CIRCULAR 110

Test Data for New Mexico Clay Materials Part 1, Central New Mexico

(Bernalillo, Los Alamos, Sandoval, and Santa Fe Counties)

by WILLIAM L. HAWKS

STATE BUREAU OF MINES AND MINERAL RESOURCES
NEW MEXICO INSTITUTE OF MINING AND TECHNOLOGY
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Materials Engineer, New Mexico State
Bureau of Mines and Mineral Resources

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CAMPUS STATION SOCORRO, NEW MEXICO

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ABSTRACT

Since the late 1930's approximately 65 samples of clay materials have been collected and tested by various investigators in the area of Bernalillo, Los Alamos, Sandoval, and Santa Fe Counties. Most of the accumulated data is here published for the first time.

The area has three operating ceramic-product plants, all in Bernalillo County. The principal products are brick, wall tile, and portland cement.

Brick clays are currently being mined from the Madera Limestone near Cedro and the Mancos Shale in Cerrillos. Other deposits that show promise of commercial possibilities are Mancos shales at Tongue and Placitas, shales from the Sandia and Abo Formations near Sandia Park, shales in the Mesaverde Formation near Coyote, and a fire clay in the Morrison Formation near San Ysidro.

INTRODUCTION

This report is the first of a series of five reports on the clays and shales of New Mexico. The state has been divided into five areas: central, northwest, northeast, southwest, and southeast (fig. 1). The central area, comprising Bernalillo, Los Alamos, Sandoval, and Santa Fe Counties, is the subject of this report. It is not an exhaustive study of all clays and shales in the area, but merely an accumulation of data developed to date by the New Mexico State Bureau of Mines and Mineral Resources.

Many geologic terms, such as clay, shale, mudstone, bentonite, and claystone, are used to identify rocks containing clay minerals. In this report all rocks containing clay minerals are considered clays and the terms "clay" and "shale" are used interchangeably to describe such rocks.

A number of Bureau personnel have been involved in the field work and testing of the clay samples presented in this report. Claude E. Needham and Nels P. Peterson, professors of geology, New Mexico Institute of Mining and Technology (New Mexico Tech), sampled and tested clays for the Bureau during the summers of 1937, 1938, and 1939. T. D. Benjovsky, mining engineer, conducted many engineering investigations of clay deposits throughout the state in 1946 and 1947. Donn M. Clippinger, materials engineer, made a series of engineering reports on a number of clays during 1947-1950. Roy W. Foster, petroleum geologist, developed considerable ceramic test data on shales that he had sampled for oil-shale and lightweight-aggregate projects during 1963-1966. William L. Hawks, ceramic engineer, sampled and tested numerous clays in the Bureau clay-testing laboratory during 1964-1966.

Needham and Peterson started a sequential numbering system for their clay samples. This practice was continued by Benjovsky and Clippinger. In this report the Needham and Peterson samples are prefixed with NP, Benjovsky samples with TDB, and Clippinger samples with C. Foster samples are identified by the State Highway Department quadrangle number followed by a sequential number for that quadrangle (e. g., 42-9 is the ninth sample locality in quadrangle 42). Hawks' sample numbers consist of a one- or two-letter abbreviation of the county, followed by the year the sample was collected and a sequential number for that year; SD65-2 would be the second sample collected during 1965 in Sandoval County.

Testing procedures employed by the earlier investigators are unknown, but all of their available data are included herein. The laboratory procedures used by Foster and Hawks are described in the appendix.

Figure 1. Map showing subdivision of New Mexico into five clay-study areas.

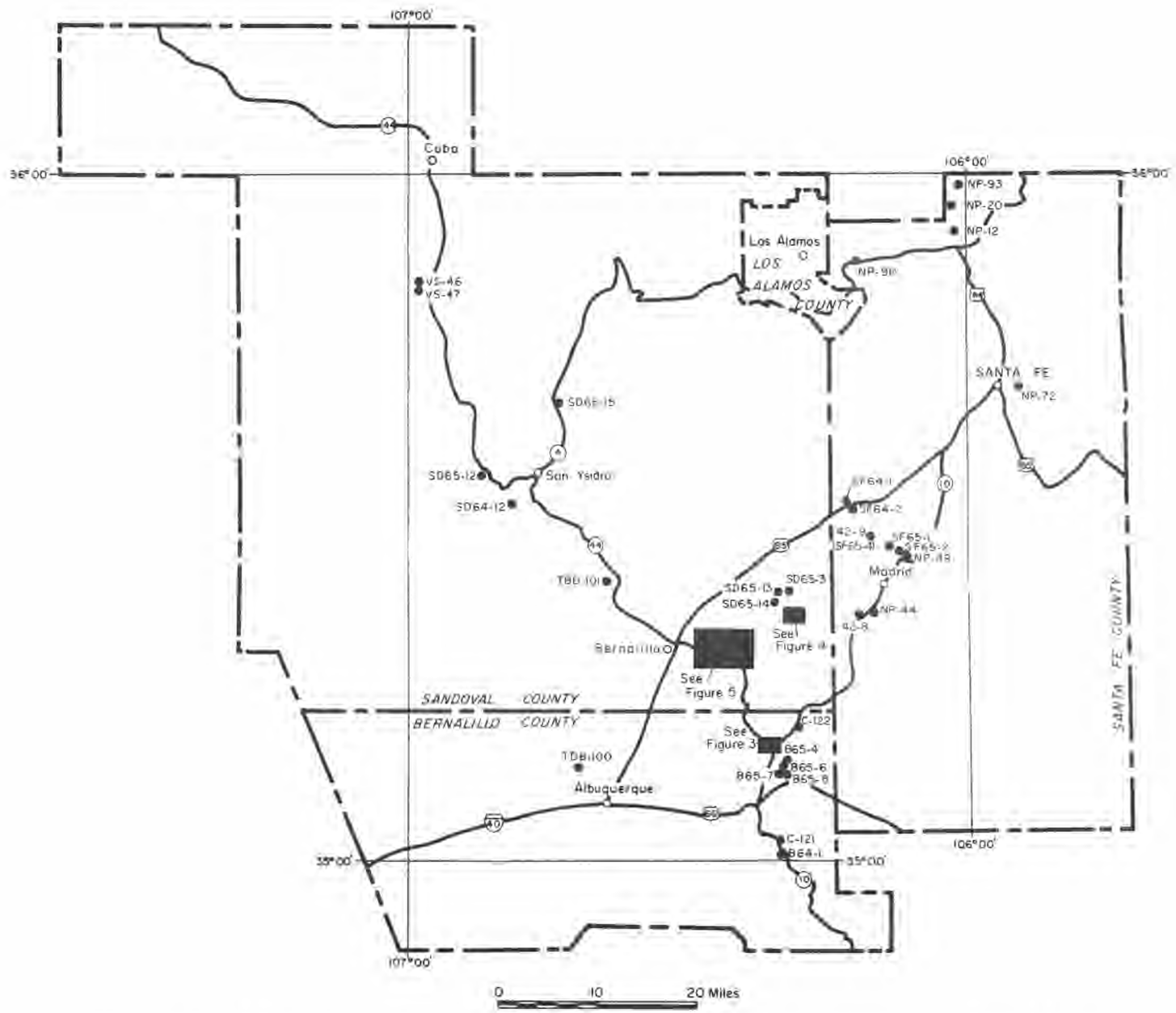

Figure 2. Map showing locations of clay samples in the central New Mexico clay-study area.

ACKNOWLEDGMENTS

Thanks are due the student assistants who conducted most of the laboratory tests. My samples were prepared and tested by Frederick Kastner and Robert Kelher. Foster's samples were tested by Lewis Culver, Phil Luce, Doris Mallard, Bur Maras, and James Tyree. Special thanks are extended to Roy W. Foster for contributing the ceramic test data he had collected on numerous shale samples. George R. Leland, mining engineer, and Wayne R. Hammond, geologist, both of Albuquerque, collected a number of my samples in the Albuquerque area. Joel N. Van Sant, U. S. Bureau of Mines, generously allowed the use of the sample locations from his notes on "Refractory Clays of Arizona and New Mexico. "

BERNALILLO COUNTY

Ceramic Industry

The Kinney Brick Company, formerly known as the New Mexico Clay Products Company, operates a brick plant 5 miles south of Albuquerque. Up to 1960 they used an alluvial clay that was mined from pits adjacent to the plant. They now mine a Pennsylvanian shale from the Madera Limestone 8.5 miles south of Tijeras on State Highway 10 (table 3, sample B64-1). The overburden is stripped and the shale is mined with bulldozers and scrapers. A stockpile is built in the center of the mined-out area and trucked to the Albuquerque plant as required. The bricks are formed by the "stiff-mud" process and dried in auxiliary heated tunnel dryers. The bricks are fired in three gas-fired shuttle kilns, each with a capacity of approximately 10,000 bricks per 26-hour cycle.

The Albuquerque Brick and Tile Company operated a brick plant 6.5 miles northwest of the Santa Fe Railway station at Albuquerque in 1946 and 1947. They mined a sandy alluvial clay from pits adjacent to the plant (sample TDB-100). They used the "stiff-mud" process and fired all their brick in a single gas-fired, circular, downdraft (beehive) kiln, with a capacity of 80, 000 brick per firing. The plant was apparently idle in 1949 and under the name of Cairns Brick and Supply Company. Shale from the old Albuquerque Brick and Tile Company pit at Tongue was used for raw material (table 5, samples SD64-3, SD66-3). The plant ceased operation in 1953.

The Aztec Ceramics Company operates a wall-tile plant about 8 miles south of Albuquerque. Aztec Ceramics of San Antonio, Texas, took over the operation of the plant formerly known as the Desert Ceramics Corporation. The Albuquerque plant produces 4-1/4" x 4-1/4" glazed wall tile in a limited range of colors. Trim pieces and a full range of colors are made at the Aztec plant in San Antonio. All raw materials are imported from outside the state. The talc comes from New York and the clays from Tennessee and Georgia.

The Ideal Cement Company operates a portland cement plant at Tijeras. This 14-million-dollar, highly automated plant was dedicated in June 1959. The center stratum of the quarry near the plant contains what is known as "kiln-feed" rock, that is, rock containing the proper proportions of cement-making ingredients--limestone, alumina, silica, and iron oxide. The upper stratum is high in calcium and the lower stratum high in silica and alumina. Additives such as iron oxide and gypsum are purchased locally (Pit & Quarry, 1959).

The only other known ceramic operation in the county is the Adobe Builders Supply Company. They produce adobe brick from alluvial clay for the local market.

Clays

Sandia Park Area

Clays sampled in the Sandia Park area (fig. 3) came from the Sandia and Abo Formations and include specimens collected by Hawks (table 1), Foster (table 2), and Clippinger (table 4, sample C-119).

Sandia Formation

Sample B65-2 (table 1) was taken from a roadcut east of State Highway 44, 1 mile northwest of Sandia Park, just north of the entrance to the Sulphur Canyon picnic area in SW 1/4 sec. 14, T. 11 N., R. 5 E. The clay develops a good brick-red color and could be used in structural clay products.

Sample B65-3 (table 1) was taken 150 yards northwest of B65-2 from a roadcut just south of the entrance to the Doc Long picnic area in SW 1/4 sec. 14, T. 11 N. , R. 5 E. The test bars bloated and split when fired at

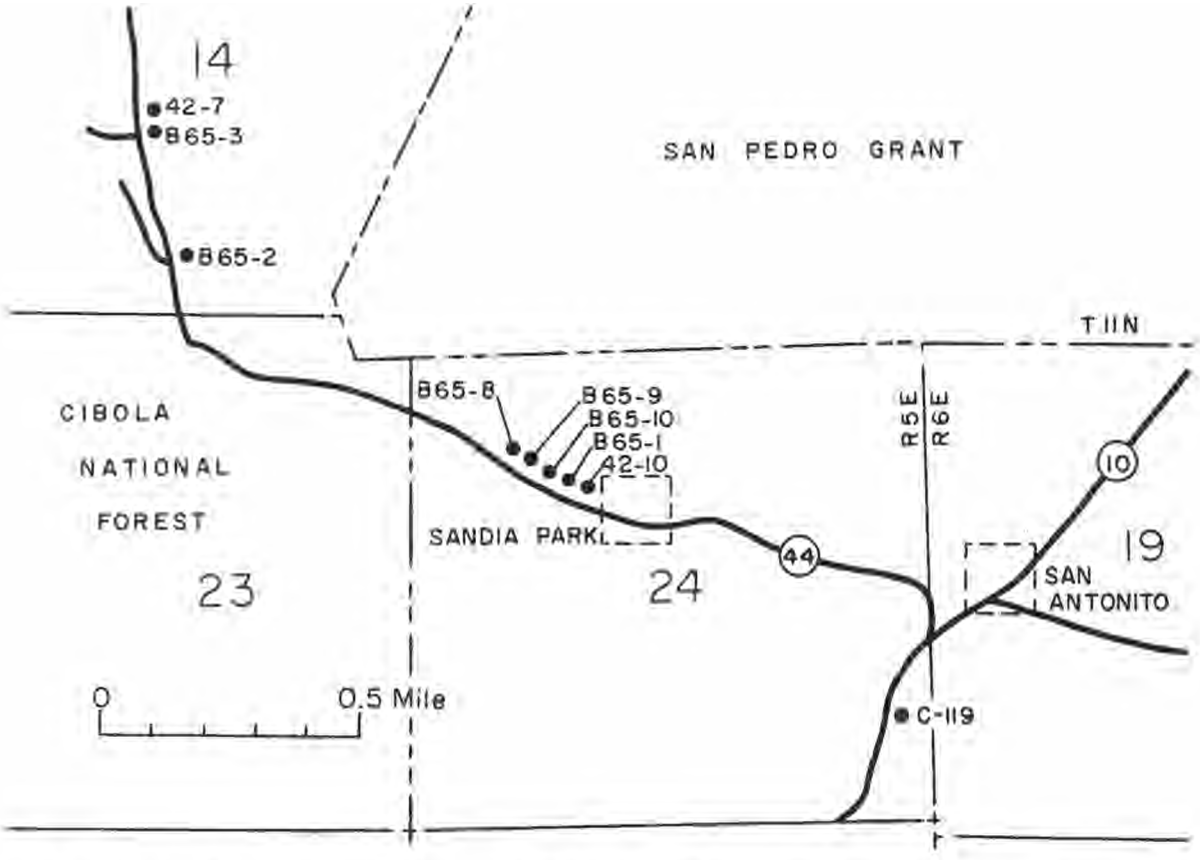

Figure 3. Map showing locations of clay samples in the Sandia Park area, Bernalillo County.

1,800°F. As earlier tests by Foster indicated nonuniform expansion, no further expansion tests were conducted.

Eight Foster samples from locality 42-7, which is the same as B65-3, were collected from the shales in the roadcuts, and test results are shown in Table 2. Machine-made test bars were made of a blend of samples 42-7-8A and 42-7-8B and reported as B65-11 (table 1). The bars fired to 1,900°F were badly bloated.

Abo Formation

Foster's locality 42-10 and B65-1 were from a roadcut north of State Highway 44 in Sandia Park in NW 1/4 sec. 24, T. 11 N., R. 5 E. Samples B65-8, B65-9, and B65-10 were taken to the west of B65-1. Locality B65-8, the farthest west, was 0.2 mile west of Sandia Park and B65-10 was just west of B65-1 (fig. 3). Sample B65-8 was the only specimen of Abo shale in the Sandia Park area that did not show lime-popping in the fired bars. Sample B65-8 also had good fired colors and would be suitable for structural clay products.

Gutierrez Canyon Area

Clay materials sampled in the Gutierrez Canyon area (fig. 2; table 3) came from the Mancos Shale.

Mancos Shale

Sample B65-4 was taken near C sec. 29, T. 11 N., R. 6 E. The bars fired at 1, 800°F and 1, 90 0°F were badly cracked and had black cores, indicating a high carbon content and low fusion. Further testing might prove it useful as a lightweight aggregate.

Sample B65-5 was from just east of the road in SW 1/4 sec. 32, T. 11 N., R. 6 E. The slight lime-popping indicates a borderline lime content that makes its use in clay products questionable.

Sample B65-6 was from weathered shale in SW1/4 sec. 29, T. 11 N., R. 6 E., 1,000 feet south of sample B65-4. The sample had a high sand content that produced rather low modulus of rupture readings. If blended with a fatter clay, this material might be used in clay products.

Sample B65-7 was another sample of weathered shale from the same locality, 1,000 feet south of B65-6. The lime content was too high for use in structural clay products.

Table 1. -Test Data for Hawks' Clay Samples from Sandia Park Area, Bernalillo County

Geologic unit	SANDIA			SANDIA			SANDIA			
Sample number	B65-2			B65-3			B65-11			
Raw color	yellowish gray			yellowish gray			yellowish gray			
Munsell designation	10Y7/1			5Y6/1			5Y6/1			
Water of plasticity (%)	18.6			18.6			16.6			
Drying behavior	good			good			good			
Linear drying shrinkage (%)	5.9			5.0			5.5			
Dry modulus of rupture (psi)	569			525			765			
Firing temperature (°F)	1800	1900	2000	1800	1900	2000	1800	1900	2000	
Firing behavior	good	good	good	bloated			good	bloated		
Color	reddish orange	reddish orange	reddish brown	reddish brown			moderate brown	reddish brown		
Munsell designation	10R6/6	10R7/8	10R5/6	10R5/6			5YR5/8	10R4/6		
Firing shrinkage (%)	3.2	5.1	7.1	1.7			2.0	-1.2		
Total shrinkage (%)	9.1	11.0	13.0	6.7			7.5	4.3		
Modulus of rupture (psi)	3166	4178	4643	2056			3994	2260		
Water absorption (%) (5 hr)	9.1	4.0	0.5	10.6			6.1	6.1		
Apparent specific gravity	2.57	2.60	2.47	2.23			2.76	1.90		
Bulk density (g/cu cm)	2.09	2.21	2.34	1.80			1.97	1.68		
Ignition loss (%)	8.7	8.7	8.8	6.5			5.8	6.4		
Pyrometric cone equivalent	cone 14 - dark brown									

Geologic unit	ABO			ABO			ABO			ABO		
Sample number	B65-1			B65-8			B65-9			B65-10		
Raw color	reddish brown			reddish brown			pale red			pale red		
Munsell designation	10R4/4			10R4/4			10R5/4			10R5/4		
Water of plasticity (%)	14.7			17.5			14.5			13.9		
Drying behavior	good			good			good			good		
Linear drying shrinkage (%)	5.0			6.0			5.0			3.5		
Dry modulus of rupture (psi)	663			680			negligible			negligible		
Firing temperature (°F)	1800	1900	2000	1800	1900	2000	1800	1900	2000	1800	1900	2000
Firing behavior	few lime pops	few lime pops	bloated	good	good	good	lime pops cracked	lime pops	blistered	few lime pops	few lime pops	
Color	reddish brown	pale red	moderate brown	reddish brown	reddish brown	reddish brown	reddish orange	pale red	light brown	reddish brown	reddish brown	
Munsell designation	10R4/6	10R5/4	5YR5/4	10R5/6	10R5/6	10R4/4	10R6/6	10R6/4	5YR6/4	10R4/6	10R4/4	
Firing shrinkage (%)	2.5	2.8	2.2	0.8	1.0	3.2	0.5	1.0	2.8	2.5	4.9	
Total shrinkage (%)	7.5	7.8	7.2	6.8	7.0	9.2	5.5	6.0	7.8	6.0	8.4	
Modulus of rupture (psi)	4000	4030	4404	2720	2918	4624	1790	2520	4400	2220	3213	
Water absorption (%) (5 hr)	2.2	2.5	0.4	11.6	7.1	1.7	14.0	8.0	3.6	7.7	2.8	
Apparent specific gravity	2.28	2.31	2.10	2.58	2.35	2.25	2.58	2.37	2.18	2.64	2.51	
Bulk density (g/cu cm)	2.17	2.16	2.08	1.98	2.02	2.16	1.91	2.00	1.98	2.19	2.34	
Ignition loss (%)	8.9	9.0	8.8	10.0	10.0	9.1	12.6	12.6	12.6	5.9	6.2	
Pyrometric cone equivalent	cone 5 - dark gray			cone 6 - dark brown						cone 6 - dull black		

Table 2. -Test Data for Foster's Clay Samples from Sandia Park Area, Bernalillo County

Geologic unit	SANDIA	SANDIA	SANDIA	SANDIA	SANDIA	SANDIA
Sample number	42-7-1*	42-7-2*	42-7-3*	42-7-4*	42-7-5*	42-7-6*
Raw color	yellowish gray	yellowish gray	olive gray	yellowish gray	olive gray	olive gray
Munsell designation	5Y8/2	5Y6/1	5Y6/2	5Y4/1	5Y4/2	5Y5/2
Plasticity	fair	good	fair	poor	poor	good
Drying behavior	good	good	good	good	good	good
Linear drying shrinkage (%)	6.3	7.0	3.0	6.3	5.7	4.4
Scumming	slight	slight	none	none	none	none
Firing temperature (°F)	1900 2100	1900 2100	1900 2100	1900 2100	1900 2100	1900 2100
Color	moderate brown mottled	grayish yellow	moderate brown	grayish yellow	light brown	light brown
Munsell designation	5YR6/4	5Y8/4	5YR5/8	5Y8/4	5YR6/8	5YR6/8
Firing behavior	good good	good good	good good	good good	good good	cracks cracks
Apparent specific gravity	1.68 2.05	2.52 2.32	2.61	2.61 2.34	2.58 2.38	2.63 2.19
Hardness	hard hard	hard hard	hard hard	soft soft	hard hard	hard hard
Efflorescence	none none	moderate none	moderate moderate	moderate moderate	slight moderate	slight none
Absorption (%) (24 hr)	8.9 2.3	9.4 6.8	13.5	14.6 1.6	15.8 3.2	19.6 3.7
Saturation coefficient	.805 .159	.776 .170	.679	.855 .227	.742 .481	.672 .386
Ignition loss (%)	8.8 10.5	10.5 10.9	9.7	16.9 23.8	17.9 17.5	13.7 18.0
Firing shrinkage (%)	6.0 4.0	6.0 9.3	4.0 11.0	3.3 10.6	3.4 10.7	2.0 10.7
Total shrinkage (%)	12.3 2.3	13.0 16.3	7.0 14.0	9.6 16.9	9.1 16.3	6.4 15.1

Geologic unit	SANDIA	SANDIA	SANDIA	ABO
Sample number	42-7-7*	42-7-8A	42-7-8B	42-10-1*
Raw color	yellowish gray	yellowish gray	yellowish gray	pale red
Munsell designation	5Y7/2	5Y7/1	5Y7/2	10R5/4
Plasticity	good	good	good	fair
Drying behavior	good	warps	good	cracks, warps
Linear drying shrinkage (%)	2.7	6.0	9.3	3.3
Scumming	none	none	none	none
Firing temperature (°F)	1900 2100	1900 2100	1900 2100	1900 2100
Color	orange pink	moderate brown olive brown	moderate brown reddish brown	light brown
Munsell designation	5YR7/4	5YR4/6 5Y4/4	5YR5/8 10R4/4	5YR6/6
Firing behavior	good melted	good good	warps good	good melted
Apparent specific gravity	2.18	2.19 2.01	2.04 2.31	2.53
Hardness	hard	hard hard	hard hard	hard
Efflorescence	moderate	moderate moderate	slight slight	heavy
Absorption (%) (24 hr)	22.8	8.0 7.4	0.9 1.1	15.6
Saturation coefficient	disintegrated	.489 .298	.495 .249	.840
Ignition loss (%)	18.8	22.0 22.6	13.1 11.2	11.3
Firing shrinkage (%)	0.0	14.0 7.3	12.7 4.0	2.0
Total shrinkage (%)	2.7	20.0 13.3	22.0 13.3	5.3

* Minerals present (x-ray diffraction):

42-7-1: illite, kaolinite, quartz.
42-7-2: illite, kaolinite, quartz. calcite.
42-7-3: illite, quartz.
42-7-4: illite, quartz.
42-7-5: illite, quartz.
42-7-6: illite, quartz.
42-7-7: illite, montmorillonite, quartz, calcite.
42-10-1: quartz.

Table 3. –Test Data for Hawks' Clay Samples from Gutierrez Canyon and Cedro Areas, Bernalillo County

Geologic unit	MANCOS			MANCOS			MANCOS		
Sample number	B65-4			B65-5			B65-6		
Raw color	yellowish gray			yellowish brown			yellowish brown		
Munsell designation	5Y5/1			10YR7/2			10YR7/2		
Water of plasticity (%)	23.4			21.3			17.6		
Drying behavior	good			good			good		
Linear drying shrinkage (%)	7.1			7.0			6.0		
Dry modulus of rupture (psi)	765			731			639		
Firing temperature (°F)	1800	1900	2000	1800	1900	2000	1800	1900	2000
Firing behavior	cracks	cracks		few lime pops	few lime pops	few lime pops	good	good	good
Color	light brown	light brown		light brown	light brown	moderate brown	light brown	reddish brown	reddish brown
Munsell designation	5YR6/8	5YR6/8		5YR6/6	5YR7/8	5YR5/4	5YR6/8	10R5/6	10R4/4
Firing shrinkage (%)	1.1	1.0		-0.5	-0.5	2.8	0.0	1.0	4.3
Total shrinkage (%)	8.2	8.1		6.5	6.5	9.8	6.0	7.0	10.3
Modulus of rupture (psi)	1990	3520		2574	2820	4872	860	970	2286
Water absorption (%) (5 hr)	8.8	2.6		15.1	18.1	5.41	14.5	16.4	10.0
Apparent specific gravity	2.26	1.94		2.40	2.64	2.31	2.41	2.60	2.52
Bulk density (g/cu cm)	1.89	1.85		1.76	1.79	2.03	1.78	1.82	2.02
Ignition loss (%)	11.2	12.1		12.8	13.1	13.0	5.1	5.3	5.2
Pyrometric cone equivalent									

Geologic unit	MANCOS			MADERA					
Sample number	B65-7			B64-1					
Raw color	yellowish brown			medium gray					
Munsell designation	10YR5/2			N5.5					
Water of plasticity (%)	19.3			18.9					
Drying behavior	good			good					
Linear drying shrinkage (%)	9.5			6.0					
Dry modulus of rupture (psi)	368			1006					
Firing temperature (°F)	1800	1900	2000	1800	1900	2000			
Firing behavior	lime pops cracks			good	good	small cracks			
Color	reddish brown			reddish brown	reddish brown	reddish brown			
Munsell designation	10R5/8			10R5/10	10R5/8	10R5/10			
Firing shrinkage (%)	1.5			0.0	-0.4	-0.4			
Total shrinkage (%)	11.0			6.0	5.6	5.6			
Modulus of rupture (psi)	552			2750	2594	2165			
Water absorption (%) (5 hr)	10.7			12.4	12.1	10.8			
Apparent specific gravity	2.43			2.36	2.36	2.44			
Bulk density (g/cu cm)	1.94			1.86	1.86	1.87			
Ignition loss (%)	8.4			13.2	13.2	13.2			
Pyrometric cone equivalent				cone 4 – dark olive					

Miscellaneous Samples

Sample B64-1 (table 3) was a shale interbed from the Madera Limestone west of State Highway 10, 8.5 miles south of Tijeras in sec. 18, T. 9 N., R. 6 E. This clay is being mined by the Kinney Brick Company for the manufacture of common and face brick.

Sample TDB-100 was alluvial clay being mined by the Albuquerque Brick & Tile Company adjacent to their plant northwest of Albuquerque in 1946 (fig. 2). Benjovsky made the following report:

Location: W 1/2 NE 1/4 and E 1/2 NW 1/4 sec. 35, T. 11 N. , R. 2 E.

Type deposit: Bedded, overlain by wind-blown sand from few feet to perhaps as much as 8 to 10 feet. Thickness of sample 5.5 feet taken in face of cut in deposit. Physical characteristics - brown to reddish color with some banding as to colors. Extent - from observation of deposit in arroyo and on north bank of same deposit can overlay entire plot of ground, 120 acres and extend for long distances in the surrounding area, perhaps 1 mile north and as much, or more, south. Burns red in brick kiln. Contains a smattering of limestone, $CaCO_3$.

Proximity to railroad: About 6 miles from Santa Fe depot, town of Albuquerque, New Mexico. Go west, cross bridge on Rio Grande River on west Central, turn north on dirt road 4- 1/2 miles north to brick plant of Trott, Atherton, and Leverett, which is located on the property.

Ownership: Trott, Atherton, Leverett, Ben Luchini.

Operating: Yes, making common red pressed brick and tile.

Market: Local for builders and contractors,

Chemical Analysis:

	55.46 %
$A1_2O_3$	16.56
Fe_2O_3	4.70
	n. d.
	5.00
	2.63
	tr
Na_2O	0,92
K_2	1.94
Phosphates	nil
Ignition Loss	12.35
Total	99.56 %

Clippinger sampled some clays in cooperation with Frank Angel, Jr., Supervisor, Mountain Schools, Bernalillo County Public Schools, in 1948. They were trying to locate a supply of red-burning clays suitable for use in school pottery classes. The only data available are the chemical analyses and general location of the clays (table 4; figs. 2, 3).

Table 4. -Chemical Analyses of Clippinger's Clay Samples from Bernalillo County

	Clay Number			
	C-119	C-120B	C-121	C-122
SiO_2	54.48	57.96	54.68	57.22
Al_2O_3	16.31	10.95	14.40	16.79
Fe_2O_3	4.29	2.65	5.08	6.15
CaO	9.09	13.06	8.95	5.27
MgO	2.56	2.07	3.22	2.55
Na_2O K_2O	1.66	1.57	0.88	2.37
Ignition loss	11.66	11.80	12.56	9.72
Total	100.05	100.06	99.77	100.07

Locations:
C-119 1/4 mile south of San Antonito on State Highway 10.
C -120B Sirando Gonzales Ranchito.
C-121 1/2 mile north of Cedro on State Highway 10.
C-122 Red clay 3 miles north of San Antonito.

LOS ALAMOS COUNTY

Los Alamos County has no history of ceramic production. Clay samples and test data for this area are unavailable.

SANDOVAL COUNTY

Ceramic Industry

The Albuquerque Brick and Tile Company operated a brick plant near the Tongue ruins, 5 miles east of U. S. Highway 85 along the Arroyo Tongue, until 1944. The equipment was then moved to a new plant site just west of Albuquerque. They continued to mine the Mancos Shale from the pits adjacent to the old Tongue plant and shipped it to the new location. The Albuquerque plant shut down in 1953 and the mining operations at Tongue ceased.

The Jemez, Zia, and Santo Domingo Pueblos all produce limited amounts of pottery for the tourist trade. Their raw materials are normally the alluvial clays and shales found in the immediate vicinity of their pueblos.

Clays

Tongue Area

Clay materials in the Tongue area (fig. 4) come from the Mancos Shale and Chinle Formation. Samples include those of Hawks (table 5) and Needham and Peterson (table 6).

Mancos Shale

Sample SD64-3 is the shale that had most recently been mined from the pit at the site of the Tongue Brick plant in NW 1/4 sec. 18, T. 13 N., R. 6 E.

Sample SD66-3 is also from the clay pit, but was taken from a section of the pit containing a much higher sand content and enough gypsum to cause some lime pops when fired at 1,800°F and 1,900°F. The lime-popping is reduced when fired to 2, 000°F, and the clay develops a light-buff color. The high sand content causes a higher absorption than that of sample SD64-3. This clay would have to be blended with "fatter" (more plastic) clays to be suitable for structural clay and pipe products.

Sample SD66-2 was taken approximately 0.2 mile east of the Tongue pit near the top of the Mancos Shale. It exhibited higher drying shrinkage than the other Mancos shales sampled in the area and bloated and split when fired to 1,800°F. Further testing might show that this clay is suitable for an expanded aggregate.

Sample SD66-1 was taken 0.5 mile north of the pit on the north side

of Arroyo Tongue in SW 1/4 sec. 7, T. 13 N., R. 6 E. The fired bars appear to contain a considerable number of lime particles, but have developed enough strength to keep lime popping to a minimum. This clay would be useable in most heavy clay products.

Sample SD65-4 was from about 1,000 feet northeast of SD66-1 and exhibits similar physical properties with a somewhat lower absorption.

Sample SD65-3 was from 1.6 miles north of the pit in SW 1/4 sec. 6, T. 13 N., R. 6 E. The high sand content results in a rather high absorption. Its physical properties are similar to those of SD66-3, but it contains less lime. This material could be used for shrinkage control when blended with more plastics clays.

Sample NP-30 was the clay being mined from the Albuquerque Brick and Tile Company pit at Tongue around 1938. The "tempering water" (water of plasticity) and drying shrinkage do not relate to either SD64-3 or SD66-3, which were taken from the pit as it now stands.

Sample NP-48 was identified as a Cretaceous shale from the bank farther east of the 1938 workings along the bank of the creek.

Chinle Formation

Sample SD65-13 represents the top of the Chinle section exposed on the east side of Arroyo Tongue. The sample was taken east of the road just south of the gypsum mine, approximately 3.5 miles east of U. S. Highway 85 in SW 1/4 sec. 1, T. 13 N., R. 5 E. The low shrinkage and high absorption indicate a high sand content. This material might be used to control the shrinkage in structural clay products.

Sample SD65-14 is alluvium on the west side of Arroyo Tongue, 0.5 mile south of SD65-13. The red color suggests that the alluvium is mostly weathered Chinle shale. The bars fired to the best brick-red colors of any of the clays in the area.

Coyote Area

The clay materials tested from the Coyote area (fig. 4) comprise five samples from the Mesaverde Formation; firing properties of two samples are given in Table 7.

Mesaverde Formation

Sample SD64-9 was a grab sample of a gray shale 1,000 feet west of the Coyote coal mine portal in SW1/4 sec. 17, T. 13 N., R. 6 E. No test bars were made of this sample. The pyrometric cone equivalent (PCE) was cone 15-16, spotted medium gray.

Table 5. -Test Data for Hawks' Clay Samples from Tonque Area, Sandoval County

Geologic unit	MANCOS			MANCOS			MANCOS			MANCOS		
Sample number	SD64-3			SD66-3			SD66-2			SD66-1		
Raw color	yellowish brown			yellowish brown			olive gray			yellowish gray		
Munsell designation	10YR5/2			10YR7/2			5Y5/2			5Y7/2		
Water of plasticity (%)	17.2			12.5			21.3			21.9		
Drying behavior	good-slight scumming			good			slightly warped			good		
Linear drying shrinkage (%)	6.2			4.1			9.5			7.4		
Dry modulus of rupture (psi)	921			590			1270			1450		
Firing temperature (°F)	1800	1900	2000	1800	1900	2000	1800	1900	2000	1800	1900	2000
Firing behavior	good	good	good	lime pops	lime pops	good	good			good	good	good
Color	light brown	light brown	grayish orange	orange pink	pale orange	yellowish brown	reddish brown			light brown	light brown	moderate brown
Munsell designation	5YR5/8	5YR6/6	10YR7/4	5YR7/4	10YR8/2	10YR7/2	10R5/10			5YR6/6	5YR6/6	5YR5/4
Firing shrinkage (%)	-0.5	-0.2	0.2	-0.1	0.5	2.1	1.2			0.6	0.6	1.5
Total shrinkage (%)	5.7	6.0	6.4	4.0	4.6	6.2	10.7			8.0	8.0	8.9
Modulus of rupture (psi)	1918	2206	2302	637	658	1210	3254			2248	2238	3148
Water absorption (%) (5 hr)	18.4	18.8	16.3	20.3	20.9	19.6	5.8			14.2	11.9	11.9
Apparent specific gravity	2.70	2.70	2.62	2.30	2.58	2.40	1.71			2.39	2.51	2.51
Bulk density (g/cu cm)	1.80	1.79	1.80	1.56	1.68	1.63	1.60			1.78	1.68	1.93
Ignition loss (%)	11.3	11.4	11.5	11.2	11.3	11.0	6.6			8.95	9.20	8.95
Pyrometric cone equivalent												

Geologic unit	MANCOS			MANCOS			CHINLE			CHINLE		
Sample number	SD65-4			SD65-3			SD65-13			SD65-14		
Raw color	olive gray			yellowish gray			light brown			pale red		
Munsell designation	5Y6/2			5Y7/2			5YR6/4			10R5/4		
Water of plasticity (%)	24.8			21.8			18.5			25.2		
Drying behavior	good			good			good			good		
Linear drying shrinkage (%)	8.0			8.0			4.5			7.2		
Dry modulus of rupture (psi)	1175			720			378			920		
Firing temperature (°F)	1800	1900	2000	1800	1900	2000	1800	1900	2000	1800	1900	2000
Firing behavior	good	good	good	good	good	good	good	good	good	good	good	good
Color	light brown	light brown	light brown	light brown	light brown	light brown	light brown	light brown	grayish orange	reddish orange	pale red	moderate brown
Munsell designation	5YR6/8	5YR6/8	5YR6/6	5YR7/6	5YR7/6	5YR7/6	5YR7/6	5YR7/6	10R6/6	10YR8/4	10R5/4	5YR5/4
Firing shrinkage (%)	0.0	0.5	0.8	-0.5	-0.5	-0.5	-1.0	-1.0	0.5	0.8	1.0	3.5
Total shrinkage (%)	8.0	8.5	8.8	7.5	7.5	7.5	3.5	3.5	5.0	8.0	8.2	10.7
Modulus of rupture (psi)	3332	3452	2936	1327	1688	1722	642	680	1602	2770	2092	4122
Water absorption (%) (5 hr)	11.0	11.7	7.2	18.8	19.5	19.8	15.1	18.6	17.8	14.5	9.2	2.36
Apparent specific gravity	2.32	2.35	2.19	2.57	2.65	2.65	2.26	2.36	2.51	2.69	2.48	2.40
Bulk density (g/cu cm)	1.85	1.84	1.89	1.74	1.74	1.73	1.68	1.66	1.73	1.94	2.02	2.18
Ignition loss (%)	11.4	11.8	12.4	11.0	11.0	11.0	7.9	8.0	7.7	7.6	8.2	8.8
Pyrometric cone equivalent	cone 6 - dark brown			cone 8 - olive			cone 6 - light olive					

Sample SD64-10 was a grab sample of a dark chocolate shale from immediately below SD64-9. The PCE was cone 19, with a light-gray, bloated cone. No bars were tested.

Sample SD64-11 was a chocolate shale taken from a prospect trench 500 feet west of the coal mine portal. No bars were tested. The PCE was cone 16, spotted medium gray, bloated.

Sample SD65-5 was taken just north of the road, approximately 1,000

Table 6.–Test Data and Chemical Analysis for Needham and Peterson's Clay Samples from Tonque Area, Sandoval County

	Sample Number		Chemical Analysis (percent)	
	NP-30	NP-48		
Raw color	gray	gray	SiO_2	49.98
Apparent specific gravity	2.34	1.88	Al_2O_3	19.80
True specific gravity	2.46	2.45	Fe_2O_3	3.75
Slaking time (mins)	70	3	TiO_2	1.04
Plasticity	fair	good	CaO	6.02
Cohesion	good	strong	MgO	1.94
Tempering water (%)	27.2	29.7	Na_2O	2.03
Linear drying shrinkage (%)	8.5	9.7	K_2O	0.87
Tendency to crack	none	none	Ignition loss	14.47
Tensile strength of air-dried briquettes (psi)	177	147	Total	99.60

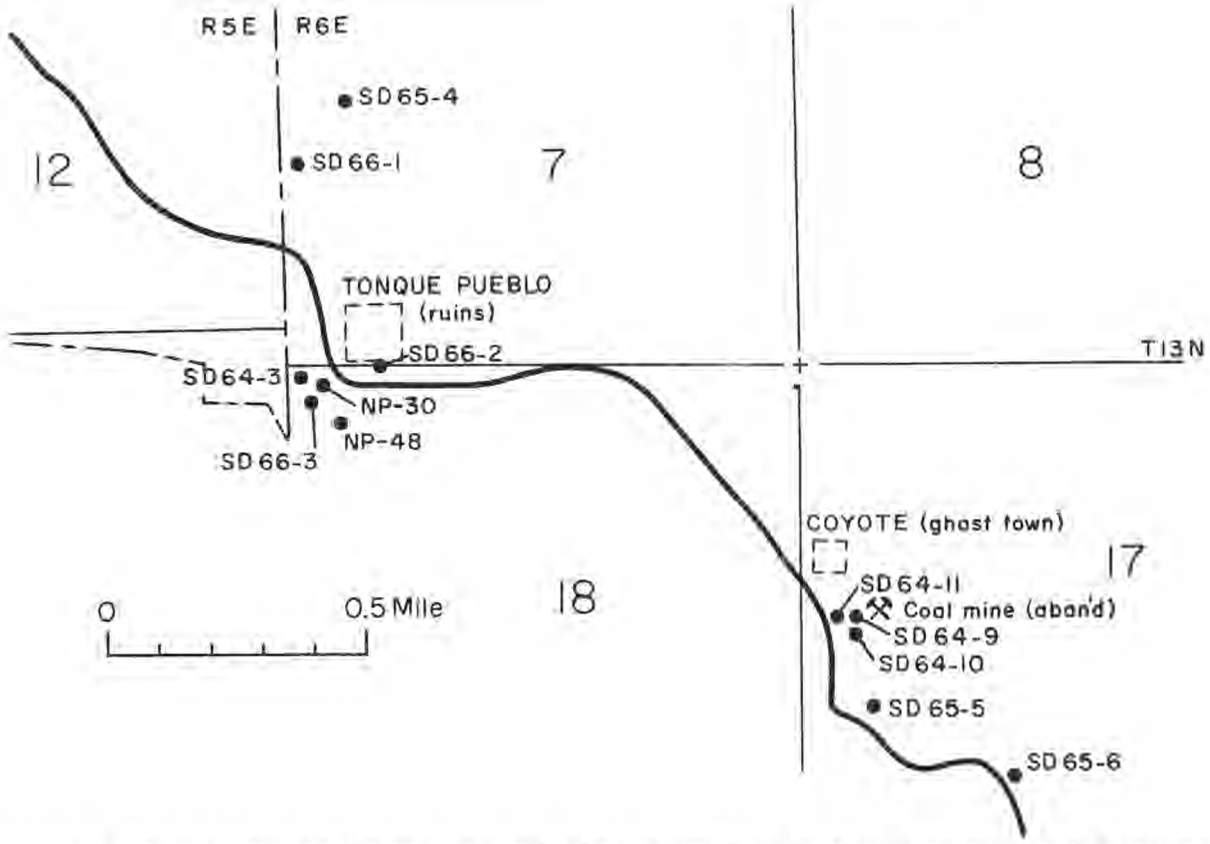

Figure 4. Map showing locations of clay samples in the Tonque and Coyote areas, Sandoval County.

Table 7. -Test Data for Hawks' Clay Samples from Coyote Area, Sandoval County

Geologic unit	MESAVERDE			MESAVERDE		
Sample number	SD65-5			SD65-6		
Raw color	yellowish brown			yellowish brown		
Munsell designation	10YR5/10			10YR7/2		
Water of plasticity (%)	27.5			26.2		
Drying behavior	warped & cracked			good		
Linear drying shrinkage (%)	10.0			11.0		
Dry modulus of rupture (psi)	690			1458		
Firing temperature (°F)	1800	1900	2000	1800	1900	2000
Firing behavior	severe bloating			cracked	good	
Color	moderate brown			moderate brown	moderate brown	
Munsell designation	5YR5/10			5YR5/8	5YR5/8	
Firing shrinkage (%)	1.8			1.0	2.5	
Total shrinkage (%)	11.8			12.0	13.5	
Modulus of rupture (psi)				4036	4210	
Water absorption (%) (5 hr)	2.5			8.9	6.1	
Apparent specific gravity	1.74			2.49	2.50	
Bulk density (g/cu cm)	1.66			2.04	2.16	
Ignition loss (%)	10.8			7.5	7.7	
Pyrometric cone equivalent						

feet south of the coal mine portal. The bars warped and cracked during drying and bloated and split when fired to 1, 800°F.

Sample SD65-6 was taken from the east side of the road approximately 2, 000 feet southeast of the mine portal. The bars dried satisfactorily but cracked when fired to 1, 800°F. Firing to 1,900°F developed enough strength to stop the cracking. This clay could be used for structural and pipe products.

Placitas Area

Clay materials in the Placitas area (fig. 5) were sampled from the Santa Rosa, Chinle, and Morrison Formations, the Mancos Shale, and the Mesaverde Formation. Firing data are available for all but Mesaverde samples (table 8) and chemical analyses are available for Mancos and Mesaverde samples (table 9).

Santa Rosa Formation

Sample SD64-7 was purple shale from NE 1/4 sec. 1, T. 12 N., R. 4E. The bars blistered and cracked when fired to 1,800°F. Not recommended for commercial use.

Chinle Formation

Sample SD64-6 was taken from the red Chinle shale above SD 64-7.

The high lime content evident in the fired bars prohibits its use in commercial clay products.

Morrison Formation

Sample SD64-4 is red mudstone taken from the south wall of a small west-flowing arroyo in NE1/4 *sec.* 1, T. 12 N., R. 4 E. The lime pops at 1, 800°F were eliminated by firing to 2, 000°F. The interesting colors of the 2, 100°F bars might be used to develop a broad range of colors in face brick.

Sample SD65-8 is from the south side of State Highway 44, approximately 1 mile west of Placitas in SE 1/4 sec. 31, T. 13 N., R. 5 E. The lime content, plus the cracking when fired, makes this clay undesirable for commercial use.

Mancos Shale

Sample SD64-5 was the greenish - gray shale in the roadcut on the

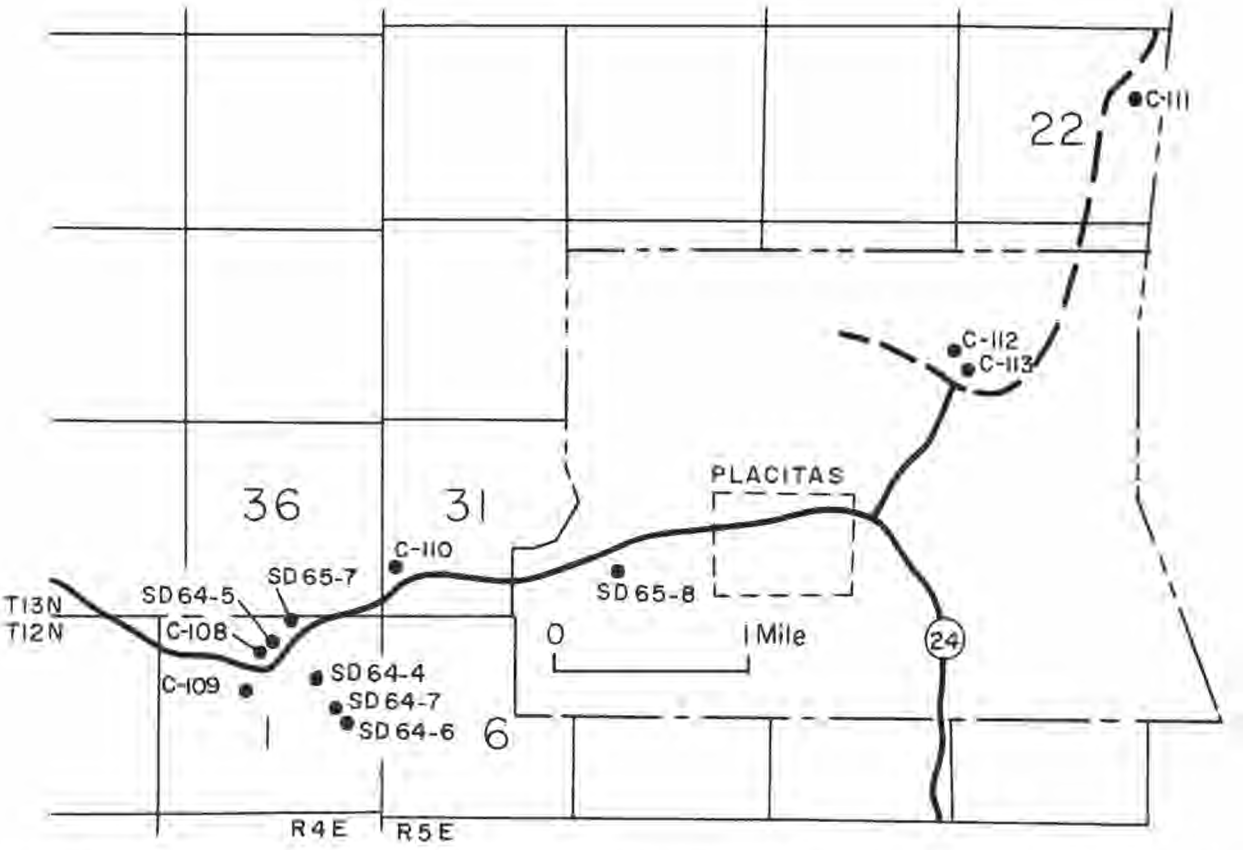

Figure 5. Map showing locations of clay samples in the Placitas area, Sandoval County.

Table 8.—Test Data for Hawks' Clay Samples from Placitas Area, Sandoval County

Geologic unit	SANTA ROSA			CHINLE			MORRISON		
Sample number	SD64-7			SD64-6			SD64-4		
Raw color	grayish red			pale red			reddish brown		
Munsell designation	10R4/2			10R5/4			10R4/4		
Water of plasticity (%)	34.2			22.6			16.2		
Drying behavior	cracked			good			good		
Linear drying shrinkage (%)	9.9			8.0			6.0		
Dry modulus of rupture (psi)	526			337			943		
Firing temperature (°F)	1800	1900	2000	1800	1900	2000	1800	2000	2100
Firing behavior	blistered			lime pops		lime pops	few lime pops	slight scumming	slight scumming
Color	reddish brown			reddish brown		reddish brown	reddish brown	moderate brown	reddish brown
Munsell designation	10R4/6			10R4/6		10R4/6	10R4/6	5YR4/8	10R3/4
Firing shrinkage (%)	5.9			2.0		1.6	1.0	1.0	4.2
Total shrinkage (%)	15.8			10.0		9.6	7.0	7.0	10.2
Modulus of rupture (psi)	1114			below scale		3035	3038	4506	6058
Water absorption (%) (5 hr)	1.00			- -		6.3	7.5	9.2	1.3
Apparent specific gravity	2.30			- -		2.32	2.43	2.48	2.17
Bulk density (g/cu cm)	2.24			- -		2.02	2.04	2.02	2.32
Ignition loss (%)	6.8			8.3		9.0	9.0	9.2	9.0
Pyrometric cone equivalent									

Geologic unit	MORRISON			MANCOS			MANCOS		
Sample number	SD65-8			SD64-5			SD65-7		
Raw color	yellowish gray			yellowish brown			yellowish gray		
Munsell designation	5Y7/2			10YR5/2			5Y8/1		
Water of plasticity (%)	19.8			21.8			23.6		
Drying behavior	good			good			good		
Linear drying shrinkage (%)	7.0			6.3			8.5		
Dry modulus of rupture (psi)	962			1098			1416		
Firing temperature (°F)	1800	1900	2000	1800	1900	2000	1800	1900	2000
Firing behavior	lime pops cracked	lime pops cracked	cracked	lime pops		few lime pops	lime pops	few lime pops	good
Color	moderate brown	moderate brown	yellowish brown	moderate brown		light brown	grayish orange	grayish yellow	olive brown
Munsell designation	5YR6/6	5YR6/6	10YR6/4	5YR5/8		5YR6/6	10YR8/4	5Y8/4	5Y7/6
Firing shrinkage (%)	0.8	1.0	2.4	0.3		0.7	-0.1	0.5	1.2
Total shrinkage (%)	7.8	8.0	9.4	6.6		7.0	8.4	9.0	9.7
Modulus of rupture (psi)	2950	2950	3550	2532		3660	3388	2970	3062
Water absorption (%) (5 hr)	16.2	13.5	1.9	13.0		13.1	11.0	15.4	12.8
Apparent specific gravity	2.72	2.60	2.06	2.42		2.38	2.33	2.54	2.46
Bulk density (g/cu cm)	1.86	1.93	1.97	1.83		1.82	1.91	1.86	1.87
Ignition loss (%)	11.1	11.6	12.0	15.0		15.4	14.8	15.0	15.2
Pyrometric cone equivalent									

north side of State Highway 44, approximately 2.5 miles west of Placitas in NE1/4 sec. 1, T. 12 N., R. 4 E.

Sample SD65-7 was the light-gray shale underlying SD64-5 in the same roadcut. The dry and fired physical properties of these two samples were quite similar except for color. The buff colors developed by sample SD65-7 would produce premium-grade face brick.

The only data available on samples C-108 and C-109 are their locations and chemical analyses. Sample C-108 was apparently taken from the same roadcut as samples SD64 - 5 and SD65 -7, from a shale outcrop in NW 1/4 sec. 1, T. 12 N., R. 4 E. These shale beds are by State Highway 44, 4.6 miles east of North Bernalillo. A north-south fault has exposed the shale beds, which are reported to be Upper Cretaceous in age, probably Mancos shales. The sample was cut on the north side of the highway, where the outcrop is about 20 feet high and extends for more than 100 feet along the highway. This clay is light tan and contains scattered selenite crystals.

Sample C-109 was cut from an exposure in a small wash a few hundred feet east and on the south side of State Highway 44 across from C-108. This shale crops out in a wash for about 50 feet. These beds dip 20°N and strike westward. The shale is tan with some gray from included organic material. The shale contains a small amount of gypsum in fractures and seams.

Mesaverde Formation

The following samples are assumed to have been taken from the Mesaverde Formation (table 9).

Sample C-110 was taken in SW 1/4 sec. 31, T. 13 N., R. 5 E., in the roadcut of State Highway 44, 5.9 miles east of North Bernalillo. This gray shale is exposed in the roadcut for about 50 feet.

Sample C-111 was cut at the collar of an inclined prospect shaft in the hillside east of the ranch 3 miles north - northeast of Placitas. This prospect is in sec. 22, T. 13 N., R. 5 E., and may be reached by traveling northward 3 miles on a road that turns left from State Highway 44 0.7 mile northeast of Placitas. A 7-foot cut was made perpendicular to the bedding. This is a tan and gray shale. It is rather sandy and contains a few nodules of limestone.

Samples C-112 and C-113 were taken near an abandoned coal mine about a mile north of Placitas. The mine may be reached by traveling eastward on State Highway 44 from the Placitas post office for 0.6 mile and taking a graded road northward for 0.9 mile.

Sample C-112 was cut across 20 feet of an exposure of shale in the wash below the mine. In this exposure the shale beds are about 35 feet thick. The shale is gray and contains a few sandy lenses, but for the most part it is fine-grained.

Sample C-113 was a light-gray clay from above the coal seam in the

Table 9.–Chemical Analyses of Clippinger's Clay Samples from Placitas Area, Sandoval County

	Sample Number					
	Mancos		Mesaverde			
	C-108	C-109	C-110	C-111	C-112	C-113
SiO_2	43.84	62.58	33.32	48.20	62.22	69.84
Al_2O_3	14.88	12.48	8.34	12.94	14.92	15.98
Fe_2O_3	3.30	2.72	1.50	4.00	3.70	2.40
CaO	15.20	4.60	28.00	15.00	2.05	0.45
MgO	2.41	3.41	1.74	1.24	1.84	0.95
SO_3	0.58	0.78	0.07	0.01	0.61	0.02
Ignition loss	18.00	11.26	25.50	16.08	11.51	7.04
Total*	98.21	97.83	98.47	97.47	96.85	96.68

* Total does not include alkalies.

mine. It was thought that this material might be a fire clay. The beds from which C-112 and C-113 were cut strike N80°W and dip 70°N.

Santa Ana-San Ysidro-Jemez Springs Area

Data are available for four samples from the area around San Ysidro, one each from the Abo, Chinle, and Morrison Formations (table 10) and one from an unknown geologic unit.

Abo Formation

Sample SD65-15 was taken from the east side of State Highway 4, 7. 6 miles north of Jemez Pueblo. The high lime content makes it unsuitable for commercial use.

Chinle Formation

Sample SD65-12 was taken just south of State Highway 44, 6.5 miles west of San Ysidro. The high lime content and the bloating at 2, 000°F make it unsuitable for structural clay products. Further testing might prove this clay could be used as a lightweight aggregate.

Morrison Formation

Sample 5D64-12 was a gray shale from a prospect pit on Gossett claim "Whale #1" in SW 1/4 sec. 22, T. 15 N. , R. 1 E. The site is reached by traveling 2. 5 miles southward from San Ysidro on State Highway 44 to the entrance of the American Gypsum Company mine, then southwestward for

Table 10. –Test Data for Hawks' Clay Samples from Santa Ana-San Ysidro-Jemez Springs Area, Sandoval County

Geologic unit	ABO			CHINLE			MORRISON		
Sample number	SD65-15			SD65-12			SD64-12		
Raw color	moderate red			reddish brown			medium gray		
Munsell designation	10R5/4			10R4/6			10YR6/1		
Water of plasticity (%)	18.6			25.2			31.3		
Drying behavior	good			good			good		
Linear drying shrinkage (%)	6.5			9.2			9.5		
Dry modulus of rupture (psi)	1080			1455			224		
Firing temperature (°F)	1800	1900	2000	1800	1900	2000	1800	1900	2000
Firing behavior	lime pops	lime pops	few lime pops	few lime pops	few lime pops	bloated	cracked	cracked	cracked
Color	moderate brown	orange pink	grayish orange	reddish brown	reddish brown	dark brown	orange pink	orange pink	orange pink
Munsell designation	5YR6/6	5YR7/6	10YR7/4	10R5/6	10R4/4	5YR3/4	5YR8/2	5YR8/2	5YR8/2
Firing shrinkage (%)	1.1	1.3	1.2	2.6	1.6	0.8	2.0	2.5	4.7
Total shrinkage (%)	7.6	7.8	7.7	11.8	10.8	10.0	11.5	12.0	14.2
Modulus of rupture (psi)	3620	3780	4566	5300	4720	4035	735	810	1200
Water absorption (%) (5 hr)	7.7	10.5	4.7	0.7	8.2	1.5	16.4	15.7	10.4
Apparent specific gravity	2.34	2.52	2.20	2.23	2.37	1.74	2.69	2.73	2.65
Bulk density (g/cu cm)	2.02	1.99	2.00	2.20	1.89	1.69	1.87	1.91	2.07
Ignition loss (%)	13.8	13.7	13.6	7.1	7.1	6.8	11.0	11.2	11.2
Pyrometric cone equivalent	cone 4 - dark olive brown						cone 32 - light brown		

2.2 miles, and then northwestward for 1.2 miles. The clay could be classified as a "semi flint" fireclay and would be suitable for the manufacture of high-duty firebrick. The cracking that occurs during firing could be eliminated by the addition of calcined fire clay. This clay could also be used to produce premium-grade, buff-colored face brick.

Geology Unknown

Sample B-101 was collected by T. D. Benjovsky on December 15, 1946. He made the following report:

Location: Sec, 29, T. 14 N., R. 3 E., Sandoval County, New Mexico.

Type deposit: Bedded sedimentary deposit with sandstone foot and hanging walls. Strike of clay outcrop is east and west with a dip south of 5°, thickness 18" to 4',

Outcrops: The deposit of clay is exposed on the north and south slopes of a large drainage wash that drains eastward into the Jemez Valley. This has cut through the clay deposit for a distance laterally of a mile or more and in depth below clay bed of only a few feet, Most of outcrops on sides of the wash occur from 5' to 15' above the bottom of the wash, Erosion on the north and south slopes has covered parts of clay outcrop with considerable debris so that clay outcrops appear to be intermittent along the strike, when in reality it can be considered a continuous outcrop for a mile or more in distance.

Physical characteristics: The clay deposit is of very fine texture in the exposures seen over three-fourths of a mile lateral distance. The color in place, however, shows a pale-blue tinge of color near the center of the deposit. This color is thought to be due to moisture content and it appears from 8" to 14" thick; on both foot and hanging sides the clay is a flat white. On exposure in dumps where the clay deposit has been prospected, all material is white in the dumps.

Samples: I visited three outcrops in process of sampling. Full section sample of about 100 pounds was cut of bedded clay marked Clay 100. I also took sample of about 100 pounds representative of the bedded deposit, eliminating the pale blue colored central part of the bed 8" to14" thick labeled 100-A,

Proximity to railroad and truck transportation: The deposit is approximately 12 miles north of Bernalillo, county seat of Sandoval County. The deposit is one-half to three-fourths of a mile west of paved Highway No, 44. There is no road from paved highway to the clay deposit, excepting a trail that follows west up the large wash, Only on rare occasions it is possible to drive an automobile to the deposit.

Ownership: The area is within the borders of the Santa Ana Indian Pueblo. The Vibro Block Company, 503 North 4th Street, Albuquerque, New Mexico, leases the same. Pete McAtee, 503 North 4th Street, Albuquerque, New Mexico, is secretary of the company.
Operating: No.
Market: None. The market for this clay has to be developed.
Possibility: If the clay is valuable enough in dollars, it is advantageously located. Would require road construction of perhaps 3 to 4 miles. Can be mined by underground methods like coal, room and pillar. Has sandstone foot and hanging walls. Only a very small amount could be mined by open-cut methods, as overburden very soon becomes too thick to remove.

The following analysis was reported by the Homer Laughlin China Company, Newell, West Virginia:

General Test 2428: Clay 101, Sandoval County, New Mexico

SiO_2	58.39
$R_2O_3(Fe_2O_3\text{-}Al_2O_3)$	21.90
CaO	3.05
MgO	4.00
Ignition Loss	12.11
Total	99.45
Fusion color	brown
Absorption-cone 7	vitreous
Fired color	brown
Raw color	white

101 Pale Cream meta-bentonite, Sandoval, sec. 29, T. 14 N., R. 3 E.

Silica	55.72 %
Alumina	15.34
Iron oxide	2.82
Calcium oxide	2.30
Magnesia	4.30
Soda, Potash	1.10
Ignition loss	18.82
Total	100.40 %

Analysis by: S. W. Port Cement Co.
Notes: SiO_2 by soda fusion and double evaporation. No correction applied for silica loss in R_2O_3 or R_2O_3 in SiO_2. SO_3 test on acid solution only; not on fused samples. Alkalies estimated from combined weight of soda and potash.

La Ventana Area

Mesaverde Formation

Van Sant made the following notes on clays sampled in the La Ventana area:

Predominantly Upper Cretaceous, Dakota Sandstone outcrops in the eastern edge of the area (La Ventana Mesa) and the eastern edge of Nacimiento fault brings Precambrian rocks against Cretaceous sediments, Mancos Shale overlies the Dakota Sandstone and is exposed on the eastern and southern flanks of La Ventana Mesa, La Ventana Sandstone caps the mesa and intermediate members of the Mesaverde Formation are exposed on the south side. The Mesaverde Formation (Hosta Sandstone, Allison and Gibson Coals, La Ventana Sandstone, and Chacra Sandstone) covers most of the area.

Location 7: Sec, 31, T. 19 N. , R. 1 W. , sample VS-46; 6 ft, of shale on the north side of arroyo near the base of the sandstone cliff and above 50 ft, talus slope. Grayish to pale¯ brown shale, concoidal fracture, PCE-17.

Location 8: Sec, 31, T. 19 N. , R. 1 W. , 0, 25 mile south of VS -46, Road passes near a knoll with a carbonaceous shale exposed on 'the south face, Sample VS-47; 5 ft, of shale between two thin coal seams. Expanded when fired to 2, 400°F.

SANTA FE COUNTY

Ceramic Industry

The New Mexico State Penitentiary operated a brick plant intermittently from the late 1800's (Talmage and Wootton, 1937) to 1953 (New Mexico State Mine Inspector's Reports, 1912-1968). They mined red-burning Pennsylvanian shales (table 14, sample NP-72) about 2 miles east of town on the Cerro Gordo road (Spiegel and Baldwin, 1963). The brick made from these clays is fairly dense and apparently quite durable. The brick may be seen on a number of buildings in Santa Fe.

Clays

Santa Fe Area

Pennsylvanian

Sample NP-72 (table 14) was from one of the pits operated by the state penitentiary. The pits are located about 2 miles east of the center of Santa Fe on the Cerro Gordo road.

Cerrillos Area

Data are available on clay materials from the Morrison Formation and Mancos Shale at several localities in the Cerrillos area south of Santa Fe. Hawks' samples comprised one Morrison sample and three Mancos samples (table 11), all from different localities. Table 11 also includes data on sample SF65-4, which is a composite of six Mancos samples collected by Foster from his locality 42-9 (table 12). Foster also collected five Mancos samples from one locality in the Ortiz Mountains south of Madrid (table 13). Needham and Peterson collected two samples in the Cerrillos area (table 14, samples NP-44 and NP-49).

Morrison Formation

Sample SF64-1 was mottled red and gray shale from a roadcut in La

Table 11. –Test Data for Hawks' Clay Samples from Cerrillos Area, Santa Fe County

Geologic unit	MORRISON			MANCOS			MANCOS		
Sample number	SF64-1			SF64-2			SF65-1		
Raw color	pale red			yellowish brown			yellowish gray		
Munsell designation	10R5/4			10YR6/4			5Y5/1		
Water of plasticity (%)	17.2			21.6			15.2		
Drying behavior	good			good			good		
Linear drying shrinkage (%)	5.7			7.1			4.0		
Dry modulus of rupture (psi)	540			520			338		
Firing temperature (°F)	1800	1900	2000	1800	1900	2000	1800	1900	2000
Firing behavior	lime pops	lime pops	few lime pops	lime pops cracks	lime pops cracks	bloated	good	good	good
Color	reddish brown	reddish brown	reddish orange	reddish brown	reddish brown	reddish brown	orange pink	orange pink	grayish orange
Munsell designation	10R4/10	10R5/10	10R6/6	10R5/10	10R5/8	10R4/6	5YR8/4	5YR8/4	10YR7/4
Firing shrinkage (%)	-0.1	0.3	0.3	1.9	2.2	2.6	0.5	0.0	2.9
Total shrinkage (%)	5.6	6.0	6.0	9.0	9.3	9.7	4.5	4.0	6.9
Modulus of rupture (psi)	1020	1133	1424	3612	1475	2670	1992	2340	3050
Water absorption (%) (5 hr)	14.7	15.3	14.2	5.5	5.9	5.8	19.1	20.2	13.6
Apparent specific gravity	2.63	2.61	2.57	2.36	2.35	2.47	2.56	2.75	2.50
Bulk density (g/cu cm)	1.90	1.86	1.88	2.12	2.07	1.86	1.72	2.37	1.90
Ignition loss (%)	11.7	11.6	11.8	12.2	12.1	12.1	18.9	19.1	19.1
Pyrometric cone equivalent									

Geologic unit	MANCOS			MANCOS			
Sample number	SF65-2			SF65-3			
Raw color	yellowish gray			medium gray			
Munsell designation	5Y6/1			N4.5			
Water of plasticity (%)	18.4			16.6			
Drying behavior	good			good			
Linear drying shrinkage (%)	6.0			4.7			
Dry modulus of rupture (psi)	451			687			
Firing temperature (°F)	1800	1900	2000	1800	1900	2000	
Firing behavior	good	good	good	good	good	good	
Color	reddish orange	reddish brown	reddish brown	orange pink	grayish orange	yellowish brown	
Munsell designation	10R6/10	10R5/8	10R4/8	5YR7/4	10YR8/4	10YR7/2	
Firing shrinkage (%)	1.0	2.0	3.8	-0.6	-0.2	0.8	
Total shrinkage (%)	7.0	8.0	9.8	4.1	4.5	5.5	
Modulus of rupture (psi)	1470	1980	3352	2212	1754	2040	
Water absorption (%) (5 hr)	8.9	11.3	6.17	16.6	16.3	15.4	
Apparent specific gravity	2.49	2.66	2.45	2.52	2.82	2.56	
Bulk density (g/cu cm)	2.04	2.04	2.12	1.78	1.94	1.83	
Ignition loss (%)	3.5	3.4	4.5	14.8	15.0	15.5	
Pyrometric cone equivalent	cone 10 - brown						

Bajada Hill on the north side of State Highway 85 in NE1/4 sec. 20, T. 15 N., R. 7 E. The high lime content makes it unsuitable for use in clay products.

Mancos Shale

Sample SF64-2 was an iron-stained gray shale from a roadcut in La Bajada Hill on the south side of State Highway 85, east of SF64-1, in NW] /4 sec. 21, T. 15 N., R. 7 E. The high lime content and the bloating at 2, 000 °F makes it unsuitable for structural clay products. Further testing might prove it useful as a lightweight aggregate.

Foster locality 42-9 (table 12) is in SW1/4 sec. 2, T. 14 N., R. 7 E., between the railroad and a dirt road about 3 miles northwest of Cerrillos .

Table 12.–Test Data for Foster's Clay Samples from Cerrillos Area, Santa Fe County

Geologic unit	MANCOS	MANCOS	MANCOS
Sample number	42-9-1	42-9-2	42-9-3
Raw color	yellowish gray	yellowish gray	yellowish gray
Munsell designation	5Y5/1	5Y5/1	5Y5/1
Plasticity	fair	high	high
Drying behavior	good	good	good
Linear drying shrinkage (%)	0.7	1.7	1.7
Scumming	none	none	none
Firing temperature (°F)	1900 2100	1900 2100	1900 2100
Color	pale orange	pale orange	pale orange
Munsell designation	10YR8/2	10YR8/2	10YR8/2
Firing behavior	good melted	good melted	good melted
Apparent specific gravity	2.46	2.62	2.47
Hardness	hard	hard	hard
Efflorescence	heavy	moderate	slight
Absorption (%) (24 hr)	19.5	19.7	17.9
Saturation coefficient	.826	.844	.834
Ignition loss (%)	16.4	18.1	16.4
Firing shrinkage (%)	0.6	0.3	0.3
Total shrinkage (%)	1.2	2.0	2.0

Geologic unit	MANCOS	MANCOS	MANCOS
Sample number	42-9-4	42-9-5	42-9-6
Raw color	pale brown	medium gray	yellowish gray
Munsell designation	10YR5/1	N5.5	5Y5/1
Plasticity	good	fair	good
Drying behavior	cracked	good	good
Linear drying shrinkage (%)	1.7	0.7	1.3
Scumming	none	none	none
Firing temperature (°F)	1900 2100	1900 2100	1900 2100
Color	grayish yellow	pale orange	orange pink
Munsell designation	5Y8/4	10YR8/2	5YR8/2
Firing behavior	good melted	good melted	good melted
Apparent specific gravity	2.36	2.50	2.53
Hardness	hard	hard	hard
Efflorescence	heavy	heavy	moderate
Absorption (%) (24 hr)	18.4	20.4	23.6
Saturation coefficient	.847	.828	.865
Ignition loss (%)	14.4	18.2	19.5
Firing shrinkage (%)	0.3	0.6	1.4
Total shrinkage (%)	2.0	1.3	2.7

Table 13.–Test Data for Foster's Clay Samples from Ortiz Mountains (Cerrillos Area), Santa Fe County

Geologic unit	MANCOS	MANCOS	MANCOS
Sample number	42-8-1	42-8-2	42-8-3
Raw color	yellowish gray	dark gray	yellowish gray
Munsell designation	10Y5/1	N3.5	5Y7/1
Plasticity	fair	good	good
Drying behavior	good	good	good
Linear drying shrinkage (%)	4.0	3.3	2.0
Scumming	none	slight	none
Firing temperature (°F)	1900 2100	1900 2000	1900 2000
Color	orange pink	orange pink	orange pink grayish orange
Munsell designation	5YR8/4	5YR7/4	5YR7/4 10YR8/4
Firing behavior	good melted	good melted	good good
Apparent specific gravity	2.54	2.64	2.58
Hardness	hard	hard	hard soft
Efflorescence	slight	slight	slight slight
Absorption (%) (24 hr)	22.1	24.4	22.0 17.6
Saturation coefficient	.821	.789	.744
Ignition loss (%)	16.1	11.0	8.4 10.5
Firing shrinkage (%)	0.7	0.0	0.0 2.0
Total shrinkage (%)	3.33	3.3	2.0 4.0

Geologic unit	MANCOS	MANCOS	
Sample number	42-8-4	42-8-6	
Raw color	medium gray	medium gray	
Munsell designation	N5.5	N6	
Plasticity	fair	poor	
Drying behavior	good	good	
Linear drying shrinkage (%)	1.3	2.0	
Scumming	none	none	
Firing temperature (°F)	1900 2000	1900 2000	
Color	orange pink yellowish brown	grayish orange	
Munsell designation	5YR7/4 10YR4/4	10YR8/4	
Firing behavior	good warps blisters	good melted	
Apparent specific gravity	2.45 2.27	2.82	
Hardness	hard hard	hard	
Efflorescence	none none	slight	
Absorption (%) (24 hr)	21.6 3.3	19.8	
Saturation coefficient	.783 .532	.820	
Ignition loss (%)	7.2 8.3	13.2	
Firing shrinkage (%)	0.7 0.7	0.0	
Total shrinkage (%)	2.00 2.00	2.00	

Six samples were taken from a thick section of Mancos Shale containing very little gypsum and iron staining, but including a few thin beds of limestone. Test bars were made of a composite of the six samples and reported as SF65-4 (table 11). A light-colored face brick might be developed from this clay.

Sample SF65-2 was taken 0.25 mile west of Cerrillos in NE 1/4 sec. 18, T. 14 N., R. 8 E. This clay burns to a good brick-red color and could be used for the manufacture of face brick.

Locality NP-49 is given as just north of the Santa Fe tracks at Cerrillos. This could put it near either SF65-1 or SF65-2. The chemical analysis shows a very high lime content, making its use in clay products doubtful.

Sample SF65-1 was taken 1.25 miles northwest of Cerrillos in NE1/4 sec. 13, T. 14 N., R. 7 E. This shale is similar to that used by the Kinney Brick Company in Albuquerque for their light-colored brick.

Foster's locality 42-8 is on the west side of State Highway 10 in the Ortiz Mountains in SE 1/4 sec 16, T. 13 N., R. 7 E. Most of the briquettes melted when fired to 2, 100°F. This indicates that the clay has a short firing range and would cause trouble in the manufacture of clay products. Expansion tests indicate a good lightweight aggregate can be obtained, but again the temperature range would be so narrow that it would not be commercially feasible.

The location information on sample NP-44 places it near 42-8. Its high lime content makes it unsuitable for clay products. The lime-silica-alumina ratio places the composition near the lowest temperature eutectic in the CaO-SiO2-A1$_2$0. system.

Table 14. -Test Data and Chemical Analyses for Needham and Peterson's Clay Samples from Santa Fe County

	Clay Number					
	NP-72	NP-49	NP-44	NP-12	NP-20	NP-93
Apparent specific gravity	2.21	2.40	2.45	1.64	1.20	
True specific gravity	2.59	2.48	2.60	2.30	2.20	
Plasticity	good	poor	poor		fair	
Cohesion	strong	weak	weak		weak	
Tempering water (%)	25.7	18.2	18.8		50.5	
Linear drying shrinkage (%)	7.8	3.1	2.4		4.9	
Tendency to crack	none	none	none		none	
Slaking time	does not slake	does not slake	does not slake	does not slake	does not slake	
Tensile strength of air-dried briquettes (psi)	151	42	16		43	
Chemical analysis:						
SiO_2	59.21	49.06	49.50			60.00
Al_2O_3	24.02	11.62	10.60			21.50
Fe_2O_3	3.98	3.20	3.10			2.50
CaO	2.70	14.65	15.30			3.50
MgO	0.99	2.33	2.33			2.66
Ignition loss	7.96	16.32	17.00			8.12
Total	98.86	97.18	97.83			98.28

Espanola Area

Bentonite s

Needham and Peterson sampled four bentonites in the Espanola area (table 14).

Sample NP-12 was a bentonitic tuff 2 miles south of Pojoaque. It was found to be nonslaking, so very little testing was done on this sample.

Table 15. -Rotary-Mud Analysis for Bentonite (Sample NP-90) from Española Area, Santa Fe County

CLAY TESTS	
Specific gravity	2.15
pH	6
ROTARY-MUD TESTS*	
Weight:	
Lbs/cu ft	80.0
Lbs/gal	10.7
Specific gravity	1.28
Viscosity:	
Marsh Funnel (secs)	32
Stormer (centipoises)	88
Free water separating (%):	
1st hr	0
2nd hr	0
18th hr	0
Elutriation:	
Percent sand in mud	0.15
Yield:	
Bbls mud/ton clay	14.02

Wall building:
(16/32-in.- thick filter cake; 100 psi; atmospheric temperature)

time (mins)	water off (cc)	rate (cc/min)
1	7.0	7.0
5	15.5	2.1
10	22.0	1.3
15	26.0	1.2
30	38.0	0.67
60	53.0	0.50
5-15	12.5	1.25

* Mix of 31.8% clay and 68.2% water to yield mud with Marsh Funnel viscosity (500 cc in, 500 cc out) in the range of 25 to 35 secs.

Sample NP-20 was a bentonite from the Patterson claims south of . This sample was also found to be nonsmoking.

Sample NP-90 was a gray bentonite from north of State Highway 4 at the east boundary of the Bandelier National Monument. A rotary-mud analysis was run on this sample (table 15). The yield was 14 barrels of mud per ton of clay, which is inadequate for a good drilling mud.

Sample NP-93 was a pink bentonite from sec. 6, T. 20 N., R. 9 E., near Santa Cruz. Only its chemical analysis is available (table 14).

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APPENDIX
LABORATORY PROCEDURES

PREPARATION OF TEST SPECIMENS

Foster samples (soft mud): The samples were ground to a minus-20-mesh particle size, blended with water, and hand molded into 3/8" x 1-3/4" x 3" briquettes. The briquettes were dried in an electric dryer and fired in an electric furnace.

Hawks samples (stiff mud): The samples were ground to a minus-10-mesh particle size, blended with water, and extruded from a deairing auger machine into 7"-long, 1"-diameter cylinders. The cylinders (bars) were dried in an electric dryer and fired in a gas-fired kiln.

PHYSICAL PROPERTIES

Unfired Properties

Drying behavior: The dry specimens were inspected for cracks, warping, and other visible defects.

Scumming: Scumming on the surface of the dry specimen was recorded as none, slight, moderate, or heavy.

Water of plasticity: The water of plasticity, or the percent water required to produce a workable clay-and-water mixture, based on the dry weight of the specimen, was calculated as follows:

$$\text{Water of plasticity (\%)} = \frac{Wp - Wd}{Wd} \times 100$$

Wp = plastic weight
Wd = oven-dry weight

Linear drying shrinkage: The linear drying shrinkage, based on the plastic length, was calculated as follows:

$$\text{Linear drying shrinkage (\%)} = \frac{Lp - Ld}{Lp} \times 100$$

Lp = plastic length
Ld = oven-dried length

Fired Properties

Firing behavior: The fired specimens were visually inspected for defects, such as cracks, warping, bloating, lime pops, and blistering.

Total shrinkage: Total linear shrinkage was calculated as follows:

$$\text{Total shrinkage (\%)} = \frac{Lp - Lf}{Lp} \times 100$$

Lp = plastic length
Lf = fired length

Firing shrinkage: Percent firing shrinkage is percent total shrinkage less percent drying shrinkage. Expansion is reported as negative shrinkage.

Ignition loss: The weight loss when the dry specimen is fired is reported as ignition loss.

$$\text{Ignition loss (\%)} = \frac{Wd - Wf}{Wd} \times 100$$

Wd = dry weight
Wf = fired weight

Modulus of rupture: The modulus of rupture was determined using a three-point suspension. The formula for calculating the modulus of rupture for a circular cross section is:

$$\text{Modulus of rupture (psi)} = \frac{8WL}{\pi d^3}$$

W = breaking load (lbs)
L = distance between supports (in)
d = diameter of the specimen at the break (in)

Absorption:

24-hour soak: The specimens were soaked in distilled water for 24 hours, and the weight of the saturated specimen in air was recorded.

5-hour boil: The specimens were boiled in distilled water for 5 hours and the weight of the saturated specimen in air and submerged in water were recorded.

Absorption is calculated with the following formula (specify whether 24-hour soak or 5-hour boil):

$$\text{Absorption (\%)} = \frac{W - D}{D} \times 100$$

W = saturated weight in air
D = dry weight

Saturation coefficient: The saturation coefficient is the ratio of the weight of water absorbed during the 24-hour soak to the weight of water absorbed during the 5-hour boil.

$$\text{Saturation coefficient} = \frac{W_{24} - D}{W_5 - D}$$

W_{24} = saturated weight after 24-hour soak
W_5 = saturated weight after 5-hour boil
D = dry weight

Apparent specific gravity: The apparent specific gravity is the specific gravity of that portion of the test specimen that is impervious to water.

$$\text{Apparent specific gravity} = \frac{D}{D - S}$$

D = dry weight
S = saturated weight in water

Bulk density:

$$\text{Bulk density (g/cu cm)} = \frac{D}{W - S}$$

D = dry weight (g)
W = saturated weight in air (g)
S = saturated weight suspended in water (g)

Efflorescence: The test specimens were placed on end in a container filled with 1 inch of distilled water. Water is added to maintain a constant level for 7 days. The specimens were then oven dried and the degree of efflorescence recorded as none, slight, moderate, or heavy.

Color: The color names used for both raw and fired colors are adapted from

the Rock-Color Chart distributed by the Geological Society of America. The numerical designations represent the hue, value, and chroma according to the Munsell color system.

Pyrometric cone equivalent (PCE): This test is used to determine the refractoriness of a clay. Small cones were molded of the clay to be tested and mounted on a refractory plaque together with a series of standard cones. The plaque was then subjected to a specified heating rate in a gas-fired furnace. When the test clay cone softened enough to bend down and touch the plaque, the number of the standard cone that deformed at the same time was recorded as the clay's pyrometric cone equivalent (PCE).

Chemical analyses: Atomic absorption and standard silicate analysis methods were used to determine the chemical analyses of the raw clays.