THE GEOLOGY OF THE MORE REFRACTORY CLAYS AND SHALES OF IOWA

BY

S. L. GALPIN

CONTENTS

LIST OF ILLUSTRATIONS

REFRACTORY SHALES IN IOWA

All types of shale or clay softening under heat at or above 1370° C (Cone 12) and occurring in possible commercial quantities in Iowa come within the scope of this report.

Beyer and Williams[1] in their report on the Clays of Iowa have shown the distribution of clays and shales within the state. More recently, Beecher[2] has demonstrated that a few of these deposits contain clays of medium to fairly high refractoriness. The work upon which this report is based was undertaken to provide further information regarding the nature and occurrence of these more refractory deposits.

Previous reports had shown that the geologic range of the more refractory clays is limited to: (1) the Niagaran Series (Silurian); (2) the Des Moines Series of the Pennsylvanian (Upper Coal Measures); and (3) the Dakata and Benton of the Cretaceous. (See Plate I.)

White Clay in the Niagaran Series.

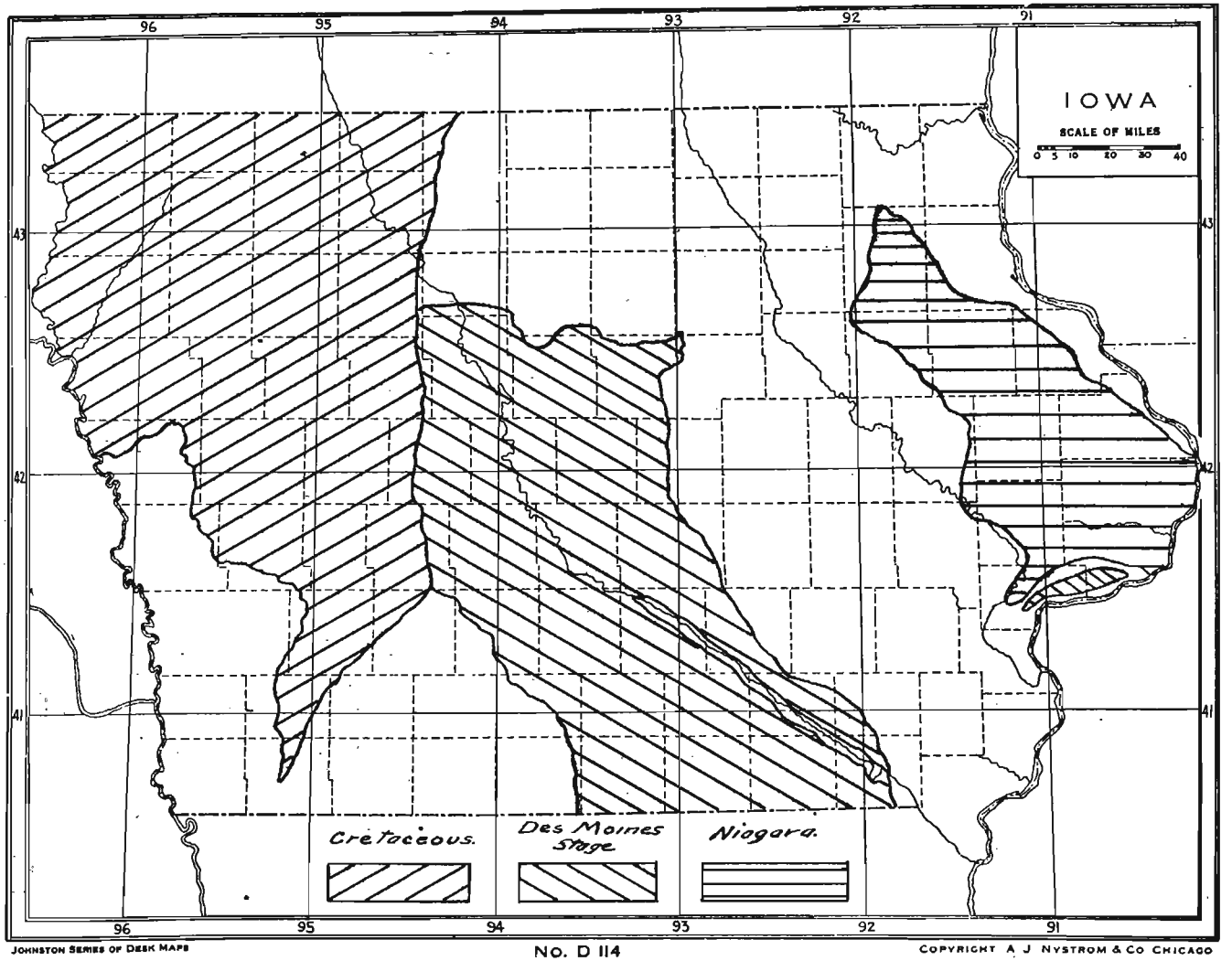
The Niagaran is essentially a limestone series, but includes some inconspicuous syngenetic clayey lentils which are more or less cemented by calcite, and a few epigenetic white clay deposits which occupy solution caverns. The lentils are less than a foot in thickness but of considerable horizontal extent. They occur seventy to perhaps one hundred forty feet above the base of the Niagaran, within what is known as the "Pentamerus" division of the series.

The clay of the cave or pocket deposits seems, because of its similarity and association, to have been derived from the lentils, through the action of ground water. Balls of white clay, of diameters up to two feet, were noted in the thin glacial drift near one of the pocket deposits. The clay from each type of

---

1 The Geology of Clays, Beyer, S. W., and Williams, I. A., Iowa Geological Survey, Annual Report, Volume XIV, 1903.

2 An investigation of Iowa Fire Clays, Beecher, Milton F., Engineering Experimental Station, Iowa State College, Bulletin 40, 1915.



JOHNSTON SERIES OF DESK MAPS

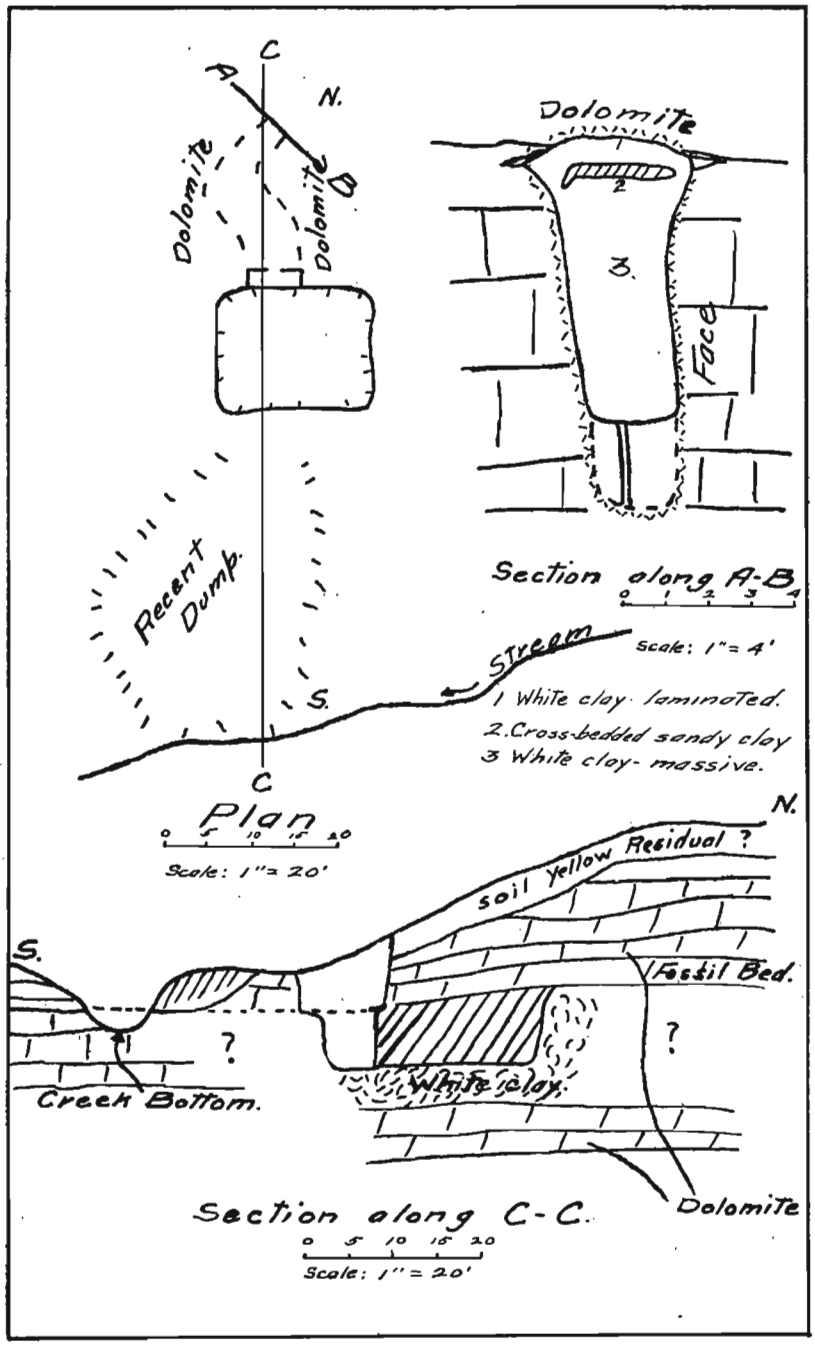
NO. D 114

Showing distribution of outcrops of formations containing somewhat refractory clays.

deposit resembles that from the others except that in the lentils there is, in many places, sufficient calcite to cement the clay and to cause ready effervescence when it is tested with acid. Where it is not cemented by calcite, it is a white or nearly white soft clay, resembling the sedimentary kaolin of the South Atlantic Coastal Plain. Only the cave or pocket deposits hold any promise as possible commercial sources of white clay.

On the Eggers farm, in section 10, Deep Creek township, five miles northeast from the town of Goose Lake, Clinton county, there is a natural exposure of white clay thirty feet up the east side of a small ravine. The clay crops between two crumbling buttresses of rusty limestone and is covered for the most part by wash from higher ground and by glacial fill. Testing with an augur indicated a maximum depth of six feet, a width north and south of twenty feet and a probable length east and west of at least fifty feet. Because of the thickening of the drift the extension into the hill could not be determined. Samples obtained by boring show that the deposit is not wholly uniform. The clay lying near the limestone walls and floor was of more bluish color and contained white lumps of calcareous and silicious material. Samples of the two varieties of clay were examined microscopically and after blending were tested for working and burning properties. The results of tests are given with those of the clay next described.

The second deposit examined is on the Peter Jess farm (W. ½ sec. 35, T. 84, R. 6 E.) four and one-half miles east from Miles and about the same distance southwest from Sabula, Jackson county. This deposit was prospected some years ago and reports state that about two car loads of clay were shipped out. The old workings were reopened in 1922 through the efforts of Mr. Simon Gage and others of Sabula. This deposit shows more clearly the mode of origin of these clay pockets than that on the Eggers farm . The accompanying sketches, (Pl. II) indicate the shape and relationships of the clay body. It is quite apparent that the deposit fills an old cavern which resulted from the solution of the limestone along two series of vertical joint planes, one striking northwest and the other northeast. In a distance of twenty-five feet the trend changes three times. The roof of



Plan and vertical sections of white clay deposit near Miles.

the cave is a highly fossiliferous layer of dolomite. Just below this there was originally a thin layer of clay of the lentil type. The continuation of this lentil may be followed some distance along the banks of the nearby stream. Below the lentil the wall-rock is again dolomitic. The clay filling of the cave is packed tightly to the roof and shows stratification, especially in the upper part, where some brown sand appears in a four inch cross-bedded layer. Except for the uppermost foot, the deposit lies below the level of the nearby stream. The vertical thickness of the clay is about eight feet, the width three to six feet and the length, so far as the deposit has been worked, about twenty-five feet. From the nature of the origin of the deposit, it is likely to continue back into the hill a considerable distance, but nothing may be said as to the probable amount of clay obtainable. As the roof and wall rock is disintegrated to a brown sand for the depth of about an inch much care must be exercised to keep the clay clean as this sand adheres very persistently to the damp clay. A sample of this clay collected by Mr. J. B. Fidlar in 1916 was used in making laboratory tests.

Results of tests: Mechanical Analysis.

		Residue in percentage of sample used.		
	Slaked in	On No. 48 sieve	On No. 100 sieve	On No. 200 sieve
White Clay Eggers Farm	About 3 minutes	per cent 0.66	per cent 0.64	per cent 0.34
Bluish white Clay, Eggers	4 minutes	4.04	2.74	1.46
White Clay Jess Farm	2 minutes	0.4	0.54	1.70

In a microscopic examination of the material separated by sieving substantially the same materials were identified in each sample. On the 48 mesh sieve granular particles of calcite and fragments of quartz predominate. On the 100 mesh sieve unusual quartz crystals were retained. These crystals are doubly terminated, but the ends instead of being sharp are more or less completely rounded as if by etching. No prism facets were seen, there being instead an arrangement producing a series of re-entrants like the folds of an accordion's bellows. No evidence of twinning was noted. On the 200 mesh sieve some plates of

kaolinite (?) were found in addition to the substances already noted. The best developed plates show a roughly hexagonal outline with angles of approximately 54°, 58° and 64°. A very little limonite and possibly pyrolusite also appear here.

It would seem from the sieve residues that washing of this clay through a 100 mesh sieve would eliminate most of its injurious impurities.

Tests of Working and Burning Qualities. Unwashed clay.

	Temper. Water	Per cent Drying Shrinkage	Per cent Fire Shrinkage	Per cent Absorption	Color
		Linear	*Linear*		
Clay from Eggers Farm	30 per cent wt. dry clay	5.7	Cone 4, 5 per cent	17.5	White
			Cone 6, 7 per cent	10.6	Light Gray
			Cone 8, 8 per cent	9.3	Light Gray
			Cone 10, 7 per cent	4.4	Light Gray
Clay from Jess Farm	33 per cent wt. dry clay	7.2	Cone 4, 7 per cent	11.5	White
			Cone 6, 10.5 per cent	5.2	Gray, white specked
			Cone 8, 13.5 per cent	0.7	Gray, white specked
			Cone 10, 9.8 per cent	1.0	Gray, white specked

Both samples slake readily, develop good plasticity and become steel hard at "cone 4".

Beecher[3] reports that a sample of white clay from northern Clinton county (presumably from the Eggers farm) fused at cone 30 and showed upon chemical analysis a composition like that of kaolin. Other tests upon the same material indicate that it fires with little warpage. So far as known these clays are the most refractory of any in Iowa.

Other deposits have been reported from Clinton and Jackson counties. A thickness of twelve feet of white clay is said to have been found in an excavation for a foundation at Miles. Report states that in sinking a well for the Chicago, Milwaukee and St. Paul Railway at Delmar white clay was encountered from a depth of 106 to 140 feet. Unfortunately, samples from these deposits were not to be had, so no estimate of the quality of the material may be given. No other deposits worth mention were found although a careful search was made over the region. This

[3] Beecher, Milton F., An Investigation of Iowa Fire Clays. Op. cit.

is not to be taken as proof that there is none, since but a small part of the surface affords rock exposures.

In properties these white clays resemble kaolin, but they are more plastic. Their bonding power is not so great as that of ball clay. The material has qualities which should make it of considerable value if deposits of sufficient quantity are uncovered. However, no strong hope of this is offered by the nature of those now known.

The Des Moines Series.

Rocks belonging to this series are found at the surface or directly below the drift in about twenty counties. The accompanying sketch map (Pl. I) shows the approximate boundaries of the areas so occupied. As the series has a gentle but general dip to the southwest, younger sedimentary rocks cover it to the west of the area indicated on the map, while on the east erosion has exposed formations of greater age. The thickness of the existing portion of the series increases from the eastern border to possibly four hundred feet on the west.

Shale and clay beds, with less extensive layers of sandstone, coal and limestone make up this lower division of the Pennsylvanian of Iowa. The assemblage of sediments bears evidence of deposition in shallow water. Preceding the Des Moines epoch, this region had been for a long time subjected to erosion. The general slope of the land at that time seems to have been toward the southwest. The principal streams naturally followed this slope, but the tributaries likely had northwest or southeast courses parallelling the strike of the then exposed rocks. The rocks now representing the Des Moines series were deposited as muds, sands and similar material as the pre-Pennsylvanian surface was slowly submerged. During the greater part of the epoch physiographic conditions existed which were similar to those along the Gulf coast of today. The position of the seashore was often shifting. These shiftings, together with actual warping of the land surface, resulted in a complete series of sediments, some representing subaerial; some, fresh water; and some, marine deposits. The land surface remaining above sea level was low. The climate was moist, temperate and lacking in

marked seasonal extremes. As a result there were doubtless many streams, most if not all of them sluggish. Marshes and broad tidal flats bordered the sea, while swampy conditions prevailed far inland along the stream courses. Vegetation was abundant.

Because of the slow flow of the streams, no mineral sediment coarser than sand was carried by them. Their load was largely clay and silt. Considerable amounts of soluble material such as bicarbonates of calcium, magnesium and iron also were transported. Sand was deposited in stream channels, estuaries, and along parts at least of the seashore. Silts and muds were dropped upon flood plains, in lagoons, estuaries, swamps and marshes, upon tidal flats, and in the sea wherever the absence of currents allowed. Some, probably much of the soluble material of the river waters was carried considerable distances offshore although a portion was absorbed and entrapped by the fine material of the muds. As a result of the various conditions of deposition we find today several different kinds of shale and clay beds in the Des Moines series. Of these, three rather distinct types providing somewhat refractory clay may be distinguished.

The most abundant variety is a nonlaminated clay often found below coal beds and termed "fire clay". While in some states clays of this type are highly refractory, yet in Iowa there are few known occurrences of underclays possessing this characteristic. These clays are usually readily recognized because of certain peculiarities. Unlike most clay deposits the underclays are not laminated. When it is damp and undisturbed a deposit of this kind has a massive appearance, but on drying out shrinkage reduces it to irregular, many-sided small chunks. The beds are from a few inches to occasionally ten feet thick, three or four feet being a fair average. They thicken and thin in an apparently irregular manner. Single beds are seldom continuously traceable over an area greater than a few square miles, and within such an area they may show many differences in thickness and constitution. They rest upon shale, sandstone, coal or limestone, and any of these rocks may cover them. Coal, however, is far the most common overlying stratum. The natural color of the "fire clays" is some shade of gray, blue, green, pink,

purple or in some instances it is nearly black. Close examination of a hand specimen usually reveals the presence of fossil leaf, stem or root fragments, the carbonaceous material being replaced more or less by pyrite or marcasite. Other harmful minerals usually evident to some extent are limonite, siderite, calcite and gypsum. Plasticity is usually high as is also the shrinkage and strength of both green and finished ware made from these clays. Most of the Iowa "fire clays" reach minimum porosity between cones 6 and 10 and soften at cones 12 to 24. A few thin seams provide material of greater refractoriness, and some have been found to fuse as readily as cone 4. Many of these clays are light burning, the purer representatives giving buff or gray colored ware. Except where the coarser grains of pyrite and siderite have been removed, black specks and blisters appear on burning.

The origin of underclays is not entirely clear. Their close association with coal led to the suggestion that they represent the soil which supported coal forming flora. More recently Stout[4] has proposed that the underclays represent the ash from the natural oxidation of vegetable matter, which but for that oxidation, would have formed coal. This seems reasonable if we include the admixture of varying but considerable amounts of clayey sediments with the residue from oxidized vegetation. Whatever their origin, these clay deposits show great similarity to coal beds in shape and extent and they are most commonly directly overlain by coal or by some rock containing much carbonaceous matter.

The second type of clay is smooth, plastic and laminated and usually gray or dove-colored although occasionally black or white. Thin layers of such clay are not infrequent, but beds over three feet in thickness are rare. In properties they are closely related to the underclays. In some cases, at least, the laminated shale may be made up of material from the same source as the "underclays" but transported and redeposited in water where growing vegetation could not serve to destroy the laminations usually formed during sedimentation.

The third type is a massive gritty shale, usually light gray in

4 Stout, Wilbur, Theory of the Origin of Clays; Trans. Am. Ceramic Soc., XVII, 1915.

color. The thickness of deposits of this kind may vary from fifteen feet to only a foot within a horizontal distance of a few hundred feet. Pyrite is usually present in replacements of vegetable fragments, except where it has been removed through weathering and bleaching. Calcite, siderite and gypsum are not present in noticeable amounts. Occasionally such shales may be found to pass either laterally or vertically into sandstone. Transition into other shales, except in one or two cases where sandstone changed gradually upward into underclay, was not noted. There is a suggestion that some of these sandy shales are the result of chemical or biochemical reactions of solutions of aluminum sulfate (derived from weathering pyritic shale) with silica of sandstone. Logan[5] has proposed such an origin for the kaolin deposits of Indiana. Nothing approaching the purity of the Indiana deposits has been found, however, in Iowa. Shales of this class are of medium to low plasticity and low shrinkage. They attain minimum porosity at cone 6 to cone 16. A few deposits yield material softening at about cone 30. Others soften at cones 18 to 24. Because of their low shrinkage and slight tendency to warp, the better of these shales should be admirably suited to the manufacture of architectural terra cotta. Only those free from pyrite could be utilized, however, unless washing were resorted to.

THE MUSCATINE DISTRICT.

An outlier of Pennsylvanian strata extends from a short distance west of Muscatine eastward within two miles of Davenport. Shales here lie unconformably upon beds of Devonian limestone. Light burning shales have been dug at times near Fairport for use in local potteries. At present, clay is brought from the Illinois side of the river. Satisfactory exposures, either natural or artificial, are scarce. Small lentils of nearly white clay may be observed at Muscatine on the bluffs at the eastern edge of the city. Three feet of fissile white shale is exposed here at a level about fifty feet above Mississippi river. In sections 13 and 24, Montpelier township, there are exposures of a

5 Logan, W. N., Kaolin of Indiana: The Department of Conservation, State of Indiana, Publication 6, 1919.

light gray shale twenty to thirty feet above the base of the Pennsylvanian. While some of these beds have a thickness of as much as four feet locally, yet they seem to have no great lateral extent. Black shale usually is found above the white clay. The quality of some of these deposits seems good, there being little visible impurity, but unless the future brings to light more persistent beds there is little prospect for their extensive development.

THE SOUTHEASTERN DISTRICT.

This district comprises Lee, Van Buren, Des Moines, Henry, Jefferson, Wapello, Keokuk and Mahaska counties.

Shales of the Des Moines series in this region belong to the lower portion of the series. They rest upon the eroded surface of the St. Louis limestone (Mississippian). As there was considerable relief in this surface, the early Pennsylvanian deposits were laid down in the drowned valleys only and therefore at any horizon they form an irregular series. The thickening and thinning of individual deposits and the lack of continuous outcrops render useless any attempt toward correlation of beds in different parts of the region. Because of the general cover of glacial drift natural shale and clay exposures are confined to gullies and valleys of the smaller streams, and are by no means abundant in them. Road cuts, clay pits and coal mine shafts have brought to light other occurrences. The evidence gathered indicates an abundance of material here that will withstand temperatures above the softening point of cone 12. Several deposits have yielded clays fusing near cone 25. The "under clay" type is the most important in this region and may be found in beds from two to as much as ten feet in thickness.

A few outliers of Pennsylvanian rocks occur in Des Moines, Henry and Lee counties, and clays of good quality have been utilized from some of them, notably those at the Jester farm (Sec. 6, T. 69 N., R. 4 W.), about six miles southwest from Danville; at the Ed Noble farm (SE. ¼ sec. 36, T. 70 N., R. 5 W.), about one mile northwest from Jester's; and at the Otis Watson farm near Danville. Little has been done at these pits during the past few years and the exposures are not good.

On the Noble farm the clay lies about thirty-five feet above the St. Louis limestone. A sample of the material taken in 1918 by Prof. J. E. Smith gave the following results upon testing:

Sample No. 78. Noble farm, southeastern Henry county.

	After drying	Cone 2	Cone 6	Cone 10
Total linear shrinkage, per cent	6.25	9.38	10.9	10.9
Absorption, per cent		9.5	5.2	2.4
Color		Gray	Gray	Gray
Hardness	Steel hard at Cone .02			

The exposure on the B. B. Jester farm is better, showing:

	Feet
Soil and sandy drift	0 — 3
Sandstone	12
Black shale	0 — ⅔
Coal	1
Black shale	1 — 1½
White clay	4 — 9

A sample (No. 4) of the white clay was taken by Mr. J. B. Fidlar in 1915, and was tested with the following results:

Sample No. 4, B. B. Jester farm, southwestern Des Moines county.

	After drying	Cone 2	Cone 6	Cone 8	Cone 10
Total shrinkage, per cent	5.5	6.0	7.5	8.0	9.0
Absorption		16.4	13.8	12.0	11.0
Color		light gray	gray	buff	light brown
Hardness		softer than steel	softer than steel	softer than steel	about steel hard

Tempering water, 20.1 per cent. Plasticity good.

Iron specks become noticeable at cone 2 and are bad at cone 10. Despite these the clay appears to be at least a second grade fireclay. This clay was formerly used in pottery manufacture in Burlington. A considerable quantity is available for open pit working, and geologic conditions seem favorable for mining, as a twelve to twenty foot sandstone layer could be used for roof. The six mile haul to railroad is a serious drawback, otherwise this deposit would doubtless be actively developed.

Washing this clay through a 200 mesh sieve removes only 0.3 per cent of the original clay. Microscopic examination of the separate shows mainly quartz, a little pyrite, granular calcite and a micalike mineral of low index of refraction (hydromica?).

White clay has been worked on the Otis Watson farm near Danville. At present the exposures are poor. The clay, which is about four feet thick, seems to be below a thick layer of soft sandstone. A sample collected by Mr. Fidlar has the following properties:

Sample No. 5. Otis Watson farm, Danville, Iowa.

	After drying	Cone 2	Cone 6	Cone 8	Cone 10
Total shrinkage, per cent.	7.6	15.5	18	17.5	17.
Absorption, per cent		7.59	0.58	0.58	0.46
Color		light gray	dark gray	dark gray	dark gray
Hardness		harder than steel			

Tempering water, 31.5 per cent.

Only a few iron specks appear on the burned test pieces. This clay was formerly blended with Jester clays in the manufacture of pottery at Burlington. When washed through a 200 mesh screen 2.8 per cent of the original sample was held on the screen. This residue consisted of cherty material, root fragments, granular calcite, a little pyrite and a few scales of limonite.

Near Denova in Henry county light gray to nearly white clays outcrop at scattered points in sections 25, 26, 27, 34 and 35, township 71 north, range 7 west. It cannot be said that these outcrops belong to a single bed, but as they occur at about the same level and usually within twenty feet above the St. Louis limestone they evidently are of a single horizon. The beds are from two to four feet in thickness and are associated with darker shales. Turley Bros. of Burlington used several car loads of this clay for pottery, but no development has gone on since about 1912.

Tests of samples of this clay by Beecher[6] gave the following results:

Beecher's No. 26, sec. 26, Tippecanoe Twp., Henry county.

	After drying	Cone 3	Cone 5	Cone 8	Cone 10
Shrinkage, per cent	3.5	5	6	6.9	6.2
Absorption, per cent		8.4	5.4	3.5	3.7
Color		buff	buff	buff	buff
Final fusion, Cone 22					

6 Beecher, Milton F., An Investigation of Iowa Fireclays: Eng. Exp. Sta. Iowa State College, Bulletin 40, 1915.

Beecher's No. 36. Southwest of sec. 26, Tippecanoe Twp., Henry county.

	After drying	Cone 3	Cone 5	Cone 10
Shrinkage, per cent	7.5	11	12.5	
Absorption, per cent		7.4	4.6	
Color		buff	buff	dark buff
Final fusion, Cone 24+				

The variation in properties shown by these samples taken from two cuts in the same section is borne out by differences to be noted in the texture of the clay. At one place there will be no grit noticeable while at another, nearby, there may be a considerable amount of fine grit. Gypsum is present in a few places, but as it is in fair sized crystals, its removal by washing is not difficult. Pyrite seems to be absent although this may be due to weathering of clay at the surface.

It is worthy of note that these clays are all less than forty feet above the top of Mississippian limestones. In one instance, near Denova, the clay seems definitely to lie in valleys in the limestone surface, and it is possible that most of the occurrences are of this sort. If so the horizontal persistence of these beds is much less than is commonly thought.

Van Buren County.—While "underclays" are associated with the coal lenses of the county, they are as a rule so irregular both in character and thickness as to render their value for ceramic uses doubtful.

Of the deposits examined, all but one contained such quantities of pyrite that they were not sampled. The one exception was a thirty inch seam of dark gray gritless clay lying between two coal beds and twenty feet above the St. Louis limestone. This deposit is in the northwest quarter of section 36, township 68 north, range 8 west, and about one mile north from Farmington. Unlike the usual "fire clay" this bed is distinctly laminated. Microscopic examination of the material held upon a 200 mesh sieve disclosed the presence of numerous amber-colored particles having trigonal or oval outlines and in many cases point decorated surfaces. These were taken to be spores or spore cases. In addition minute grains and replacements of pyrite and many carbonized vegetable fragments were seen. Tests of a sample of the clay gave the following results:

Clay sample from near Farmington, Van Buren county.

	Drying	Cone 2	Cone 6	Cone 10
Total linear shrinkage, per cent	7.	13.5	13.6	14.1
Absorption, per cent		14.+	9.5	5.6
Color		Buff	Gray	Gray specked

Tempering water, 27.95 per cent weight dry clay.
Slaking, rather slow.
Oxidation, slow, but no evidences of swelling.

The clay has been used locally in the manufacture of common pottery. That so used was obtained at the same time the adjacent coals were mined.

Jefferson County.—Although the Des Moines shales are present over most of the county, the average thickness does not exceed fifty feet. Good natural outcrops are rare, and artificial exposures are but little more numerous. Two clay samples were taken in this county, the first from below an eight inch coal seam in what is known as Raney's clay pit, two and one half miles west from Fairfield. The sample was taken by Mr. J. B. Fidlar who reports twelve to fourteen feet of gray clay and shale below an eight inch coal seam. The results of tests on this sample follow:

Sample No. 6.

	Drying	Cone 2	Cone 6	Cone 10
Total linear shrinkage, per cent	6.1	11.1	12.1	12.6
Absorption, per cent		10.3	3.2	2.4
Color		light buff	gray	yellowish gray
Hardness		steel hard	harder than steel	harder than steel

Tempering water 24.4 per cent.

Beecher reports[7] tests on an eight foot stratum of gray gritty shale from near Fairfield. His sample (No. 34) burned a light buff at cone 11, shrank but 6 per cent at cone 10 and fused at cone 23. There are considerable quantities of this clay available without excessive stripping.

The second sample came from a natural exposure on the north bank of Cedar creek just east of the bridge on the Fairfield-Libertyville road. The nature of the clay and shale series is shown in the accompanying sketch. (See fig. 1.) The sample included

7 Op. cit., p. 71.

all the section excepting the drift, sandstone and coal layers. Tests of this composite sample representing a total thickness of about thirty feet of clays and shale resulted as follows:

Shale and clay from section 3, township 71 north, range 11 west.

	Drying	Cone 2	Cone 6	Cone 10
Total linear shrinkage, per cent	5.8	10.	10.4	11.
Absorption, per cent		13.5	8.5	6.3
Color		Buff	Gray	Gray, specked and blistered

Tempering water 18.7 per cent.

Cedar creek section.

	Feet
Soil and drift	0–80
Dark shale, gray clay	3
Coal	1/12
Gray fire clay	2
Sandy clay	2½– 3
Drab fire clay	1
Coal (pyritic)	¼
Drab fire clay Dark gritty shale	10
Sandstone	½– 1½
Black shale	2½
Coal	⅜
Fire clay, some gypsum	3
Fire clay, some grit	4
Gray clay shale	2
Coaly shale	1
Unexposed to creek level	3
To top of St. Louis limestone	5–10

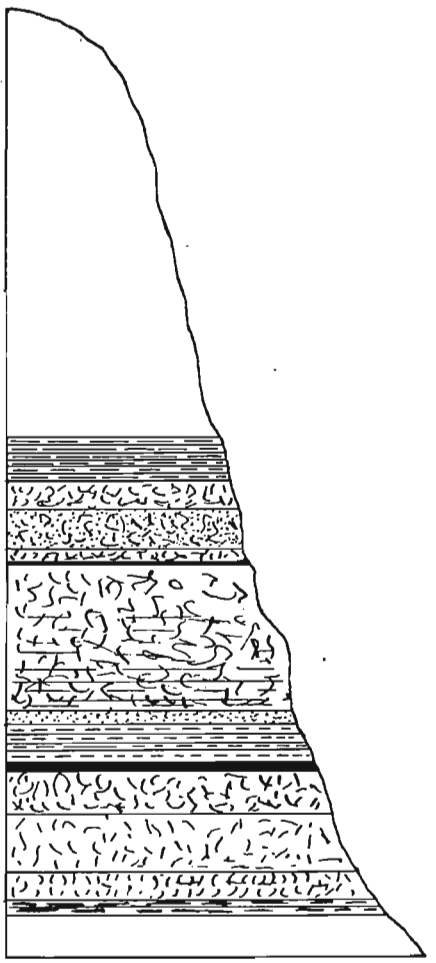


FIG. 1—Cedar Creek exposure near Fairfield-Liberty road.

Washing would considerably improve the quality of this clay as pyrite and gypsum are both in evidence. Considering the number and thickness of strata represented in the sample, the showing under test is remarkable. Conditions near this outcrop are favorable to strip pit operation. Fairfield is not over three miles distant and a branch line of the Chicago, Rock Island and Pacific Railway passes within two hundred yards to the east. The region seems worth investigation toward commercial development for the manufacture of vitrified clay wares.

Washington County.—Washington county contains a few scattered outliers of Des Moines series rocks, but as nothing of importance in the way of refractory clays had been previously reported, no work was done here.

Wapello County.—Samples of underclays were obtained from many localities in Wapello county. The results of tests on these samples indicate that there are few deposits, however, which might afford clays fusing above cone 12. A sample from thirteen feet of gray shale exposed in a gully in the southeast quarter of section 26, Washington township, and one mile east from Eldon, softened at cone 6. Another sample from near the center of the southeast quarter of section 22, one mile north of Eldon, gave the following results upon test:

Four feet of gray fire clay outcropping at stream level.

	Drying	Cone 2	Cone 6	Cone 10
Total linear shrinkage, per cent	7.6	12.1	11.1	15.
Absorption, per cent		11.9	11.2	?
Color		Buff	Gray	Brown

Tempering water 28 per cent.
The test pieces were beginning to fuse at cone 10.

Two samples were secured from near Laddsdale, one from below the No. 3 coal in the Anchor No. 2 mine, the other from a roadside exposure near the middle of the south half of section 31, Washington township. The second sample comes from a spot about three-fourths of a mile west from the source of the first and from a horizon some fifty feet higher. The clay below the coal is said to range from one to six feet in thickness. In different parts of the mine its character is different. Where the clay was sampled, the upper third is decidedly gritty, the lower

third is smooth while the middle represents gradational material between the two extremes. Tests of this sample show low shrinkage, and fusion at cone 12.

The roadside exposure shows the following sequence:

		Feet
8.	Drift, variable	
7.	Shale, black; exposed	2
6.	Shale, gray; 1 inch limestone lentil	3
5.	Coal	¼
4.	Fire clay, gritty	1½
3.	Shale, gray limestone, lentils	2½
2.	Coal	3½
1.	Fire clay (exposed)	3

The sample was taken from 1, 4 and 6 and gave the following results upon test:

	Drying	Cone 2	Cone 6	Cone 10
Total linear shrinkage, per cent	6.7	10.9	9	13.3
Absorption, per cent		9.1	10	5.3
Color		Buff	Gray-buff	Gray

Tempering water 19.4 per cent.

As the drift thickens abruptly up the hill only a limited amount of clay could be obtained here by open cut.

"Fire clays" are exposed at and near Ottumwa in many places. Samples from what appeared to be the purest clays were collected and tested, but all failed to stand up at cone 12. The accompanying sketch (fig. 2) shows the succession of strata in the pit of the Morey Clay Products Company as it was in 1918. The "pottery clay" near the top of the bank fuses at about cone 10. The gritty fire clay formerly used in making paving brick was not tested owing to the amount of limonite and pyrite contained.

Mahaska and Keokuk counties show little promise for the more refractory clays. Clays of the fire clay type are present below the coal worked near What Cheer. They are, however, decidedly sandy. Pyritic replacements of upright leaves and stems are frequent. These clays are "short" and tend to check and blister in burning. Because of the high content of pyrite the fusion point is below cone 12. Gritty underclays occur below the coal in some sections in Mahaska county, but in many cases sand-

stone replaces the clay. A gritty fire clay was formerly worked at Oskaloosa, speckled buff face brick resulting. This clay resembles closely that mentioned as occurring at and near What Cheer.

	Feet
Loess	8
Yellow clay	6
Black shale	¼
Pottery clay, pinkish, smooth	3
Gray to buff shale, some limestone lentils	8
Shale, black, pyritic	7
Coal	1¼
Sandstone and gritty fire clay	7

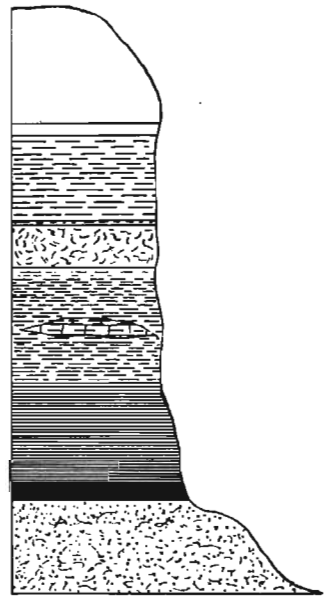


Fig. 2.—Ideal Section. Morey Clay Products Co., Ottumwa.

Outcrops of plastic underclay may be seen near Given, about seven miles south of Oskaloosa. The clay lies close to stream level. The overlying coal has been rather generally mined out and as a consequence very limited amounts of the clay are economically available.

Thin seams of plastic "fire clay" are rather common near New Sharon, in the northern part of Mahaska county. No deposit of sufficient thickness to be commercially promising was discovered.

THE SOUTHERN DISTRICT.

The southern district includes Davis, Appanoose, Wayne, Lucas, Monroe, Marion and Warren counties. The three southernmost counties, Davis, Appanoose and Wayne, have little to offer in the way of even somewhat refractory clays. "Underclays"

are sufficiently abundant but samples from Mystic, Centerville and Cincinnati fused at or below cone 6. Pyrite and siderite in these clays render oxidation extremely difficult. This is unfortunate as large amounts are heaped upon the surface consequent to mining of coal from the thin Mystic seam.

The four remaining counties of the group are more promising although no deposits worthy of note were found in Lucas county. In Monroe county some of the clays and shales occurring below and above the worked coals are fairly refractory. Beecher[8] reports that light gray shale from above the coal in the Crescent Coal Company mine at White City fused at cone 18 and light gray shale from below the coal fused at cone 16. Both samples burn dark red.

At Lockman the following sequence of beds is reported by Mr. T. J. Evans:

		Feet	Inches
5.	Drift and sandrock	12	
4.	Shale, white and plastic	20	
3.	Coal		3
2.	Shale, black, coaly		4
1.	Shale, white, plastic	20	

Tests of a sample from No. 4 of this series, submitted by Mr. J. R. Clause of Lockman, resulted as follows:

	Cone 3	Cone 6	Cone 10
Absorption, per cent	5.5	5.3	8.6
Color	Brown	Brown	Lustrous brown
Hardness	Harder than steel		

Iron specks become noticeable at cone 3 and above.

Underclays occur with the coal at Ward and Hiteman in different thicknesses up to eight feet. The clay is smooth and slickensided, but contains much pyrite in fine disseminated grains and replacing vegetable matter. In most other mining districts of the county, coal is underlain by only thin clay or by sandstone. As the coal beds worked are usually thick, little or no clay is taken up.

In Marion county the only known refractory clays lie below the coal beds. Beecher gives the following information in his

8 Beecher, M. F., Op. cit., page 60.

report[9] regarding the firing properties of one of these deposits located near Morgan Valley:

	Drying	Cone 3	Cone 8	Cone 10
Total linear shrinkage, per cent	1.9	5.5	7.	6.
Absorption, per cent		6.5	2.3	9.*
Color		Brown	Brown	Brown *Black Cored

Fuses at cone 20-21.

Samples of other underclays collected in this county by Mr. J. B. Fidlar did not prove equal to cone 10 in refractoriness.

Natural outcrops of shale series including some fire clay types occur in the sharply cut valleys of eastern and northern Warren county. Of four samples from over the county none was as refractory as cone 12. The most refractory sample fused at cone 11. It was obtained from a three foot stratum of light colored gritty shale at the clay pit of the Carlisle Brick and Tile Company, one mile west of Carlisle. Because it is overlain by two feet of black carbonaceous shale this particular stratum is no longer used.

The northeastern quarter of Madison county contains many good exposures of Des Moines series shales, but according to the report of Beyer and Williams[10] no promising fire clays are to be seen. The same condition exists in western Warren county.

THE CENTRAL DISTRICT.

The central district includes Jasper, Polk, Dallas, Boone, Story and Marshall counties. The underclays of this district show variations similar to those of districts already treated. Apparently no dependence may be placed upon the refractoriness of this type. Some beds yield an easily fused clay while others from no great distance may stand up better than cone 20.

In Jasper county natural clay and shale exposures are rare and poor, and the material obtainable from such outcrops is hardly representative of the beds they indicate. Sandy fire clays and sandstone are the common associates with the coal seams.

Tests by Beecher[11] of gritty clays from above and below the

9 Op. cit., p. 71.
10 Op. cit., p. 447 et seq.
11 Op. cit., p. 55.

coal in mines of the Colfax Consolidated Coal Company gave softening points at cones 17 and 19 respectively. The refractoriness of these clays seems due in large measure to the quartz which they contain. They are not of good plasticity.

Polk and Dallas counties afford through their many clay pits and mines abundant opportunity for the discovery of refractory clays. Few, however were found, although many samples have been tested. Only the occurrences of clays that were found to fuse above cone 12 will be mentioned.

In the Maple Block No. 2 mine, about three and one-half miles northeast of Des Moines, a four to six foot stratum of dark clay is below the coal (3rd vein, depth from surface at shaft 165 feet). The clay is somewhat fissile and contains a little pyrite. The lower three feet of the clay appears to be of better quality than that next the coal. A sample of this clay taken from an entry where a fault had raised the clay nearly to the roof (a quarter of a mile east and a quarter of a mile north from the shaft) fused at cone 13.

Two coals are worked at the Bloomfield mine (SW. ¼ of sec. 12, Saylor township). The upper coal has no fire clay with it, but a little over four feet of clay underlies the lower. The following results were obtained upon testing a sample taken from the head of an entry directly below East 14th Street:

	Drying	Cone 2	Cone 6	Cone 10
Total linear shrinkage, per cent	4.7	7.8	9.4	11.
Absorption, per cent		11.7	6.5	3.3
Color		Gray	Gray	Buff with iron specks
Hardness				Harder than steel.
Fusion cone 14				

In the pit of the Redfield Brick and Tile Company just west of Redfield, Dallas county, fire clay occurs as shown in the accompanying section. (See fig. 3.) A sample taken from stratum No. 2 of the section tested as follows:

Four foot layer of purplish clay, Redfield Brick & Tile Co.

	Drying	Cone 2	Cone 6	Cone 10
Total linear shrinkage, per cent	9.4	9.4	11	11
Absorption, per cent		12	9	6.4
Color		Purplish gray	Gray	Buff iron specks
Hardness (none given)				

Plasticity good.
Fusion point, cone 21 according to Beecher[12].

Fire clay, said to have been refractory, was formerly worked below a thin coal at a depth of 160 feet at Van Meter. With the closing of the mine this operation ceased. Clay of the fire clay type is exposed in old workings of the Platt Company at Van

Redfield Brick and Tile Co.

	FEET	INCHES
Soil and drift	10	
Shale, gray, silty, carrying iron stained concretions Shale, brownish, rather massive	16	
Unconformity?		
Shale, black		8
Fire clay, purple mottled	1	10
Shale, yellow at top, purple at bottom	6	
Shale, heavy-bedded, gray, with partings	10	
Calcareous layer, highly fossiliferous, soft or hard		3–6
Fire clay, gray to purplish	4– 5	
Greenish gray sandy shale. Exposed	2	

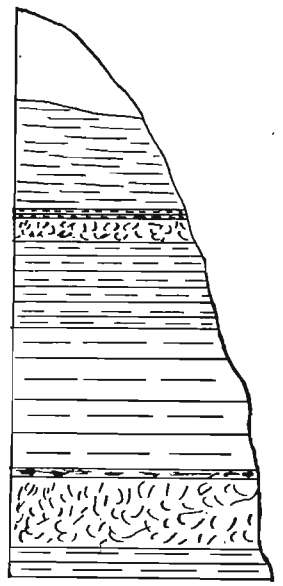


FIG. 3—Vertical section in clay pit at Redfield.

Meter, but according to local report it is neither particularly refractory nor of good working qualities.

Fire clay occurs toward the bottom of the Adel Clay Products Company's pit, one mile west from Adel. This clay has been used as a bond with fire brick grog in making brick for use in the kilns at the company's plant.

[12] Op. cit., p. 60.

Boone Paving B. & T. Co.

	FEET
Drift	
Sandstone ledges	6
Gray shale	5
Clayey sandstone	7
Smooth laminated red and gray shale	7–8
Sandstone	2
Purple massive clay	7
Hard red & blue shale	3–4
Smooth black shale	1
Limestone	½
Coal	½
Gray shale	2
Cap rock	5/6
Fire clay	1
Shale	6
Sandy shale	2
Fine gray-blue shale	1
Blue shale	3
Sandy fissile shale	1
Dark gray fissile shale	½
Coal	¼
Fire clay, gritty	2½
Coal	2–2½
Dove fire clay	2
Concealed to low water level	7

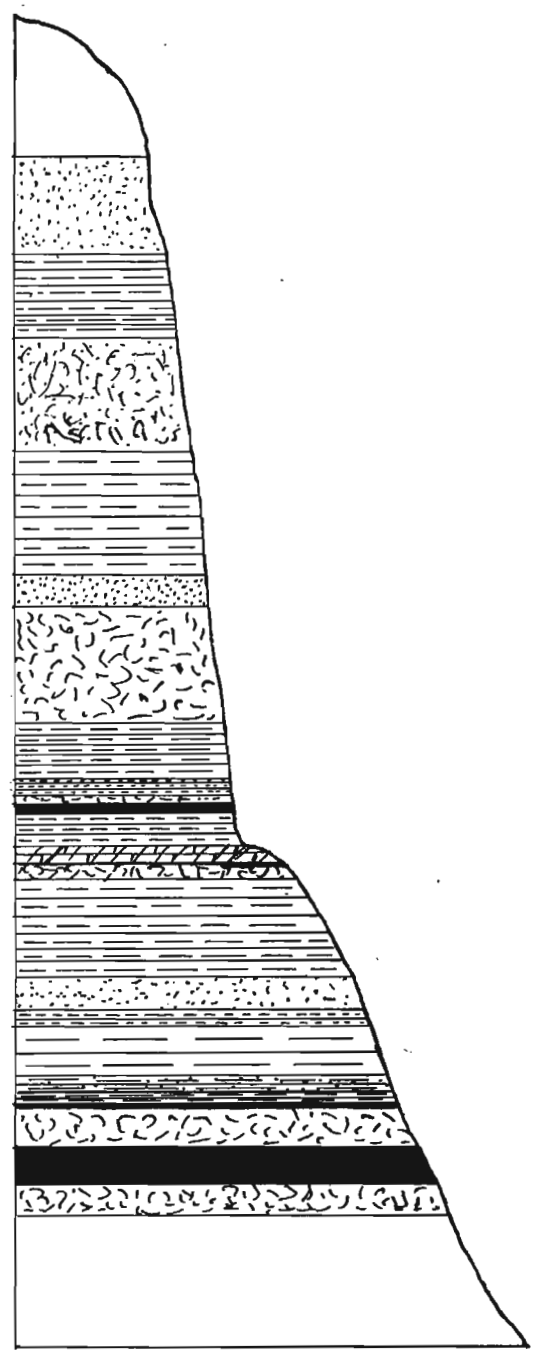


FIG. 4—Boone Paving Brick and Tile Co.

Rocks of the Des Moines stage appear in eastern Guthrie county but no important refractory clays have been seen or reported there.

In Boone county the most refractory clays now available are to be found at Logansport in the pit of the Boone Paving Brick and Tile Company, and in the underclay at the Boone Block Coal Mine, about half way between Logansport and West Boone.

At the clay pit a generalized section shows a great variety of sedimentary rocks. (See accompanying sketch, fig. 4.) The west end of the pit shows fewer strata than the eastern excavation. Two samples were taken from the west end (now abandoned), one being taken from a three foot layer of white, gritty but plastic clay lying above the "cap rock" which forms a floor of the old workings. The second sample is from a three foot blue-gray fire clay stratum about fifteen feet below the horizon of the first sample. Results of tests follow:

Gritty white clay, Logansport.

	Drying	Cone 2	Cone 6	Cone 10
Total linear shrinkage, per cent	6.25	6.25	6.25	9.4
Absorption, per cent		14.2	11.1	7.4
Color		Gray	Gray	Gray, a few iron specks
Hardness		Steel hard	Harder than steel	

Fuses at cone 20.

Gray fire clay, Logansport.

	Drying	Cone 2	Cone 6	Cone 10
Total linear shrinkage, per cent	3.13	6.25	7.8	9.4
Absorption, per cent		15.9	7.4	7.7
Color		White	Dirty white	Dirty white no specks whatever
Hardness		Steel hard	Harder than steel	

Fuses at cone 18.

The sample from the Boone Block Mine was obtained from the dump heap. The stratum under the coal is seldom over two feet thick, but much clay is taken up to give height in the entries.

Clay from below coal, Boone Block Mine.

	Drying	Cone 2	Cone 6	Cone 10
Total linear shrinkage, per cent	7.3	10.9	12.5	12.5
Absorption, per cent		7.6	2.1	4.0
Color		Dirty white	Gray, iron specks	Gray, iron specks
Hardness		Harder than steel		

Fuses at cone 16.

These tests would seem to indicate that the region between Boone and Des Moines river could provide large amounts of clay fusing between cones 16 and 20. However, little clay of this kind is available except through mining, or bench working.

Story and Marshall counties to the east and Greene county to the west of Boone have not proven worth further mention as regions of accessible refractory clays.

THE NORTHERN DISTRICT.

Included in the northern district are Webster, Hamilton and Hardin counties. These counties lie along the northern border of Pennsylvanian rocks in Iowa. Consequently the greater part of the series found here is of the lower one hundred feet of the Des Moines strata. Exposures of shale and clay are confined to the deeper valleys. The irregularity of the strata so characteristic of the Des Moines series elsewhere in the state is thoroughly illustrated through this region.

In Webster county the area most promising as a possible producer of more refractory clays lies along Des Moines river from Lehigh to Fort Dodge. Within this territory there are several clay strata of considerable refractoriness. These all seem to be of the massive sandy clay or shale variety. Smooth, highly plastic underclays are abundant, and appear in practically every clay pit of the region, but as a rule do not provide material fusing above cone 12. The sandy clays are thicker, more regular in thickness and less changeable in character than the more plastic fire clays. The greater uniformity of thickness may be attributed in part if not wholly to their greater resistance to "squeezing", a feature common to the typical underclays.

At the pit of the LeHigh Sewer Pipe and Tile Company strata shown in the accompanying section (fig. 5) are worked. Former-

ly shales at lower levels were used. Beecher[13] gives the results of tests upon a six foot bed of gray sandy clay lying below a four foot coal seam. This clay fuses at cone 21, and shrinks but 3.5 per cent at cone 10. The absorption remains high at cone 10, but there is considerable warpage. Great quantities of clay of this or similar kind are present in the hills about Lehigh. However, the heavy burden of glacial drift is a serious handicap to their development. On the east side of the river, some clay has been mined and the future will probably see more of such work.

Lehigh Sewer Pipe and Tile Co.

	FEET
Drift, variable but thick	0–40
Shale, red, smooth, finely laminated	1½
Shale, gray, sandy, some reddish areas	6
Shale, red, fissile	3
Shale, sandy	2
Sandstone	1
Shale, mottled gray and red	4– 5
Sandstone	1½– 2
Shale, red for the most part	5
Sandstone, clayey above	3– 4
Clay (Fire clay type)	0– 2
Shale, mottled gray and red; to pit floor	4– 6
Shale, gray. Reported	12–14

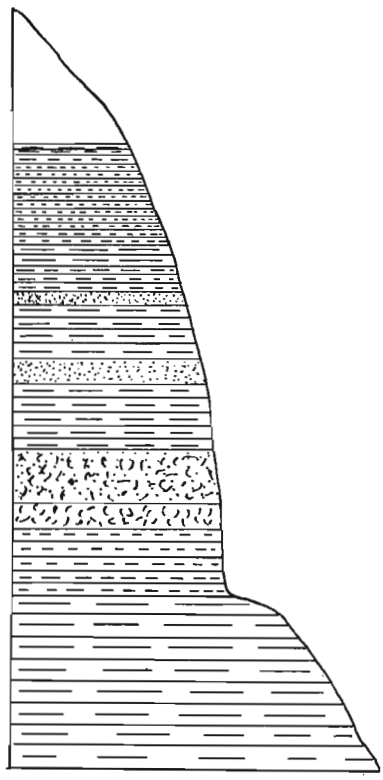


FIG. 5—Lehigh Sewer Pipe & Tile Co., Lehigh, Webster county.

At the pit of the Kalo Brick and Tile Company forty feet of shale and clay are utilized. The following section shows the succession of strata:

13 Op. Cit.

		FEET
6.	Shale, fissile but hard	3
5.	Sandstone, thick-bedded, hard	3
4.	Shale, black to gray, ocherous streaks	10
3.	Shale, black, clay ironstone concretions	20
2.	"Fire clay", gray, some pyrite	4
1.	Clay more sandy than No. 2	

VINCENT'S PIT,
Shady Oak Station.

	FEET
Drift	5–10
Gypsum	0– 8
Conglomerate with limestone and chert pebbles	1– 2½
Sandy and calcareous shale	1
Shale, fissile, blue and red	4
Shale, red concretions	1½
Shale, black, "rubbery"	4– 8
Coal and black coaly shale, Pyrite abundant	1– 1¼
Fire clay, smooth to gritty, very uneven, pink to gray	1– 5
Reddish iron-cemented band	0– 2
Shale, massive, gray, more sandy toward bottom. Bottom of pit	2– 3
Sandstone	20
Shale, black, fissile, numerous "kidney rock" concretions	15
Cap-rock, cone-in-cone at top	4
Coal blossom	1/6
Fire clay, gritty	4– 6
Shale, black, fissile; to river level	15

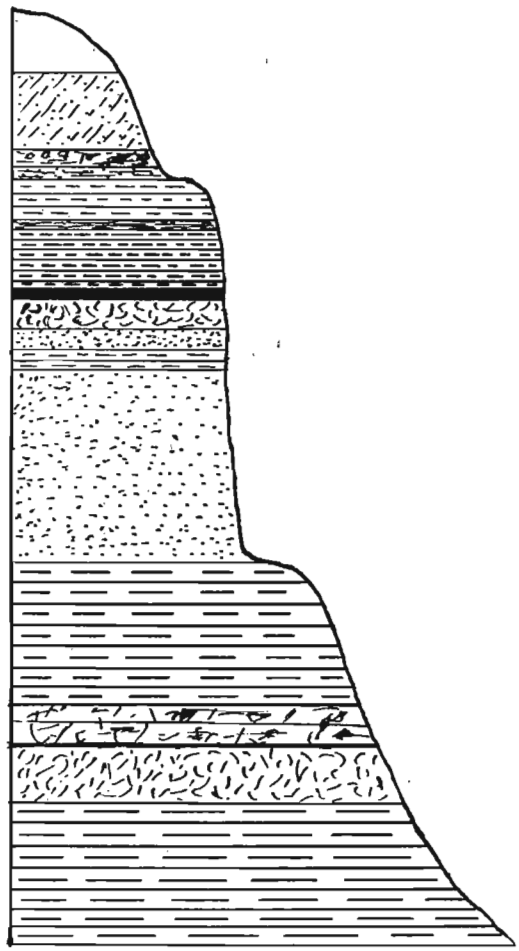


FIG. 6—Section at Shady Oak, Webster county.

Number 2 above was sampled by Professor J. E. Smith. Results of tests on this sample follow:

Fire clay, Kalo. (Schnurr Brothers).

	Drying	Cone 2	Cone 6	Cone 10
Total linear shrinkage, per cent	7.8	12.5	12.5	12.5
Absorption, per cent		6.8	3.4	4.2
Color		Buff	Brown, iron specks	Brown, iron specks
Hardness			Harder than steel	

Shales and clays are well exposed near Shady Oak in the Vincent Clay Pit and in natural outcrops. The accompanying sketch (fig. 6) represents the sedimentary beds of that vicinity. Tests on a sample of the lower fire clay (No. 2) resulted as follows:

Lower Fire clay, Shady Oak.

	Drying	Cone 2	Cone 6	Cone 10
Total linear shrinkage, per cent	7.8	7.8	9.4	9.4
Absorption, per cent		12.0	8.1	8.7
Color		Buff	Buff	Buff
Hardness			Harder than steel	

Another sample from the same horizon fused at cone 29-30, according to Mr. B. T. Sweely.

Only one clay sample from Hamilton county proved worth mention. This was obtained by Mr. Roddewig in the southwest quarter of section 16, township 87 north, range 26 west, in the west bank of Boone river, four feet above water level. The exposure shows:

		Feet	Inches
8.	Drift	25–75	
7.	Shale, coaly	3	
6.	Limestone		10
5.	Shale, coaly	2	
4.	Fire clay	3	
3.	Coal		10
2.	Fire clay		15
1.	Slump to water	2	

Both fire clays were sampled but that below the coal fused below cone 10. The upper clay fused at cone 12.

Refractory clays have been reported from near Eldora in Hardin county. Beecher[14] tested three such clays from the F. Berninghausen farm, on the west side of Iowa river, north of Eldora. All three samples fused above cone 20. Clay from a seven foot stratum burned buff at cone 11 without appreciable

14 Op. cit., p. 56 et seq.

warpage and fused at cone 23-24. Unfortunately these clays proved to be of very limited extent and were soon worked out. No deposit of workable size could be found in this region at the time of our visit (1918). It is quite probable that other lenses of clay equal to that tested by Beecher occur, but past experience would not encourage one to hope for extensive deposits.

Des Moines series shales are supposed to occur in southern Humboldt county, but nothing of interest related to the present work was found there.

The Cretaceous.

Rocks of Cretaceous age are thought to underlie most of the western third of Iowa, yet, because of a thick mantle of glacial drift or loess, there are but few outcrops. Those of interest are confined to three localities: the Sioux City district, the region about Auburn, Sac county, and the vicinity of Red Oak, Montgomery county.

So far as is known, the shales in all these districts belong to the Dakota and the Benton divisions. The Cretaceous shales of Iowa are, as a rule, more silicious and refractory than those of earlier age. They most closely resemble the shales of the Des Moines series. In many cases the resemblance is such that distinction is hardly possible upon appearances alone.

Montgomery county was not visited as the report on Iowa Clays[15] shows no refractory stratum as much as three feet in thickness.

In southeastern Sac, and the adjacent part of Calhoun county there are a few exposures of clay and shale. The only clay of refractory appearance was found on the south bank of Coon river three-eighths of a mile south from Grant City. The clay rises ten feet above stream level and is of the fire clay type. A sample of this clay was tested with results as follows:

Fire clay, Grant City, Sac county.

	Drying	Cone 2	Cone 6	Cone 10
Total linear shrinkage, per cent	9.4	10.9	12.5	12.5
Absorption, per cent		9.3	3.4	3.4
Color		Buff	Gray	Gray
Hardness			Harder than steel	

15 Beyer and Williams, Op. cit.

Little may be said of the extent of this deposit. The strata in the clay pit of the Auburn Brick & Tile Company a short distance to the east show nothing of this kind.

The best exposures of Cretaceous shales are found along the river at and near Sioux City. At Sergeant Bluff, seven miles south from Sioux City, excavation of clay for brick making has exposed a thick section of shale and sandstone. The following beds appeared in 1918 and probably are to be assigned to the Dakota division of the Cretaceous:

		Feet
7.	Loess	40
6.	Shale, soft, sandy, yellow	0 — 20
5.	Clay, white	5/12 to 2
4.	Sandstone	20
3.	Lignite	1½
2.	Shale, blue and gray	20
1.	Shale, gray to white, gritty, shown by test pits	50

Samples were taken (1) from material thrown out in digging test pit; (2), from a six foot layer near the base of No. 2 above; (3), from No. 5 above. Mechanical analysis of these samples shows that they contain little that will not pass a 200 mesh sieve except quartz grains. Results of working tests follow:

Clay from 50 foot gray-white shale below pit.

	Drying	Cone 2	Cone 6	Cone 10
Total linear shrinkage, per cent	7.8	9.4	12.5	.11
Absorption, per cent		7.8	3.5	.01
Color		White	Gray, iron specks	Gray, iron specks
Hardness		Harder than steel		

Clay slakes readily, works a little short.

Six foot stratum of gray massive shale.

	Drying	Cone 2	Cone 6	Cone 10
Total linear shrinkage, per cent	7.8	7.8	9.4	9.4
Absorption, per cent		11.3	8.4	8.5
Color		Buff	Buff	Buff
Hardness		Harder than steel		

Two foot stratum of white clay above sandstone.

	Drying	Cone 2	Cone 6	Cone 10
Total linear shrinkage, per cent	7.8	9.4	12.5	12.5
Absorption, per cent		8.5	.02	.01
Color		Buff	Gray	Gray
Hardness		Harder than steel		

It seems quite probable that the whole assemblage of clays here would fuse at better than cone 10. Beecher[16] tested two clays from Sergeant Bluff, one evidently from the six foot stratum reported above. His sample fused at cone 27, gave 6.2 per cent shrinkage at cone 10 and showed very slight warpage at cone 11. These clays should be excellent material for the manufacture of architectural terra cotta.

Pits of the Sioux City Brick and Tile Company at North Riv-

	FEET
Loess	10–20
Sandy yellow shales	12
Dove shale, smooth	12
Shale	10
Ocher sandstone	13
Sandstone	10
Sandy shale	2
Shaly sandstone	12
Shale	3
Lignite	½
Fire clay	6
Gray shale	¼
Lignite	½
Fire clay	3

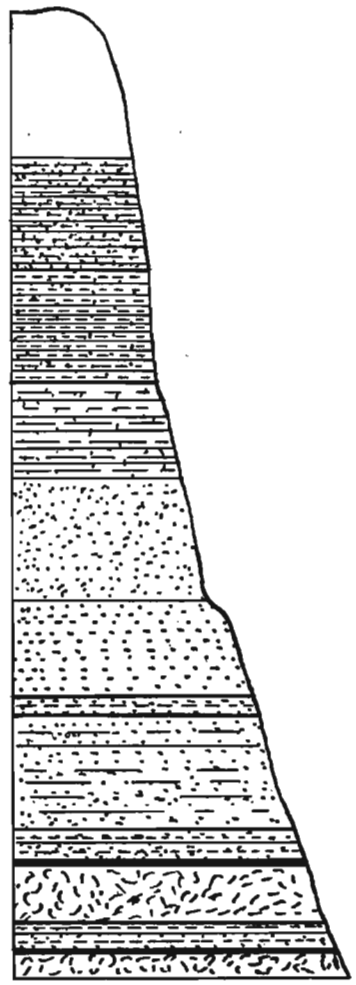


FIG. 7—Pit at North Riverside, Sioux City.

16 Op. cit., p. 60.

erside expose another thick shale series, but one quite different from that at Sergeant Bluff as may be seen from the accompanying section. (See fig. 7.) The North Riverside strata are presumed to represent a geologically younger series than those at the Bluff, that is the Graneros shale member of the Benton stage.

Fire clay of considerable purity has been reported from Crill's Mill, Plymouth County.[17] Very little could be found at this place at the time of our visit owing to mud left by a recent flood.

Conclusions.

Nothing so far discovered would indicate that Iowa possesses any strictly first grade refractory clays in commercial quantities. Its clays of the fire clay or underclay type seldom reach cone 25 in fusion. As a rule the more refractory of these clays are rather lacking in plasticity. Lack of uniformity in thickness and constitution is detrimental to their exploitation for particular uses.

Only a few deposits merit any special attention because of their commercial possibilities. These are such as the Jester and Denova clays in southeastern Iowa, the gritty underclays of Boone and Webster counties, and the white, gritty shales of Woodbury county. Apparently the white clays of Jackson and Clinton counties are the only ones which might be considered as possible refractory bond clays. Their known extent is too limited to warrant much investment in development.

Acknowledgments.

The writer wishes to acknowledge the assistance rendered by Mr. J. B. Fidlar and Prof. J. E. Smith in the field and by Mr. Lowell Hewitt and Mr. Ed Roddewig in conducting the clay tests.

---

17 Beyer and Williams, Op. cit.