed of three basic adobe brick types including this light gray adobe, a reddish-yellowish-brown and a grayish brown adobe. The latter two adobes have less clay and silt than the light gray adobe.

The process of locating a future potential source area involved not only the characterization of the historic adobe, but also identifying and characterizing the probable historic source area for this adobe. The historic sites of likely source areas had been identified but this characterization study was able to show data confirming the location. This data is presented in the following tables.

The data presented in Table 1 from the three historic "Old" Fort Bowie adobes and the historic adobe source area clearly are very similar. The natural material has been described geologically as the Bisbee shaly siltstone. It is limited in extent with a very small area near Apache Springs and a larger area east and north of the residence area. Besides being distinctly different in color, its particle size distribution has a higher clay and silt content than the other adobes, and clay mineralogy data presented later show it has more expanding type clays. All of these characteristics make a poor quality adobe, and this might explain why a "New" Fort was constructed.

Table 2 presents descriptive material and data about the reddish-yellowish brown adobe material. The source area for this strong brown to reddish-yellowish brown material is quite limited in extent. It is quite evident that it came from the Apache Spring area in the vicinity of the Wikiup. The cut banks and overall borrow pit appearance plus the data presented in Table 2 match very well.

Table 1 - Field characterization data estimates and selected laboratory analysis for the light gray adobe from "Old" Fort Bowie, the probable historic source area, and a potential source area.

<u>Sample Identification</u>	<u>Soil Color</u>	<u>Moist</u>
	<u>Dry</u>	
Historic "Old" Fort Bowie Adobe (~~Lab #101~~) (#1)	5Y 7/2 (light gray)	5Y 6/2 (light olive gray)
Historic "Old" Fort Bowie Adobe (~~Lab #102~~)	5Y 7/2 (light gray)	5Y 6/2-6/3 (light olive gray to pale olive)
Historic "Old" Fort Bowie Adobe (~~Lab #108~~) (#3)	2.5Y or 5Y 7/2 (light gray)	2.5Y or 5Y 6/2 (light brownish gray to light gray)
From Apache Springs Bank Along Foot Trail (~~Lab #98~~) (Probable historic source area #4)	5Y 6/2 or 7/2 (light olive gray to light gray) (mottles of strong brown staining)	10YR 6/2 (light brownish gray)
From Road Cut--150 meters NE of residence (~~Lab #100~~) (Future source area #5)	10YR 7/2 and 8/1 (light gray and white)	10YR 7/2 (light gray)

Particle Size Distribution Data

	<u>%Gravel</u>	<u>%Sand</u>	<u>%Silt</u>	<u>%Clay</u>	<u>Textural Class</u>
Lab #102	25 (16)*	40 (65)	26	34	clay loam
Lab #2	35 (31)	51 (57)	18	31	sandy clay loam (gravelly)
Lab #3	35 (35)	43 (53)	24	33	clay loam (gravelly)
Probable historic source area (#4)	30 (29)	40 (44)	26	34	clay loam (gravelly)
Lab #100	10 (5)	42 (29)	30	28	clay loam
Future source area (#5)					

*Data in () is laboratory analyses of the same samples. ~~from Dr. Dennis Penn's laboratory~~

Table 2 - Field characterization data estimates and selected laboratory analysis for the reddish-yellowish brown adobe from "New" Fort Bowie, the probable historic source area, a potential source area, and a historic gray mortar.

<u>Sample Identification</u>	<u>Soil Color</u>	
	<u>Dry</u>	<u>Moist</u>
Historic Post Trader Adobe From East Wall (~~Lab #109~~ #1)	10YR 6/4 (light yellowish brown)	10YR 4/4-5/4 (yellowish brown)
Historic Corral Wall Adobe (~~Lab #104~~) (#2)	10YR 6/4 to 7.5YR 5/6-6/6 (light yellowish brown to strong brown)	10YR 4/4 (dark yellowish brown)
Borrow Pit - Apache Springs (~~Lab #106~~) (#3)	10YR 6/4 (light yellowish brown)	7.5YR 4/4, 10YR 4/4 (brown to dark yellowish brown)
Borrow Pit - Apache Springs (~~Lab #107~~) (#4)	10YR 6/4 (light yellowish brown)	10YR 4/4 (brown)
Borrow Pit - Apache Springs (~~Lab #99~~) (#5)	7.5YR 6/6 (reddish yellow)	7.5YR 4/6 (strong brown)
Soil Bank Near Trail Parking Lot (~~Lab #97~~) (#6)	7.5YR 6/6 (reddish yellow)	7.5YR 4/6 (strong brown)
Corral Wall Gray Mortar or Brick? (~~Lab #105~~) (#7)	2.5Y 7/2 (light gray)	5Y 6/2-7/2 (light olive gray to light gray)

Particle Size Distribution Data

	<u>%Gravel</u>	<u>%Sand</u>	<u>%Silt</u>	<u>%Clay</u>	<u>Textural Class</u>
Lab #109 #1	35 (19)*	71 (61)	8	21	sandy clay loam (gravelly)
Lab #104 #2	25 (13)	72 (64)	8	20	sandy clay loam
Lab #106 #3	35 (22)	69 (61)	9	22	sandy clay loam (gravelly)
Lab #107 #4	35 (19)	67 (63)	10	23	sandy clay loam (gravelly)
Lab #99 #5	30 (28)	72 (62)	7	21	sandy clay loam (gravelly)
Lab #97 #6	20 (16)	60 (60)	17	23	sandy clay loam
Lab #105 #7	25 (14)	45 (34)	25	30	clay loam

*Data in () is laboratory analyses from ~~Dr. Penn's laboratory~~ *of the same sample*

This material is alluvial-colluvial from the granite type rock of the area. Although there are extensive areas of granite on the Site, there is relatively little rock free, deep, reddish brown deposits. Most places the soil is shallow and rocky limiting its use. We found only a single source area besides the original source area near the Wikiup. This site is located about 400 meters west and 50 meter south of the parking area at the start of the Fort Bowie trail. ~~Figure 9 is a picture of this deposit.~~ Granite sediments eroded from north facing slopes are dark brown from the higher organic matter content found on north slopes, whereas the granite alluvium-colluvium from these sample sites was eroded mostly off south facing slopes.

Table 3 presents descriptive material and data about the grayish-brown adobe material used in the construction of the "New" Fort. This adobe was used almost exclusively in the construction of some buildings. The texture of this material is comparable to the reddish-yellowish brown adobe, but the enrichment of organic matter has darkened the color. The potential source area for this material is quite extensive. It is dominantly alluvial in origin being washed off the higher slopes, particularly from the north facing slopes.

We believe this material was more commonly used after the Fort water supply was established. Initially it was easier to prepare the bricks near the water source and transport them to the Fort area. But in later years, the water was available at the Fort, so they made the brick from materials in the vicinity. We looked for any evidence of where this type of adobe material might have been removed, but found none.

CLAY MINERALOGY COMPOSITION, LIQUID LIMIT, PLASTIC LIMIT,
SOLUBLE SALTS, AND pH LABORATORY CHARACTERIZATION DATA

Table 4 presents clay mineralogy data and liquid limits, plastic limits, plasticity index, PPM soluble salts, sodium, potassium, and pH. This data shows the light gray adobe from the "Old" Fort, are characteristically higher in montmorillonite and vermiculite, both expanding type clay mineral types. The liquid limit values too are higher for the light gray adobes, reflecting the high total clay content being clay loams as compared to sandy clay loams.

Table 3 - Field characterization data estimates and selected laboratory analyses for the grayish brown "New" Fort Bowie adobe.

<u>Sample Identification</u>	<u>Soil Color</u>	
	<u>Dry</u>	<u>Moist</u>
Post Trader - West Wall (#1) (~~Lab #103~~)	10YR 6/3 (pale brown)	10YR 3/2 (very dark grayish brown)
Post Trader - West Wall (#2) (~~Lab #110~~)	10YR 6/3 (pale brown)	10YR 3/2-3/3 (very dark grayish brown to dark brown)
Southeast Corner Officer's Quarters (~~Lab #111~~) (#3)	10YR 5/3 (brown)	10YR 3/2-2/2 (very dark brown to very dark grayish brown)

Particle Size Distribution Data

	<u>% Gravel</u>	<u>% Sand</u>	<u>% Silt</u>	<u>% Clay</u>	<u>Textural Class</u>
Lab #103	40 (25)*	70 (54)	10	20	sandy clay loam (gravelly)
Lab #110 ²	35 (29)	59 (51)	17	24	sandy clay loam (gravelly)
Lab #111 ³	35 (20)	60 (73)	17	23	sandy clay loam (gravelly)

of the same samples.
*Data in () is laboratory analyses ~~from Dr. Dennis Fenn's laboratory.~~

Table 4 - Clay mineralogy characterization results and liquid limits, plastic limits, plasticity index, PPM total soluble salts, PPM sodium PPM potassium, and pH.

	Lab #	Mont- morillonite	Vermi- culite	Mica- illite	Kaolinite	Liquid Limit	Plastic Limit	Plasticity Index	PPM Salt	PPM Sodium	PPM Potassium	pH
Light Gray Adobe (Table 1)	101 1	4*	1*	3*	2*	23.0**	19.0**	4.0**	300	13	6	8.0
	102 2	3	1	3	3	20.9	18.8	2.1	820	42	5	7.9
	108 3	4	0	3	2							
	98 4	4	0	3	2	31.7	17.9	13.8	2170	320	16	7.9
	100 5	4	1	3	2	25.3	18.4	6.9	3130	192	140	7.7
Reddish- Yellowish Brown Adobe (Table 2)	109 1	3	0	4	2							
	104 2	2	0	4	3							
	106 3	2	0	4	3							
	107 4	2	0	4	2							
	99 5	2	0	4	3	18.3	14.4	3.9	4010	204	14	7.5
	97 6	3	0	4	3	18.8	17.2	1.6	2100	368	6	7.9
	105 7	5	0	3	2							
Grayish Brown Adobe (Table 3)	103 1	2	0	3	2	22.7	20.2	2.5				
	110 2	3	0	3	2							
	111 3	4	0	3	2							

*Relative notations used to indicate amount of that clay mineral present.

5 = Dominant, 4 = Large Amount, 3 = Medium Amount, 2 = Small Amount, 1 = Trace, and 0 = None Present.

**Data are presented as % moisture in sample calculated on weight basis.

The reddish-yellowish brown adobe and the grayish brown adobe materials have similar clay mineralogy suites. The mica-illite and kaolinite predominate in these samples with Montmorillonite and vermiculite being present in smaller quantities. This is as expected because both materials are probably from granitic type parent rock, but one is higher in organic matter.

The soluble salt content is high in some samples sampled for adobe source areas. This data is probably non-representative because the samples were collected from the bank surfaces, and salt accumulated from capillary action and evaporation.

SUMMARY AND CONCLUSIONS

A brief review of the physichemical properties of adobe building material and an in-field plus laboratory analyses of the Historic Fort Bowie Adobe was completed. The Fort was constructed of three basic adobe types: a light gray clay loam type, a reddish-yellowish brown sandy clay loam (gravelly) type, and a grayish brown sandy clay loam to sandy loam (gravelly) type. Data about each adobe type plus information on source areas of each adobe for future restoration work were presented. Results of this study also permit a positive identification of the historic source area for each adobe and the location of source areas for unamended soil material to be used in future restoration work.

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