The Art and Science of the Glacial Lake Clays of the Sugar Creek Valley, Bradford County, Pennsylvania

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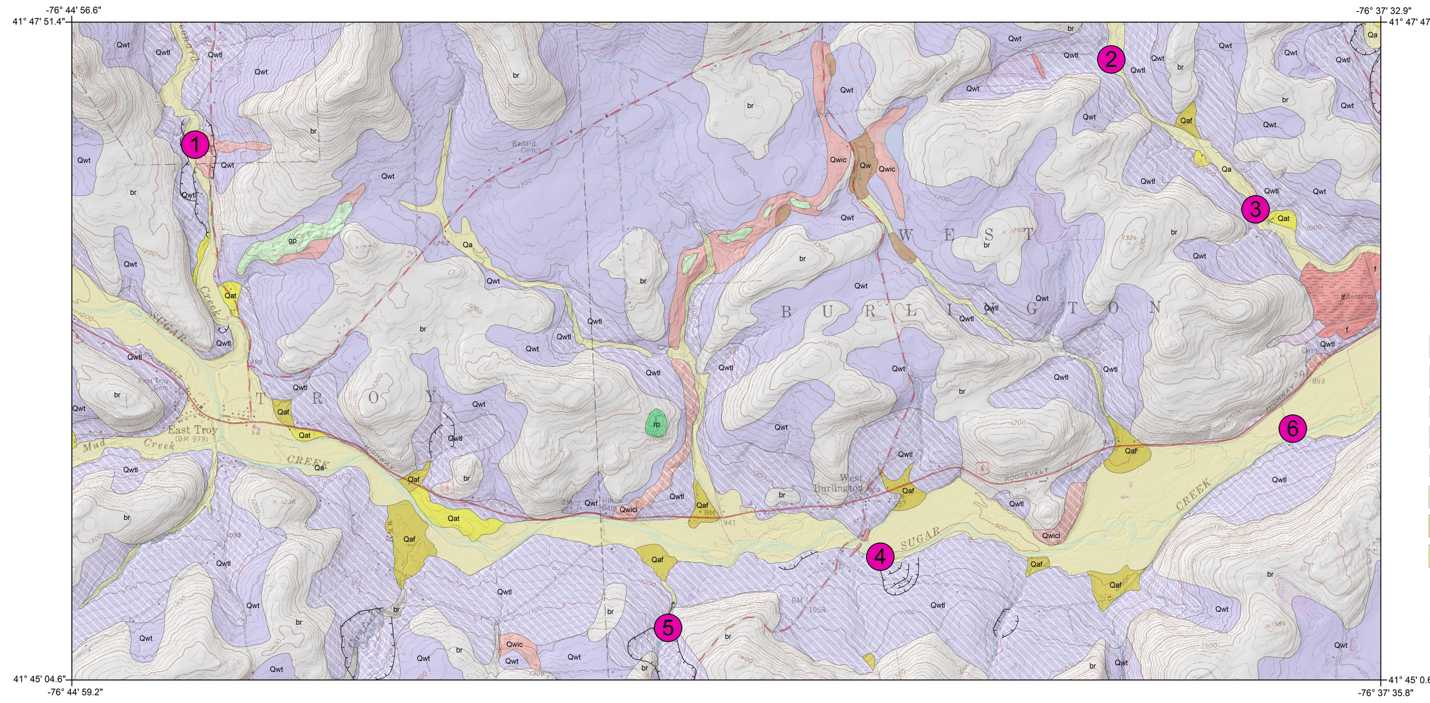
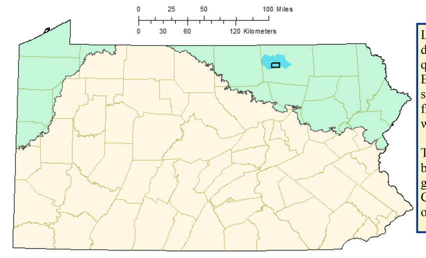
Abstract

During the retreat of the Wisconsinan glaciation, the mouth of Sugar Creek in Bradford County, Pennsylvania was dammed by the receding ice sheet; thus flooding Sugar Creek and its tributaries, and creating a glacial lake. Glacial flour settled to the lake bottom and accumulated varved clay deposits locally exceeding 70 feet thick. Six samples of clay were taken from the upper reaches of the Sugar Creek lake deposit within the East Troy 7.5-minute quadrangle and were characterized for its potential as a ceramic art medium. X-ray diffraction of the clay shows an average mineral composition of 49% mica, 29%, quartz, 14% chlorite, 6% plagioclase, 1.5% dolomite, and 0.5% calcite. Firing test shows a limited range from bisque to maturity of 1900° F to 2100° F. Vitrification occurs at ~2100° F. The clay has a moderate to high plasticity, a water of plasticity of 21.97% to 25.25%, linear dry shrinkage of 6% to 8.5%, moderate to high green strength, and moderate to poor bonding strength. All samples classify as clay to silty clay on the USDA textural triangle. Test samples prove the clay can be used for small pots, terra cotta sculptures, and ornamental tiles. Glazing requires a low-fired ceramic glaze, such as used in slip casting, due to the clay's tendency to bloat or melt at ~2200° F. Because the glacial lake clay will slump when undercut, as well as cause significant alterations to the local hydrogeology, this clay is not a commercially viable resource with exception to the casual hobbyist and the low-volume producing potter.





Left: Geologic map displaying the surficial deposits of the southern third of the East Troy quadrangle, modified by Aaron Bierly from Braun (2013). Sample numbers are placed inside the clay sample site. All samples came from clay exposures except for sample 6 which was from core.

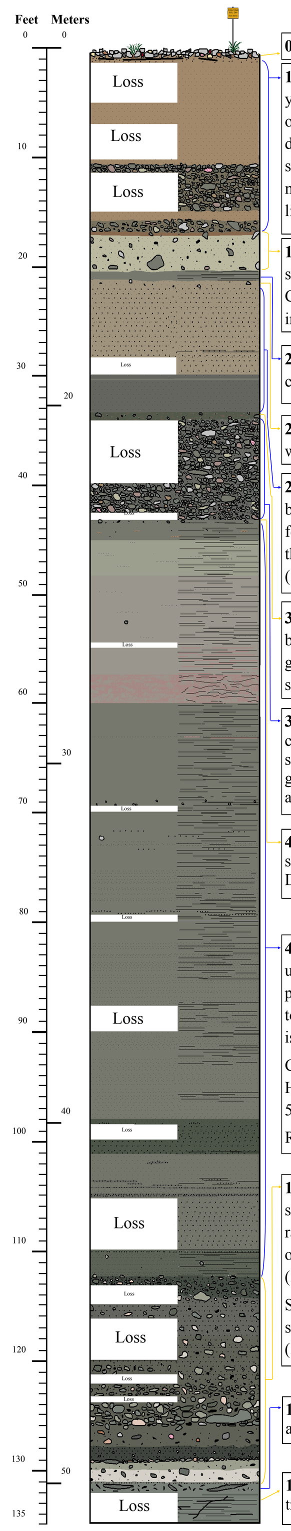
The reference map immediately left of text box displays the extent of the Wisconsinan glaciation in Pennsylvania (green), Sugar Creek watershed (blue), and the southern third of the East Troy quadrangle (black rectangle).

Legend

- br — bedrock
- f — fill
- gp — gravel pit
- lf — land fill
- rp — rock pit
- Qa — Alluvium
- Qaf — Alluvial fan
- Qat — Alluvial terrace
- Qw — wetland
- Qwic — Wisconsinan ice-contact stratified drift
- Qwicl — Wisconsinan ice-contact stratified drift underlain by glacial lake clays
- Qwl — Wisconsinan glacial lake deposit
- Qwt — Wisconsinan till
- Qwtl — Wisconsinan till underlain with glacial lake clay
- Slump
- Clay Sample Site

Scale: 0 0.25 0.5 1 Miles; 0 0.275 0.55 1.1 Kilometers

Depth (Feet, Meters) — **Geologic Column** — **Generalized Description**



0.0' to 1.0' - Gravel, sand, and asphalt (Road fill)

1.0' to 16.9' - Silt and Silty Gravel (Flood, stream channel, & reworked till): Silt zones are moderate yellowish brown (10YR 5/4), coarse silt to very fine grained sand. Rare granules and small pebbles were observed. Laminations observed in core could be a sedimentary feature or a result of settling during the drilling. Gravel and gravel diamict zones are poorly sorted, with clasts ranging in size from granule to small cobble. Matrix ranges from silt to very fine sand with scattered coarser sand grains. Color is between moderate yellowish brown to dark yellowish brown (~ 10YR 4.5/3). Clast lithologies include quartzite, limestone, and sandstone.

16.9' to 20.15' - Diamict (Till?): Overall matrix fines downward from sandy silt to clayey silt. Entire section is non-calcareous. Color is dominantly between yellowish gray and dusky yellow (~ 5Y 6.5/3). Clast size ranges from granules to cobbles larger than core diameter (three inches). Clasts lithologies include sandstone and quartzite.

20.15' to 21.35' - Clay (Varve or varve rip-up): Light olive gray (5Y 5/2), very slightly to slightly calcareous silty clay to clay, dominantly laminated, with rare scattered very coarse sand grains or granules.

21.35' to 21.8' - Diamict (Till): Pale yellowish brown (10YR 5/2), slightly calcareous clayey silt matrix with abundant scattered fine sand grains. Clasts are granules in size.

21.8' to 33.05' - Silt & sand: Grain size ranges dominantly between silt and fine sand. Sorting ranges between moderate and well sorted and locally poorly sorted. Grains are angular to subrounded. Top 3.2 feet is calcareous, and a sulfur-like odor is released with the reacting 10% hydrochloric acid locally throughout the section. Color ranges from olive gray (5Y 4/1), pale brown (5YR 5/2), to brownish gray (5YR 4/1). Sand laminations and rare granules/pebbles observed.

33.05' to 34.0' - Diamict (Till): Matrix is silt to very fine sand with scattered coarser sand grains. Very bottom is of section is calcareous. Entire section is mottled dark reddish brown (10R 3/4) and light olive gray (5Y 3/2). Clast size ranges from granules to moderate-sized pebbles. Clast lithologies include sandstone and crinoid-bearing sandstone.

34.0' to 43.1': Silty-sandy gravel: Matrix of the gravel is dominantly silt to fine sand with scattered coarser sand grains. The bottom 0.3 feet has a higher silt content. Sands are typically subangular to subrounded and poorly sorted. Clast size ranges from granules to moderate-sized pebbles. Clast lithology is gray sandstone. A slight odor of sulfur was detected prior to acid application and was enhanced during the application. The entire section is calcareous and is brownish gray (5YR 4/1).

43.1' - 43.5': Diamict (Transition zone): Matrix is calcareous, light olive gray (5Y 5/2) silt with scattered sand grains. Clast size ranges from granules to large pebbles. Clast lithology is sandstone. Deformed laminations observed at 43.2 feet.

43.5' to 112.7': Clay and silt (Glacial lake sediment): Laminated clay and silt, with clay dominant in the upper portions of the section. Very fine to fine grained sand laminations and sand zones present in lower portion of section. Sand is generally moderately well to well sorted and angular to subrounded. Clay tends to be non-calcareous, while silt and sand are commonly slightly calcareous to calcareous. Clay consistency is very soft to soft, becoming increasingly stiffer with higher silt content.
Color ranges between light olive gray (5Y 6/1), olive gray (5Y 4/1) and brownish gray (5YR 4/1). However, interbedded pale red (5R 6/2) and light olive gray (5Y 6/1) clays were observed from 55.0 to 57.60. From 57.60 to 60.15, jumbled layers and mottling of previously stated colors occur.
Rare isolated clasts ranging from very coarse sand to moderate sized pebbles were observed.

112.7' to 131.35': Gravel, sand, and diamict: Gravel and diamict zones range from diamict to poorly sorted gravel with fines (clast bound). Matrix material ranges from silty clay to very coarse sand. Clast size ranges from granule to cobble. Clast lithology is dominantly sandstone. One igneous crystalline (granitoid or granodiorite) clast was observed. Color is olive gray (5Y 4/1), medium light gray (N6), brownish gray (5YR 4/1), or grayish red (5R 4/2).
Sand horizons are very fine to very coarse sand with granules and small pebbles, moderate to poorly sorted, and angular to rounded. Sand is calcareous. Color is light olive gray (5Y 5/2) to olive black (5Y 4/1) or light brownish gray (5YR 6/1).

131.35' to 132.1': Diamict (Basal till): Matrix is calcareous, medium gray (N5) clay/silty clay. Clasts are highly disorganized and appear to be native local bedrock.

132.1' to 135': Loss (Bedrock): Material pulverized during drilling. Electro-resistivity survey and basal till member suggests bedrock contact

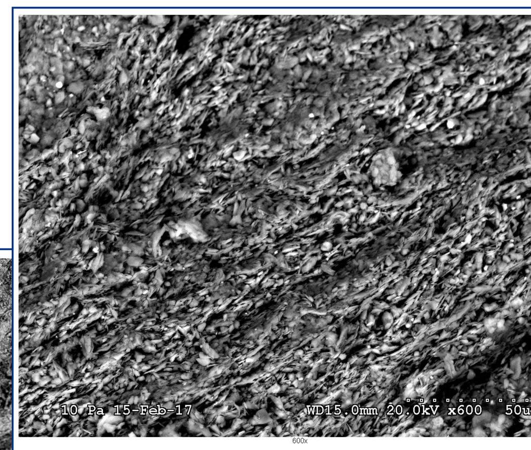
Geology of the Sugar Creek Valley in the East Troy Quadrangle

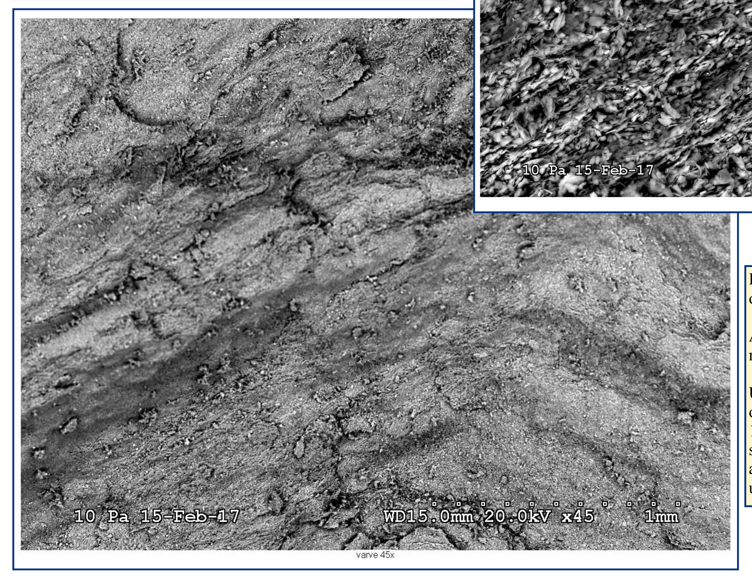
A locally common stratigraphic sequence can be observed in the valley bottom of Sugar Creek. Low-angle (1° to 5°), north-northwest dipping bedrock of the Lock Haven Formation are overlain by till, sand, and gravel. These sand and gravel horizons create a confined aquifer which has produced artesian wells in the area. Overlying this aquifer are the glacial varves which can range from a few feet up to 70 feet thick and are the source of the sampled clays. The glacier must have briefly re-advanced up the valley, for an upper sand and gravel horizon is present followed by a thin varve deposit. The glacier finally retreats out of the valley near Towanda, draining the lake, and allowing the modern-day Sugar Creek drainage to form.

	Sample 1		Sample 2		Sample 3		Sample 4		Sample 5		Sample 6	
Scan	1	2	1	2	1	2	1	2	1	2	1	2
Quartz	25	25	18	18	39	42	22	21	33	33	33	36
Mica	57	50	62	53	41	37	51	64	40	48	45	45
Chlorite	9	19	11	16	13	15	17	11	15	16	13	13
Plagioclase	4	2	9	13	6	5	7	0	10	6	7	6
Calcite	1	1	0	0	0	0	1	0	1	0	0	0
Dolomite	4	2	0	0	1	1	1	3	1	2	1	0
Total Scan %	100	99	100	100	100	100	99	99	100	100	99	100

Table above displays semi-quantitative mineral percentages of the six samples of glacial lake clay. Each sample was scanned twice. Based on these analyses, a consistent pattern can be seen with mica being the dominant mineral followed in decreasing quantity: quartz, chlorite, plagioclase, dolomite, and calcite. XRD analysis conducted by John Barnes of the Pennsylvania Geological Survey.

Left: Photo of a sampled glacial lake clay deposit in the East Troy Quadrangle. Note one foot-long ruler for scale.





Left: Scanning electron microscope image of sample 6.

Above: SEM image is a further magnification of the photo to the left.

Using the SEM we can see that grain size of the sample ranges from approximately 1 to 10 microns, which on the Wentworth scale is clay up to fine silt. Note the alignment of the detrital mica flakes in the upper image.

Clay Preparation

1. Clay is dried.
2. Clay is crushed to pieces less than one inch in diameter.
3. Clay is hydrated in a five-gallon bucket with equal weight ratio of dry clay to water with no deflocculent.
4. Clay is mixed into a thick slurry.
5. Clay slurry is sieved to removed coarse aggregate at approximately a 16 mesh.
6. Slurry is poured over a plaster-of-paris block and let dry to the consistency of firm bread dough.

Images (Above): Roger Pollok systematically preparing clay sample 2. Photos by Jill Pollok.

Raw Properties

Six properties of the clay were assessed before firing but after clay preparation. These properties were analyzed for their importance in wheel-thrown pottery and sculpting. Properties analyzed included plasticity, dry shrinkage, water of plasticity, bonding properties (for attaching handles), and green (dry) strength (fragility of dry ware). Samples of each clay were given to production potters Ian Stainton of Potters Mills, Pennsylvania and Jason Bloom of Julian, Pennsylvania for their assessment on the clay's workability. Sculptor, Roger Pollok, assessed the clay's properties for sculpting and modeling.

Images (Above): The four images above show artist Jason Bloom (top two photos) and Ian Stainton (bottom two photos) testing the clay's plasticity by "throwing" a pot of each clay sample. Photos by Roger Pollok.

Plasticity

A qualitative study was done for plasticity. Each artist was given a subsample of each glacial clay and evaluated its use as a medium. Clay samples 2 and 4 had a moderate to high plasticity and threw well on a potter's wheel. Samples 1, 3, and 5 displayed a moderate plasticity and, generally, the clay held shape with pots bearing vertical walls. The clay pot's walls would become unstable if the walls became too thin or if the pot's walls diverged too far from vertical. Ribbon tests were conducted and all clays could be rolled to 1/8, of an inch and several could be rolled to 1/16 of an inch. Higher silt concentrations in some samples were likely the source of plasticity degradation.

Water of Plasticity

Water of plasticity was calculated by mixing each sample to a plastic, sculptable, throwable consistency and rolling and cutting them into test tiles. Weight measurements were taken for each plastic tile and then again when the tile dried. The water of plasticity percentage can then be calculated from the weight difference. Qualitatively, the artists found that the optimal plasticity of the glacial clay has a narrow moisture range.

	Wet Weight (Grams)	Dry Weight (Grams)	Weight Difference (Grams)	Water of Plasticity (Percentage)
Sample 1	30.5	23.3	7.2	23.61%
Sample 2	29.7	22.2	7.5	25.25%
Sample 3	29.1	22.6	6.5	22.34%
Sample 4	31.6	24.2	7.4	23.42%
Sample 5	30.5	23.8	6.7	21.97%
Sample 6	30.5	23.5	7.0	22.95%

Table (Above): Table displaying the water of plasticity data of the clay samples.

Green (Dry) Strength

Green strength is the strength of the clay particles to hold together as the clay goes from a plastic state to a dried state. No quantitative analysis was performed but a qualitative assessment on the test sculptures was performed by physically trying to snap test tiles and by picking up dried pots by the handles and rims. All samples but sample 4 showed high resistance to breaking (compressive strength and tensile strength). Most sculptures lacked cracking as the bust dried, also suggesting a high green strength. Sample 4 has a moderate green strength but, it did not cause any dried pots or sculptures made from it to break.

Bonding Strength

Bonding strength refers to the ability to successfully attach independent clay accessories to the main clay body (ex. attaching a handle to a cup). This is particularly important in sculpting where numerous applications of additional clay are required to add anatomical features and props (ex. ears and clothing) to the sculpture. Qualitatively, the glacial clay has a moderate to poor bonding strength which is acceptable for simple robust additions like handles but becomes problematic with multiple clay applications such as needed in sculpting. Both physical and chemical factors affect bonding strength. The coarser-grained silts are likely responsible for the degradation of the bonding strength.

Image (Above): Roger Pollok adding a clay eyelid to a sculpture using clay sample number 6. The multiple additions of clay to the main bust makes the clay's ability to bond to other pieces of clay important. Though clearly usable, the clay's higher silt content made attaching additional pieces difficult and makes the clay less than ideal for this type of work. Photo by Joanne Kempher.

Dry-Shrinkage

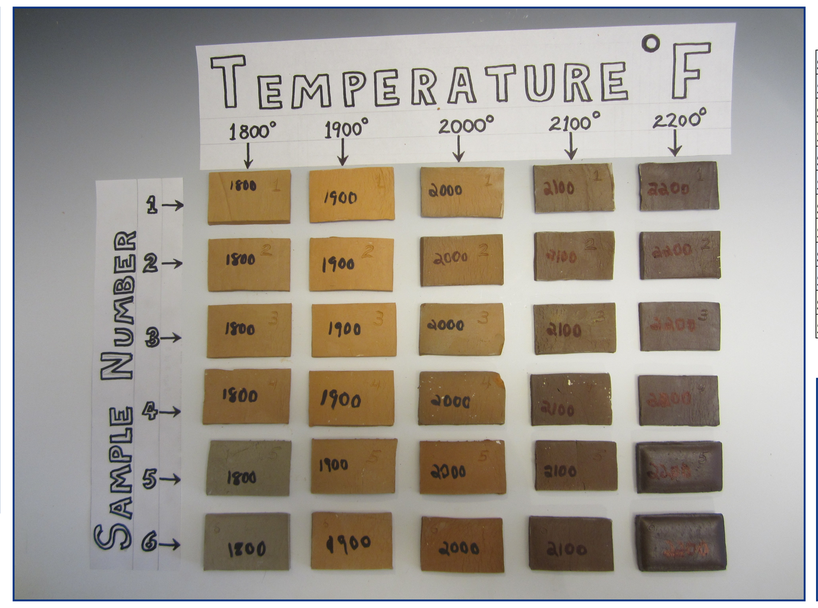
Dry-shrinkage test required cutting out a rectangular, 1.5 inch by 2.5 inch plastic by 0.25 inch (wet) clay tile and measuring the test tile's dimensions after drying. Results are in table to the right.

	Percent Linear Dry Shrinkage
Sample 1	6.8%
Sample 2	7.0%
Sample 3	6.2%
Sample 4	6.0%
Sample 5	7.3%
Sample 6	8.5%

Table (Left): Displays the percentage the clay had shrunk from being in the plastic (wet) state to the dry state.

Firing Test

Five dried test tiles of each clay sample (total of 30 tiles) were loaded into a gas-fired kiln and heated to 1800° F. After soaking at that temperature for 15 minutes, a tile from each clay was pulled from the furnace and allowed to cool. The kiln was raised an additional 100° F and allowed to soak, another sample was pulled and allowed to cool. This was done in 100° F increments from 1800° F to 2200° F.



	Dry Length (Inches)	Length at 1800°F	Length at 1900°F	Length at 2000°F	Length at 2100°F	Length at 2200°F
Sample 1	2.329	2.332	2.363	2.263	2.163	2.123
Shrinkage Percentage	-	-0.1%	-1.5%	2.8%	7.1%	8.8%
Sample 2	2.325	2.335	2.323	2.193	2.134	2.087
Shrinkage Percentage	-	-0.4%	0.1%	5.7%	8.2%	10.2%
Sample 3	2.345	2.356	2.319	2.276	2.162	2.11
Shrinkage Percentage	-	-0.5%	1.1%	2.9%	7.8%	10.0%
Sample 4	2.35	2.396	2.323	2.295	2.101	2.102
Shrinkage Percentage	-	-2.0%	1.1%	2.3%	10.6%	10.6%
Sample 5	2.3175	2.295	2.282	2.267	2.116	2.210
Shrinkage Percentage	-	1.0%	1.5%	2.2%	8.7%	4.6% *
Sample 6	2.2875	2.309	2.145	2.145	2.149	2.243
Shrinkage Percentage	-	-0.9%	6.2%	6.2%	6.1% *	1.9% *

Table (Above): Displays the linear firing shrinkage of the six glacial samples in relation to the kiln temperature. Percentages in red indicate clay expansion. All percentages are based on the original dry length. Percentages with red asterisk have begun to bloat.

Figure (Left): Chart displaying the clay tiles produced during the firing tests. Note all samples are a nice "terra cotta" color at a bisque firing temperature of 1900° F. Also note that samples 5 and 6 begin to bloat at 2200° constraining the maturity firing temperature to 2100° F. Photo by Roger Pollok.

Image (Above): Bisque-fired busts sculpted by Roger Pollok using the glacial clays. From left to right, steel worker (clay sample 1), coal miner (clay samples 2 and 4), Lenni Lenape (clay sample 6), and farmer (clay sample 5). Clay sample 3 contained too much silt resulting in a low plasticity, and the sculpture collapsed before firing.

Image (Right): Pottery created by Jason Bloom and Ian Stainton using the six glacial clay samples. Numbers under the bisque-fired pieces represent the clay sample used. Note the grayish orange color which is the result of iron-bearing minerals in the clay.

Photos by Roger Pollok.

Images (Above): Selected samples of the finalized glazed pottery from Jason Bloom (left photo) and Ian Stainton (right photo). These pieces were fired at 2100° F. Photos by Roger Pollok.

Image (Left): Artist and geologist, Roger Pollok pours a glaze into the bisque-fired pieces of pottery. Photo by Joanne Kempher.

References

Braun, D. 2013, Pennsylvania Geologic Data Exploration (PAGEODE) Interactive Map, Retrieved February 2, 2017, http://www.gis.dcnr.state.pa.us/geology/

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