NORTH DAKOTA GEOLOGICAL SURVEY

Wilson M. Laird, State Geologist

INVESTIGATION

OF

LAKE AGASSIZ

CLAY DEPOSITS

by

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ABSTRACT

At present more brick are shipped into North Dakota than are made at the two existing plants located in the southwestern part of the state. Although there are no brick plants in the Red River Valley, at the turn of the century Grand Forks had four brick plants and was the center of the industry. There were also several other plants in the valley using about five feet of the yellow silt layer of the Lake Agassiz deposit as raw material for common brick. The reserves of these independent plants were limited and not too consistent, and consequently the production of good quality brick for an extended period was not feasible. The kilns used were inefficient and produced large percentages of underfired and overfired brick.

None of these former brick plants used the greenish gray clay occurring below the yellow silt, although some blending of the silt and clay was tried. Preliminary tests have been run on samples of silt and clay from different parts of the valley in order to check the uniformity and to investigate the possibility of making face brick. Various blends of raw and preheated clay and silt were tried and the following tests performed: determination of linear drying shrinkage and water of plasticity from handmade specimens: determination of fired linear shrinkage as well as apparent porosity and water absorption of specimens fired to various temperatures; and differential thermal analysis to determine minerals present.

The results of this investigation indicate that good common brick, building or drain tile can be readily made from the silt and clay units of the Lake Agassiz deposits. The occurrence of fine cracks, stickiness, and high drying shrinkage in trial pieces containing only raw portions of the clay unit, is overcome by the addition of preheated clay.

Several of the trial pieces have desirable face brick properties, but the firing range is so limited that careful control would be required. Samples of the silt unit produced the most pleasing face brick trial pieces.

INTRODUCTION

General discussion of brick clays

A modern classification of brick clays should distinguish between common brick and face brick clays.

Any clay or shale which is plastic enough to be shaped and will burn hard and strong at temperatures below 2150°F. is suitable for common brick. These clays are usually high in iron and lime content, but this is only of secondary importance since the vitrification range and color may vary considerably. Surface clays or soft shales are used for common brick to be used for backing up face brick, stone or plaster.

Iron is always present in clay to some extent and is very important because it determines largely the color to which clay will burn. With 4 per cent or over, the clay will burn to a pale or dark red. Lime is an important fluxing constituent of clays and when present in large quantities it affects the color of fired clay. High lime content will neutralize in part the color given by the iron, so that clays high in lime burn buff, even if they contain considerable iron.

A clay or shale suitable for face brick must produce a hard, pleasing surface which is durable under all conditions of atmosphere and climate. Red burning surface clays or shales and buff or white burning refractory clays are suitable for face brick. Face brick must have low drying and firing shrinkage and a minimum of warpage, because the bricks are required to be of uniform size and have true shape.

A very important property of all face brick clay is that it must fire to a hard, strong, comparatively dense piece at a low temperature. (Red burning clay: 1705°F. - 2075°F., and buff burning clay: 2210°F. - 2237°F.)

Lake Agassiz clays

Deposits laid down in large Pleistocene lakes cover extensive areas in North Dakota. The largest of these bodies of water was Lake Agassiz, which occupied the Red River Valley and extended north into Manitoba, with an area of 110,000 square miles, or more than the combined area of the Great Lakes. The lake was brought into existence when the continental ice sheet, during its retreat northward, gradually uncovered the broad depression known as the Red River Valley and formed an immense dam of ice at the north which prevented drainage from the melting glacier from finding an outlet in that direction.

The rivers emptying into Lake Agassiz carried large quantities of sediment, which were distributed by the waves and currents and settled to the bottom. These lacustrine deposits consist of medium greenish-gray clay and yellow silt, and occupy the larger part of the Red River counties, namely, Richland, Cass, Traill, Grand Forks, Walsh, and Pembina. Rominger and Ruttledge (1) state that the clay ranges in thickness from 70 feet at Fargo to 50 feet at Grand Forks. It extends east and west as far as the highest beaches of Lake Agassiz and rests on glacial drift. Overlying the clay is yellow silt ranging in thickness from 15 to 20 feet, near the center of the valley.

Historical Summary of Red River Valley brick making

Clapp (2) states that common brick were probably first made at Fargo some time in the seventies. The industry spread through the Red River Valley, so that by

1885 plants were in operation at Fargo, Grand Forks, and Minto. Grand Forks took the lead in the production and by 1905 there were four plants in operation in Grand Forks. Other plants in operation at this time were located at Walhalla, Grafton, Drayton, Hillsboro, and Abercrombie.

In all of these brick plants, with the exception of Hillsboro, about 5 feet of the yellow silt underlying the surface loam was used to produce cream colored common brick. This silt is sandy, calcareous clay containing roots and other carbonaceous material.

The clay was shovelled directly into two-wheeled dump carts and conveyed to a pug mill for mixing with the proper amount of tempering water. From there it went to a brick machine with a capacity of about 45,000 bricks a day. The bricks were dried in very large yards with covered pallet racks, each yard having a capacity of about 300,000 brick. The latter were dried in six to seven days and then burned in scove kilns with wood as fuel. The clay dried and burned readily and produced a cream colored brick which was very porous but was good enough for common structural purposes. About 30 men were employed at each plant, and they were in operation from the first of May to September first.

All of these brick plants were of a temporary nature and are now only historic relics. They had limited clay reserves and consequently the production of good quality brick for an extended period was not feasible. Large percentages of underfired and overfired brick resulted from the inefficient kilns.

EXPERIMENTAL PROCEDURE

Field methods

Several samples of the Lake Agassiz silt and clay were obtained through the cooperation of the United States Geological Survey, the North Dakota Geological

Survey, and the U. S. Army Corps of Engineers. The samples were designated with the prefix 53, 54, 55, or 56 to denote the year they were gathered.

Hvorslev (3) describes rotary drilling rigs similar to the one used by the U. S. Geological Survey in their program of determining the ground water supplies of North Dakota. The Corps of Engineers drilled several holes at the site of the Grand Forks flood control levee and obtained continuous, undisturbed samples of the Lake Agassiz clay unit by using a 5" fixed piston sampler. The functioning of this type of sampler and a summary of its advantages is given by Taylor (4).

The samples tested were from Fargo, Grand Forks, Grafton and Neche, and therefore were representative of the Red River Valley in North Dakota. Portions of the samples representing 10 foot intervals from below the surface loam to a depth of about 50 feet were used and various blends were tested.

Laboratory methods

A preliminary investigation to determine if a particular clay or shale is suitable for the manufacture of common brick or face brick involves several tests on both unfired and fired samples.

The use of differential thermal analysis tests provides a rapid determination of any existing correlation between samples taken at corresponding depths at various locations, and requires very small samples.

The clay minerals present in the clay, as indicated by the differential thermal analyses, will give the general properties of the clay. A clay material containing montmorillonite or illite is apt to have high plasticity and high shrinkage and will probably burn red and have a short vitrification range. If the mineral kaolinite is present, the clay is apt to be refractory and light firing and have low plasticity and a relatively long vitrification range. If carbonate is present, the clay will require careful preparation and firing technique.

The following important fired and unfired properties can be determined, using only a few trial pieces of suitable dimensions: water of plasticity, linear drying and firing shrinkage, fired color, fired apparent porosity, and water absorption. It is advisable also to determine the transverse strength of dried trial pieces.

The fired appearance of face brick is very important, so it is necessary to fire trial pieces at various temperatures in order to determine the extent of the firing range giving the required hardness and uniformity of color and a minimum of warping.

To give a more conclusive evaluation of the samples being tested, the following tests could also be performed: Chemical analysis, transverse strength of fired trial pieces, X-ray analysis, and particle sizing.

The investigation of various samples of Lake Agassiz silt and clay was part of the long range program of the North Dakota Geological Survey to promote the use of North Dakota clays and shales in additional ceramic industries.

The grinding, mixing, and drying procedure followed while testing the clays and silt included in this report is identical to that outlined by the author (5) in his previous report on some clays and shales of North Dakota. The reader should see this report for the detailed method.

1. The samples were crushed in a Sturtevant fine crusher and then ground to finer than 20 mesh material in a Denver Fire Clay disc pulverizer.
2. Prior to making trial pieces, ten pound samples or mixtures of samples were mixed with sufficient water to give the best working consistency. After aging in a damp box for 24 hours, the batches were hand wedged to thoroughly mix the water with the material.
3. Trial pieces with original dimensions of 1"x1"x12" were made in a steel mold. A frame with wires placed 2 inches apart was used to obtain smaller trial pieces.

4. After removal from the wire cutter, the plastic volumes and weights of 3 trial pieces from each batch were obtained by means of a displacement volumeter containing mercury. The volume displaced by the trial pieces was read on a burette graduated in cubic centimeters. After drying, the weights and volumes were again recorded and the water of plasticity, shrinkage water, pore water and volume changes calculated.

5. The dried volumes were taken of all trial pieces that were to be fired in a Harper Electric Globar Furnace. Samples were fired at intervals of two pyrometric cones from cone 09 to cone 3 to obtain the proper firing range.

6. After firing, a record was made of the color (using the standard Munsell chart), fired volume, fired dried weight, and other visible characteristics. The trial pieces were immersed in boiling water for two hours, and then wiped lightly with a damp towel and weighed in air. The apparent porosity and water absorption values were calculated.

7. Both the linear drying and firing shrinkage values were obtained by using a Westman's Conversion Table, which is based on the per cent volume drying or firing shrinkage.

FORMULAS FOR CALCULATIONS

1. The volume drying shrinkage (per cent of plastic volume) is converted to linear drying shrinkage by means of a Westman's Conversion Table. The values obtained from these tables have been calculated, using the following formula:

$$\left[1 - \sqrt[3]{1 - \frac{b}{100}}\right] \times 100$$

b is the volume drying shrinkage (plastic basis)

2. The percentage water of plasticity is calculated from the formula:

$$\frac{\text{Wt. of freshly molded trial piece - wt. of dried trial piece}}{\text{Wt. of dried trial piece}} \text{ X } 100$$

3. The volume firing shrinkage (per cent of dry volume) is converted to linear firing shrinkage by means of a Westman's Conversion Table. The values obtained from these tables have been calculated using the following formula:

$$\left[1 - \sqrt[3]{1 \frac{b}{100}}\right] \text{X } 100$$

b is volume firing shrinkage (dry, unfired basis).

4. The apparent porosity is calculated from the formula:

$$\text{Percentage apparent porosity } \frac{W-D}{V} \text{ X } 100$$

W is saturated wt. in grams of the fired trial piece.
D is the dried fired wt. of the trial piece.
V is the volume of the trial piece in cubic centimeters.

5. The water absorption values are calculated from $\frac{W-D}{D}$ X 100

6. The percentage shrinkage water is calculated from the formula:

$$\frac{\text{Plastic vol. in cc. - dry vol. in cc.}}{\text{Dry weight in grams}} \text{ X } 100$$

7. The percentage pore water is calculated from the formula:

Percentage water of plasticity - percentage shrinkage water.

OBSERVATIONS AND DISCUSSION

The samples tested for this report are from Fargo, Grand Forks, Emerado, Grafton, and Neche areas. The locations of the samples are shown in Figure 1. From Fargo to Neche is a distance of about 150 miles and includes the major portion of the Red River Valley in North Dakota. The logs of test holes indicate that the thickness of the "silt unit" ranges from 10 to 30 feet and that at a depth of

25 to 30 feet and to at least 50 feet there is a dark greenish gray, sticky plastic clay.

General Discussion

The field samples show that the Lake Agassiz deposits have the following characteristics:

1. The 'silt unit' is a yellow, sandy clay.
2. The 'clay unit' is medium greenish gray, sticky plastic clay.

It is fine grained and non-stratified.

There were only sufficient amounts of samples 54-58 and 54-59 to enable differential thermal analyses to be run. Differential thermal curves for the samples tested for this report are shown in Figures 2 and 3. Tables 1,2, and 3, pages 13-16, give the results of the differential thermal analyses.

The following samples were large enough to enable several trial pieces to be made: 53-38, 54-27, 54-28, 55-13 and 56-3. Group 1 in this report consists of various raw clay mixtures as well as raw clay and preheated mixtures of sample 54-27. Group 2 is composed of the following samples: 53-38, 54-28, 55-13 and 56-3.

Differential thermal analyses show that all the portions of the samples below a depth of 5 feet contain montmorillonite as the basic clay mineral. With the exception of sample 54-28, the samples of the 'silt unit' contain carbonate but no organic material, whereas the 'clay unit' samples contain organic material and produce only slight indication of the presence of carbonates. The samples of 54-28 are from 3 to 105 feet in depth and the differential thermal curves indicate the presence of organic material and carbonate throughout.

The temperature obtained with the differential thermal analysis is 2000°F. or approximately cone 04 to 02. The color of the fired differential thermal analysis trials for sample 54-59 from 0 to 30 feet in depth is pale reddish brown, and from 30 to 90 feet it is light brown. For sample 54-58 the color of the differential thermal analysis trials is uniformly light brown in color from 3 to 105 feet.

Table 1

Results of Differential Thermal Analyses

Sample No.	Type of Reaction	Temperature Range (F)	Minerals Present
53-38	Endothermic	100- 400	Montmorillonite
	Endothermic	1450-1500	Carbonate (slight)
54-27 A (10-15 ft)	Endothermic	100- 500	Montmorillonite
	Endothermic	1400-1600	Carbonate
54-27 B (15-20 ft)	Endothermic	100- 500	Montmorillonite
	Endothermic	900-1400	Montmorillonite
	Endothermic	1400-1550	Montmorillonite
54-27 C (20-30 ft)	Endothermic	100- 700	Montmorillonite
	Endothermic	900-1200	Montmorillonite
	Endothermic	1450-1550	Carbonate
54-27 D (30-40 ft)	Endothermic	100- 500	Montmorillonite
	Exothermic	500- 700	Organic
	Endothermic	900-1200	Montmorillonite
	Endothermic	1400-1550	Carbonate
54-27 E (40-50 ft)	Endothermic	100- 500	Montmorillonite
	Exothermic	500- 900	Organic
	Endothermic	900-1200	Montmorillonite
	Endothermic	1400-1450	Carbonate (slight)
54-28 A (0-10 ft)	Endothermic	50- 550	Montmorillonite
54-28 B (10-20 ft)	Endothermic	100- 600	Montmorillonite
	Endothermic	1450-1550	Carbonate
54-28 C (20-30 ft)	Endothermic	50- 600	Montmorillonite
	Endothermic	1400-1500	Carbonate
54-28 D (30-40 ft)	Endothermic	50- 550	Montmorillonite
	Exothermic	550- 950	Organic (slight)
	Endothermic	1400-1500	Carbonate (slight)
54-28 E (40-50 ft)	Endothermic	100- 500	Montmorillonite
	Exothermic	500- 900	Organic
	Endothermic	1400-1500	Carbonate (slight)
54-28 F (50-60 ft)	Endothermic	100- 500	Montmorillonite
	Exothermic	500- 900	Organic
	Endothermic	900-1400	Montmorillonite

Table 2

Results of Differential Thermal Analyses

Sample No.	Type of Reaction	Temperature Range (F)	Minerals Present
54-30	Endothermic	100- 600	Montmorillonite
	Exothermic	600-1000	Organic (slight)
	Endothermic	1000-1400	Montmorillonite
54-50 (P3) (30-33 ft)	Endothermic	100- 500	Montmorillonite
	Exothermic	500- 900	Organic (slight)
	Endothermic	900-1600	Montmorillonite
54-50 (P7) (40-43 ft)	Endothermic	100- 500	Montmorillonite
	Exothermic	600- 900	Organic
	Endothermic	900-1600	Montmorillonite
54-51 (44 ft)	Endothermic	100- 600	Montmorillonite
	Exothermic	600- 900	Organic
	Endothermic	1500-1600	Carbonate (sharp)
54-58 A (3 ft)	Exothermic	500-1000	Organic
	Endothermic	1400-1550	Carbonate (sharp)
54-58 B (10 ft)	Endothermic	100- 500	Montmorillonite
	Exothermic	550- 700	Organic
	Endothermic	1350-1600	Carbonate (sharp)
54-58 C (20 ft)	Endothermic	100- 600	Montmorillonite
	Endothermic	1350-1600	Carbonate (sharp)
54-58 D (30 ft)	Endothermic	100- 600	Montmorillonite
	Exothermic	600- 900	Organic (slight)
	Endothermic	1400-1650	Carbonate
54-58 E (35 ft)	Endothermic	100- 600	Montmorillonite
	Exothermic	600- 900	Organic
	Endothermic	1400-1550	Carbonate
54-58 F (40 ft)	Endothermic	100- 600	Montmorillonite (very slight) (gray, sandy)
54-58 G (45 ft)	Endothermic	100- 500	Montmorillonite
	Exothermic	500-1000	Organic
	Endothermic	1300-1500	Carbonate

54-58 H (50 ft)	Endothermic	50- 550	Montmorillonite
	Exothermic	550- 800	Organic
	Endothermic	800-1200	Montmorillonite

Table 3

Results of Differential Thermal Analyses

Sample No.	Type of Reaction	Temperature Range (F)	Minerals Present
54-59 A (0-10)	Endothermic	50- 600	Montmorillonite
	Endothermic	1450-1550	Carbonate
54-59 B (10-15)	Endothermic	100- 500	Montmorillonite
	Exothermic	400- 800	organic
	Endothermic	1400-1550	Carbonate
54-59 C (15-20)	Endothermic	50- 600	Montmorillonite
	Exothermic	600- 800	Organic
	Endothermic	1450-1550	Carbonate
54-59 D (20-25 ft)	Endothermic	100- 600	Montmorillonite
	Exothermic	700-1000	Organic (slight)
	Endothermic	1450-1550	Carbonate
54-59 E (25-30 ft)	Endothermic	50- 600	Montmorillonite
	Endothermic	1350-1500	Carbonate
54-59 F (30-35 ft)	Endothermic	75- 600	Montmorillonite
54-59 G (35-40 ft)	Endothermic	75- 600	Montmorillonite
54-59 H (40-45 ft)	Endothermic	75- 600	Montmorillonite
	Exothermic	600- 800	Organic (slight)
54-59 I (45-50 ft)	Endothermic	100- 600	Montmorillonite
	Exothermic	600- 900	Organic (slight)
54-59 J (50-55 ft)	Endothermic	50- 550	Montmorillonite
55-13	Endothermic	100- 650	Montmorillonite
	Endothermic	1400-1575	Carbonate (sharp)
56-3	Endothermic	100- 250	Montmorillonite
	Endothermic	1450-1550	Carbonate

Group I

Samples: 54-27 series.

(A)	10-15 feet	(raw clay)		-	yellow, sandy clay with iron stains.
(B)	15-20	" "	"	-	yellow, sandy dark greenish gray clay mixed.
(C)	20-30	" "	"	-	" " " " " " "
(D)	30-40	" "	"	-	dark greenish gray, sticky, plastic clay.
(E)	40-50	" "	"		
(F)	10-20	" "	"		
(G)	10-50	" "	"		
(H)	10-30	" "	"		
(1)	40-50	" "	"		(50% raw clay, 50% preheated to 1000°F)
(2)	40-50	" "	"		(37.6% raw clay, 62.4% preheated)
(3)					(50% raw 54-27 (F): 25% 54-27 (C): and 25% 54-27 (C) Preheated.
(4)					1 part 54-27 (F) raw 1 part 54-27 (C) raw 1 part 54-27 (C) preheated 1 part 54-27 (D) raw 1 part 54-27 (D) preheated 1 part 54-27 (E) raw 1 part 54-27 (E) preheated

When making trial pieces from samples 54-27 (C, D, E, F, G & H) containing no preheated clay, it was observed that they were quite tough, slightly to rather sticky, slightly plastic, and were not easily deformed by the wire cutter or by handling. Referring to Table 4, page 19, it is observed that there is a direct correlation between dry linear shrinkage and percent shrinkage water. There is no definite correlation between water of plasticity and dry linear shrinkage. Trial pieces from sample 54-27 (D) have a very high per cent of shrinkage water and practically no pore water.

For samples 54-27 (B, C, D, and E) slaking tests gave the following times for complete slaking: 44, 74, 98, and 56 minutes. Table 4, page 19, indicates that sample 54-27 D has the highest dry shrinkage of this series.

Table 4

Water of Plasticity, Shrinkage Water, Pore Water, Dry and Fired Linear Shrinkage, Apparent Porosity and Absorption Values

Group 1

	54-27 (C)	54-27 (D)	54-27 (E)	54-27 (F)	54-27 (G)	54-27 (H)
Water of Plasticity (%)	43.4	36.3	40.1	41.4	38.1	42.4
Shrinkage Water (%)	26.2	35.6	24.4	29.2	26.1	23.7
Pore Water (%)	17.2	0.7	16.3	12.2	12.0	18.7
Dry Linear Shrinkage (%)	12.1	14.3	11.4	13.6	12.2	11.5
Fired Linear Shrinkage (%)						
Cone 09	0.7	1.1	0.8	1.7	3.6	
08	1.6	2.4	1.3	1.5	1.1	
06	1.7	2.6	2.2	2.5	2.9	---
04	1.5	2.9	3.0	3.3	3.4	
02	6.3	3.7	6.7	3.9	6.0	1.7
1	6.8	*	4.0	10.0	9.9	---
3	*	*	*	8.1	*	3.4
Porosity (%)						
Cone 09	42.1	39.5	40.3	43.9	37.8	
08	41.1	39.0	38.8	47.8	38.8	
06	41.1	37.5	36.6	41.2	38.5	---
04	38.4	35.0	34.2	36.8	37.2	
02	24.7	21.8	22.9	35.4		25.2
1	6.0		2.2		9.9	
3	*	*	*	3.8	*	5.1
Absorption (%)						
Cone 09	26.1	24.6	24.5	25.8	22.1	
08	25.1	24.4	23.6	28.3	22.3	
06	24.2	21.9	21.0	23.7	22.5	---
04	22.7	19.8	19.8	20.8	20.6	
02	13.2	12.0	12.3	18.7		14.7
1	3.1	*	1.3		4.8	
3	*	*	*	1.8	*	2.9

* - bloated

Table 5

Water of Plasticity, Shrinkage Water, Pore Water, Dry and Fired Linear Shrinkage, Apparent Porosity, and Absorption Values

Group 1 (continued)

	54-27 (1)	54-27 (2)	54-27 (3)	54-27 (4)
Water of Plasticity (%)	38.4	27.6	24.5	43.5
Shrinkage Water (%)	14.4	9.3	12.2	23.1
Pore Water (%)	14.0	18.3	12.3	20.1
Dry Linear Shrinkage (%)	6.9	4.4	6.5	10.3
Fired Linear Shrinkage (%)				
Cone 09	2.6			
08	1.9			
06	2.3	2.8	1.4	2.3
04	2.6			
02	7.0	6.0	5.3	5.8
1	10.7	12.8	5.8	10.0
3	4.2			
Porosity (%)				
Cone 09	44.7			
08	42.3			
06	44.8	39.0	29.9	39.2
04	41.4			
02	34.2	30.4	27.0	29.3
1	23.0	5.4	4.2	1.8
3	3.0			
Absorption (%)				
Cone 09	27.7			
08	26.9			
06	27.8	25.8	18.5	24.6
04	25.7			
02	19.0	15.7	14.6	15.1
1	11.5	2.5	2.3	0.6
3	1.9			

The mixtures containing preheated clays (listed in Table 5) were quite tough, not sticky, slightly plastic and did not deform easily. The trial pieces were faster drying than those made from the samples listed in Table 4. Table 5 indicates that the addition of preheated clay produces lower dry linear shrinkage than that obtained with raw clays. Test pieces made with preheated clay mixtures, when in the plastic condition, tended to tear or produce jagged edges when cut with a wire. Hullock (6), in his paper on the "Preheat treatment of a Western Canadian Common Brick Clay", states that preheating reduced drying losses and increased green and fired strength.

Dry trial pieces made from samples listed in Table 4 have fine hair cracks which produced complete parting of some of the trial pieces during firing, and consequently severe warping.

Trial pieces made from samples listed in Table 4, and fired to temperatures between cones 09 and 04, are all uniform in color, namely half way between Munsell designated moderate orange pink and light brown. As observed from Table 4, page 19, the fired linear shrinkage, porosity and absorption values for these trial pieces fired between cones 09 and 04 are very nearly the same. These same trial pieces are not warped or bloated, have only a trace of white efflorescence and can be scratched by a steel knife. The change in linear shrinkage between the interval from cone 09 to 04 is very small, as shown in Table 4, page 19. However, trial pieces for samples 54-27 (F, G, 1) contract slightly between cones 09 and 08 and expand at cone 06.

Of the trial pieces made from samples listed in Table 5 only those from sample 54-27 (1) were fired between cones 09 and 04, and ranged in color from moderate reddish orange to light brown. As shown in Table 5, the fired linear shrinkage, porosity and absorption values are almost identical with those for samples listed in Table 4. There is no evidence of cracking in the dry or fired trial pieces from samples listed in Table 5.

At cone 02, for trial pieces from samples listed in Tables 4 and 5, there is a marked deviation from the near straight line relationship observed for shrinkage and absorption between cones 09 and 04. There is a visible darkening of color, and increase in shrinkage.

At cone 1, as shown in Tables 4 and 5, pages 19 and 20, there is no longer correlation between the fired shrinkage, porosity, absorption, and fired color of trial pieces made from samples listed in Tables 4 and 5. Most of the trial pieces of these same samples fired to cone 3 are badly bloated. A hand made brick of sample 54-27 E was fired to cone 1 and was badly bloated. A brick from sample 54-27 H fired to cone 2 was badly bloated.

Group 2

Samples : 53-38, 54-28, 55-13, 56-3.

The field sample of 53-38 is a plastic, medium gray clay: samples 54-28 (A, B & C) are yellow sandy clay, and those of 54-28 D & E are dark greenish gray sticky, plastic clay: samples 55-13 and 56-3 are yellow sandy clay.

Referring to Table 6, page 24, as noted for group 1, the dry linear shrinkages have a direct correlation with the shrinkage water. It is also observed that the shrinkage of the 40 to 50 foot portion of sample 54-28 is slightly higher than that of the 30 to 40 foot portion. For sample 54-27 of group 1, the 30 to 40 foot portion had a higher dry shrinkage than the 40 to 50 foot portion. The dry linear shrinkages of trial pieces made from samples 55-13 and 56-3 are considerably less than for trial pieces made from samples 54-27 (C, D, E, F, G & H) and 54-28 (D & E). The shrinkage of sample 53-38 is about the same as trial pieces made from samples 54-28 (D & E).

Table 6

Water of Plasticity, Shrinkage Water, Pore Water, Dry and Fired Linear Shrinkage, Apparent Porosity, and Absorption Values.

Group 2

	53-38	54-28 (D)	54-28 (E)	55-13	56-3
Water of Plasticity (%)	42.9	40.1	49.3	31.3	33.4
Shrinkage Water (%)	23.1	23.6	27.5	14.1	16.2
Pore Water (%)	19.8	16.4	21.8	17.2	17.2
Dry Linear Shrinkage (%)	11.0	11.4	12.4	7.4	8.1
Fired Linear Shrinkage (%)					
Cone 09		cracked	4.2	1.9	
08	1.0	2.0			
06	2.0	4.9	3.9		0.3
04		5.6	3.6		
02	5.3	0.5	*	0.7	2.9
1	8.1	*	*	6.4	8.4
3				7.3	
4	*				
Porosity (%)					
Cone 09			35.7	50.2	
08	29.6	35.5	34.6		
06	28.2	33.9	32.7		37.9
04		28.9	26.3		
02	6.0	16.9	*	43.5	34.0
1	0.0			25.5	18.4
3				16.2	
4	*				
Absorption (%)					
Cone 09			19.5	32.4	
08	17.9	20.0	19.0		
06	17.5	17.9	17.7		24.3
04		14.7	14.5		
02	3.0	10.0	*	27.9	20.0

1	0.0	13.6	9.6
3		7.5	
4	*		

* bloated

Trial pieces made from samples 54-28 D & E were quite tough, sticky, slightly plastic, not easily deformed and very slow drying. Sample 55-13 produced trial pieces which were very plastic and easily deformed, whereas sample 56-3 was quite tough and only slightly plastic. Trial pieces from sample 53-38 were very tough, slightly plastic and not easily deformed.

The trial pieces of sample 53-38 fired between cone 09 and 04 are halfway between moderate orange pink and light brown in color and have no fine cracks. At cone 02 there is a marked increase in linear shrinkage and a distinct darkening of the color. At cone 2 there is a slight bloating and at cone 4 the trial pieces were badly bloated.

The trial pieces of samples 54-28 D & E fired between cone 09 and 04 are moderate reddish brown in color, and splitting is prevalent because of drying cracks. As shown by Table 6, page 24 there is no correlation between linear fired shrinkage, porosity, and absorption for samples 54-28 D & E. At cone 02 there is severe bloating for both 54-28 D & E. There is no correlation between fired linear shrinkage porosity, and absorption values for trial pieces from samples 54-27 D & E, and as shown in Table 6, page 24, the same applies to trial pieces from samples 54-28 D & E.

Between cones 09 and 02 the fired color of the trial pieces from samples 55-13 is halfway between moderate orange pink and light brown, but the absorption and porosity values are very high. There is only slight variation in fired linear shrinkage values. At cone 1 there is a marked increase in fired shrinkage and distinctive change in color to a very pleasing mottled pale brown with dark specks. There is also a marked increase in the absorption and porosity values. At cone 3 the color has deepened and porosity and absorption dropped considerably.

Trial pieces from sample 56-3 were fired to cone 1 and have practically the same color as the trial pieces of sample 55-13 fired to the same temperature.

CONCLUSIONS

1. Based on the results of this investigation, good common brick, building or drain tile can be readily made from the silt and clay units of the Lake Agassiz deposits. With careful control of firing, good face brick can be made from some of the clays of the Red River Valley.

2. With reference to page 4 of this report, the following characteristics of all the samples tested are ideal for common brick:

> Fairly uniform moderate reddish orange to light brown color when fired between cones 09 and 04, with little variation in fired linear shrinkage, porosity, and absorption.

3. Trial pieces made from samples which contain only raw portions of the greenish-gray clay have fine cracks which cause splitting of trial pieces during firing and promote bloating. The addition of preheated clay eliminates the fine cracks, permits drying ease, and reduces any sticky condition. It also reduces the dry linear shrinkage considerably but does not appreciably alter the fired shrinkage.

4. The very high absorption values of the trial pieces fired between cones 09 and 04, as well as the soft surfaces would make them undesirable as face brick, since they would not be durable under all conditions of atmosphere and exposure.

5. Although the differential thermal analyses curves indicate the presence of carbonate in the silt unit, the fired colors of the trial pieces indicate no bleaching. Because of iron staining in the silt unit, it is possible that there is a higher percent of iron oxide in the "silt unit" samples than in the "clay unit" samples. To produce the reddish-brown color in the clay unit trial pieces there must be at least 4% iron

oxide present.

6. Samples 55-13 and 56-3, taken immediately below the top soil, will produce a very pleasing face brick when fired between cones 1 and 3. The absorption is quite low and there is no warping or cracking. However, the short firing range of two cones would require close firing control.

7. It seems to be a common property of the clays tested within a cone temperature interval of 3 cones starting at about cone 2, that there is a pronounced increase in shrinkage followed by expansion or bloating. Several of the trial pieces fired within this range have desirable face brick properties, but the range is so short that it would not be feasible to make face brick from these samples.

8. Severe bloating seems prevalent in the clays from the clay unit, whereas, the samples of the silt unit have very little bloating. Since the clay unit has considerable organic material and the silt unit practically none, it appears that the bloating is caused by organic material.

9. As indicated by the author (7) in a previous report on lightweight aggregate, the bloating characteristics of the Red River Valley clays are desirable for the production of suitable lightweight aggregate.

10. The appearance of the raw clays and fired differential thermal analysis samples, as well as the results of the differential thermal curves, indicates that from Fargo to Neche within the valley, there are only slight differences in the properties of the clays at corresponding depths.

SUGGESTIONS FOR FURTHER RESEARCH

1. Since common brick are rapidly being replaced by the use of concrete block, it is suggested that further work be done with samples similar to 55-13 and 56-3, which appeared very suitable as face brick clays. This would include the manufacture of several hand or machine made brick, and subsequent determination of dry and fired shrinkages, fired color and absorption, and dry and fired strength.

2. Although bloating is undesirable for brick manufacturing, the possibility of combining the manufacture of brick and lightweight aggregate from the different clays in the same clay deposit should not be overlooked.

3. To fully account for variations in physical properties, further work should include:

    1. Chemical analyses
    2. Particle size determination.

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Appendix I

LOCATION AND DESCRIPTION OF SAMPLES TESTED

Sample No. 53-38

Emerado area.

NE 1/4 Section 14, T. 152 N., R. 52 W., Grand Forks County.

A plastic, medium gray clay mixed with limonite and having 2 feet of overburden. Taken from the bank of Kelly's Slough, south of the N. P. Railroad and about 20 yards west of a road running south from school No. 22.

Sample No. 54-27 (A-E)

Grand Forks area.

SE 1/4 Section 5, T. 151 N., R. 50 W., Grand Forks County.

A State Water Conservation Commission drilling rig was used to obtain samples of the Lake Agassiz deposits at the campus of the University of North Dakota. An 8" hole was drilled to a depth of 50 feet, about 100 yards east of the east wall of the stadium. The description and depth of the samples taken is as follows:

10-15 feet (A) - yellow, sandy clay with iron stains.

15-20 feet (B) - yellow, sandy clay with iron stains.

20-30 feet (C) - yellow, sandy, medium greenish gray, plastic clay.

30-40 feet (D) - medium greenish gray, sticky plastic clay.

40-50 feet (E) - medium greenish gray, sticky plastic clay.

Sample No. 54-28 (A-E)

Neche area.

NW 1/4 Section 31, T. 164 N., R. 53 W., Pembina County

The USGS drilling crew took the following samples from a test hole:

0-10 feet (A) - yellow, sandy clay.

10-20 feet (B) - yellow, sandy clay.

20-30 feet (C) - yellow, sandy clay.

30-40 feet (D) - medium greenish gray, sticky plastic clay.

40-50 feet (E) - medium greenish gray, sticky plastic clay.

Sample No. 54-29 and 54-30

Emerado area.

SW 1/4 Section 13, T. 152 N., R. 52 W., Grand Forks County.

Lake Agassiz deposit on south bank of Kelly's Slough. 1/4 mile south of the N.P. Railroad crossing, and 100 feet east of the center line of the road. A gully has been cut off by runoff and provided an excellent spot for sampling. There is one foot of overburden below which is one foot of laminated clay consisting of yellow sandy clay, medium gray clay and iron oxide staining. Below the laminated clay is sticky, medium gray clay which extends to an unknown depth. Sample 54-29 is the laminated clay and 54-30 is the medium gray clay below.

Sample No. 54-50 (P3 and P7)

Grand Forks area.

NW 1/4 Section 11, T. 151 N., R. 50 W., Grand Forks County.

Medium greenish gray clay of the Lake Agassiz deposits, taken from cores supplied by the U. S. Army Corps of Engineers during the test drilling at the site of the Grand Forks Flood Control Levee in 1954. Sample No. 54-50 was obtained from a hole drilled on the west bank of the Red River. The portion P3 is from Elev. 780.6 to 778.1, and the P7 portion is from Elev. 768.1 to 770.6.

Sample No. 54-51

Grand Forks area.

SW 1/4 Section 11, T. 151 N., R. 50 W., Grand Forks County.

Medium greenish gray, plastic clay of the Lake Agassiz deposits, obtained at Elev. 780 by the U. S. Army Corps of Engineers in 1954 at the site of the Grand Forks Flood Control Levee.

Sample No. 54-58

Fargo area.

NW 1/4 SE 1/4 Section 6, T. 139 N., R. 48 W., Cass County.

Lake Agassiz deposits sampled from 0 to 105 feet, at which depth hard pan was reached. The samples are portions of 2" cores taken by the Raymond Concrete Pile Co., and obtained by permission of the City Engineer of Fargo. The descriptions of the samples taken are as follows:

0-20 feet - yellow, sandy clay.

20-30 feet - yellow, sandy, medium greenish gray, plastic clay mixed.

30-105 feet - medium greenish gray, sticky plastic clay.

(gray sand at 40 feet, medium greenish gray clay at 45 feet)

Sample No. 54-59

Grafton area.

SE 1/4 NE 1/4 Section 19, T. 157 N., R. 52 W., Walsh County.

Lake Agassiz deposit including the silt and clay unit. Samples were obtained from a USGS test hole.

0-10 feet - yellow, sandy clay.

10-30 feet - yellow, sandy medium greenish gray, plastic clay.

30-90 feet - medium greenish gray, sticky plastic clay.

Sample No. 55-13

Grand Forks area.

SE 1/4 Section 4, T. 151 N., R. 50 W., Grand Forks County.

A yellow clay from the site of the addition to the St. James Academy in Grand Forks. The sample is representative of a seven foot layer with 2 feet of overburden.

Sample 56-3

Grand Forks area.

SW 1/4 Section 3, T. 151 N., R. 50 W., Grand Forks County.

A yellow, sandy, clay from the site of the new Grand Forks Armory. A representative sample was taken of a seven foot layer which has 4 feet of overburden.

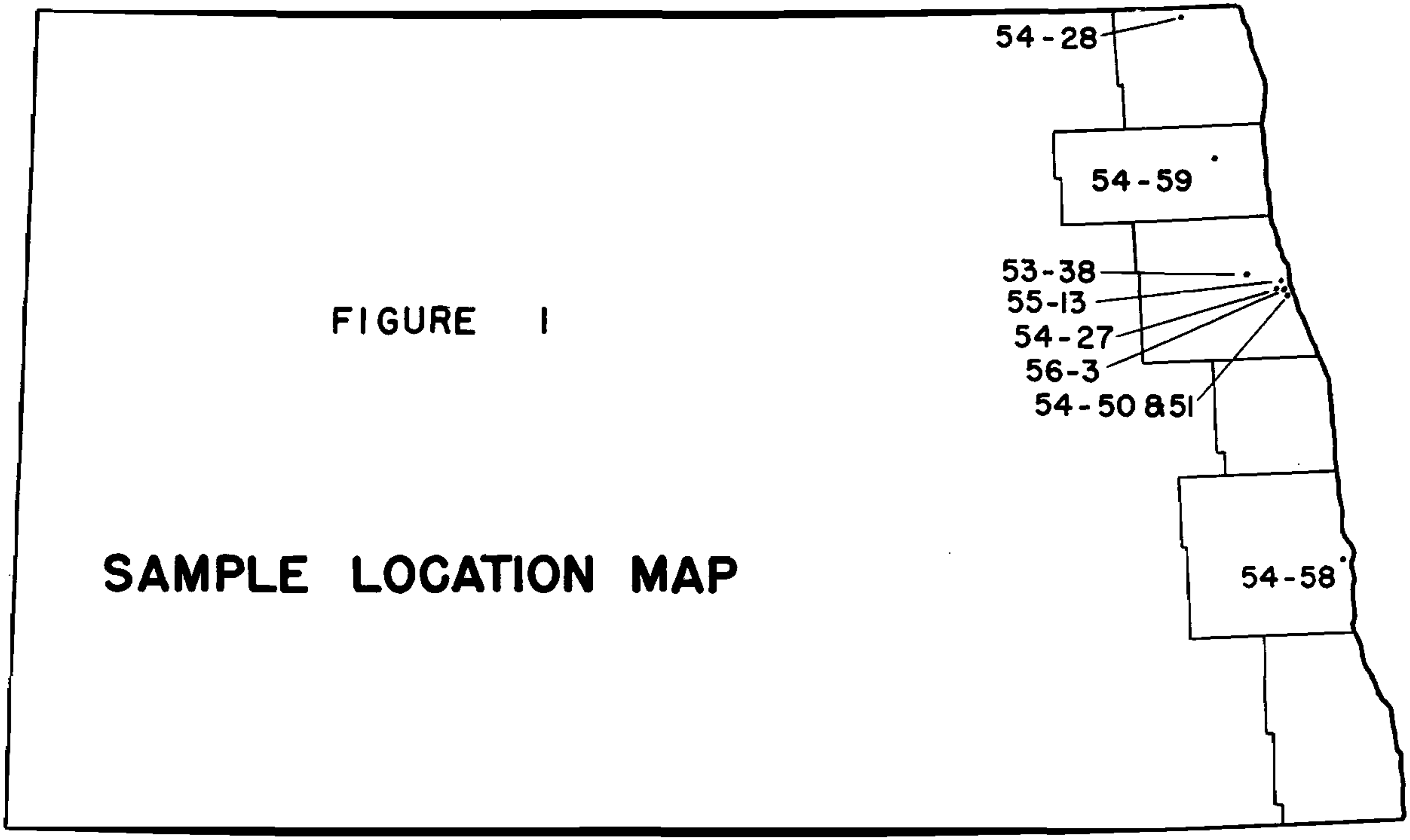
FIGURE 1
SAMPLE LOCATION MAP
54-28
54-59
53-38
55-13
54-27
56-3
54-50 & 51
54-58

FIGURE 2 - DIFFERENTIAL THERMAL CURVES

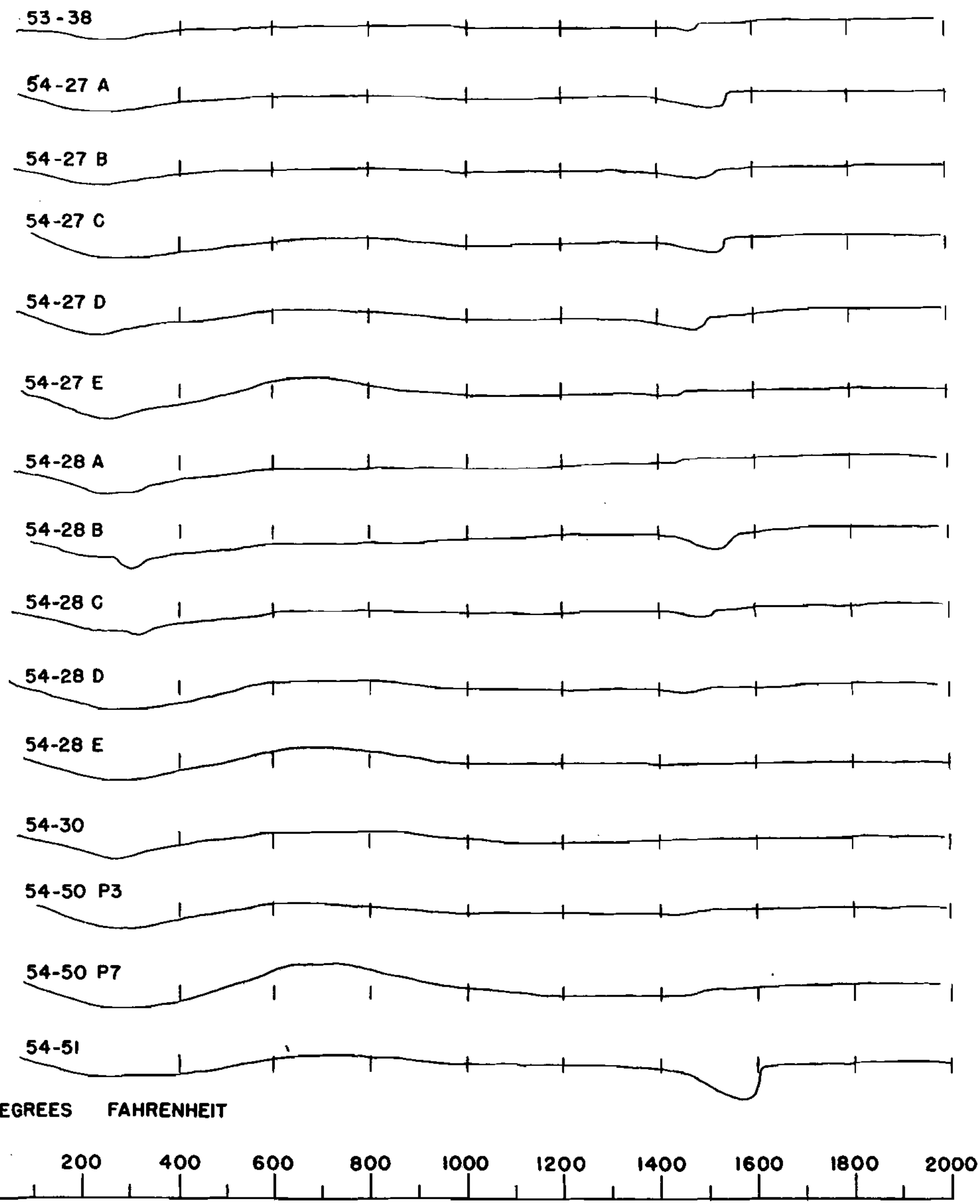

FIGURE 3 - DIFFERENTIAL THERMAL CURVES