1912

Fire clays of Phelps County

Arthur Harrison Cronk

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FIRE CLAYS OF PHELPS COUNTY

by

Arthur Harrison Cronk.

A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

DEGREE OF

BACHELOR OF SCIENCE IN MINE ENGINEERING
(Mining Geology Option Course)

Rolla, Mo.

1912.

Approved by

Professor of Geology and Mineralogy.
FIRE CLAYS OF PHELPS COUNTY.

CLAY AND CLAY PROPERTIES.......................... 1
Definition ........................................ 1
Classification ..................................... 2
Chemical Properties ............................... 3
Physical Properties ............................... 4

FIRE CLAYS OF PHELPS COUNTY .................... 6
Chemical Properties ............................... 6
Physical Properties ............................... 8

OCCURRENCE....................................... 10

DEPOSITS OCCURRING NEAR ST. JAMES ............ 13
The Delicella Property ......................... 13
Pit No.1 ........................................ 13
Pit No.2 ........................................ 14
Pit No.3 ........................................ 14
Pit No.4 ........................................ 15
Dawson Bank ...................................... 16
Matlock Pit ....................................... 16
Gronebalt Pit .................................... 16

DEPOSITS OCCURRING NEAR DILLON .............. 17
Goettleman Property ............................ 17
Pit No.1 ........................................ 17
Pit No.2 ........................................ 17

DEPOSITS OCCURRING NEAR ROLLA ................ 19
Romine Pit ...................................... 19
Hill Pit ......................................... 19
Kelly Pit ............................................. 20
Cemetery Pit ........................................ 20
Cowan Prospect ....................................... 21
DEPOSITS OCCURRING NEAR KNOBVIEW ............ 22
Weathers Bank ........................................ 22

ORIGIN:

WHEELER'S THEORY .................................... 23
PROPOSED HYPOTHESIS OF ORIGIN .............. 25
Definition.

A clay may be defined as a fine grained mixture of the mineral kaolinite with fragments of other minerals, such as silicates, oxides, hydrates, and often organic compounds; the mass possessing plasticity when wet, and becoming rock hard when burned at least to a temperature of redness.

Kaolinite is the basis of all true clays and is a hydrated silicate of alumina, having the chemical formula of $\text{Al}_2\text{O}_3, 2\text{SiO}_2, 2\text{H}_2\text{O}$, giving the following percentage of the oxides:

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicia ($\text{SiO}_2$)</td>
<td>46.3</td>
</tr>
<tr>
<td>Alumina ($\text{Al}_2\text{O}_3$)</td>
<td>39.8</td>
</tr>
<tr>
<td>Water ($\text{H}_2\text{O}$)</td>
<td>13.9</td>
</tr>
</tbody>
</table>

The purity of the clay depends upon the percentage of kaolinite present. A clay which has a small percentage of kaolin is known as a "lean clay" and one with a high percentage as a "fat clay."

Kaolin occurs both in plastic and non-plastic forms. The massive or amorphous variety is called "pholerite" and generally has the following composition:
Silica 32.3 %
Alumina 45.0 %
Water 15.7 %
100.0 %

However, there is no definite chemical composition of pholerite and different results have been obtained, varying somewhat in the percentage of silica and alumina.

Classification

The best classification is given by W. Ries, being based upon the method of accumulation and physical properties.

I. Residual clays (by decomposition of rocks in water.)

(1) Kaolin or china clays (white burning.)

   (a) Veins derived from pegmatites.
   (b) Blanket deposits derived from extensive areas of igneous and metamorphic rocks.
   (c) Pockets in limestone (as indéanite.)

(2) Red burning residuals (from different kind of rocks.)

II. Colluvial clays, representing deposits formed by wash from the foregoing.

III. Transported clays.

(1) Deposited in water.

   (a) Marine clays or shales.
   (b) White burning clays, Ball clays, Fire clays or shales, buff burning, Impure clays or shales, calcareous and noncalcareous.
III. (cont.)
(c) Lacustrine clays (deposited in lakes and swamps.)

Fire clays or shales,
Impure clays or shales, red burning,
Calcareous clays, surface character.
(d) Flood plain clays, usually sandy.
(e) Estuarine clays, impure and finely laminated.

2. Glacial clays found in the drift and often may be red or cream burning.
3. Wind-formed deposits, loess.
4. Chemical deposits (some flint clays.)

**Chemical Properties.**

There are two methods of analyzing clays, known as the (1) ultimate and (2) the rational.

The ultimate analysis is generally employed, the various elements contained in the clay being considered combined as oxides. These might be expressed as follows:

```
Fluxes

{ High temperature fluxes
  { (SiO₂
  (Al₂O₃

{ Low Temperature fluxes
  { (Fe₂O₃
  (CaO
  (MgO
  (K₂O
  (Na₂O

Loss on ignition
  (Water
  (CO₂
```

-3-
From the ultimate analysis can be determined the purity of the clay, refractility, color to which the clay burns, quantity of water, excess of silica, quantity of organic matter (if determined) and the calcareous nature.

The rational analysis has the purpose of determining the mineralogical composition, such as quartz, feldspar, kaolinite. These percentages can be determined by using the ultimate analysis. The potash and soda are figured to feldspar, the alumina required is deducted from the total alumina and the difference used as the starting point to figure the kaolinite substance. The remaining SiO₂ giving the quartz.

The factors used for feldspars are

\[
\begin{align*}
\text{Al}_2\text{O}_3 \text{ for } \% \text{K}_2\text{O} & = \% \text{K}_2\text{O} \times 1.0888 \\
\text{SiO}_2 & = \% \times 3.3284 \\
\text{Al}_2\text{O}_3 & = \% \text{Na}_2\text{O} \times 1.6525 \\
\text{SiO}_2 & = \% \times 5.8221
\end{align*}
\]

For Kaoline

\[
\begin{align*}
\text{SiO}_2 \text{ for } \% \text{Al}_2\text{O}_3 & = \% \text{Al}_2\text{O}_3 \times 1.1772 \\
\text{H}_2\text{O} & = \% \times 0.3544
\end{align*}
\]

Physical Properties.

These can be classed as plasticity, texture, tensile strength, shrinkage, porosity, specific gravity,
fusibility, color, slaking, and absorption.

The most important of these is the plasticity, as this property determines whether or not the clay can be molded into the desired shape.

Texture is also important as it influences the plasticity, shrinkage, porosity, fusibility, etc.

Tensile strength of a clay is the resistance it offers to rupture or being pulled apart when air dried. Upon this property depends the method of handling, molding and drying, and the ability to carry a large quantity of non-plastic material.

Shrinkage is always considered a foremost factor in the clay products industry. This property regulates the speed of air drying and the manner of burning, etc. Shrinkage varies with the percentage of SiO₂.

Porosity influences the amount of water the clay will absorb, rate of drying, and resistance to weathering after being burned.

The fusibility of a clay determines whether or not it can be used as a fire clay. According to Récs, a clay must be able to withstand a temperature above 2400° F. to be classed as a fire clay.

The fusibility is conditioned by (±) amount of fluxes, size of grain, the homogeneity of the mass, condition of the fire, and form of the chemical com-
Color of an unburned clay depends upon its iron, manganese, and carbonaceous matter. The burned product will vary in color due to the iron content.

**FIRE CLAYS OF PHELPS COUNTY.**

The fire clays of Phelps County are known as flint or non-plastic fire clays, states that it should have plasticity, these clays lack that very important property. The name "flint" is applied because of the sharp, conchoidal fracture similar to that of flint. The dense compact nature also suggests the name. The color varies from a light buff to a kaolin white. The hardness is from 2.5 to 3.5, with a density of from 2.5 to 2.33.

The lack of plasticity, conchoidal fracture, hardness, and high specific gravity shows the marked differences from other fire clays.

**Chemical Properties.**

The flint fire clays approach kaolin in purity, and are very low in quartz and fluxes. An average of three chemical analyses of samples from different localities gave the following results:
Alumina (Al$_2$O$_3$) 40.00
Water (H$_2$O) 13.40
Iron Oxide (Fe$_2$O$_3$) .48
CaO .27
MgO Trace

A comparison of the analyses of this fire clay, kaolinite, and pholerite show that they are similar chemically.

<table>
<thead>
<tr>
<th></th>
<th>Flint Clay</th>
<th>Kaolinite</th>
<th>Pholerite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica (SiO$_2$)</td>
<td>45.06</td>
<td>48.3</td>
<td>37.3</td>
</tr>
<tr>
<td>Alumina (Al$_2$O$_3$)</td>
<td>40.00</td>
<td>39.8</td>
<td>45.0</td>
</tr>
<tr>
<td>Water (H$_2$O)</td>
<td>13.4</td>
<td>13.9</td>
<td>15.7</td>
</tr>
</tbody>
</table>

This evidently places the flint fire clay between the kaolin and pholerite. Very probably it is a mixture of the two clays.

The low temperature fluxes are generally under 1%. Iron is always present in small amounts although existing in the oxidized condition and not as pyrite. The lime is comparatively low in reference to the limestone region in which the clays occur. The small amount of lime would probably counteract the coloring due to the iron and would give a light colored burned product.

The unusually high per cent of combined water
is a very serious drawback to the clay. Unless calcined before burning, this would result in an excessive fire shrinkage.

The alumina is also very high for a clay, while the silica content is low.

**Physical Properties.**

The flint fire clays have several physical properties which differ from the ordinary fire clay. They have a sharp conchoidal fracture, a very dense structure, and a hardness of 2.5 to 3.5. The density averages about 2.38, which is high for a fire clay and especially for a fire clay occurring as a surface deposit. The non-plasticity is a factor of importance in that it is necessary to mix with the flint clay a bond or fat clay. Even after passing a sample through a 200 mesh screen and then mixed with water, the mixture would not mould without cracking. The tensile strength is low, varying from ten to twenty pounds per square inch. This property of a clay depends partly upon the plasticity, as a plastic clay has a tensile strength of 100 to 200 pounds per square inch.

The air shrinkage is low, being about 3%, while the fire shrinkage is high, varying from 8% to 13%, with an average of 10%. This large fire shrinkage would make it necessary to calcine the clay before burning.
The flint fire clays probably lead all other fire clays in their refractorine character. A sample from the St. James deposit was used to make the fire test. This was "ucked down" and passed through a 200 mesh screen. It was necessary to mix the clay with dextrine and water to hold the particles together to enable molding into the desired shape, that of a Seger cone. After air drying for two days, the fire test was made in an ordinary Deville furnace. This furnace consists essentially of an iron cylinder lined with some very refractory material. It stands about two feet high and is one foot in diameter. At the bottom is fitted a pipe to connect with the blast. Coke is used for the fuel and a very high temperature can be obtained.

The clay to be tested is molded into the form of a Seger cone and is placed in a "cheese", which is a cylindrical shaped crucible fitted with a cover. Seger cones are placed beside the clay cone and the cheese is then lowered into the furnace.

As it was not known where the flint clay would fuse, Seger cones, numbers ten and seventeen were used. After carefully raising the temperature to avoid splintering of the cones, it was soon found that the clay cone could stand a higher temperature, as only the Seger cones were fused. Then Seger cones \#20 and \#23 were used.
These cones also fused and cones \( \#17 \) and \( \#20 \) were placed in the cheese. Cone \( \#27 \) was completely fused but cone \( \#20 \), which fuses at 2,140°F or 1,170°C, was but slightly affected. Cone \( \#30 \) was left in and cone \( \#33 \) was next placed in the cheese. By raising the temperature cone \( \#30 \) was fused and cone \( \#33 \) had started. This last temperature was above 3,250°F or 1,790°C, and the flint fire clay was not affected. This fire test positively shows that the flint clay can be subjected to temperature used in any kind of an industrial furnace.

**OCCURRENCE.**

The flint fire clays occur in isolated pockets without respect to topography, being found on the hill tops, slopes, and in the valleys, and generally in the Jefferson City formation. This is also true of flint clays occurring in other parts of Missouri. They occupy the characteristic sink holes and other depressions which are common in limestone regions. These sink holes are probably formed by the dissolving out of material by underground waters, and allowing the overhanging strata to fall in. In appearance they resemble an inverted cone, varying from thirty feet to one hundred and fifty feet in diameter and from ten to one hundred feet deep.

The central part of the sink hole is filled with the flint clay, while the sides are defined by a
a rim of sandstone. In several cases the sandstone dips at steep angles showing the sink-like formation due to slump. While the sink holes occur in the limestone, the clays are closely associated with Carboniferous sandstone, shale, and coal in several places.

A cross section of one of these pits would have the following appearance:

![Cross section diagram]

The clay is very much jointed and fractured and varies in color, due to the amount of iron present. The central portion is free from sand, while towards the sides the clay contains well rounded grains of quartz. Bordering the sloping rock is found a sandstone, the cementing material being the clay.

The flint fire clay of Phelps County have been most extensively worked at St. James and to a lesser
extent at Rolla, Dixon, and Knobview. Only the deposits near the railroad can be profitably worked. Very likely other pockets can be located, but the distance from shipping points have not warranted their prospecting.

At the present time none of the pits are being worked although the present price of $2.50 f. o. b. railroad cars will probably encourage future work.

The method of mining is comparatively simple. The overburden of soil which is generally about three feet, which having been removed, the jointing of the clay allows it to be easily broken by bars and picks. It is then loaded into wagons and hauled to the nearest shipping point. The wages paid average about $1.50 per day. The haul from the pit to the shipping point will average about fifty cents a ton for a distance of two miles. The cost of mining, hauling, loading on cars, etc., will average about ninety cents or $1.00 per ton.

Most of the fire clay has been shipped to St. Louis and sold to commissioner merchants, who in turn sell it to the clay products companies. Some clay has also been sent to Chicago. The clay is used for high grade refractory work, and could be used for white ware if it possessed the required plasticity. It is generally mixed as a gang with some plastic clay.
CLAY DEPOSITS OCCURING NEAR ST. JAMES.

During the years 1862 to 1889, St. James was an active shipping point. The clays brought $2.75 a ton at St. James, but competition from other banks nearer the market soon forced the price down. Since then little work has been done at this point.

At the present time the most important banks are owned by Stephen Delicella, and are located on Section 18, Township 38 N, Range 7 W., which is about one mile north of town.

Delicella Property.

Pit No. 1
This bank is situated on the SE. 1/4 of the NW. 1/4, Section 18, and is on the side of a gently sloping hill. The pit is 75 feet long, 40 feet wide, and about 40 feet deep. Water stands in it to a depth of about 25 feet. On the north side of the pit is a ten foot exposure of fire clay. The characteristic rim rock is exposed on the east side and dips toward the center of the pit. The clay is massive and jointed, and is a buff color. It is over lain by two feet of soil.

A chemical analysis of the clay gave the following results:
Silica ($\text{Al}_2\text{O}_3$) 43.54 %
Alumina ($\text{Al}_2\text{O}_3$) 39.86 %
Iron Oxide ($\text{Fe}_2\text{O}_3$) .52 %
Lime ($\text{CaO}$) .24 %
Water ($-105^\circ$) .56 %
Water ($+105^\circ$) 13.86 %
$\sum$ 95.58 %

Pit No. II
Southeast of Pit No. I., about one hundred
paces and in the bottom of a small valley. This pit is
located directly in the course of a small stream. It
is full of water and the nature of the pit could not be
determined further than that it is circular in shape
and about fifty feet across. The clay was not exposed
but the rim rock could be seen above the south side.
This pit has produced about 500 tons of clay.

Pit No. III
Located on the SE, 1/4 of the SW, 1/4 of the
same section. The pit is near the head of a small val-
ley, is circular in form, about 150 feet in diameter.
The pit is 20 feet deep to water surface. The clay is
covered by three feet of soil. The west and south sides
of the bank are composed of heavily stained brown to red
fireclay. Sandstone flanks the north face, dipping
into the pit at an angle of 40°, and also on the east
Bank at a steep angle. About 15,000 tons have been shipped from this bank. However, judging from the appearance of the sides of the pit, it is about worked out.

Pit No. IV.

Located 100 paces west of the above pit, at the crest of a gently sloping hill, is elliptical in shape, and about 125 feet long, 75 feet wide, and about 30 feet deep. The clay is white to a faint buff in color, very compact and breaking with a conchoidal fracture. Toward the sides it is somewhat iron stained and sandy. It is overlain by three feet of soil and residuum. On all sides occurs a white, coarse grained sandstone, which dips at an angle of 30° to 70° towards the center of the basin. The pit is about worked out.

Below is a sketch of the pit which represents the characteristic flint fire clay deposits.

Section
**Dawson Bank.**

About three-quarters of a mile west of St. James and 150 paces west of the "Frisco" Railroad, on Section 30, SW. 1/4. It is 50 feet in diameter and is about worked out, as the sandstone occurs on all sides, dipping towards the center of the pit.

**Matlock Pit.**

Two and one-half miles northwest of town, on Section 11, NE1/4. Pit is 40 feet wide and about 30 feet deep.

**Gronebalt Pit.**

Three and one-quarter miles north of St. James, in Section 7. It is 140 feet in diameter and has produced only a few car loads of clay.
CLAY DEPOSITS NEAR DILLON.

The only banks of importance occur on the Goettleman farm on Section 30.

Goettleman Property.

Pit No. I.

Located about two and a half miles from Dillon, on the SE. 1/4 of the SE. 1/4 of Section 30, situated near the crest of a hill. It is 80 feet long and 50 feet wide and about 20 feet deep. The flint fire clay is exposed on the north side, showing good jointing. The clay shows no gradation into the soil above which is red in color, and about two feet thick. The joint cracks show an iron stain near the surface but this dies out with depth. The fire clay is compact, cream colored, and fairly free from sand. The characteristic sandstone is not found apparent, but this may be due to the worked portion being located near the center of the pit.

On the south and east sides of the pit, occur the red shales which are said to mark the Carboniferous formation. These shales are iron stained but contain white spots which resemble the fire clays in appearance.

Pit No. II.

Located on the NE. 1/4 of the SW. 1/4 of Section 30, near crest of a gently sloping hill. It is about
75 feet long, 50 feet wide, and 15 feet deep to the surface of the water. Flint fire clay is exposed on the north and east sides. In the latter case the clay is about ten feet thick, has the characteristic fracturing very well developed, and is cream colored. On the north side the clay has a somewhat purple color due to iron stain.

The south wall consists of a soft sandstone which is the side of a small dome-like hill composed of the same material. At the northern limit of the deposit occurs a well bedded sandstone showing alternate red and white layers. This sandstone is composed of a mixture of well rounded quartz particles and clay.

The fine clay dips toward the center of the pit and is somewhat gritty toward the north edge, where it comes in contact with the sandstone. About two feet of residuum covers the clay. Both of these pits warrant future development.
CLAY DEPOSITS OCCURRING NEAR ROLLA.

Homine Pit.

About one mile southeast of Rolla (NE.1/4 of Section 1, Township 37 N, Range 7 W.) and near the base of a gently sloping hill. This pit is about 75 feet long, 50 feet wide, and 10 feet deep. It is full of water and but little could be seen of the nature of the deposit. The clay appearing above the water is stained red, purple, and bluish by iron. On the east side is a small outcrop of which dips into the pit. This deposit has the appearance of being extensively worked at one time.

Hill Pit.

Located on the Hill farm about one and a half miles east of Rolla, (Township 37 N, Range 7 W., Section 6). This is only a small pit and only a few tons have been mined. The pit is full of water and is about ten feet deep. The clay is dense, flesh colored, and overlain with about two feet of soil. A sharp contact occurs between the soil and clay. The deposit is fairly free from iron stain and the clay is of good quality. On the south side is an exposure of dipping toward center of pit.
Kelly Pit.

Located one mile southwest of Rolla (Township 37 N, Range 8 W, Section 11, SW. 1/4). The pit is near the crest of a gently sloping hill and is about 12 feet deep, 100 feet long, and 40 feet wide. It is composed of an impure clay which is stained with iron. It is well bedded, the bedding showing alternate layers of white and red clay. The bedding planes are perpendicular, while slickensides and small faults found in hard specimens show that movement has taken place after deposition of the clay.

Although the pit is in the Jefferson City formation, sandstone outcrops on the north and east sides and dips into the pit at an angle of about 30°.

Cemetery Pit.

Pit located on NE.1/4, Section 14, about one mile south of Rolla. This pit is found on the south side of a gently sloping hill, circular in form, 30 feet in diameter, and about 10 feet deep. Sandstone occurs on all sides of the pit and no clay outcrop is visible. The sandstone dips toward the center of the pit which is full of water. On the east side of the pit, a small outcrop of slickensided clayey sandstone is to be seen.
Jewan Prospect.

This is located near the junction of the "Frisco" Railroad and the Missouri Arkansas & Gulf Railway. The clay is overlain with a white sandstone cemented by a clay. This prospect is reported to have been drilled to a depth of 100 feet. The nearness to a shipping point and the ease with which a short railroad spur could be connected to the deposit are factors which would enable this clay to be mined at a low cost.
North of Knobview on the NE 1/4 of Section 1, Township 38 N, Range 6 W, is a clay deposit. The pit opened on the side hill for a distance of 25 feet, shows from five to ten feet of clay. The clay is capped by three feet of white to gray course limestone, which dips about 10° to the north. The clay is non-plastic, not uniform in color or texture but varies from light gray to dark gray to drab in color, with occasional red stains of iron. A shaft thirty feet deep was sunk for coal some years ago to within a few feet of the clay. A seam of lignite three or four inches was struck under which was a black pyrite shale that continued to the bottom of the shaft. The shaft discloses an overlying sandstone that dips about 35° to the south or in the reverse direction to the sandstone over the clay. This probably shows that the pit was operated at about the center of the basin.

*Clay Deposits by Wheeler, Missouri Geological Survey, Vol. XI.*
From the field evidence two theories can be deduced regarding the probable origin.

The first one is given by Wheeler in his report on the Clays of Missouri.

"That the flint clays are primarily sedimentary deposits in sink-holes and have been subsequently altered chemically due to leaching. The clays having been derived from the chemical disintegration of the limestones in which they occur, the residual clay of which has gradually washed into sink-holes. The rate of accumulation would be very slow during which the clay would be constantly exposed to the prolonged action of surface waters which would have a strong solvent action on the lime, magnesia, iron, and alkalies. The course silicious matter that is found in most limestones would be washed into the sink-holes at much less rapid rate than the clay material, and form as a deposit of sand on reaching the edge of the sink-hole and thus accounting for the sandstone fringe that lines the sides of the pocket."

The arguments against this as seen in the field are (1) that the sandstone fringe is often well stratified; (2) if the sandstone fringe was due to the above, it would very likely show cross bedding, which is not the case;

*Clay Deposits by Wheeler, Missouri Geological Survey, Vol. XI.*

-23-
(3) the sandstone fringe would contain some angular particles of quartz but such has not been found; (4) the pits occurring at the tops of hills would not have a very large drainage into them; (5) in some flint clay deposits are found alternating layers of clay and sandstone; (6) the general nature of a clay derived from a limestone does not conform with the character of these clays; (7) the fact that the flint fire clays have a very high specific gravity (2.5) points toward deep burial and not surface conditions.
PROPOSED HYPOTHESIS OF ORIGIN.

The following hypothesis of origin is offered for the derivation of the flint fire clays.

These clays are the remains of marine shales laid down in the same manner in which our sandstones are formed.

At the close of the Mississippian Period, the land surface was exposed to a long period of erosion. The work of the underground waters produced the sink-holes and depressions which are characteristic of this country. Upon the encroachment of the Pennsylvanian Sea, the eroded surface was covered by marine sediments, filling the old erosion valleys and sink-holes. Upon elevation of the land, the forces of erosion cut away the more exposed surfaces, leaving behind the shales which occupied the sink-holes and other sheltered points. These shales are now represented by the flint fire clays which have been leached of their impurities by the action of surface waters.

The presence of stratification shows that the clay was laid down under fairly deep water conditions. These deposits are closely associated with the remains of the Carboniferous rocks which points towards their being laid down during the same age. In a railroad cut.
cast of Rolla on the "Frisco" Railroad are found white, red and blue colored shales, interbedded with sandstone. These shales have the characteristic physical appearance of the flint clays, and the sandstones are thought to be Pennsylvanian Age. Near Cooks Station, in Crawford County, a flint fire clay deposit occurs between two tilted layers of sandstone, and in the immediate vicinity is a thick deposit of lignite coal occupying a sink-hole.

From the field notes of the Missouri Geological Survey, the following statement can be made:

"Near Gerald, Franklin County, Missouri, SE.1/4 of the SW1/4 of Section 11, Township 42 and Range 4 W, in the banks of a small branch ravine is an outcrop of about ten feet of dark reddish colored shale, having a conchoidal fracture, very uniform in character, and overlain by a heavy bed of sandstone. Near the top of the shale and next to the sandstone the shale is streaked with white." This shale shows the characteristics of the flint clays and the white part is probably due to the leaching out of the iron.

The fractured nature of the flint clay is very likely due to further solution of the ground water dissolving out material below the clay and allowing
the overlying clay to settle, as evidenced by the slickensides of the clay and the small faults which are seen in the hard specimens.