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SAUDI ARABIAN PROJECT REPORT **226**

RAW MATERIALS FOR STRUCTURAL CLAY PRODUCTS IN THE ABHA-KHAMIS MUSHAYT AREA, KINGDOM OF SAUDI ARABIA

By

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ABSTRACT

Abha and Khamis Mushayt, rapidly growing twin cities in southwestern Saudi Arabia, would benefit greatly by having an indigenous source of structural clay products. Conventional sources of high-quality raw materials, i.e., clay and shale, are lacking in the dominantly igneous and metamorphic terrain. Although not of high quality, colluvium and wadi silts are the most probable sources of raw material for hollow ware. The thick, widespread wadi silts near Hamdah are the largest potential source of raw material, but are 125 km from the market area. The siliceous kaolinite in the As Sarat laterite might be beneficiated to a suitable raw material for ceramic tile by grinding and possibly by addition of kaolinite from near Suleiman.

INTRODUCTION

Abha, located at 18°12'N. and 42°30'E. (fig. 1), is a city of about 30,000 inhabitants. Khamis Mushayt, a city of about the same size, is located 25 km northeast. Abha and Khamis Mushayt have developed and are continuing to develop rapidly from rural villages with unpaved streets to modern cities. In addition to recent construction of residences, shops, and public buildings, the military and transportation

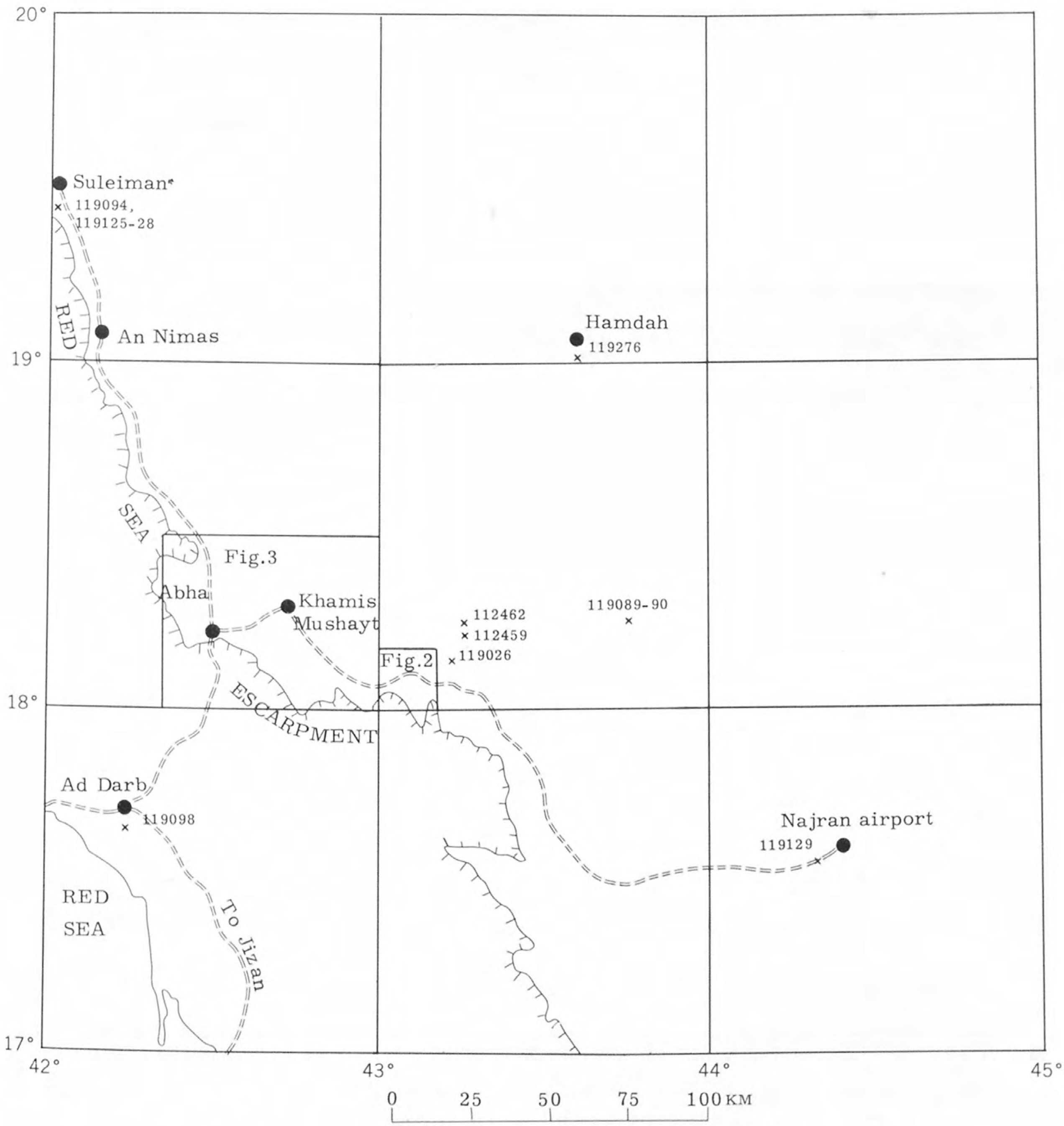

Figure 1.- Map showing area of report and location of samples not shown on figures 2 and 3.

facilities have been greatly enlarged. Because of the area's scenic beauty and cool climate, much recreational use is expected.

Most material for the increasing construction must be imported. Only aggregate, adobe, concrete block, concrete tile, and rubble stone are produced locally.

The two major transportation arteries are the highways from At Ta'if and Jizan, both incomplete at this time. Even when complete, they pose formidable barriers to the importation of bulk products. The highway from Jizan to Abha, 175 km long, climbs 2000 m up the Red Sea escarpment. The highway from Jiddah to Abha via At Ta'if, 575 km long, also climbs the escarpment and then passes through about 450 km of undulatory, in some stretches rugged, terrain.

The major construction material in the Abha area is concrete block. Aggregate is plentiful but all portland cement must be imported. To this date no limestone or marble deposit suitable for cement raw material has been found more accessible to Abha than the deposits near Jizan.

Brick, therefore, could relieve some of the area's dependence on concrete block. A suitable clay deposit might provide the raw material for hollow ware and even ceramic tile.

Previous work

Our early interest focussed on the As Sarat laterite exposed 60 km east of Khamis Mushayt and shale exposed near Ad Darb (fig. 1) as the most probable sources of clay. Wadi deposits were for the most part considered unavailable because their current and highest use is agricultural. Bedrock consists largely of metamorphic and igneous rocks. Except possibly in the Baid Formation near the coast, there is no shale or clay, other than in wadi, colluvium, laterite, or saprolite deposits.

The most detailed, comprehensive, and recent published work on the laterite is Overstreet and others' (1977) Tertiary laterite of the As Sarat mountains, Asir Province, Kingdom of Saudi Arabia. The report summarizes J.B. Philby's discovery of the laterite in 1936 and his report published 16 years later. It also summarizes the previous work by Glen Brown and Roy Jackson (USGS) in 1951, by Gus Goudarzi (USGS) in 1954, and by W.C. Overstreet (USGS) in 1964 and 1965.

The As Sarat mountains have recently been mapped by D.B. Stoeser and R.E. Anderson (USGS) as part of the 30 minute quadrangles: the Wadi Tarib quadrangle (1978) and Wadi Atf quadrangle (1978).

No report on the Baid Formation or wadi, colluvium, and saprolite deposits as raw materials for structural clay products has been published. A few unpublished reports mention the possibility of suitable clays in the Baid Formation, apparently based mainly on published descriptions of measured sections (Skipwith, 1973).

Acknowledgments

The work described herein was done in accordance with the work agreement between the Ministry of Petroleum and Mineral Resources and the U.S. Geological Survey.

The firing tests on most of the samples described in this report were performed under the direction of Alain Batel in the French Bureau de Recherches Geologiques et Minieres (BRGM) laboratory in Jiddah. Firing tests on three samples were performed under the direction of Sam Patterson in the USGS laboratory, Reston, Virginia, U.S.A. Beneficiation and firing tests of the As Sarat laterite were performed by the U.S. Bureau of Mines in its Metallurgy Research Center, Tuscaloosa, Alabama, U.S.A.

POTENTIAL RAW MATERIALS

As Sarat laterite

The As Sarat laterite comprises the bedrock altered by weathering beneath, and prior to the deposition of, basalt in the As Sarat mountains located between lats 17°45'N. and 18°20'N. and longs 43°E. and 43°30'E. in southwestern Saudi Arabia. The area covered by the laterite is about 1000 sq km. Because much of the weathered rock is not laterite, the term is inexact.

The light-gray laterite can be divided into four units. The lowest unit, which has been called a saprolite, differs from the underlying bedrock most consistently in that the laterite has a light color. In some areas, especially along some wadis and gentle slopes, it is soft and friable, a true saprolite. Elsewhere it is hard. Whether the bedrock is schist, granite, or other rock type, the original texture remains. Where measured, this unit is about 10 m thick but elsewhere it appears to range from 3 to 15 m thick. In some areas it was the only unit recognized.

The next unit in succession, which we call the building stone unit for reasons described below, cannot be distinguished from the lowest unit when viewed from a distance. It differs markedly in texture, however, in that, of the original phenocrysts, only quartz remains in a pale gray or pink aphanitic matrix of kaolinite cemented by silica, cristobalite in part (see Appendix). Much of the unit has an orbicular aspect because of red mottling, and in most areas is hard and brittle. The unit is not developed everywhere. Where measured, the building stone unit is from 10 to 17 m thick and is the only part of the As Sarat laterite that could be mined cheaply in large quantity. At several localities (fig. 2) from 10 to 100 million tonnes lie at the surface within a few kilometers of the Khamis Mushayt-Najran highway.

The natives of the As Sarat pry out blocks of the building stone unit by hand, chisel them slightly, and lay them as supporting walls for houses and other buildings. The small fragments are used to fill the interstices. The inner and, in some instances, the outer wall may be plastered with adobe and lime. The primary reason the laterite is used--rather than basalt, for example--is that the laterite is easy to quarry and to shape. It has supplementary advantages of a relatively low specific gravity, an almost white color, and the availability of large blocks.

A third unit, not developed everywhere, is similar in texture to the building stone unit, but mustard yellow in color, probably due to iron concentration, and less than 5 m

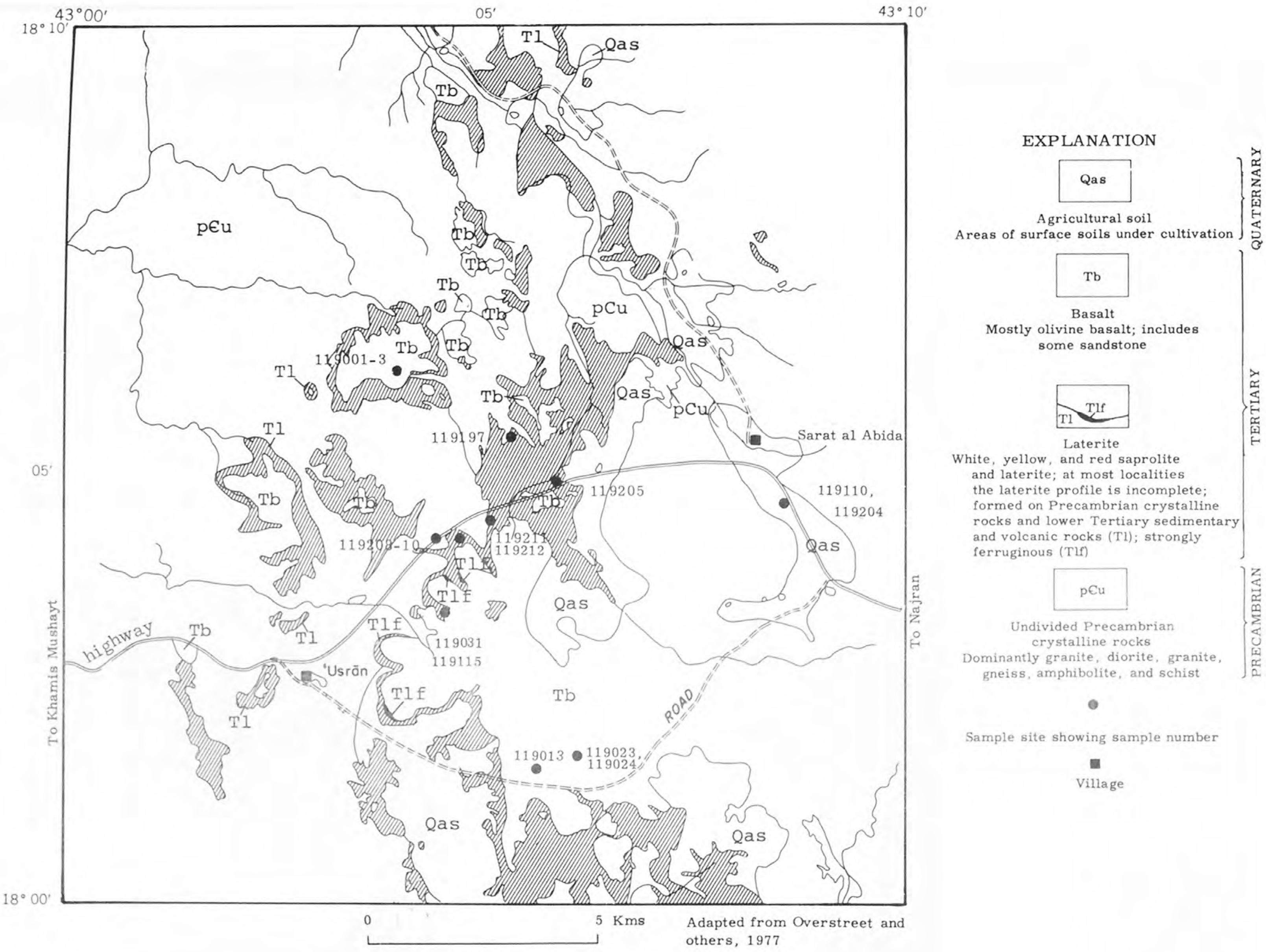

Figure 2. - Geologic map showing distribution of As Sarat laterite and location of samples.

thick. The mustard yellow unit in turn is overlain in some places by a fourth unit of red laterite with a concretionary and conglomeratic texture. In some exposures, a similar concretionary layer is only superficial slope wash developed after deposition of the basalt. At a few localities the concretionary unit is not ferruginous.

In small areas the building stone unit may be weathered into a soft clay, some of which has been carried downslope and redeposited as lenses of sedimentary kaolinite having a volume of only a few cubic meters.

Numerous mineralogical and chemical analyses reveal the dominant minerals in the laterite to be kaolinite and quartz. The average chemical composition is probably approximated in the composite samples from four stratigraphic sections sampled by Goudarzi (table 1).

Saprolite

In addition to the saprolite at the base of the As Sarat laterite, part of the As Sarat basalt is saprolitic. In both cases, the distribution of the true--i.e., soft--saprolite is patchy, and the thickness, although unknown, is probably at best only a few meters. The most common minerals in the saprolites sampled in the As Sarat area, regardless of parent rock type, are quartz, montmorillonite, and feldspar (table 2).

Composite sample 119023-119024 was collected within the basalt flows themselves and may or may not be considered part of the As Sarat laterite. "Partially laterized" basalts low in the section have been reported (Overstreet and others, 1977,

Table 1.--Partial chemical analyses of composite samples of As Sarat laterite [from Overstreet and others, 1977, p. 15-16].

Sample nos.	Thickness (m)	SiO_2	Al_2O_3	Total Fe as Fe_2O_3	TiO_2
54781-54782	28	67.6	17.5	4.3	0.68
54784	25	71.2	15.0	4.5	0.31
54785-54786	30	64.6	20.2	4.9	0.53
54796-54797	22	57.7	20.6	5.9	0.81

SAMPLE NUMBER AND THICKNESS		MINERALOGY: Chlorite	Kaolinite	Illite	Montmorillonite	Feldspar	Quartz	Mica	Calcite	Dolomite	OVEN-DRIED CONDITION	CONDITION OF TEST PIECES AFTER FIRING (wk-weak; wh-white; fri-friable; + severe; shr-shrinking; excel-excellent; frags-fragments; pr-poor; eff-efflorescense): 600°C	800°C	950°C	1000°C	1050°C	1150°C	1200°C	PARAMETERS OF TEST PIECES FIRED AT 1050°C: Drying shrinkage	Firing shrinkage (%)	Open porosity 1 (%)	Closed porosity 2 (%)	Absorbed water (%)	Specific gravity 3	Apparent specific gravity 4
AS SARAT LATERITE																										
Building stone unit																										
119026	10m		A				A	T			good			wk, fri		wk	wk		0.7	1.1	48.1	6.4	36.7	2.9	1.3
Building stone unit and wadi clay																										
119223	10	T	A		A	X	A	X	X		good			good	good	good			5.1	0.8	42.0	7.5	28.3	2.9	1.5
119224	10	X	A		X		A	X	X		good			good	good	good			4.5	0.3	38.8	7.6	25.8	2.8	1.5
119225	10	X	A		X		A	X	X		good			good	good	good			1.7	-0.1	37.3	9.3	23.9	2.9	1.6
119226	10	T	A		A		A	X	X		good			good	good	good			4.4	0.2	43.0	3.1	26.8	3.0	1.6
Sedimentary kaolinite																										
119013	<1		A				X				good			good		good		good	3.8	1.9	29.7	2.9	17.5	2.7	1.9
112459[5]	<1		A				A		X		good	excel	cracks		+cracks				4						
112461[5]	<1		A				A		X		good	excel	frags		frags				4						
112462[5]	<1		A				A		X		good	excel	+cracks		frags				4						
SAPROLITE																										
119024 & 119023	?			T	X				T		cracked			broken		+cracks		frags	13.8	5.8[6]	29.1[6]	18.1[6]	20.5[6]	2.7[6]	1.4[2]
119031	5?				X	X		T	X		good			good		good	good, shr		2.4	2.0	54.9	2.8	26.2	2.8	1.2
119115	5?				X	X	X				good			good		good	good		4.1	1.4	40.8	5.1	25.5	3.0	1.6
119208[7]	1										good			good	good	good			2.1	0.0	40.0	2.7	23.7	3.0	1.7
119209[7]	1										good			good	good	good			2.6	0.5	44.2	4.1	26.8	3.2	1.6
119210[7]	1										friable			lost					0.4	-1.3	39.0	8.5	25.3	2.9	1.5
119215[7]	<1										fair			pr, fri	pr, fri	pr, fri			broken						
Suleiman clay																										
119094	1-3				X	X	X				good			weak		good	much shr		1.9	4.2	60.9	2.9	38.9	2.8	1.0
119125	1-3		A				A				friable			wk, fri		good, wh	good, wh		0.8	1.2	40.1	10.0	45.8	3.1	1.5
119126	1-3		A				A				friable			wk, fri		wk, fri	excel, wh		0.2	1.2	42.8	4.0	49.2	2.9	1.5
119127	1-3		A				A				friable			wk, fri		wk, fri	excel, wh		0.0	-0.3	51.7	2.7	59.9	2.9	1.3
119128	1-3		A				A				friable			wk, fri		wk, fri	excel, wh		0.2	1.4	44.0	4.8	47.4	3.0	1.6
COLLUVIUM																										
119001,2,3	2.4			X	X				X	X	cracked			broken		broken			12.5	2.9	41.0	1.1	25.2	2.8	1.7
119012	1	X			X	X	X	T	X		good			good		good	much shr		1.2	0.3	56.3	2.8	28.0	2.8	1.1
119110	3	X			X	X	X	T	X	X	good			good		good	much shr		2.2	0.6	43.9	1.4	26.6	3.0	1.6
119117	1-2	X			X	X	X			T	good			good		good	melting		7.9	1.8	31.4	6.5	17.0	3.0	1.9
119204	2.8	T			A	X	X		X	X	good			good	good	good			9.1	1.3	33.8	0.6	18.2	2.8	1.9
119206	1	X			A	X	A	X			good			good	good	good			7.6	0.5	27.9	7.7	14.4	3.0	1.9
119216	1	X			X	X	A	X			good			broken	broken	broken			broken						
119219 & 119220	1	X			X	A	A	X			good			good	good	good			8.1	-0.4	31.2	4.3	16.8	2.9	1.9
WADI SILT AND CLAY																										
119089 & 119090	5	X			X	X	X	T	X		good			good, eff		good, eff	good, eff		2.7	0.6	39.9	3.4	23.7	3.0	1.7
119098	4	X			X	X	X	T			good			wk, fri		good, eff	melting		3.0	-1.9	55.6	4.0	28.3	2.9	1.2
119114	3	X			X	X	X	T			good			good		good	good, black		5.3	0.3	36.5	3.8	21.3	2.9	1.7
119116	1	X				X	X	T	T		good			good, eff		good, eff	melting		1.0	0.3	38.4	2.4	22.7	2.9	1.7
119129[3]	4										good			good	good	good			6.5	-0.6	41.2	2.5	24.4	3.0	1.7
119202	1.7	X			X	A	A	X	X		good			good	good	good			3.4	-0.6	37.7	4.6	22.6	2.9	1.7
119203	1.7	X			X	A	A	X	T		good			good	good	good			2.8	-1.4	36.8	4.9	21.8	2.9	1.7
119214	<1	X			X	A	A	X			fair			good	good	good			2.3	-1.2	36.7	3.6	21.1	2.9	1.7
119217	2	A			X	A	A	X			good			good	good	good			7.7	0.2	31.2	3.1	16.5	2.9	1.9
119218	1	X			X	A	A	X			good			good	good	good			2.2	-0.4	38.5	3.2	23.1	2.9	1.7
119276[3]	10				X	X	X	X	X		good			good	good	good			5.0	0.5	40.9	18.8	60.1	4.1	1.7
STRUCTURAL TILE MANUFACTURED FROM WADI FATIMA SILT																					26.0	12.5	13.1	3.2	2.0

1 - Volume of voids open to boundaries of test piece; 2 - Volume of voids not open to boundaries of test piece; 3 - Specific gravity of test piece excluding voids; 4 - Specific gravity of test piece including voids; 5 - Fired in U.S. Geol. Survey lab in Reston, Va. All other samples fired in Bureau de Recherches Geologiques et Minieres lab in Jiddah; 6 - Fired at 1200°C; 7 - Not analyzed by X-ray. A - Abundant T - Trace X - Present

Table 2. - Mineralogy and results of firing tests on samples collected in southwestern Arabia as possible raw material for structural clay products

p. 10) but, at this sample location, the weathered basalt unit is 57 m thick, placing its top far above the laterite, as generally considered. It is composed of hard, spheroidally weathered basalt layers interbedded with saprolite. The upper 16 m of the exposure is a gentle slope covered by red clay that contains pale green phenocrysts of expandable clay believed to be montmorillonite and is overlain by fresh basalt. This deeply weathered rock, which was the material sampled, may extend only a few tens of centimeters into the slope. No extensive deposits of similar material were observed.

An exceptional deposit of saprolitized granite is exposed along the At Ta'if-Abha highway about 5 km southeast of Suleiman (fig. 1). It is apparently only a few meters thick and does not extend over a large area. It is composed of kaolinite, quartz, and biotite and is so friable that it can be disaggregated by sieving. Much of the saprolite has been removed for fill material during construction of the highway.

Colluvium

Throughout much of the area examined, a thin colluvium covers the low areas between rock outcrops and wadis. Only about a meter thick at most places visited, it ranges from a mixture of silt and clay to a mixture of gravel, sand, silt, and clay. It is largely uncultivated but considerable effort has been made recently to render it agricultural. We observed many areas that had been or were being divided into plots by new "fences" of bulldozed colluvium. Unfortunately, the colluvium having the greatest potential as a raw material for structural clay products also has greatest potential for agriculture.

Wadi silt and clay

The major wadis in the Abha-Khamis Mushayt area are Wadi Bisha and Wadi Tindahah (fig. 3). Both wadis are bordered by extensive deposits of sand, silt, and clay, much of which is intensely cultivated. The thickness of wadi fill is as much as 10 m where excavated for construction but at that location the fill is largely sand. Observations in excavations of various sorts indicate the maximum thickness of wadi silts and clays to be only a meter or two. Tributary wadis are less intensely cultivated and detailed exploration might discover deposits containing adequate clay. The probability of extensive deposits is small, however, and the probability of thick deposits is almost nil.

More promising deposits of wadi silts and clays are at a considerable distance from Abha and Khamis Mushayt, along Wadi Tathlith near Hamdah (fig. 1). The wadi deposits near Ad Darb and Najran are several meters thick and cover several square kilometers, much but not all of which is intensely cultivated. The wadi deposits near Hamdah are thick, cover a large area, and are not cultivated.

Baid Formation

The Baid Formation, of Miocene age, is described by Brown and Jackson (1959), in part, as a "gray, red, and green siliceous and tuffaceous shale". The Baid crops out approximately 60 km south-southwest of Abha near Ad Darb (fig. 1). According to Skipwith (1973, p. 21), the lower 1200 m are concealed by recent deposits. The upper 1200 m are "chiefly

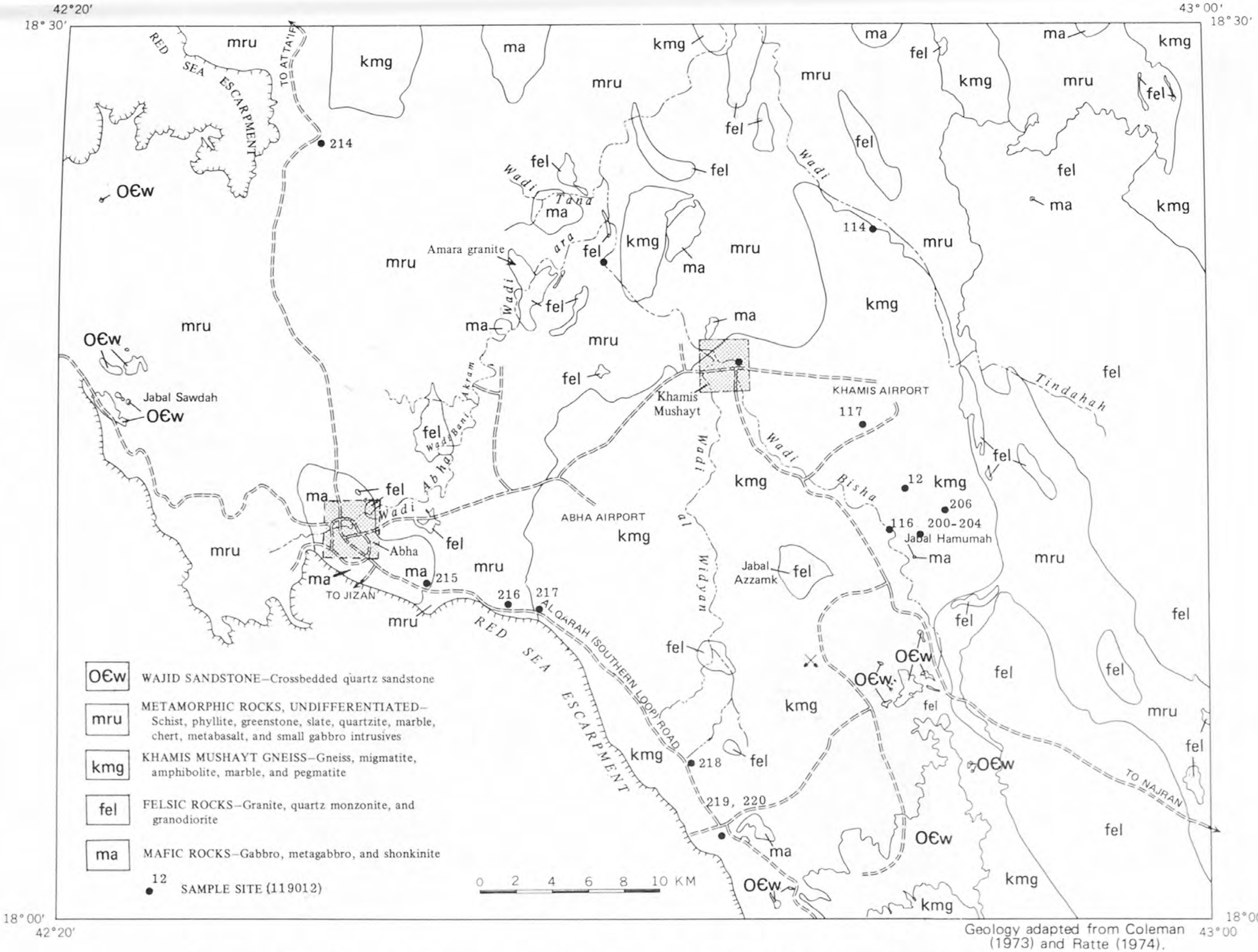

Figure 3.- Reconnaissance geologic map of the Abha-Khamis Mushayt area showing location of samples.

gray, buff, red and green silicite with fish fossils and intercalated green or mauve shale (chloricite, illite, and montmorillonite), volcanic tuffs and diabase sills".

The Baid crops out east and southeast of Ad Darb in many scattered low hills and escarpments. The regional strike is north-northwest and regional dip is west, but locally the beds have highly variable orientation. The low ridges are held up by tightly cemented siltstone, the valleys underlain by siltstone that contains paper-thin intercalated layers of green, red, and brown shale. The topographic lows are discontinuous, and most are less than a few hundred meters long. In land-vehicle and helicopter traverses crisscrossing the area, we found no shales possibly suitable as raw material for structural clay products.

FIRING TESTS

Procedure

All samples were collected from outcrops, road cuts, or shallow trenches. Three samples (112459, 112461, and 112462) were fired in the USGS laboratories in Reston. The remainder were fired in the BRGM laboratory in Jiddah. Clay samples fired by the BRGM were first crushed and sieved to 500 microns (32 mesh). If the amount of sample was sufficient, a homogeneous paste of sample plus water was extruded under vacuum as bricks measuring 2 x 2 x 8 cms. If the amount of sample was insufficient, the paste was formed manually in teflon molds about 60 mm in diameter.

The test pieces were then dried in air and in an oven at 105°C for at least 24 hours, then fired at 950°, 1000°, 1050°, 1150°, or 1200°C in a muffle furnace. For each firing, the temperature was increased at the rate of 100°C per hour, held for two hours, and then the furnace was cooled at a rate of 200°C per hour.

The following determinations were made: on each dried test piece the water loss and shrinkage upon drying; on each fired test piece the weight loss, true and apparent specific gravity, closed and open porosity, and amount of water that could be absorbed (table 2).

As Sarat laterite

Building stone unit

Sample 119026, representative of the building stone unit, is so refractory that even fired to 1150°C it produces a weak brick. Firing tests on beneficiated samples (see below) suggest that the unit would fire to strong test pieces at higher temperatures.

To obtain plasticity and flux, material from the building stone unit was combined with an equal proportion of wadi silts and clays or colluvium. Composite samples 119223-119226 showed considerable shrinkage upon drying but fired to strong orange test pieces of high porosity.

Sedimentary kaolinite

Although only sample 119013 of the sedimentary clays appears to be a satisfactory raw material for structural clay products, samples 112459, 112461, and 112462 appear geologically and physically very similar to it. Sam Patterson (written commun., 1975) reports that these three samples contain calcite, possibly leached from the overlying basalt, which could account for their poor firing characteristics. Benedetto and Baudet (1975, p. 9), however, state that a carbonate content of 5 to 15 percent is suitable for a good fired product and that a carbonate content of 10 percent is optimum.

Saprolite

Because of the incomplete degradation of the feldspars and the abundance of coarse quartz, some of the saprolite test specimens (119210 and 119215) did not hold together well on drying.

Although composite sample 119023-119024 tested poorly, the basalt saprolite would be a likely source of plastic clay to give the proper firing characteristics of refractory non-plastic clay.

Sample 119031 of granite saprolite collected along a wadi under an overhanging ledge of the building stone unit shrank excessively during firing at 1150°C. Sample 119115 of mixed granite and gabbro saprolite collected nearby did not shrink but effloresced slightly.

Sample 119209 collected over schist and 119208 collected over schist and granite fired to strong test pieces, whereas sample 119210 collected over the same granite did not.

The Suleiman saprolite is a potential raw material for ceramic rather than structural clay products. The minus 200-mesh fraction of three uncrushed samples average 13 percent of the total sample weight but the clay content is probably higher. The average total iron oxide content of three samples is 1.5 percent. Leaching in HCl produces exceptionally white clay. The untreated clay (table 1, samples 119094 and 119125-119128) fires nearly white and shows considerable promise for ceramic use. It merits further testing.

Colluvium

All colluvium deposits sampled probably represent fairly what is available in the area. Most samples fired to strong but porous test peices. Samples 119012 and 119117 collected near the Khamis Mushayt airport are especially significant. Although a thickness of less than 2 m is to be expected, similar material might be found patchily distributed in a wide area underlain by the Khamis Mushayt gneiss.

Composite sample 119001-119003, which we once considered to have the most favorable geologic implications, was collected from an irrigation ditch dug through the colluvium across a laterite-capped mesa. It was hoped that this unit, about 2 m thick, might cover broad areas. Even under the flat topography at the site, however, hard building stone crops out a few tens of meters from the trench in all directions and no sites more favorable for the development of a thick colluvium were observed. Moreover, the sample contained montmorillonite, calcite, and dolomite and the firing tests were entirely negative (table 2).

Wadi silt and clay

In general the wadi silts and clays produce the same quality of fired test pieces: orange, fairly dense but with an open porosity of about 35 to 40 percent, and a slight shrinkage or slight expansion. None of them appears to be high-quality raw material but they appear to be of similar quality to tile presently produced from wadi silts elsewhere in the Kingdom (table 2).

Efflorescence in samples from northeast of Khamis Mushayt (fig. 1, 11989-90), Ad Darb (119098), and Wadi Bisha (119116) suggests an appreciable salt or gypsum content in the silt in those areas.

BENEFICIATION TESTS

Crude beneficiation tests were run on two composite samples of the building stone unit to see if a kaolinite-rich fraction could be separated readily from the whole rock.

Sample 119197 (fig. 2), a composite of 5 samples from a unit 8.5 m thick, was ground to the following size distribution, in percent:

+100	mesh	29
-100+200	mesh	34
-200+325	mesh	35
-325	mesh	2

The entire sample was slurried with water and decanted after 30 seconds. Decanting was repeated until virtually all suspended fraction was removed. The decanted portion was then left in concentrated HCl for 24 hours. That some benefication was accomplished is evident from table 3.

Table 3.--Partial chemical analyses of As Sarat laterite sample 119197: the residue from decanting and the decanted fraction after soaking in HCl. [Analyzed by Ibrahim Baraja, Masoud Shah, Abdul Aziz Khan, and Husein Karam, U.S. Geol. Survey Mission, Jiddah.]

	SiO_2	Al_2O_3	Fe_2O_3
Residue	72.4	15.8	1.44
Decanted fraction	67.1	19.5	.80

Samples 119211 and 119212 (fig. 2), collected from two small building-stone quarries, were sent to the U.S. Bureau of Mines, Tuscaloosa, Alabama, for beneficiation and firing tests (see Appendix).

The results are encouraging. The samples as submitted contained about 40 percent kaolinite. Although estimates as high as 70 percent kaolinite, based on X-ray analyses in the USGS Jiddah laboratory, have been made on other samples, it seems likely that the highest average grade to be expected for a large deposit is 40 percent kaolinite.

Through attrition grinding a minus 10 micron fraction that contained 50 percent kaolinite and represented 50 percent recovery was produced. Some of the discrete quartz grains in the laterite apparently are left in the coarser fraction. The siliceous cement (cristobalite in part) could not be mechanically separated from the kaolinite.

At 1000°, 1050°, 1100°, 1150°, 1200°, and 1250°C, the minus 10 micron fraction fired to test pieces of good quality. The pieces fired below 1150°C can be readily broken at the corners but the pieces fired at 1150°C and above cannot. The color ranges from a very pale pink at the lowest firing temperature to bone white at the highest. According to H. Heystek (see Appendix), the fired color is acceptable for whiteware but cristobalite will produce dunting (hairline cracks) in products such as dinner ware.

CONCLUSIONS

Of the deposits investigated, the most promising source of large amounts of raw material for structural clay products in southwestern Saudi Arabia are wadi deposits and colluvium, especially the wadi silts and clays near Wadi Tindahah (fig. 3), Ad Darb, Najran, and Hamdah (fig. 1). Only in those wadis are the deposits possibly large enough so that a small area could sustain a plant for 20 years.

The Wadi Tindahah deposit is closest to Abha but appears to be the smallest of the three and to be mostly cultivated. A sacrifice of agricultural land, possibly already in production, would have to be made.

The Wadi Itwad deposit near Ad Darb (fig. 1) covers a large area, and part of it is not currently cultivated. In spite of the appreciable salt and flux content, the deposit is worth consideration.

The Wadi Najran deposits (fig. 1), also partly cultivated, are close to a large concentration of population and the test piece (119129), even though calcareous, fired well.

The Wadi Tathlith deposit near Hamdah (fig. 1) is the thickest deposit of wadi silt sampled, and it is uncultivated.

Its distance from population centers (125 km from Khamis Mushayt) may virtually eliminate it for now as a raw material for structural clay products, but if the track to Tathlith is paved distance would no longer preclude development.

In terms of product quality, colluvium is a raw material as good as wadi silt. Only about 1 m thick on the average, it would remove two to ten times as much area from farming or grazing. However, its productivity is generally less and the area available is much greater.

In all of these areas detailed mapping, sampling, and testing are required to delineate the best location for mining operations.

In general the saprolites are too thin and patchy to be considered a raw material for structural clay products. High in montmorillonite, they might be mixed with other materials such as wadi silts or the As Sarat laterite.

The Suleiman saprolite is a potential source of kaolinite for whiteware, at least for a cottage industry. At little effort or cost most of the quartz can be removed by dry sieving. Although detailed mapping might prove up more reserves than are apparent, we doubt that they are sufficient to support long-term production of more than a few tons per day.

Insofar as we can determine, the As Sarat laterite is not a potential raw material for structural clay products. The building stone unit is too hard and siliceous, the deposits of sedimentary clay derived therefrom are too small, and the saprolite developed on it is thin, patchy, and where tested does not make satisfactory laboratory bricks. The beneficiated laterite has promise as a raw material for whiteware, especially ceramic tile, which is in great demand in the Kingdom. The building stone unit would be an excellent source of alumina and silica for portland cement and probably would be satisfactory for white cement. Perhaps the most immediate economic potential for the laterite would be to increase the production of building stone by some simple mechanization. A caterpillar tractor with a tooth on the blade could pry the stone loose from the outcrops, and a mechnical breaker could be used to trim it into well shaped blocks. Some sawed lateriate is now sold in Abha as dimension stone.

RECOMMENDATIONS

1. Further beneficiation and firing tests should be made on the As Sarat laterite as a raw material for ceramic tile.
2. The As Sarat laterite should be prospected with the aim of discovering a large, minable deposit averaging at least 40 percent kaolinite.
3. Additional samples of the Suleiman clays should be collected for testing as raw material for whiteware and as an additive to the As Sarat laterite.
4. Additional samples of the clay deposits near Hamdah should be collected for testing as raw material for structural clay products.

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APPENDIX

United States Department of the Interior

BUREAU OF MINES

TUSCALOOSA METALLURGY RESEARCH CENTER
P.O. BOX L
UNIVERSITY, ALABAMA 35486

January 12, 1978

Memorandum

To: Research Director, Tuscaloosa Metallurgy Research Center

From: Research Supervisor, Tuscaloosa Metallurgy Research Center

Subject: As Sarat Laterite Sample

The laterite sample submitted by Frank Simons of the USGS was evaluated to determine its potential as a ceramic raw material. The results, based on X-ray diffraction, attrition grinding, size fractionation and firing tests were as follows:

<u>Mineralogy</u>: The material as received contained about 40 percent kaolinite. Quartz and cristobalite were the other major mineral phases present.

<u>Beneficiation</u>: The sample did not slake in water and it was necessary to grind the material to separate the mineral phases. Cristobalite appeared to be the cementing phase and was intimately associated with the kaolinite down to the minus 2-micrometer size fraction.

The best results obtained by attrition grinding and size fractionation was a 50 percent recovery of the starting material as a minus 10-micron fraction containing 50 percent kaolinite, less quartz than in the head sample, and the rest cristobalite. A minus 2-micron fraction representing 25 percent of the starting material was upgraded to about 60 percent kaolinite with very little (less than 3 percent) quartz present and the rest cristobalite. It does not appear to be practical or possible to separate the cristobalite from the kaolinite.

<u>Ceramic properties</u>: The minus 10-micron material was extruded as briquettes and fired to 1000, 1050, 1100, 1150, 1200, and 1250° C. The results are listed in the attached report sheet. Samples of the fired pieces are also included. The fired color appears to be acceptable for whiteware (dinnerware, glazed wall tile and sanitary ware) bodies, but the presence of cristobalite will result in dunting (hairline cracks) in products such as vitreous dinnerware. Its use as a raw material for high-absorption glazed wall tile is possible, but must be determined through testing under commercial production conditions.

H. Heystek

TUSCALOOSA METALLURGY RESEARCH CENTER

Preliminary Ceramic Evaluation

Tuscaloosa Number SA-1-1

Date Received 10-6-77 Date Reported 1-12-87

Sender's Name U.S. Geological Survey - American Embassy

Sender's Identification As Sarat Laterite Type Material Kaolin

Raw Properties:

Water of Plasticity, Percent 59.3 Working Properties Plastic

Color Bone White Drying Shrinkage, Percent 5.0 Dry Strength Good

Slow Firing Test:

Temp. °C	Munsell Color	Moh's Hardness	Percent Linear Shk.	Percent Abs.	Percent Appr. Por.	Bulk Density gm/cc
1000	10 YR 9/1	2	5.0	47.1	52.6	1.12
1050	10 YR 9/1	2	5.0	46.5	51.9	1.12
1100	10 YR 9/1	2	7.5	45.3	51.1	1.13
1150	10 YR 9/1	2	7.5	44.4	50.8	1.14
1200	10 YR 9/1	2	7.5	42.3	49.2	1.16
1250	white	2	7.5	41.1	48.7	1.18

pH 6.5 HCl Effervescence None Other Tests --

Preliminary Bloating Test: Negative

Temp. °C	Percent absorption	Bulk Density gm/cc	Remarks

Potential Use Whiteware bodies--but the presence of substantial amounts of cristobalite will cause dunting in low absorption bodies.

The data presented in this report are based on laboratory tests that are preliminary in nature and will not suffice for plant or process design. It does not preclude the use of the material in mixes.