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Preliminary report on the geology and mineralogy of clays on the Pine Ridge Indian Reservation, South Dakota

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with a chapter on usability tests
by H. P. Hamlin, U. S. Bureau of Mines

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Summary

Clays suitable for pottery, brick, tile, and semirefractories are present in certain zones of rocks on the Pine Ridge Indian Reservation.

Mineralogical analyses were made of about 100 samples representing the principal rock formations on the Reservation, and usability tests were made on 16 of these samples.

Light-colored clay, sandy clay, and sandstone of Tertiary age form the badland areas and underlie the upland areas of Pine Ridge. Older dark-gray shale and calcareous (calcite-bearing) rocks of Cretaceous age are present in the north and west parts of the Reservation. These Tertiary rocks and most parts of the Cretaceous rocks contain either too much swelling clay, or in some cases, too much calcite or sand for ceramic purposes. Swelling clays cause excessive shrinkage and cracking during drying. Few, if any of these swelling clays, however, are of sufficient purity to make them valuable as drilling muds or for other common commercial uses of such clays.

A weathered zone averaging about 15 feet thick was formed on the older dark-gray shale (the Pierre shale) and, in the southwest part of the Reservation, also on calcareous rocks (the Niobrara formation) before the younger (Tertiary) sand and clay beds were deposited.

This weathering changed the composition of the older rocks, making some of them more usable for ceramic purposes. The general areas of outcrop of the weathered zone are shown in the geologic map by the line of contact between the rocks of Cretaceous and Tertiary age.

Effect of weathering on the Cretaceous rocks was variable. In general, calcite was leached and kaolinite was formed. Effects of the weathering are most pronounced on the calcareous rocks in the southwest corner of the Reservation. In a few places, enough kaolinite has developed in the upper several feet of the weathered zone, for the clay to be semirefractory and suitable for chimney brick and flue tile. More commonly, the clay is less refractory and suitable for pottery and heavy clay products like brick and tile.

In the weathered zone developed on the dark-gray shale, generally too much swelling clay is present for ceramic uses. Much of this clay can be made usable by addition of 10-20 percent of sand or prefired grog to reduce shrinkage. Supply of such clay is enormous and should be sufficient for the most ambitious development.

Some areas of potentially usable clay on the Reservation are indicated in the report. Many other deposits of usable clay in the weathered zone undoubtedly are present, but were not visited or sampled during this reconnaissance study. It should be emphasized that clay in the weathered zone is highly variable. Therefore, further sampling and testing to outline the lateral extent of usable clay deposits must precede any large-scale mining development. Before additional sampling and testing is undertaken, economic factors such as markets, fuel costs, and transportation of products such as brick and tile with low value/weight ratio should be evaluated.

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Preliminary report on the geology and mineralogy of clays on the Pine Ridge Indian Reservation, South Dakota

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Introduction

The following report was prepared by the U. S. Geological Survey at the request of the Bureau of Indian Affairs. The report is based on two weeks fieldwork, four weeks laboratory work, and on the results of usability tests made by the Bureau of Mines.

The investigation was a reconnaissance survey of types of clay present in all the major geologic units on the Reservation, and their economic potential. General geologic data indicated that certain zones of the Chadron and Brule formations contained clays similar to those utilized elsewhere and that clay in the Brule formation already was being used in small amounts for souvenir pottery.

Weathered zones developed below the White River group and possible paleosoils within the group appear to merit special attention, because soil-forming processes may have changed the normal mineralogy of the rocks.

In this report, some data are given in more detail than may presently be needed so that, if clay resources are developed further, all information will be available to those carrying out the development. Potential usability of materials will be discussed with only cursory reference to minability and other economic factors, because thickness of beds at localities sampled for this report probably are not maximum thicknesses present on the Reservation, and because economic factors such as markets and availability of cheap fuel for burning brick and tile may change.

The writer gratefully acknowledges the help of Professor John C. Clark of the South Dakota School of Mines who helped familiarize the writer with the stratigraphic sequence on the Pine Ridge Indian Reservation.

Geology

Previous work

Most of the geologic work on the Reservation has consisted of detailed and generalized descriptions of stratigraphic sections, mostly in connection with paleontological work in the White River badlands (O'Harra, 1920; Sinclair, 1921; Ward, 1922; Wanless, 1922, 1923; Wood and Mannhardt, 1925; Clark, 1937, 1954; Bump, 1956; Macdonald, 1955).

No detailed geologic maps of most of the Pine Ridge Indian Reservation have been made. Studies by R. J. Dunham (1961) which include a small part of the Reservation southwest of Pine Ridge were most helpful. Data from detailed mapping just north of the Reservation near Sheep Mountain Table by Moore and Levish (1955) and Kepferle[1]

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[1] Kepferle, R. C., 1954, The geology of a portion of the White River badlands, Pennington County, South Dakota: South Dakota School of Mines, unpublished master's thesis.

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may be extrapolated into the Reservation. For most of the Reservation, the state geologic maps (Darton, 1951; Petsch, 1953) provide the only available information.

Two types of maps have been used to determine sample localities and place names used in this report: (1) in areas near the White River, 7½-minute topographic quadrangle maps of the U. S. Geological Survey; (2) elsewhere, 1:250,000 Martin and Hot Springs sheets of the Army Map Service.

Sedimentary rocks

Sedimentary rocks of Late Cretaceous and Tertiary age make up the bedrock on the Pine Ridge Indian Reservation (table 1). The gray shales and calcareous rocks of Late Cretaceous age are all marine; they have about the same appearance throughout the Reservation. The Tertiary rocks are all terrestrial and are composed of variable layers from a few to several tens of feet thick which differ in sand-silt-clay ratios, color, carbonate content, and resistance to weathering. Generally, the more sandy rocks of Tertiary age have lighter colors, are more calcareous, and form steeper slopes on outcrops than do the more clayey rocks.

The sedimentary rocks generally dip very gently to the south and southeast, so Cretaceous rocks represented by the upper part of the Pierre shale are exposed mainly in the north, and progressively younger Tertiary rocks are exposed to the south and east (see geologic map, fig. 1a). In an area southwest of Pine Ridge older Upper Cretaceous rocks, including the Sharon Springs member of the Pierre shale, the Niobrara formation, and the Carlile shale, are brought to the surface by folding and faulting.

Table 1.--Stratigraphic units on the Pine Ridge Indian Reservation

Age	Units			Approximate thickness (in feet)	Description
Pliocene	Ogallala formation			?	Sandstone and tuffaceous sandstone and siltstone.
Miocene	Arikaree formation			500±	Mostly thick bedded, buff siltstone; includes a 50-foot bed of resistant white volcanic ash at its base which caps several prominent mesas in the badlands.
Oligocene	White River Group	Brule formation	Poleslide member of Bump (1956)	100-150	Massive, pink, nodular silty clays, commonly weathering to steep, nearly vertical walls in badlands areas.
			Scenic member of Bump (1956)	100-150	Banded pink, gray, red, and green clay cemented in varying degrees with calcite. Locally prominent bands of nodules. Weathers to step-like slopes.
		Chadron formation	upper	50-100	Green claystone weathering to rounded mounds. Thin limestone beds in upper part.
			lower	0-75	Occurrence very local (Clark, 1937). In east; white, fine-grained sandstone beds 5-20 feet thick. In west; red and green sand and claystone filling channels in shale of Cretaceous age.

p. 4a follows

Table 1.--Stratigraphic units on the Pine Ridge Indian Reservation (con.)

Age	Units		Approximate thickness (in feet)	Description
Eocene(?)	"Eocene(?) weathered zone"		0-70	Mottled red, yellow, light gray, and purple clay grading down into yellow, oxidized rock.
Late Cretaceous	Pierre shale	Younger part of Pierre shale	1300	Dark-gray shale with zones of carbonate nodules.
		Sharon Springs member	50-100	Hard, fissile, dark-gray shale interbedded with bentonite beds.
	Niobrara formation		300	Chalk and calcareous gray shale.
	Carlile shale		---	Gray shale.

p. 5 follows

The Ogallala formation, which occurs only in isolated outcrops, is not shown on the map in figure 1a.

"Eocene(?) weathered zone"

A remarkable feature of the stratigraphic sequence on the Pine Ridge Reservation and adjacent areas is the "Eocene(?) weathered zone" developed in most places below the White River group. It is composed of mottled rocks commonly 10 to 30 feet thick, but is as much as 70 feet thick near the town of Interior. These rocks were called the Interior formation by Ward (1922 and 1926) and were interpreted as a normal stratigraphic unit equivalent to the Fox Hills sandstone which overlies the Pierre shale. Wanless (1923, p. 197) showed that "the surface of the Interior formation (of Ward) seems to have been essentially a peneplain" and "it (the Interior formation) was formed rather by weathering and leaching on the surface during a long period of pre-White River erosion . . .". Dunham (1961) has shown that southwest of Pine Ridge, this same weathered zone is developed on the Niobrara and older formations; Dunham calls this weathered zone "residual soil and weathered rock of Eocene(?) age".

This pre-White River weathered zone will be called the "Eocene(?) weathered zone" in this report in order to distinguish it from other possible weathered zones within the White River group.

The "Eocene(?) weathered zone" is composed mainly of mottled red, yellow, light gray, and purple clay which weathers to a yellow slope. Bedding of the original shale is generally perceptible. If the underlying, unaltered rock is calcareous, the weathered zone may or may not be calcareous; at many places the calcite is leached from the upper part but not from the lower part. In such outcrops, the color of the lower part commonly is predominantly yellow with some gray mottling.

In some outcrops the weathered rocks described above are overlain by several feet of more intensely weathered rock with slickensides and no bedding. This upper part of the weathered zone commonly is also mottled, but it weathers to a color which contrasts with the yellow of the thick, lower part. In some places, as at locality 1, it weathers to a near white or pale lavender. At other places, notably around the town of Interior, it weathers to a red band. This upper part is never calcareous. It was sampled separately from the rest of the weathered zone and is also separated on figure 1b.

Sampling and testing

Geological Survey

Samples were collected in May 1960. During the fieldwork it became apparent that the clay currently being used for pottery in Pine Ridge was from the "Eocene(?) weathered zone" instead of the Brule formation as previously reported; sampling of this weathered zone was therefore emphasized. Also, most of the Tertiary sedimentary rocks appeared to contain either too much swelling clay, too much calcite, or too much sand for ceramic use; therefore, these units were sampled only enough to give them adequate representation in the overall study.

Some of the samples were collected outside the Reservation because similar rocks within the Reservation could not be reached during the fieldwork.

Descriptions of the samples and the sample localities are given in the section "Description of sample localities" beginning on page 19.

Mineralogical analyses (fig. 1b) were made using X-ray diffraction techniques in May and June 1960. On the basis of these analyses, 16 samples were selected for usability tests. The selection was made on a twofold basis: (1) samples most likely to be of economic importance; (2) a complete representation of rock types present on the Reservation even if some appeared not to be of potential economic importance.

Bureau of Mines

Usability tests were performed by the Bureau of Mines at Norris, Tenn., under the supervision of Mr. H. P. Hamlin. Complete tests of the raw working properties and firing properties were made on 10 samples and preliminary tests were made on the remaining 6 samples. Test bricks and pottery were made from the more promising samples. Some of the samples were mixed with sand and with each other for testing.

The test results are included in the Bureau of Mines report of usability tests, pages 43-58, and some of these results are grouped together on table 2 of this report.

Sample numbers

Different systems of sample numbering were used by the writer and by the Bureau of Mines. In the writer's field numbers, the first digit is the locality number, the second digit is the sample number. For example, sample 6-3 is sample number 3 from locality number 6. For ceramic testing, the Bureau of Mines assigned letters from A to P to the 16 submitted samples.

In this report, the field numbers will be used. Letter designations of the Bureau of Mines are used only in the Bureau's report and in table 2 which summarizes the test data.

Mineralogy

Mineralogical composition of the samples is summarized in figure 1b. Each rectangular bar represents one of the 109 analyzed samples, the number at the lower left corner of the rectangle is the sample number, and the number at the top of a column of rectangles is the locality number. Approximate geographic locations of most of the sample localities are shown on the geologic map; approximate stratigraphic position is indicated on the left side of figure 1b. Within each rectangle, each mineral is indicated by a pattern; the abundance of the mineral estimated to the nearest 5 percent is indicated by the width of the pattern. Minerals estimated to be present in amounts of only 1-2 percent are indicated by letters to the right of the rectangle.

Thickness of the beds represented by each of the samples from the "Eocene(?) weathered zone" is indicated to the left of each rectangle (fig. 1b). Thicknesses are not given for other samples which appear to have no economic potential.

Principal components of most of the samples are quartz, kaolinite, illite, montmorillonite, and mixed-layer clay. Kaolinite is the major component of many refractories and of fine ceramic ware. Illite is a principal constituent of many heavy clay products, such as brick and sewer tile. Illitic clays also probably could be used for red-burning pottery. Montmorillonite is characterized by its ability to adsorb water and by its high plasticity. Shrinkage in drying eliminates highly montmorillonitic clays as a possible raw material for ceramic purposes, but some very pure montmorillonite clays are commercially used as drilling muds, decolorizing agents, and for other purposes. Mixed-layer clay like that in the rocks of the Pine Ridge Reservation has no present commercial use.

"Eocene(?) weathered zone" on the Niobrara formation

Unweathered samples from the Niobrara formation commonly contain 10-15 percent kaolinite, 15-20 percent illite, 15-20 percent mixed-layer clay, 20 percent fine quartz, 25 percent calcite, and small amounts of chlorite and feldspar. During development of the "Eocene(?) weathered zone" the calcite was first leached and chlorite was destroyed with little change in the ratio of the other minerals. After all the calcite was leached, kaolinite was formed, mainly at the expense of illite. Progressive increase of kaolinite upward in the weathered zone is particularly notable at localities 1 and 3, where in the nonbedded clay at the top, kaolinite composes half of the rock.

"Eocene(?) weathered zone" on the Pierre shale

The Pierre shale is commonly composed of small amounts of kaolinite and chlorite, 10-15 percent illite, 40-60 percent of montmorillonite and mixed-layer clay in highly variable proportions, 20-25 percent quartz, and small amounts of feldspar. The Sharon

Springs member generally is slightly more kaolinitic than other members of the Pierre. Thus, Pierre shale generally tends to be more montmorillonitic than the Niobrara.

Alteration due to weathering in the "Eocene(?) weathered zone" is generally less pronounced on the Pierre than on the Niobrara. As on the Niobrara, both chlorite and most feldspar was destroyed by the weathering, but on the Pierre the increase in kaolinite is only slight. In several outcrops of the "Eocene(?) weathered zone" developed on the Pierre, montmorillonite increases slightly upward in the profile, thereby making the Pierre shale even more different from the Niobrara.

Chadron formation

The dominant clays of the Chadron are montmorillonite and mixed-layer clay. This composition accounts for the frothy appearance produced by swelling clays on the surface of its outcrops. Most samples also contain minor amounts of illite, and in the lower part of the Chadron, also a little kaolinite. The kaolinite may represent weathered shale of Cretaceous age transported from nearby high areas before the area was completely buried by Tertiary deposits. Such an interpretation is in keeping with the smaller amounts of feldspar contained in the kaolinitic deposits of the lower part of the Chadron than in the rest of the Tertiary rocks.

The large amounts of montmorillonitic clay together with cristobalite in two of the samples (14-5 and 18-1) suggest that altered volcanics comprise much of the formation. Detrital quartz is abundant only in the sandy rocks (samples 1-6, 15-4, 15-5, 16-1, 23-3, 23-4, and 24-3).

Brule formation

Clays of the Brule, like those of the Chadron, are mostly montmorillonitic. Differences in weathering characteristics of the Brule and Chadron are probably caused by several factors. Most important, the Brule is more indurated by calcite. Greater abundance of illite probably indicates a larger amount of nonvolcanic components in the Brule, and abundance of glass in the Poleslide member (Bump, 1956) of the Brule indicates that all volcanic components present have not been completely altered. Furthermore, a significant proportion of the volcanics apparently altered to zeolite (clinoptilolite) rather than montmorillonitic clay.

Possible weathered zones within the Brule formation

Possible weathered zones within the Brule formation have been described by several investigators. A dark band in the Brule formation which was interpreted by Kepferle[1] as a possible soil zone

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[1] Thesis, 1954; see footnote, p. 2.

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is represented by samples 17A-11 and sample 20-3. A light band in the Brule at Toadstool Park (locality 5 of this report) called the "bench" and interpreted by Schultz, Tanner, and Harvey (1955) as a caliche soil zone is represented by sample 5-2.

None of these samples from the possible soil zones differ significantly in mineralogy from the adjacent rocks which have presumably not been affected by soil-forming processes. The mineralogical evidence does not favor soil development as an explanation for these light and dark color bands. In any case, their mineralogy does not differ significantly from the adjacent rocks, so they are of no more or less interest for economic purposes than the adjacent rock.

Arikaree formation

The mineralogical composition of the Arikaree formation is very similar to that of the upper part of Brule. Like the Brule, the Arikaree probably was derived mainly from partly altered volcanics. The thick white ash bed at the base of the formation probably represents a period of unusually intense volcanic activity.

Ogallala formation

Much of the Ogallala formation is composed of detrital quartz. In the finer-grained parts of the unit, the clays are similar to those in lower Tertiary units, indicating that volcanic debris was still coming into the area. Similarity of the clays and prevalence of plagioclase feldspar in all the Tertiary units studied indicates that the chemical composition of the volcanics probably did not vary much throughout middle Tertiary time.

Usability

Clay

Ceramics

Of the rocks present on the Pine Ridge Indian Reservation, those most usable for ceramic purposes have a mineralogical composition of about 1/3 kaolinite, 1/3 quartz, 1/6 illite, and 1/6 total montmorillonite plus mixed-layer clay (may be higher if montmorillonite is subordinate to mixed-layer clay). Physical properties of such a ceramically usable clay are: water of plasticity below 30-35 percent; smooth and plastic working; a total drying and firing shrinkage in the range of 10-15 percent with no cracking; firing to a hard, dense body with low porosity at 2000-2100°F without bloating.

The "ideal" mineralogical mixture probably could accommodate more illite, but such clays were not common on the Reservation. Too much kaolinite in a sample raises the required firing temperature and fuel costs. Too much montmorillonitic clay increases the water of plasticity, causes excessive drying and firing shrinkage, and usually causes cracking. Quartz will reduce shrinkage problems, but too much quartz (over 50 percent) gives a porous, punkey fired body.

The only rock unit tested which meets these standards comes from the "Eocene(?) weathered zone" developed on the Niobrara formation. The 3-foot clay bed now being used in Pine Ridge is apparently equivalent to sample 1-3 and similar clays can be found in the area west of Pine Ridge--for example, sample 3-2. Some samples at the top of the weathered zone--for example, 1-5 and 3-3--contain so much kaolinite that they are too refractory for pottery or brick clay and require firing to a higher temperature than desirable. Such highly kaolinitic clay, however, accounts for only a small proportion of the clays of the "Eocene(?) weathered zone." Ceramic properties of such refractory clay can be improved by mixing with more montmorillonitic clays, thereby improving the workability and lowering the required firing temperature. A mixture of sample 1-5 and 26-1 is mentioned in the report of the Bureau of Mines as an excellent clay for pottery. From a geographic viewpoint, a mixture of samples 1-5 and 1-2 would be more practical, as the samples are from the same locality.

According to the Bureau of Mines, samples with large amounts of calcite, like sample 2-4 should be avoided, so usable clays in the "Eocene(?) weathered zone" on the Niobrara are confined to the upper part where calcite has been leached. Calcite is easily detected, because it effervesces vigourously when doused by a 10 percent solution of hydrochloric acid (obtainable as muratic acid in drug stores).

Most other clays on the Reservation are unsuitable for ceramic use because they contain too much montmorillonite. A highly montmorillonitic composition, together with abundant calcite and bloating tendencies prohibits use of clays from the Tertiary formations and, without additives, most of the"Eocene(?) weathered zone" on the Pierre shale as well.

Addition of fine sand

Some of the clays in the "Eocene(?) weathered zone" on the Pierre shale are usable for ceramics if sand or some other nonhydroscopic material is added to reduce shrinkage and improve the drying characteristics. Addition of quartz sand will not make highly montmorillonitic samples like 13-2 usable, but will make usable the relatively low montmorillonite samples, such as sample 26-1. This sample, mixed with 30 percent fine sand, is an excellent pottery clay (table 2). Such materials are widespread in the "Eocene(?) weathered zone" in areas shown on figure 1a, near the contact of the White River group and the Pierre formation.

A preliminary estimate of the montmorillonite content may be made from the weathering characteristics of the outcrops. Highly montmorillonitic clay weathers to a frothy, loose slope; less montmorillonitic clays weather to a smoother and harder surface. In many outcrops of the "Eocene(?) weathered zone" on the Pierre shale, the lower part of the weathered zone appears more usable than the upper part. Final evaluation of individual outcrops, however, must be made by laboratory testing.

Some of the fine, white sand beds which occur locally at the base of the Chadron formation may be suitable for mixing with clay to reduce shrinkage. Material like sample 24-3, which contains about two-thirds quartz and one-third predominantly kaolinitic clay should be ideal. Other possible sources of sand for mixing are: (1) sand dunes observed east of Sheep Mountain Table and probably present elsewhere on the Reservation; (2) sand bars along the major streams; (3) sandy tuff beds in the base of the Arikaree formation composed largely of glass and zeolite (samples 17-7, 19-1, 19-2); (4) addition of grog. Grog commonly is made by grinding defective fired ware.

Refractories

The most kaolinitic parts of the "Eocene(?) weathered zone" (samples 1-5 and possibly 3-3) are usable for low-duty refractory brick. Such brick is suitable for fireplace linings, and brings a price about four times that of ordinary brick.

Sample 1-5 is apparently the same as sample SD-5 collected by Mr. Van Sant (written communication, 1960) of the Bureau of Mines;

sample SD-5 has a PCE (pyrometric cone equivalent) of 20. The thickness of this refractory clay varies from 3 to 6 feet. Such thicknesses should be suitable for strip mining where the overburden is thin.

Lightweight aggregates

Several of the more montmorillonitic samples tested by the Bureau of Mines exhibited bloating properties, and the more promising samples were tested for lightweight aggregates. None bloated sufficiently for commercial use.

None of the unweathered Upper Cretaceous rocks which are used elsewhere for lightweight aggregate were tested. Therefore, possible occurrence of bloating clays on the Reservation cannot be excluded by the limited tests made for this study.

Oil bleaching

Some montmorillonitic clays are used to decolorize oils. Sample 18-1 (I) was tested for this purpose, but it was found to be unsuitable.

Bentonite beds similar to those once used from Ardmore, S. Dak., for bleaching clays are present in the Sharon Springs member of the Pierre shale on the Reservation (locality 6, for example). However, as the bentonite bed at Ardmore is no longer commercially competitive, the similar clays on the Reservation presumably also are not.

Drilling muds

Some sodium montmorillonite clays are valuable as drilling muds. However, none of the clays from the Reservation appeared to warrant testing for this purpose; first, because calcium rather than sodium montmorillonites are dominant, and second, because the montmorillonite is not of sufficient purity for a drilling mud. Kepferle[1] has tested

[1] Thesis, 1954, p. 37; see footnote, p. 2.

montmorillonitic clays from the Chadron formation as drilling muds and found them unsuitable.

Zeolites

Zeolites are used extensively as water softeners and in industrial chemical processes. Some of the rock on the Reservation--for example, sample 19-2--contained about 30 percent of a zeolite called clinoptilolite. According to available information, however, all commercial zeolites currently in use are synthetic, and natural deposits are of no present value.

Conclusions

Ceramics appear to be the main use for which the clay deposits of the Pine Ridge Indian Reservation are suited. Clays suitable for ceramics, without addition of sand to improve drying characteristics, are confined to parts of the noncalcareous part of the "Eocene(?) weathered zone" where developed on the Niobrara formation; such clays occur only west of Pine Ridge in the southwest corner of the Reservation. Characteristics of even these clays can be improved by addition of 10 to 20 percent sand or grog.

At present, only about 3 feet of clay from the middle of the "Eocene(?) weathered zone" at locality 1 are used for pottery. Most, if not all, of the 14-foot thickness of this "Eocene(?) weathered zone" could be utilized if the unused upper and lower parts of the zone are mixed with the middle part. The mixture would have about the same composition as the middle part alone.

Some of the clays in the upper part of the "Eocene(?) weathered zone" are suitable for low-grade refractory brick for local use. Locality 1 might be a suitable mining site, and localities with thicknesses of refractory clay greater than 3 feet probably can be found by detailed work. Consideration should be given to local demand for low-grade refractory brick and other economic factors before such work is undertaken.

Large amounts of clay with fairly low montmorillonite content are available in the "Eocene(?) weathered zone" developed on the Pierre shale in many areas of the Reservation. With addition of about 20 percent fine sand or grog, this clay would be suitable for brick, tile, and pottery. If anticipated demand, fuel and transportation costs, and other economic factors seem favorable to a considerable expansion of the manufacture of clay products, detailed geologic mapping, probably accompanied by some form of drilling and testing program, would be necessary to select potential mining sites.

Description of sample localities

LOCALITY 1. $NW\frac{1}{4}$ $SW\frac{1}{4}$ sec. 13, T. 35 N., R. 45 W., near the fence line and $\frac{1}{2}$ mile north of the state line.

Chadron formation

12 ft	Clay, sandy, buff, plastic.
	Sample 1-6 -- from 4 feet above base.

"Eocene(?) weathered zone"

3 ft	Clay, light-gray mottled with a little red and purple; nonbedded; weathers almost white.
	Sample 1-5 -- middle of unit.
11 ft	Clay, yellow mottled with red and light gray; bedded; weathers to a slightly cracked, yellow surface.
	Sample 1-4 -- top of unit.
	Sample 1-3 -- middle of unit.
	Sample 1-2 -- bottom of unit.

Niobrara formation

1-2 ft	Shale, dark-gray, partly calcareous.
	Sample 1-1 -- noncalcareous shale.
	Sample 1-0.5 -- calcareous shale.

LOCALITY 2. Bottom of section is just north of the road in SE$\frac{1}{4}$ sec. 35; top of section is in NE$\frac{1}{4}$ sec. 35, T. 36 N., R. 46 W., north of the big fault.

Arikaree formation

25 ft± Siltstone, buff, noncalcareous.

Sample 2-10

(fault contact of Arikaree and Brule formation)

Brule formation

Scenic member (Bump, 1956)

30 ft± Siltstone and claystone, banded pastel tan, light-gray, and buff; partly calcareous.

Sample 2-9 -- light gray calcareous siltstone 14 feet above base.

Sample 2-8 -- buff, silty clay, 12 feet above base.

Chadron formation

30 ft Claystone, light-gray, slightly sandy near base; weathers frothy; chalcedony veins.

Sample 2-7 -- silty lense near top.

Sample 2-6 -- 7 ft above base.

"Eocene(?) weathered zone"

5 ft Clay, mottled red, purple, gray, and white; noncalcareous, nonbedded; weathers to red band.

Sample 2-5 -- middle.

Locality 2 (con.)

"Eocene(?) weathered zone" (con.)

25 ft	Clay, yellow with a little gray and red mottling; very calcareous; bedded, weathers to a yellow, moderately cracked slope.
	Sample 2-4 -- 22 feet above base.
	Sample 2-3 -- bentonite bed 9 feet above base.
	Sample 2-2 -- 6 feet above base.
4 ft	Clay, yellow like above mixed with dark-gray shale like below.

Niobrara formation

15 ft	Shale, dark-gray, very calcareous.
	Sample 2-1 -- 4 feet below top.

LOCALITY 3. $NW\frac{1}{4}$ sec. 27, T. 36 N., R. 47 W. in deep gully about 100 yards north of the road.

Chadron formation

3 ft	Clay, light-gray; frothy weathering.

"Eocene(?) weathered zone"

3 ft	Clay, slightly sandy, mottled red, light-gray, purple and brown; nonbedded; weathers to a reddish-white band.
	Sample 3-3 -- near top.
10 ft	Clay, mostly yellow but some red and gray mottling; slightly bedded; weathers yellow.
	Sample 3-2 -- middle.
5 ft	Shale, mostly yellow with a little light-gray mottling; calcareous.
	Sample 3-1 -- middle.

LOCALITY 4. Not used.

LOCALITY 5. Sec. 9, T. 33 N., R. 53 W., Dawes County, Nebraska. Toadstool Park is developed in a prominent channel sandstone in the lower part of the Brule formation. About 15-20 feet below this channel sandstone is a light colored band called the "bench" by Schultz, Tanner, and Harvey (1955). The "bench" is calcareous throughout its entire 4-5 foot thickness where sampled just north of Toadstool Park and contains a well-preserved mammalian jaw bone.

Sample 5-4 -- Siltstone, buff, very fresh, calcareous; just below the channel sandstone.

Sample 5-3 -- Siltstone, buff, calcareous; 2 feet above the "bench".

Sample 5-2 -- Siltstone, light-gray, calcareous; from the "bench".

Sample 5-1 -- Siltstone, argillaceous, buff, calcareous; 2 feet below the "bench".

LOCALITY 6. SE$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 13, T. 35 N., R. 46 W., on the north side of a hill just north of the state line. Exposures of the "Eocene(?) weathered zone" are poor.

"Eocene(?) weathered zone"

8 ft.	Clay, mottled purple, light gray, and orange; bedded;weathers to a red, fairly frothy slope.
	Sample 6-3 -- near top.
	Sample 6-2 -- near bottom.

Pierre shale, Sharon Springs member

50-75 ft.	Shale, dark-gray, fissile; bentonite abundant
	Sample 6-1 -- 5 feet below top.

LOCALITY 7. Samples of Niobrara are from $SE\frac{1}{4}$ $SW\frac{1}{4}$ sec. 9, T. 35 N., R. 45 W., and the samples of Pierre are from about 200 yards farther south in $NE\frac{1}{4}$ $NW\frac{1}{4}$ sec. 16.

"Eocene(?) weathered zone" (sec. 16)

10-15 ft.	Clay, mottled red and light green with a predominantly light green zone at the top and several light-colored bentonite bands throughout; bedded; weathers to a dark-red frothy slope. Sample 7-3 -- upper part. Sample 7-2 -- lower part.

Pierre shale, Sharon Springs member

?	Shale, black, fissile. Sample 7-1 -- just below "Eocene(?) weathered zone"

"Eocene(?) weathered zone" (sec. 9)

5 ft.	Clay, mottled purple and light gray; noncalcareous, nonbedded; weathers to a reddish-white band. Sample 7-6 -- middle.
15-20 ft.	Clay, mottled yellow, red, and light gray; very calcareous, bedded; weathers to yellow slope. Sample 7-5 -- middle

Niobrara formation

?	Marl, gray. Sample 7-4 -- just below "Eocene weathered."

LOACLITY 8. $NE\frac{1}{4}$ $NE\frac{1}{4}$ sec. 21, T. 35 N., R. 44 W., in a deep gully about 100 yards north of the state line road. Rocks contain Pliocene vertebrates (Green, 1956, p. 147). Upper and lower ledge-forming units are separated by 10 feet of softer rock.

Sample 8-1 -- sandstone, fine-grained calcareous; from middle of 10-foot soft unit.

Sample 8-2 -- ash, white; from top of lower ledge-forming unit.

LOCALITY 9. $NE\frac{1}{4}$ sec. 8, T. 36 N., R. 39 W., Bennett Co., South Dakota. At the head of Big Springs draw 100 feet of predominantly sandy rocks contains Pliocene vertebrates (Gregory, 1942). These are overlain by sand dunes of Pleistocene age.

Sample 9-3 -- sandstone, gray; clayey, 90 feet above base of the section.

Sample 9-1 -- sandstone, fine-grained, blocky, greenish; 75 feet above base of the section.

Sample 9-2 -- sandstone, medium-grained; 45 feet above base of the section.

LOCALITY 10. Samples taken from the upper, middle, and lower parts of the Arikaree formation between the town of Porcupine and Porcupine Butte.

Sample 10-3 -- sandstone, buff; fine-grained; taken at an elevation of 3615 feet on the south face of Porcupine Butte in SW$\frac{1}{4}$ sec. 17, T. 37 N., R. 42 W.

Sample 10-2 -- sandstone, buff; fine-grained; just below zone of nodules in a road cut 1.7 miles south of Porcupine at an elevation of 3435 feet; near the center of sec. 31, T. 38 N., R. 42 W.

Sample 10-1 -- sandstone, buff; fine-grained; about 40 feet below the conspicuous white marl in the knob near the church and road, $\frac{1}{2}$ mile northwest of Porcupine at an elevation of 3160 feet in the south-central part sec. 19, T. 38 N., R. 42 W.

LOCALITY 11. SW$\frac{1}{4}$ sec. 30, T. 37 N., R. 46 W., about $\frac{1}{4}$ mile west of the main road.

Chadron formation

20 ft.	Clay, light gray; weathers frothy; white limestone nodules.

"Eocene(?) weathered zone"

20 ft.	Clay, mostly light gray with a little yellow and red mottling; noncalcareous, bedded; weathers to a fairly frothy, yellow slope; contains numerous nodules oxidized to limonite. Sample 11-2 -- 2 feet below top. Sample 11-1 -- 12 feet below top.

(fresh Pierre shale is not exposed)

LOCALITY 12. SW$\frac{1}{4}$ sec. 19, T. 38 N., R. 46 W., in badland outcrops about 200 yards east of the main road. Upper part of Chadron and lower part of Brule are exposed. About 75 to 100 feet above the base of the Brule, pale-red and green bands are prominent and cut across stratification. Samples are from the same stratigraphic horizon.

Sample 12-1 -- siltstone, pale-green, blocky, calcareous.

Sample 12-2 -- siltstone, pale-red, blocky calcareous.

LOCALITY 13. $NE\frac{1}{4}$ $NW\frac{1}{4}$ sec. 35, T. 40 N., R. 47 W., in a small knob about 50 yards east of the main road. Top of the mound is near the top of the "Eocene(?) weathered zone".

"Eocene(?) weathered zone"

40 ft	Clay, mostly light-gray with a little limonite staining in patches; top part is slickensided and nonbedded, lower part is not slickensided and bedded; large limestone nodules in middle are unaffected except for a brown coating; weathers to a yellow, frothy surface.
	Sample 13-3 -- channel sample of the upper half of the unit.
	Sample 13-2 -- channel sample of the lower half of the unit.

Pierre shale

10-20 ft	Shale, dark-gray, noncalcareous.
	Sample 13-1 -- just below "Eocene(?) weathered zone".

LOCALITY 14. $E\frac{1}{2}$ $SE\frac{1}{4}$ sec. 36, T. 41 N., R. 47 W., and adjacent parts of sec. 31, R. 46 W., along the road ascending the west end of Cuny Table and in ravine southeast of the road.

Brule formation

Poleslide member (Bump, 1956)

120 ft	Siltstone, fairly massive, pale-brown with green spots; mostly calcareous with numerous calcareous nodules about 6 inches across; this must be a fairly complete section of Poleslide with only the upper part missing; the lower part probably intertongues with the Scenic member.
	Sample 14-3 -- siltstone, noncalcareous; 20 feet below the top.
	Sample 14-2 -- siltstone, calcareous; 40 feet above base.
	Sample 14-1 -- siltstone, calcareous; near base.

Brule formation

Scenic member (Bump, 1956)

15 ft	Siltstone, brown with green spots; slightly calcareous; weathers frothier and darker than unit above.
	Sample 14-4 -- middle.

Chadron formation

5 ft	Claystone, green, with numerous thin limestone layers.

LOCALITY 14. (con.)

Chadron formation (con.)

35 ft	Claystone, green, mostly noncalcareous; weathers frothy. Sample 14-5 -- 20 feet below top.

(base of Chadron not exposed)

LOCALITY 15. NW$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 23, T. 42 N., R. 47 W., in steep badlands between Cedar Creek and Red Shirt Table.

Brule formation

Scenic member (Bump, 1956)

75 ft±	Siltstone, pale-red, banded, partly calcareous; weathers slightly frothy.
	Sample 15-9 -- siltstone, calcareous; upper part.
	Sample 15-8 -- siltstone, noncalcareous; 35 feet above the base.

Chadron formation

20 ft	Claystone, with thin limestone beds.
45 ft	Claystone, red and green; partly calcareous; weathers frothy.
	Sample 15-7 -- claystone, pale-red; calcareous, 30 feet above base.
	Sample 15-6 -- claystone, green, noncalcareous; 15 feet above the base.
10 ft	Sandstone, fine-grained at top, coarse-grained and conglomeratic at the bottom; yellow; numerous clay fragments; weathers to white band.
	Sample 15-5 -- upper part.
	Sample 15-4 -- lower part.

LOCALITY 15. (con.)

"Eocene(?) weathered zone"

2 ft	Clay, light-gray, blocky, nonbedded. Sample 15-3 -- middle.
13 ft	Clay, light-gray with limonitic orange patches; weathers yellow. Sample 15-2 -- middle.

Pierre shale

35 ft	Shale, medium-gray, noncalcareous. Sample 15-1 -- just below "Eocene(?) weathered zone."

<u>LOCALITY 16.</u> SE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 24, T. 43 N., R. 47 W., Pennington County, South Dakota, in gully about 50-100 yards west of the main road north from the town of Red Shirt.

<u>Chadron formation</u>

10 ft	Claystone, green; weathers frothy.
	<u>Sample 16-5</u> -- middle.
40 ft	Sandstone, fine-grained, brown and green; abundant muscovite; weathers slightly frothy; 4 or 5 zones of hard, calcite-cemented, ledge-forming, crossbedded, conglomeratic sandstone.
	<u>Sample 16-4</u> -- sandstone, fine-grained, green; 30 feet above base.
	<u>Sample 16-3</u> -- sandstone, fine-grained, brown, slightly calcareous; 15 feet above base.
15 ft	Claystone, silty, red with green mottling.
	<u>Sample 16-2</u> -- 10 feet above base.
15 ft	Sandstone, medium- to coarse-grained, partly conglomeratic, muscovite; scour and fill.
	<u>Sample 16-1</u> -- 2 feet above base.

<u>Pierre shale</u>

?	Shale, dark-gray, upper 1-2 inches bleached light gray.

LOCALITY 17. NE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 22, T. 41 N., R. 44 W.; on the southeast side of Cedar Butte; section given by Wanless, 1923, p. 211, section B. Samples 1 and 8-11 are from locality 17A, an outlying knob on the west edge of NW$\frac{1}{4}$ sec. 23. (beds are horizontal; elevations give stratigraphic intervals)

Sample 17-7 -- ash, fine-grained, buff; weathers white; from the basal white ash of Miocene age at the top of Cedar Butte at an elevation of 3080 feet.

Sample 17-6 -- claystone, silty, pale salmon, very calcareous, interbedded with fine-grained sandstone; from an elevation of 2975 feet from Wanless' 72-foot bedded unit.

Sample 17-6ss -- sandstone interbedded with sample 17-6.

Sample 17-5 -- siltstone, ashy, pale salmon, slightly calcareous; from an elevation of 2940 feet from Wanless' 50-foot nodular bed.

Sample 17-4 -- siltstone, argillaceous, pale pink-gray; calcareous; elevation 2850 feet from Wanless' 45-foot unit.

Sample 17-3 -- siltstone, pale red, calcareous; elevation 2785 feet, just above red, ledge-forming sandstone in Wanless' red unit.

Sample 17-2 -- sandstone, fine-grained, buff, calcareous; elevation 2740 feet, about 20 feet below Wanless' red unit.

Sample 17A-11 -- claystone, silty, brown, calcareous, weathers fairly frothy; elevation 2745 feet from a 5-foot dark band apparently equivalent to Kepferle's [1] soil zone on Sheep Mountain Table.

Sample 17A-10 -- sandstone, medium-grained, buff, very calcareous, crossbedded; 1-foot thick bed at an elevation of 2717 feet.

Sample 17A-9 -- siltstone, argillaceous, pale brown, slightly calcareous; weathers slightly frothy; elevation 2703 feet.

Sample 17A-8 -- sandstone, fine-grained, white, very calcareous; one of three such discontinuous beds 1-2 feet thick exposed near the base of the knob; elevation 2700 feet; according to Kepferle [1] Wanless thought these light bands might represent caliche soils.

[1] Thesis, 1954, see footnote, p. 2

[1] Thesis, 1954, p. 19; see footnote, p. 2

LOCALITY 17. (cont.)

Sample 17A-1 -- siltstone, argillaceous pale green; calcareous, weathers buff, elevation 2690 feet from lowest horizon exposed, probably near the middle of the Scenic member (Bump, 1956).

LOCALITY 18. SW$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 24, T. 41 N., R. 44 W., about $\frac{1}{4}$ mile west of the main road in exposures from a cut bank on the White River northward toward Stirk Table.

Brule formation

Scenic member (Bump, 1956)

?	Siltstone, argillaceous, pale brown, banded, calcareous. Sample 18-3 -- 10 feet above base of Brule formation.

Chadron formation

70 ft	Claystone, pale green, noncalcareous; weathers frothy. Sample 18-2 -- 60 feet above base. Sample 18-1 -- 20 feet above base.

(base of section is River level)

LOCALITY 19. Near southwest corner sec. 28, T. 43 N., R. 44 E., along the foot path across the neck of land between Sheep Mountain Table and the small mesa on the south end of the Table. About 50 feet of the basal white ash of Miocene age cap the mesa and overlie the pink beds of the Poleslide member (Bump, 1956) which form the steep mesa walls.

Sample 19-2 -- ash, tan; about 50 feet above base of the white ash.

Sample 19-1 -- ash, white, near base of the white ash bed.

LOCALITY 20. $NE\frac{1}{4}$ $SE\frac{1}{4}$ sec. 8, T. 4 S., R. 13 E., along the park road ascending the east side of Sheep Mountain Table. Section after Kepferle [1]. Top of Brule formation is at an

[1] Thesis, 1954, p. 24; see footnote, p. 2

elevation of about 3100 feet.

Sample 20-1 -- siltstone, argillaceous, brown, noncalcareous; elevation 3060 feet near base of Kepferle's unit 3.

Sample 20-2 -- siltstone, pale brown, calcareous; elevation 2985 feet in Kepferle's unit 11.

Sample 20-3 -- siltstone, brown, slightly calcareous; from dark band 4 feet thick at elevation 2925 feet, which Kepferle interprets as a possible soil zone; Kepferle's unit 13.

Sample 20-4 -- siltstone, pale brown, slightly calcareous; from 2 feet below "soil zone" of sample 3.

LOCALITY 21. Center of $NW\frac{1}{4}$ sec. 10, T. 4 S., R. 13 E., just south of the park road leading to Sheep Mountain Table. Channel sandstone about 100 feet or a little less below the top of the Scenic member (Bump, 1956) which according to J. C. Clark (oral communication, 1960) is derived from the northern Black Hills. Farther south, heavy minerals in the Brule came from the Southern Black Hills.

Sample 21-1 -- sandstone, fine-grained, calcareous; from finest grained part of the channel sandstone.

LOCALITY 22. SW$\frac{1}{4}$ sec. 27, T. 3 S., R. 13 E., just southwest of the main road south from Scenic. This is the type section of the Scenic member (Bump, 1956).

Brule formation

Scenic member

100 ft	Siltstone and silty claystone, banded pale-green and pale-brown; some bands calcareous, others are not.
	Sample 22-6 -- siltstone, pale-green, calcareous; from 90 feet above base.
	Sample 22-5 -- claystone, silty, pale-brown, noncalcareous; from 65 feet above the base.
	Sample 22-4 -- claystone, silty, pale-brown, noncalcareous; from 37 feet above the base.
	Sample 22-3 -- siltstone, pale-green, calcareous; from 20 feet above base and just below prominent zone of nodules.
	Sample 22-2 -- claystone, silty, pale-brown, calcareous; from 5 feet above base.

Chadron formation

25 ft±	Claystone, pale-green, noncalcareous; weathers frothy.
	Sample 22-1 -- 10 feet below top.

LOCALITY 23. Sec. 11, T. 3 S., R. 13 E., about 2 miles northeast of Scenic. Basal white sandstones of the Chadron formation are widely exposed.

Chadron formation

10 ft±	Sandstone, coarse at base, fine-grained above; weathers white. Sample 23-4 -- sandstone, fine-grained; about 5 feet above base. Sample 23-3 -- sandstone, coarse; base.

"Eocene(?) weathered zone"

3 ft	Clay, mottled light gray and purple; nonbedded; weathers to light band. Sample 23-2 -- middle.
15 ft	Clay, mottled light gray and orange; bedded; weathers yellow. Sample 23-1 -- middle.

<u>LOCALITY 24</u>. $NE\frac{1}{4}$ $NW\frac{1}{4}$ sec. 23, T. 43 N., R. 40 W., in south cut bank of the White River. Sample 3 comes from $\frac{1}{4}$ mile to the southeast in $SW\frac{1}{4}$ $NE\frac{1}{4}$ sec. 23 in the west wall of Potato Creek where the basal sandstone of Chadron formation is thickest and best exposed.

<u>Chadron formation</u>

?	Claystone, pale-green; weathers frothy.
2-10 ft.	Sandstone, fine-grained, white.
	<u>Sample 24-3</u> -- 5 feet above base.

<u>"Eocene(?) weathered zone"</u>

10 ft.	Clay, red with purple and light gray mottling; nonbedded, slickensided.
	<u>Sample 24-2</u> -- middle.
20 ft.	Clay, mottled light gray, yellow, orange, and red; bedded.
	<u>Sample 24-1</u> -- middle.
5 ft.	Clay, mottled light gray, yellow, and orange; well bedded.
	<u>Sample 24-0.5</u> -- base, just above river level.

LOCALITY 25. $NE\frac{1}{4}$ $NW\frac{1}{4}$ sec. 3, T. 43 N., R. 36 W., about $\frac{1}{2}$ mile south of the mouth of Cottonwood Creek, high in the wall on the east side of the creek.

Chadron formation

?	Sandstone, fine-grained, white.

"Eocene(?) weathered zone"

3 ft	Clay, mottled purple orange pale green; bedded; weathers to reddish zone. Sample 25-3 -- middle.
17 ft	Clay, mottled yellowish-orange and light-gray; bedded; weathers yellow. Sample 25-2 -- middle.

Pierre shale

?	Shale, medium-gray, slightly calcareous. Sample 25-1 -- 5 feet below "Eocene(?) weathered zone".

LOCALITY 26. NE$\frac{1}{4}$ sec. 32, T. 43 N., R. 35 W., in cut bank on the south side of main creek about $\frac{1}{4}$ mile downstream (east) from bridge on route 73.

Chadron formation

5-15 ft.	Sandstone, fine-grained, white; fills channels cut into "Eocene(?) weathered zone."

"Eocene(?) weathered zone"

0-10 ft.	Clay, mottled purple, orange, and light gray; nonbedded, slickensided; weathers to red band; locally missing owing to channeling by the Chadron. Sample 26-2 -- middle.
20 ft.	Clay, mottled light gray, orange and a little purple; bedded; slickensided in upper part; weathers yellow. Sample 26-1 -- middle. Sample 26-0.5 -- bottom.

Bureau of Mines report of usability tests

The following report was prepared by Mr. H. P. Hamlin, Supervising Ceramic Engineer, of the Bureau of Mines testing plant at Norris, Tennessee. The report contains information on color, pH, unfired strength, plasticity, and drying effects of the raw clay; the color, hardness, shrinkage, porosity, and specific gravity of the fired clay; the pyrometric cone equivalent; and the potential use of each clay sample. The report covers tests on 10 of the 16 samples submitted as well as several mixtures of the clays.

Field No. 1-5

Lab. No. 1255-A

Type: Clay (Kaolinite)
Color: Lt. orchid
pH: 8.5
Unfired strength: Average

Raw Properties

Plastic and smooth working, requiring 25% water for plasticity, no drying defects, 6.0% drying shrinkage.

Fired Properties

Temp.	Color	Hardness	% Shk.	% Abs.	App. Sp. Gr.
1800	Mottled lt. pink	Crumbly hard	6.0	14.8	2.67
2000	Mottled lt. pink	Fair hard	9.5	16.4	2.80
2100	Mottled lt. pink	Hard	9.5	13.6	2.79
2200	Mottled lt. pink	Hard	10.5	13.3	2.78
2300	Mottled gray	Very hard	10.5	8.1	2.55
2400	Mottled gray	Very hard	10.5	7.7	2.23

Pyrometric cone equivalent = between cones 19 - 20
1515 - 1520°C

Potential Use: Chimney flue tile, and blending with other clays for pottery and structural products. It might be used for decorative brick although the firing temperature is rather high.

Field No. 1-3

Lab. No. 1255-B

Type: Clay
pH: 7.45
Color: Med. yellow
Unfired strength: Above average

Raw Properties

Plastic and smooth working, slightly fatty, requiring 36% water for plasticity, no drying defects, 9.5% drying shrinkage.

Fired Properties

1800	Lt. red buff	Fair hard	10.0	13.2	2.63
2000	Lt. red brown	Steel hard	16.0	0.5	2.52
2100	Red brown	Steel hard	18.5	0.2	2.47
2200	Dk. brown	Glazed	14.0	0.1	2.33
2300	Dk. brown	Exp.	12.5	6.9	2.10
2400	Dk. brown	Exp.	-	5.3	2.01

Potential Use

Brick and tile if mixed with fine sand to reduce shrinkage. Red burning pottery. The scumming tendencies were not reduced by the barium carbonate.

1255-B + 20% sand

Raw Properties

Plastic and smooth, slightly gritty, requiring 25% water for plasticity, no drying defects, 4.0% drying shrinkage.

Fired Properties

1800	Dull lt. red	Fair hard	6.5	12.1	2.62
2000	Med. Red Brown	Steel hard	11.5	2.2	2.46
2100	Red brown	Sl. glazed	11.5	1.9	2.48
2200	Dk. brown	Glazed	12.5	1.7	2.37
2300	Very Dk. brown	Exp.	8.5	7.4	2.16
2400	Very Dk. brown	Exp.	-	12.2	2.10

Field No. 2-5

Lab. No. 1255-C

Type: Clay
Color: Med. pink
pH: 8.15
Unfired strength:

Raw Properties

Long, smooth, very plastic, sticky, requiring 29% water for plasticity, no drying defects, 7.0% drying shrinkage.

Fired Properties

1800	Lt. red buff	Hard	10.0	11.8	2.65
2000	Reddish brown	Steel hard	13.5	2.8	2.51
2100	Red brown	Steel hard	14.5	0.2	2.44
2200	Dk. red brown	Steel hard	14.5	0.0	2.45
2300	Grayish brown	Sl. glazed	14.5	1.0	2.32
2400	Dull gray	Exp.	-	4.0	2.25

Potential Use

With 10 - 20% fine sand, this clay would make good common brick.

Field No. 2-4

Lab. No. 1255-D

Type: Clay
Color: Very lt. yellow
pH: 9.55
Unfired strength: Above average

Raw Properties

Plastic and smooth working, requiring 29% water for plasticity, no drying defects, 6.0% drying shrinkage.

Fired Properties

1800	Buff(scum)	Fair hard	8.5	17.1	2.40
2000	Buff (scum)	Hard	8.5	14.5	2.29
2100	Tannish brown	Melted	-	2.0	1.84

Potential Use

Sample high in soluble salts (probably $CaSO_4$). Fired specimens show heavy scumming. It might be mixed with sample A to reduce firing temperature provided silica would control scumming.

Field No. 7-3

Lab. No. 1255-E

Type: Clay
Color: Med. red-gray
pH: 8.50
Unfired strength: Above average

Raw Properties

Plastic, sticky, smooth, and fatty working, requiring 44% water for plasticity, no drying defects, 8.0% drying shrinkage.

Fired Properties

1800	Buff	Fair hard	12.0	16.6	2.63
2000	Lt. red brown	Very hard	16.5	5.0	2.47
2100	Dull med. red	Steel hard	17.5	3.9	2.52
2200	Red-brown	Glazed	17.5	4.3	2.47
2300	Dull gray	Exp.	16.5	5.4	2.12
2400	Dull gray	Exp.	14.0	5.9	1.96

Bloating test negative

Potential Use: none

1255-E+ 20% sand

Raw Properties

Long, smooth, plastic, gritty, requiring 30% water for plasticity. No drying defects, 4.5% drying shrinkage.

Fired Properties

1800	Buff	Crumbly hard	8.0	16.3	2.62
2000	Lt. red	Fair hard	11.0	9.3	2.55
2100	Red brown	Hard	12.5	8.7	2.55
2200	Brown	Glazed	12.5	8.3	2.48
2300	Gray brown	Exp.	10.0	7.5	2.26
2400	Dull gray	Exp.	7.5	8.0	2.01

Sand addition reduced shrinkage, but firing cracks developed due to the colloidal size of the clay particles.

Field No. 26-1

Lab. No. 1255-F

Type: Clay
Color: Lt. red tan
pH: 9.20
Unfired strength: Above average

Raw Properties

Plastic and smooth working, slow drying necessary to prevent cracking, requiring 42% water for plasticity, 11.0% drying shrinkage.

Fired Properties

1800	Lt. red	Fair hard	13.0	12.3	2.54
2000	Red	Steel hard	18.5	2.8	2.48
2100	Red-brown	Steel hard	18.5	1.4	2.25
2200	Red-brown	Sl. glazed	12.5	9.8	2.03
2300	Dk. brown	Exp.	9.5	12.4	1.94
2400	Dk. gray brown	Exp.	8.5	17.1	1.91

Bloating Test: Negative

Potential Use

Brick and tile if mixed with sand to decrease shrinkage (see data on miniature brick), pottery.

1255-F + 20% sand

Raw Properties

Plastic and smooth working, gritty, requiring 30% water for plasticity, no drying defects, dries readily, 7.0% drying shrinkage.

Fired Properties

1800	Lt. red	Fair hard	7.5	12.7	2.64
2000	Red	Steel hard	13.5	4.8	2.53
2100	Red-brown	Steel hard	13.5	4.1	2.44
2200	Dk. red brown	Sl. glazed	13.5	3.8	2.29
2300	Dk. brown	Exp.	10.0	7.2	2.09
2400	Dk. gray brown	Exp.	-	13.1	1.97

20% sand reduces % shrinkage approx. 5%, and increases firing range without appreciably affecting the maturing temperature.

Field No. 13-2

Lab. No. 1255-G

Type: Clay
Color: Lt. red-gray
pH: 9.15
Unfired strength: Above average

Raw Properties

Plastic, smooth, and very fatty working, requiring 41% water for plasticity, slow drying necessary to prevent cracking, 13.0% drying shrinkage.

Fired Properties

1800	Dull lt. red	Very hard	16.0	7.9	2.51
2000	Med. red	Steel hard	18.5	2.8	2.45
2100	Brown	Exp.	--	0.3	1.67
2200	Dk. brown	Exp.	--	52.6	1.71
2300					
2400					

Bloating test: Negative

Potential Use

None, shrinkage much too high, although sand additions reduce shrinkage, firing cracks developed due to the colloidal size of the clay particles.

1255-G (20% sand)

Raw Properties

Plastic, smooth, gritty working, requiring 29% water for plasticity, no drying defects, 6.0% drying shrinkage.

Fired Properties

1800	Lt. red	Crumbly soft	8.5	14.6	2.63
2000	Dull med. red	Crumbly hard	10.0	9.1	2.54
2100	Red brown	Glazed	9.0	6.6	2.18
2200	Dk. brown	Exp.	4.0	15.0	2.06
2300	Dk. brown	Exp.	-	13.1	1.69
2400	Dk. gray brown	Exp.	-	32.0	1.43

Field No. 2-8

Lab. No. 1255-H

Type: Clay
Color: Lt. gray
pH: 8.95
Unfired strength:

Raw Properties

Short, fatty, mealy, requiring 40% water for plasticity. No drying defects, 5/5% drying shrinkage.

Fired Properties

1800	Lt. red buff	Fair hard	12.5	14.3	2.43
2000	Dull red	Steel hard	19.0	3.2	2.37
2100	Brown	Glazed	-	0.1	1.91
2200	Brown	Exp.	-	18.2	-
2300	Overfired and melting		-	--	-

Bloating test: Negative

Potential Use

See sample G

Field No. 18-1

Lab. No. 1255-I

Type: Clay
Color: Lt. gray
pH: 9.0
Unfired strength:

Raw Properties

Plastic, smooth, and very fatty working, requiring 57% water for plasticity, must dry very slowly to prevent cracking, 15.5% drying shrinkage.

Fired Properties

1800	Dull red	Steel hard	22.0	0.9	2.33
2000	Red	Exp.	-	31.4	1.57
2100	Red brown	Exp.			

Oil bleaching test: Negative, both activated and unactivated

Bloating test: Negative

Potential Use

None

Field No. 2-10

Lab. No. 1255-J

Type: Clay
Color: Lt. red-gray
pH: 9.00
Unfired strength:

Raw Properties

Not too plastic, short and gritty working, requiring 32% water for plasticity, no drying defects, 2.0% drying shrinkage.

Fired Properties

1800	Lt. red	Crumbly soft	5.5	27.8	2.49
2000	Dull red	Crumbly hard	11.5	13.6	2.48
2100	Red-brown	Steel hard	17.0	1.4	2.20
2200	Dk. brown	Exp.	-	2.4	1.34

Bloating test: Negative

Potential Use

None

The Effect of 20% Sand on Shrinkage and Absorption

	1255-B Percent		20% sand + 1255-B Percent		1255-F Percent		20% sand + 1255-F Percent	
Temp. °F	Shk.	Abs.	Shk.	Abs.	Shk.	Abs.	Shk.	Abs.
110°C Dry	9.5	-	4.0	-	11.0		7.0	-
1800	10.0	13.2	6.5	12.1	13.0	12.3	7.5	12.7
2000	16.0	0.5	11.5	2.2	18.5	2.8	13.5	4.8
2100	18.5	0.2	11.5	1.9	18.5	1.1	13.5	4.1
2200	Exp.	0.1	12.5	1.7	Exp.	9.8	13.5	3.8
2300	Exp.	6.9	Exp.	7.4	Exp.	-	Exp.	7.2

The above shrinkages indicate that 20% sand will decrease shrinkage approximately 5% without changing the vitrification temperature appreciably.

The Use of $BaCO_3$ to Control Soluble Salts

In most cases, the soluble sulphates of K Na Ca Mg and Fe are responsible for scumming. From the test results of these clays, the addition of sand constituted a better control for the scumming than did the Barium carbonate, and this indicates that the scumming is due to Na and K sulphates (alkali) because $BaCO_3$ does not react with the alkali sulphates in the solid state. (See the fired specimens of sample B with 20% sand)

With the exception of D, the samples that show scumming must have the sand addition before they can be utilized, thus, scumming does not constitute too serious a problem. Further evidence that the sand will control the scumming is shown by the miniature brick.

Samples B, C, and D were mixed with water containing 10% of barium carbonate. The scumming tendencies were not reduced by the barium carbonate.

Preliminary Clay Blends

1255 50/50 A and B

Raw Properties

Plastic and smooth working, requiring 29% water for plasticity, drying shrinkage 6.5%, no drying defects.

Fired Properties

Temp.	Color	Hardness	% linear Shk.	% Abs.	Sp. Gr.
1800	Buff	Fair hard	8.5	14.2	2.65
2000	Lt. red	Steel hard	12.5	6.4	2.56
2100	Red brown	Steel hard	12.5	2.2	2.47
2200	Dk. brown	Steel hard	15.0	1.2	2.40
2300	Brown-gray	Steel hard	12.5	1.5	2.37
2400	Brown-gray	Exp.	Exp.	-	2.16

This blend has good color at 2100°F, and the mottled effect is very attractive for face brick, 10% sand would improve the properties of this blend.

1255-B 60% + 40% of a sandy Florida clay

The Florida material was approximately 90 percent fine sand and 10% clay.

Properties not determined, but the blend would probably be suitable for common brick. Fired colors are rather poor.

1255 50/50 D and F

Properties not determined. D is too high in calcite to be utilized as a blend with other clays.

1255-G 60% + 40% sand Florida clay

Properties not determined, firing cracks developed in test specimen.

Miniature Brick Tests

Miniature brick 2" x 1" x 1/2" were formed by pressing at 5000 p.s.i. 10 - 15% moisture was used for fabricating the test pieces.

No.	components	Temperature °F	Apparent Sp. Gr.	Percent linear Shk.	Percent Absorption
1255-A	1255-A*	2100	2.71	2.9	9.4
1255-A	1255-A*	2200	2.65	3.0	8.8
1255-A 1255-F	50/50	2050	2.53	5.9	4.8
1255-B	Clay & 30% sand	1900	2.68	2.8	7.1
Do.	do	2000	2.66	3.1	6.3
1255-C	Clay*	1900	2.59	7.1	3.2
1255-C	Clay*	2000	2.55	7.9	1.6
1255-D	Clay*	2000	2.50	1.9	14.1
1255-D	Clay*	2050	2.52	1.8	14.2
1255-F	Clay & 30% sand	1900	2.62	3.3	8.6
1255-F	do.	2000	2.61	3.6	7.9
1255-G	Clay & 40% flint	2050	2.43	1.0	16.0
1255-P	Clay & 30% sand	1900	2.69	2.9	9.6
1255-P	do.	2000	2.69	3.0	9.2
1255 A & P	50/50	2000	2.67	6.0	8.0
1255 A & P	50/50	2050	2.64	6.4	6.8
1255 A & F	50/50	2000	2.59	4.0	6.0
1255 A & F	50/50	2050	2.54	4.7	4.2

* 10% solution of barium carbonate used in mixing samples.

Preliminary Bloating Tests

Preliminary bloating tests were made on the samples that showed signs of expansion during the slow firing test. Slight expansion was obtained with H and G, but the bloating was not adequate for lightweight aggregate. Listed as follows are the samples tested for bloating.

Sample No.	Results	Sample No.	Results
1255-B	Negative	1255-H	Slight
1255-C	Negative	1255-J	Negative
1255-D	Negative		
1255-E	Negative		
1255-F	Negative		
1255-G	Slight		

Testing Pottery Clays

The selection of the samples used for making pottery was based on the data from the preliminary tests. All samples were ground to -20 mesh. Potters flint (finely ground silica) was used with some of the clays to increase the quartz content. With the exception of samples "A" and "C", none of the clays tested could be utilized for pottery without blending with fine sand or other clays.

In making the test pieces, the clay blends were mixed with enough water to form a plastic mass. The plastic mass was hand wedged, and the various shapes were thrown on a potter's wheel. During the throwing process, the characteristics of the blend were noted as related to this method of fabrication. On page 57 are given the unfired and fired properties of the various blends.

	Unfired properties										Fired properties					
Number	% Wt. Batch composition	Water %	Throwing characteristics 1	2	3	4	Wet green strength	Dry green strength	Drying characteristics	Linear Dry Shk.	Temp. °F	Soaking period hours	% Abs.	Linear firing Shk. %	Color
1255-A	Clay 100.0	30.0	F	S	F	G	Average	Average	Good	10.0	2000	1	11.3	3.5	Lt. red gray
1255-C	Clay 100.0	30.0	F	FS	F	P	High	High	Fair	15.0	2000	½	0.0	5.5	Med. red
1255-C	Clay 70.0 P.flint 30.0	34.0	G	FS	F	G	High	High	Excellent	12.0	2000	1	3.1	5.5	Med. red
1255-F	Clay 70.0 P.flint 30.0	32.0	G	S	E	G	High	High	Good	15.0	2000	½	1.6	4.7	Med. red
1255-P	Clay 70.0 P.flint 30.0	31.0	E	S	E	G	High	High	Good	12.5	2000	½	5.0	4.0	Med. red
1255-A-N	N - 50.0 A - 50.0	35.0	F	FS	P	P	High	High	Fair	12.0	2000	½	4.5	6.7	Red
1255-A-F	A - 50.0 F - 50.0	33.0	G	FS	F	G	High	High	Good	13.5	2000	1	3.5	6.0	Med. Red

1. Workability
   - P = Poor
   - F = Fair
   - G = Good
   - E = Excellent

2. Smoothness
   - N = Not smooth
   - G = Gritty
   - St = Sticky
   - S = Smooth
   - FS = Fairly smooth

3. Displacement
   - P = Poor
   - F = Fair
   - G = Good
   - E = Excellent

4. Water acceptance
   - N = None
   - P = Poor
   - F = Fair
   - G = Good

Discussion of Pottery Tests

1255-A

The vitrifying temperature of this clay is too high for average pottery. It could be used with some of the other clays to increase the vitrifying range, improve the drying characteristics, and decrease the firing shrinkage. It would probably make acceptable pottery if it was blended with feldspar or nepheline syenite.

1255-C

Good for red burning pottery, vitrification temperature is rather short. Additions of potters flint or fine sand improve the properties of the clay.

1255-F

This clay would not be suitable for pottery unless fine sand or potters flint is used because of the poor drying characteristics and the short vitrification range. It makes excellent red burning pottery with the added silica.

1255-P

See F. The properties of this clay in pottery are similar to F, and while the sample would probably make pottery without the addition of silica, silica improves its working and firing characteristics.

1255-A-N

Sample N was blended with A to decrease (high calcium content) the vitrifying temperature. The vitrification temperature was decreased, but the ware showed heavy scumming. This blend would be unsatisfactory for pottery, unless some method were developed to control scumming.

1255-A-F

This was the best clay blend tested. The vitrification range is long, and the overall working characteristics were very good.

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