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PROGRESS REPORT ON CLAYS AND SHALES OF MONTANA

1964 - 1965

by

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ABSTRACT

This report, fifth in a series of progress reports on a survey designed to catalog the clay and shale deposits of the state and to determine possible uses, if any, of the raw materials sampled, contains a description of 77 samples. The clays are tested for use as ceramic raw materials, as possible sources of expanded shale (lightweight aggregate for concrete), and as possible sources of alumina for the production of metallic aluminum.

INTRODUCTION

This bulletin is the fifth progress report on the survey of Montana's clay and shale resources, and is supplementary to the first four (Sahinen, U. M., Smith, R. I., and Lawson, D. C., 1958, 1960, and 1962, and Chelini, J. M., Smith, R. I., and Lawson, D. C., 1965). The purpose of the project is to catalog the clay and shale deposits of the state. It is intended to sample likely clay and shale deposits and to determine possible uses, if any, of the material sampled. The clays are tested for possible use as ceramic raw materials or as possible sources of expanded shale (lightweight concrete aggregate), and analyzed as possible sources of alumina for the production of metallic aluminum.

The survey was started in 1956 and will be continued until the readily accessible clay or shale deposits are sampled. The project was temporarily suspended during the 1961-63 biennium because of the drastic cuts in Bureau appropriations by the economy-minded 1961 Legislature. Montana is a large state, and it will be many years before the deposits are adequately sampled; therefore, progress reports such as this will be published as frequently as conditions warrant rather than withholding the results until the entire survey is completed.

ACKNOWLEDGMENTS

Clay samples were supplied by private individuals and by members of the Bureau staff. Chemical analyses were made by Frank P. Jones, who also performed the bloating tests. X-ray analyses and ceramic tests were made by Ralph I. Smith.

The writers take this opportunity to thank all those who rendered assistance in the field by guiding them to the deposits and providing local information. Many clay samples sent in by the public have been included in the survey, and the source of each of these is acknowledged in the description.

CLAY AND SHALE FOR CERAMIC USE

GENERAL STATEMENT

Field trips are conducted each summer to gather samples and to get sufficient geologic data to determine whether the deposits would warrant further examination if preliminary tests showed evidence of a clay or shale of special economic value. To date the Glacial Lake Missoula clays have been sampled in detail west of Missoula (Chelini and others, 1965, p. 16-20) and south and west of Polson (this report).

Four types of tests are conducted in the laboratory. Analyses by x-ray diffraction are made to determine the mineral composition; chemical analyses are made to determine chemical composition; ceramic tests are made to determine the physical properties; and bloating tests are made on the low-fusing clays to determine whether they are suitable for the manufacture of expanded shale (lightweight aggregate for concrete).

All samples collected are crushed to 3/8 inch and cut to about 2 pounds weight by coning and quartering. The 2-pound sample is ground to pass a 20-mesh screen. A small portion of the ground 2-pound sample is ground further to pass a 100-mesh screen. The minus 100-mesh material is used for x-ray and chemical analyses. The minus 20-mesh material is used for water-of-plasticity determinations, test cones, and test bricks.

LABORATORY PROCEDURE IN CERAMIC TESTING

A modified Atterberg test (Kinnison, 1915) is used to obtain the water-of-plasticity range and to indicate the plasticity. A 50-gram sample of the clay is mixed with water from a standard burette. The clay and water are worked with a spatula until the water is evenly distributed. Water is added until the clay-water mixture, when cut with a spatula, does not adhere to the spatula, and the clay on the sides of the cut remains standing. This is the lower plasticity limit. Water is again added in small amounts with mixing and working after each addition until the clay sticks to the spatula and the sides of the cut flow together immediately after the cut. This is the upper limit of plasticity. The amount of water used is expressed in percent, 1 gram being the weight of 1 cubic centimeter of water. The test shows the plasticity, working range, and roughly the type of clay mineral present. The best working range is found to be close to the lower plastic limit. The percentage of water used is a rough indication of the type of clay mineral present, as shown in the following tabulation (Skinner and Kelly, 1949):

Water of plasticity	Type of material
Less than 20%	Clay of little plasticity or non-clay mineral
20% to 40%	Clay of moderate plasticity, shale, flint clay
35% to 60%	Plastic clays, kaolin, and ball clays
Above 65%	Montmorillonite (bentonitic clays)

Test cones, made of the raw clay mixed with water, are molded, dried at 105°C (221°F), and fired with standard cones to obtain the Pyrometric Cone Equivalent (P.C.E.). When the test cone fuses, the number of the standard cone which reaches the same state of fusion is noted. Firing at temperatures to 2400°F is done in a Hayes Glo-Bar electric furnace equipped with a thermocouple and pyrometer accurate to 5°C (9°F). Firing above 2400°F is done in a Denver Fire Clay cone furnace fired with natural gas.

Test bricks 1 x 1 x 2 inches are hand molded, dried at 105°C (221°F) overnight, and fired at temperatures based on the prior P.C.E. determinations. Firing is continued about 8 hours in the Glo-Bar furnace, the thermocouple pyrometer being used for temperature control. The bricks are removed from the furnace when the predetermined temperature has been reached and then placed in another furnace at 1200°F. When the firing is finished, the furnace is turned off and the test bricks allowed to cool overnight. For specimens requiring temperature greater than 2400°F the Denver Fire Clay furnace is used, and the temperature is measured with a standard cone. The specimens are left in the furnace until cool. Although the fast firing in the laboratory furnaces usually gives higher temperature values than would be obtained in the slower fired commercial furnaces, the tests permit a good estimate of the firing range and the firing characteristics of the materials.

All test bricks are measured lineally before drying, after drying, and after firing. All shrinkage figures given in the tables are linear.

EXPANDED SHALE AS LIGHTWEIGHT AGGREGATE

INTRODUCTION

Expanded clay or shale for use as a lightweight aggregate in cement products was first produced commercially in 1919. The material was called Haydite after the man who first patented a process for expanding the material. During the years between 1919 and World War II, use of expanded clay and shale for lightweight aggregate increased very slowly. From the start of the war until 1946 there was a tremendous upswing in value of lightweight clay and shale products. According to Conley and others (1948), this value increased from $1, 713, 347 in 1936 to $140, 000, 000 in 1946. This growth is partly explained by the tremendous growth in building, but was also due to the discovery of its advantages for use in structural concrete in large buildings and its soundproofing qualities when used in ceilings and partitions.

Considerable research on lightweight aggregate material in the last 19 years has led to the following generalized conclusions:

(1) That in order to be classified as a lightweight aggregate, the material must not weigh more than 55 pounds per cubic foot for fine material and 75 pounds per cubic foot for coarse material.

(2) That the bloating characteristics of a material are not determined by the basic clay mineral structure, but by other minerals and clays associated with the clay as impurities. These minerals are carbonaceous material, different iron compounds, limestone, dolomite, and gypsum, which produce gases on heating.

There are two conditions necessary to bring about bloating in shales:

(1) When bloating temperature is reached, the general clay mass must be in a semimolten condition.

(2) At the same time gases must be evolving throughout the mass.

Under these conditions, the developed gases are entrapped in the fusion and cause the bloating.

Each clay or shale deposit is a problem in itself, and before any plant or operation is set up, a detailed geologic examination, economic study, and further tests should be made. The work done by the Bureau as described in this report is necessarily of a preliminary nature. Many clays and shales are tested in order to establish which ones are most suitable for bloating.

The bloated clay or shale produced by the expanding procedure shows which clays or shales can be treated for use as lightweight aggregate. In general, expanded clay or shale in well-rounded pellets, partly glazed, and of uniform fine cell structure is ideal for lightweight aggregate. The final test, however, is whether a concrete block in which the lightweight aggregate is used will meet all required specifications. Lightweight aggregate must weigh not more than 75 pounds and not less than 55 pounds per cubic foot, and load-bearing hollow concrete blocks in which it is used should have a minimum compressive strength of 800 pounds per square inch (total area), maximum water absorption of 15 pounds per cubic foot, and maximum moisture content of 40 percent.

Nonload-bearing blocks of this material should have a minimum compressive strength of 600 pounds per square inch, maximum water absorption of 15 pounds per cubic foot, and maximum moisture content of 40 percent. Weight of the 8 x 8 x 16-inch blocks can range between 24 and 40 pounds.

LABORATORY PROCEDURE IN EXPANDING TESTS

After the ceramic tests are run and tabulated, the clays are tested for bloating properties to determine whether they could be used as raw materials for expanded-shale lightweight aggregate for concrete. The material used for bloating is minus $\frac{3}{4}$ inch plus $\frac{1}{2}$ inch unless the original sample fragments are of a smaller size.

The firing is done in a heavy-duty Glo-Bar electric muffle furnace controlled by a thermostat that allows only a 5°C (9°F) drop in temperature. The samples require preheating. The firing is done at 2000°F to 2500°F in steps of 100°F for 20 minutes per run.

There seems to be no uniformity as to temperature scale used in expandability tests. Some authors use the Centigrade scale, others, the Fahrenheit. Ceramic data, on the other hand, are commonly given in degrees Fahrenheit. As this report covers both types of testing, the Fahrenheit scale will be used for sake of uniformity in this and future reports. For those readers accustomed to thinking in terms of the Centigrade scale, the corresponding temperature in Centigrade can be readily obtained by subtracting 32 degrees from the Fahrenheit reading and multiplying the remainder by five-ninths.

Specific-gravity determinations are made on a Jolly balance for those specimens of expanded shale that do not float in water. A specific gravity of minus one (-1) is assigned to those bloated specimens that float.

X-RAY DIFFRACTION DATA

Each sample of clay is air dried, cut, and ground to minus 100 mesh for x-ray and chemical analyses. The x-ray determinations are made with a Phillips-Norelco diffractometer. Copper radiation is used for all determinations. One trace of each clay is made using a speed of 2° Theta per minute. The sample is then deflocculated with sodium metaphosphate, and the clay minerals separated by filtration. The filtered clay minerals are centrifuged for 15 minutes and a new trace made. If necessary, further treatments are made such as saturation with glycerin for montmorillonite materials, solution of chlorite with warm dilute hydrochloric acid, an ammonium solution for vermiculite, and heat treatments to distinguish kaolin group minerals. Standard procedure for these treatments can be found in X-ray Identification and Crystal Structures of Clay Minerals, edited by G. W. Brindley, published by the Mineralogical Society of London. Results are shown in Table 4 appended to this report.

CHEMICAL ANALYSES

The chemical analyses are run primarily to determine the alumina content. Standard methods are used throughout. Analyses are given in Table 5 of the Appendix. Samples that contain more than 20 percent alumina are reanalyzed for available alumina.

DESCRIPTION OF CLAY SAMPLES AND DEPOSITS

SAMPLE 422

Sample 422 was collected by Bille G. Janssen, county extension agent, Sheridan County, from a clay exposed in sec. 13, T. 34 N., R. 57 E.

The material is gray illitic clay having fair plasticity, low-drying and firing shrinkage, and a narrow firing range. With careful handling it could be used for common brick. The clay is not suitable for manufacture of expanded aggregate.

SAMPLE 423

Sample 423 was collected by E. H. Kuhlmann from clay exposed north of Billings in the NE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 24, T. 1 N., R. 26 E.

The material is a mixture of major quartz, medium illite, and minor other clay minerals. The clay has good plasticity, but a high drying shrinkage, which makes it unsuitable for ceramic use. The clay is excellent for expanded aggregate, however, and has a wide firing range.

SAMPLES 424 to 427

Samples 424, 425, 426, and 427 were sent to the Bureau for mineral identification by Sam Harvey, P. O. Box 415, Harlem.

The material in these samples is a mixture of major nontronite and cristobalite and minor quartz. Because of poor working characteristics and high drying shrinkage, the material is not suitable for ceramic ware but sample 427 gives a good round bloated product at a temperature between 2300°F and 2400°F.

SAMPLES 428 and 429

Samples 428 and 429 were sent to the Bureau for mineral identification by O. R. Haglund, Seeley Lake. The material was collected in sec. 9, T. 13 N., R. 19 W.

The material is montmorillonitic clay containing minor feldspar. Both samples lack plasticity, are sandy, and crack on drying. Tests prove them unworthy for ceramic use or for manufacture of expanded aggregate.

SAMPLES 430 to 433

Samples 430 to 433 were sent to the Bureau by George Kanta, Three Forks. Sample 430 was collected from Pit 1; 431 from Pit 2, upper; 432 from Pit 2, lower; and 433 from Pit 3.

Sample 430 is impure hydromica, having low plasticity and poor working character. Firing characteristics are fair. Blended with more plastic clay it could be used as a grog for common brick.

Sample 431 is illitic clay containing much quartz. Its plasticity is low, but its drying and firing characteristics are good. Blended with more plastic clay it could be used as a grog for common brick.

Sample 432 is illitic clay containing large proportions of quartz and calcite. The plasticity is extremely low, but the firing characteristics are good. It could be used as a fluxing material with other more plastic clays.

Sample 433 is hard illitic clay having barely enough plasticity to hold together. The fired color is a pleasing red. It could be used as a grog material with more plastic clays for common brick and similar products.

None of the samples are suitable for manufacture of expanded aggregate.

SAMPLES 434 to 461

Samples 434 to 458 were collected by the senior author and Colin Reddin in the summer of 1964, in the Flathead Valley west and south of Polson. The material is Glacial Lake Missoula clay, of Pleistocene age.

Holes were drilled on one-mile spacings to a depth of 5 feet with a 2-inch soil auger. The total cuttings from each hole were bagged and returned to the Bureau laboratory for sample preparation.

Glacial Lake Missoula was formed when ice from the Cordilleran ice sheet in British Columbia moved southward down the Purcell Trench of northern Idaho and dammed the Clark Fork River near the Montana-Idaho line. This damming created a lake that reached a maximum altitude of about 4,200 feet above sea level. Its maximum depth near the ice dam was 2,000 feet and its area is estimated as 2,900 to 3,100 square miles. Water backed up about 200 miles; it extended into the Bitterroot Valley more than 60 miles south of Missoula, and into the Blackfoot Valley 25 miles east of Missoula. Interconnected valleys south and west of Polson also were flooded (Perry, 1962).

In the central parts of the lake, somewhat distant from the feeder streams, varved clay of considerable total thickness was formed. Even today, after much erosion, total thickness of the remaining clay beds exceeds 100 feet in places (Chelini and others, 1965, p. 18).

After Glacial Lake Missoula was drained, much of the lacustrine sediment was removed by erosion. Much of the clay within the Flathead Valley has been removed or reworked by the Flathead River and its tributaries, or has been covered with glacial morainal material and flood-plain silt. Many of the sample holes revealed clay-gravel mixtures, or silt interbedded with clay. In many holes, the nongravelly clay was silty (Fig. 1).

Samples 434 to 443, 447 to 449, 452 to 457, and 461 are tan silty illitic clay containing minor quantities of kaolinite and feldspar, and minor to medium quantities of calcite (Table 4, p. 32). These clay mixtures have fair working and firing characteristics, and with careful handling could be

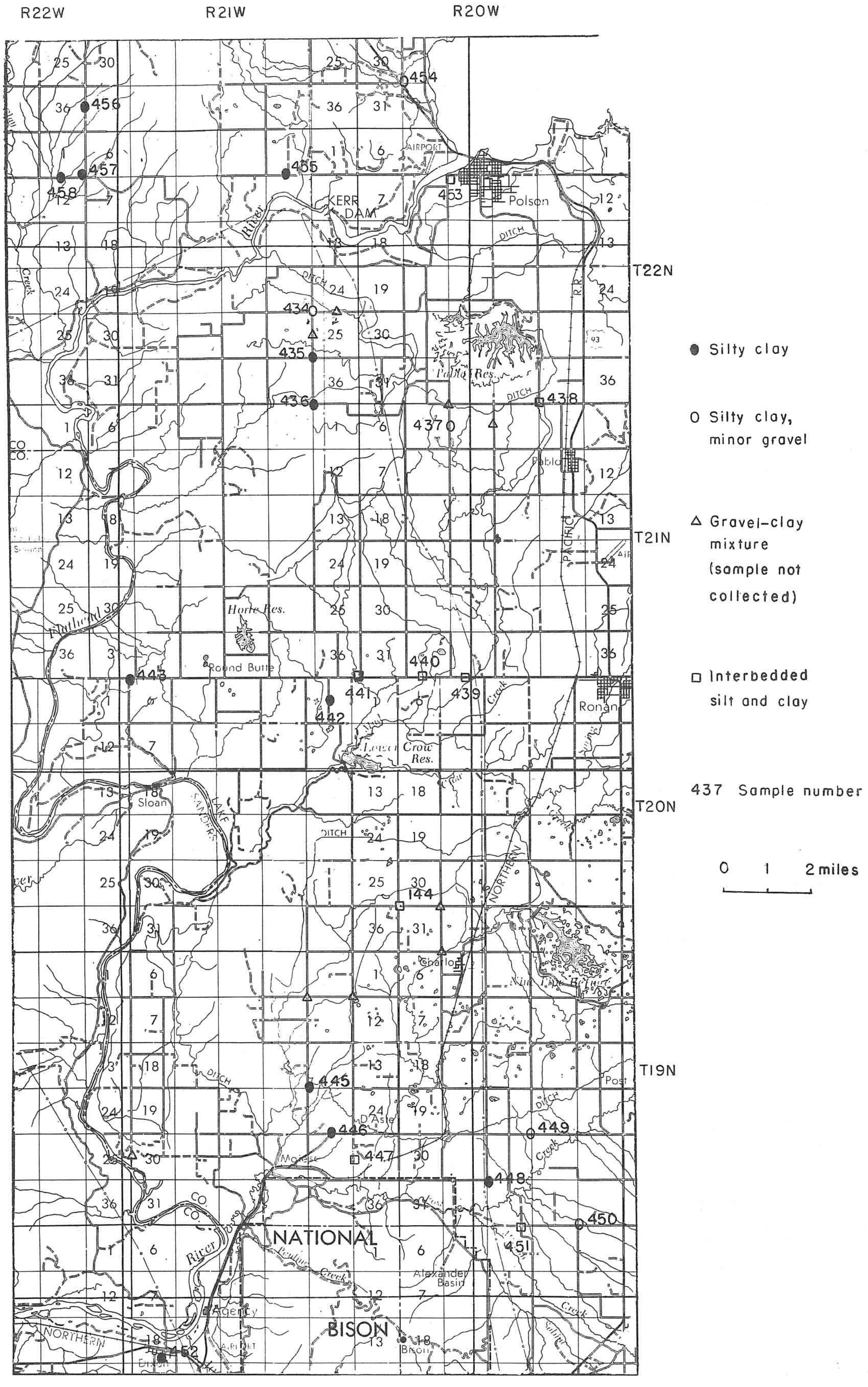

Figure 1.--Map showing location of samples 434 to 458 collected in Flathead Valley.

used for common brick. Expanded aggregate tests were not applicable to this material.

Samples 444 to 446, 450, 451, 458, and 460 were quartz-clay mixtures exhibiting no useful ceramic characteristics.

Clay sample 459 is a misnumbered sample and is void.

SAMPLE 462

Sample 462 was an 8-foot channel sample from a road cut on U. S. Highway 10A, 4 miles south of Ravalli in the SW$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 8, T. 17 N., R. 20 W. Silty clay at this locality and for about one mile southeast is about 40 feet thick and overlies gravel.

The material contains much silt-size quartz and minor illite, feldspar, and calcite. It is silty in texture, and exhibits no plasticity. Its usefulness even as grog is questionable.

SAMPLE 463

Sample 463 was collected from a Northern Pacific Railway cut near the O'Keefe Creek crossing in sec. 19, T. 14 N., R. 20 W.

The clay is light-gray hydromica containing minor impurities and is associated with impure shaly coal beds. Upon superficial examination, the quantity available seems small. The material has good firing characteristics and can be used as a blending clay for manufacture of common brick.

SAMPLE 464

Sample 464 was collected by S. L. Groff from a sequence of clay, sandstone, and conglomerate of the Bootlegger Formation in the SE$\frac{1}{4}$ sec. 28, T. 22 N., R. 1 E.

The material is light-colored bentonite containing major montmorillonite and quartz. Firing tests showed the material inferior for ceramic use, and expansion tests produced no bloating.

SAMPLE 465

Sample 465 was a pit sample collected in sec. 2, T. 14 N., R. 24 W., 6 miles west of Alberton, by Norman L. Schmidt of Alberton.

The material is impure illitic clay of low plasticity and a narrow firing range. With careful handling it could be used for common brick. Expansion tests produced no bloating.

SAMPLE 466

Sample 466 was a grab sample collected 3 miles north of Hamilton in the S$\frac{1}{2}$ sec. 11, T. 6 N., R. 21 W., by David Bennett, P. O. Box 58, Hamilton.

The material is impure bentonite containing much montmorillonite and quartz. The plasticity is low, and the firing characteristics are poor. Expansion tests produced no bloating.

SAMPLE 467

Sample 467 was obtained from a clay stockpile at Lovell Clay Products plant at Billings. Material is quarried from a pit south of Billings in sec. 21, T. 1 S., R. 26 E.

The clay is blue gray, low in clay minerals, and high in quartz and calcite; some material in the stockpile contained selenite. The plasticity is very low and the firing range is narrow. Expansion tests produced no bloating. The material possibly could be used as a fluxing material with other clays.

SAMPLES 468 to 477

Samples 468 to 477 are 8-foot auger samples collected from bentonite beds on the Crow Indian Reservation south of Billings, in the area of Hardin. These beds are estimated to include a mineable reserve of 110 million short tons of montmorillonitic clay (Knechtel and Patterson, 1956). The bentonite beds of mineable thickness are interspersed among strata belonging to Cretaceous formations ranging from Thermopolis Shale to Bearpaw Shale.

Samples 468 and 469 were collected from the Soap Creek bentonite bed in the SE$\frac{1}{4}$ sec. 19, T. 3 S., R. 32 E. Sample 468 was collected half a mile due north of ranch buildings that are on Woody Creek, 4 miles from West Creek road turnoff. Sample 469 was collected a quarter of a mile farther east. The plastic portion of the material is mostly hydromica in association with quartz, feldspar, and gypsum. Plasticity of the yellow-green material is good, but its drying shrinkage is so great that the product is unsuitable for ceramic use. Expansion tests produced no bloating.

Sample 470 was collected from bed "L" in the NE$\frac{1}{4}$ sec. 19, T. 3 S., R. 32 E. The bed forms a light streak in the north wall of the Woody Creek Valley. The fresh material is yellowish green, lacks clay minerals, and is high in quartz, calcite, and gypsum. It is unsuitable for ceramic use. Expansion tests produced no bloating.

Sample 471 was collected from bed "W" in the E$\frac{1}{2}$ sec. 8, T. 1 S., R. 35 E. The material is dark-gray illitic clay of low plasticity. It is unsuitable for ceramic use or as raw material for expanded aggregate.

Samples 472 and 473 were collected 50 feet apart in bed "V" in the SE$\frac{1}{4}$ sec. 8, T. 1 S., R. 35 E. The fresh yellowish-green material of both samples exhibits excellent plasticity, as a result of its high hydromica content, but the drying shrinkage is high, making the clay unsuitable for ceramic use. Expanded aggregate tests show that sample 472 is unsuitable but that 473 will produce a fair bloated product, though its firing range is narrow.

Sample 474 was collected from the Bearpaw Formation in the NE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 20, T. 1 S., R. 35 E. The material is dark-gray to black illite clay of good plasticity. Because the drying shrinkage is high and firing characteristics are poor, the clay is useless for ceramic products but its expansion characteristics are good.

Sample 475 was collected from bed "V" in the NE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 20, T. 1 S., R. 35 E. The fresh yellowish-green material is a mixture of illite and montmorillonite clay minerals. Its poor firing characteristics preclude its use for ceramic ware. The product gives a fair bloat, but has a narrow firing range.

Sample 476 was collected from bed "W" in the center of sec. 4, T. 3 S., R. 35 E. The light-gray material is composed chiefly of hydromica, which imparts good plasticity. Its poor firing characteristics, however, make it unsuitable for ceramic use. Expansion tests reveal a fair bloat and a medium firing range.

Sample 477 was collected from bed "W" in the center of sec. 4, T. 3 S., R. 35 E. The material is light-gray illitic clay of good plasticity and working characteristics. The firing characteristics are poor, however, and firing range so narrow as to make the clay unsuitable for ceramic use or as raw material for expanded aggregate.

SAMPLE 478

Sample 478 is a pit sample of red clay collected from the Amsden Formation at the Yellowtail Dam site in the SE$\frac{1}{4}$ sec. 18, T. 6 S., R. 31 E. The material is a mixture of the clay minerals kaolinite and hydromica but contains quartz and calcite impurities. With careful handling and blending, it could be used for common brick. Expansion tests produced no bloating.

SAMPLE 479

Sample 479 was collected from the Spokane Formation(?) east of Whitehall in the SE$\frac{1}{4}$ sec. 32, T. 1 N., R. 4 W., by U. M. Sahinen and Ralph I. Smith.

The clay minerals composing this sample are kaolinite and illite. The plasticity of the material is extremely low, and drying and firing shrinkage are moderate. With proper handling and blending it would be a good material for common brick and similar products. Expansion tests produced no bloating.

SAMPLE 480

Sample 480 was collected from the Spokane Formation(?) east of Whitehall in the SE corner sec. 32, T. 1 N., R. 4 W., by U. M. Sahinen and Ralph I. Smith. The material is hard tan-brown to red impure montmorillonitic clay with low plasticity and moderate drying shrinkage. Firing shrinkage is too high to permit use of the clay for ceramic ware. Expansion tests produced no bloating.

SAMPLE 481

Sample 481 was collected from the Spokane Formation(?) east of Whitehall in the SE corner of sec. 32, T. 1 N., R. 4 W., by U. M. Sahinen and Ralph I. Smith. The material is impure montmorillonite clay containing feldspar. The plasticity is low; drying shrinkage is moderate. The firing shrinkage, however, is too high to permit use of the clay for ceramic products. Expansion tests produced no bloating.

SAMPLES 482 to 487

Samples 482 to 487 were collected from the Spokane Formation(?) at 25-foot intervals along the face in a half circle within the Western Clay Products (presently inactive) pit east of Whitehall in the NW$\frac{1}{4}$ sec. 36, T. 2 N., R. 3 W. The samples were collected by U. M. Sahinen and Ralph I. Smith.

The tan-brown to red material contains the clay minerals kaolinite and illite in association with major quartz and hematite. The material when fired produces a bright-red brick. Though the plasticity is low, the firing and drying characteristics are good. The material is suitable for common brick. It presently is used by some hobbyists to make a variegated (tan to red-brown) pottery. Expansion tests produced no bloating.

SAMPLE 488

Sample 488 is a channel sample collected across a section of the Jens Formation on the west side of the Hoover Creek road in the NE$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 17, T. 10 N., R. 11 W.

The black fissile shale is composed of a mixture of the clay minerals illite, kaolinite, and montmorillonite. The plasticity is fair, and drying and firing shrinkage are low. With proper handling and blending it could be used for common brick. Expansion tests produced a poorly bloated product.

SAMPLES 489 to 491

Samples 489 to 491 are channel samples across a section of the Flood Member of the Blackleaf Formation, exposed in a cut on the Hoover Creek road in the center of sec. 9, T. 10 N., R. 11 W.

The black fissile shale is illite-kaolinite clay with fair plasticity and low drying and firing shrinkage. The fired color is red. With proper handling and blending it could be used for common brick. Expansion tests produced a poorly bloated product.

SAMPLE 492

Sample 492 is a channel sample collected across a section of the Flood Member of the Blackleaf Formation exposed in a cut on the Hoover Creek road in sec. 33, T. 11 N., R. 11 W. The black fissile shale is impure kaolin clay with low plasticity and drying shrinkage. The firing characteristics are good at low temperatures (minus 2000°F), but the material swells and cracks at high temperatures (plus 2200°F). With proper firing and blending it could be used for common brick. Expansion tests produced no bloating.

SAMPLE 493

Sample 493 is a channel sample collected across a section of the Kootenai Formation exposed in a cut on the Hoover Creek road in sec. 28, T. 11 N., R. 11 W. The red and green shale contains illite and chlorite clay minerals and major quartz as an impurity. The drying shrinkage is low, but the firing characteristics and plasticity are poor. The clay is unsuitable for ceramic use or as a raw material for expanded aggregate.

SAMPLE 494

Sample 494 is a channel sample collected across a section of the Kootenai Formation exposed in a side hill cut at Miller Pond in sec. 28, T. 11 N., R. 11 W. The variegated red, green, and brown shale contains illite, kaolinite, and chlorite clay minerals. The plasticity and drying shrinkage are low, and the firing characteristics are good, but the clay has a tendency to swell and crack at high temperatures (plus 2300°F). With careful firing it could be used for common brick. Expansion tests produced no bloating.

SAMPLE 495

Sample 495 is a grab sample collected from an exposed section of the Flood Member of the Blackleaf Formation south of Jens on the Dunkleberg road in the NE$\frac{1}{4}$ sec. 22, T. 9 N., R. 12 W.

The black fissile shale is impure chloritic clay with low plasticity and drying shrinkage. The firing characteristics are fair except for a tendency to swell and crack at high temperatures. With careful firing or blending with other clays, this material could be used for common brick.

SAMPLES 496 and 497

Samples 496 and 497 were collected from clay exposed in an interstate highway road cut south of Dillon. The cut caused resumption of movement of an old slide. Corrective procedure included removal of the clay body that was sampled. These samples have therefore been voided.

SAMPLE 498

Sample 498 is a 45-foot channel sample taken across Jurassic shale at Rattler Gulch in the NW$\frac{1}{4}$ sec. 15, T. 11 N., R. 13 W.

The red and maroon material is composed of major quartz, medium feldspar, and minor kaolin, illite, montmorillonite, and some hematite. Drying and firing characteristics are fair, indicating that with careful handling and firing, the clay could be used for common brick. Expansion tests produced a poorly bloated product.

SAMPLE 499

Sample 499 is a 20-foot channel sample across a gray clay seam exposed in a road cut on the Blue Joint road in the NW$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 33, T. 1 S., R. 22 W. The clay, which includes a 4-foot red core, is composed of kaolinite and contains small amounts of quartz and hematite as impurities. The plasticity and drying properties are good. With controlled firing it would be a very good material for brick and red-firing ceramic products. Expansion tests produced a poorly bloated product.

SAMPLE 500

Sample 500 was collected by E. B. Chinn of Willow Creek from shale exposed in the center of sec. 18, T. 1 N., R. 2 W. The sample was sent for mineral identification and assigned mineral identification no. 11,242.

The material is nearly devoid of clay minerals, but contains major calcite, medium vermiculite, and minor quartz, feldspar, and dolomite. Despite the high calcite content, the material burns to a nice buff brick. It could be used as a flux and binder if blended with other buff-burning clays. Expansion tests produced no bloating.

SAMPLE 501

Sample 501 is a grab sample collected from a clay body exposed in a road cut at the Josephine mine in the SE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 26, T. 8 N., R. 6 W.

The light-gray black-speckled material is illitic clay with fair plasticity and fair firing properties. The fired brick is mottled brown. With controlled handling the clay could be used for common brick or as a blending material.

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Figure 2. --Index map of Montana showing clay sample localities described in this report.

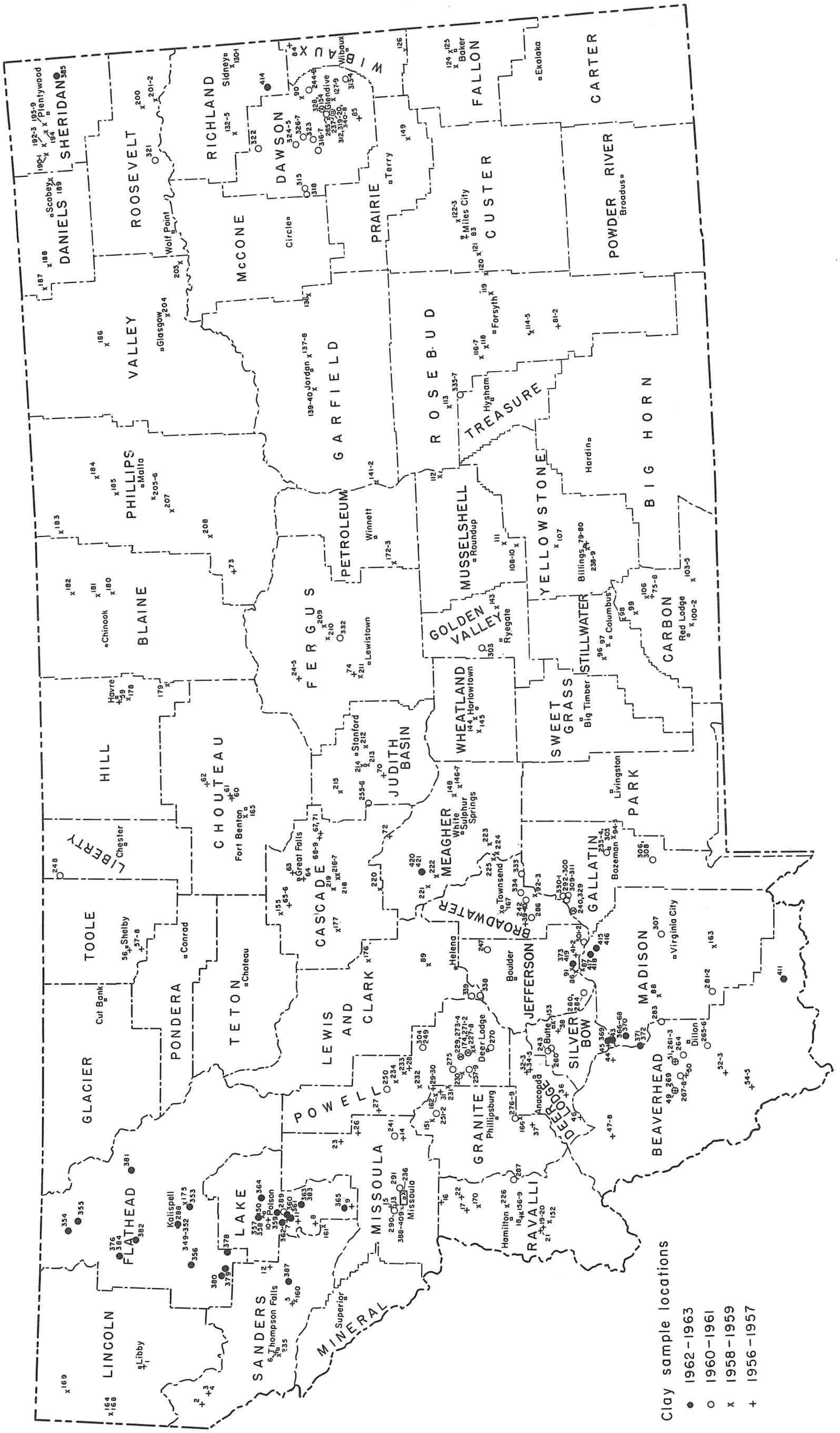

Figure 3. --Index map of Montana showing clay sample localities described in earlier progress reports.

TABLE 1.--Sample locations, Montana clay and shale.

Sample no.	Field no.	Formation	Location, collector	County	Location	Sec.	T.	R.
422	64-1	Unknown	E. of Antelope, B.G. Janssen	Sheridan	---	13	34 N.	57 E.
423	64-2	Unknown	N. of Billings, E.H. Kuhlmann	Yellowstone	NE$\frac{1}{4}$ NW$\frac{1}{4}$	24	1 N.	26 E.
424	64-3	Unknown	Sam Harvey, Harlem	---	---	--	--	--
425	64-4	Unknown	Sam Harvey, Harlem	---	---	--	--	--
426	64-5	Unknown	Sam Harvey, Harlem	---	---	--	--	--
427	64-6	Unknown	Sam Harvey, Harlem	---	---	--	--	--
428	64-7	Unknown	O.R. Haglund, Seeley Lake	Missoula	---	9	13 N.	19 W.
429	64-8	Glacial Lake Missoula	O.R. Haglund, Seeley Lake	Missoula	---	9	13 N.	19 W.
430	64-9	Unknown	George Kanta, Three Forks	Unknown	Pit 1	--	--	--
431	64-10	Unknown	George Kanta, Three Forks	Unknown	Pit 2 upper	--	--	--
432	64-11	Unknown	George Kanta, Three Forks	Unknown	Pit 2 lower	--	--	--
433	64-12	Unknown	George Kanta, Three Forks	Unknown	Pit 3	--	--	--
434	Cl-1-64	Glacial Lake Missoula	SW of Polson	Lake	SE corner	23	22 N.	21 W.
435	Cl-2-64	Glacial Lake Missoula	SW of Polson	Lake	SW corner	25	22 N.	21 W.
436	Cl-3-64	Glacial Lake Missoula	SW of Polson	Lake	SW corner	36	22 N.	21 W.
437	Cl-4-64	Glacial Lake Missoula	SW of Polson	Lake	E$\frac{1}{4}$ corner	5	21 N.	20 W.
438	Cl-5-64	Glacial Lake Missoula	SW of Polson	Lake	NE corner	3	21 N.	20 W.
439	Cl-6-64	Glacial Lake Missoula	E. of Ronan	Lake	N$\frac{1}{4}$ corner	5	20 N.	20 W.
440	Cl-7-64	Glacial Lake Missoula	E. of Ronan	Lake	N$\frac{1}{4}$ corner	6	20 N.	20 W.
441	Cl-8-64	Glacial Lake Missoula	E. of Ronan	Lake	SW corner	31	20 N.	20 W.
442	Cl-9-64	Glacial Lake Missoula	E. of Ronan	Lake	Center	2	20 N.	20 W.
443	Cl-10-64	Glacial Lake Missoula	E. of Ronan	Lake	NW$\frac{1}{4}$	6	20 N.	21 W.
444	Cl-11-64	Glacial Lake Missoula	SW of Ronan	Lake	SW corner	30	20 N.	20 W.
445	Cl-12-64	Glacial Lake Missoula	SW of Charlo	Lake	NW corner	23	19 N.	21 W.
446	Cl-13-64	Glacial Lake Missoula	SW of Charlo	Lake	N$\frac{1}{4}$ corner	26	19 N.	21 W.
447	Cl-14-64	Glacial Lake Missoula	SW of Charlo	Lake	E$\frac{1}{4}$ corner	26	19 N.	21 W.
448	Cl-15-64	Glacial Lake Missoula	SE of Charlo	Lake	SW corner	28	19 N.	20 W.
449	Cl-16-64	Glacial Lake Missoula	SE of Charlo	Lake	SW corner	22	19 N.	20 W.
450	Cl-17-64	Glacial Lake Missoula	SE of Charlo	Lake	SW corner	35	19 N.	20 W.

451	Cl-18-64	Glacial Lake Missoula	SE of Charlo	Lake	S$\frac{1}{4}$ corner	33	19 N.	20 W.
452	Cl-19-64	Glacial Lake Missoula	N. of Dixon	Sanders	SW$\frac{1}{4}$ SE$\frac{1}{4}$	18	18 N.	21 W.
453	Cl-20-64	Glacial Lake Missoula	W. of Polson	Lake	NW corner	9	22 N.	20 W.
454	Cl-21-64	Glacial Lake Missoula	NW of Polson	Lake	SW corner	29	23 N.	20 W.
455	Cl-22-64	Glacial Lake Missoula	W. of Polson	Lake	S$\frac{1}{4}$ corner	2	23 N.	21 W.
456	Cl-23-64	Glacial Lake Missoula	W. of Polson	Lake	W$\frac{1}{4}$ corner	31	23 N.	21 W.
457	Cl-24-64	Glacial Lake Missoula	SW of Polson	Lake	SW corner	6	22 N.	21 W.
458	Cl-25-64	Glacial Lake Missoula	SW of Polson	Lake	S$\frac{1}{4}$ corner	1	22 N.	21 W.
459	Sample voided		---	---	---	--	--	--
460	Cl-27-64	Glacial Lake Missoula	NW of Niarada	Flathead	E$\frac{1}{2}$ NW$\frac{1}{4}$	34	25 N.	24 W.
461	Cl-28-64	Glacial Lake Missoula	N. of Niarada	Flathead	NE corner	19	24 N.	23 W.
462	Cl-19-64	Glacial Lake Missoula	S. of Ravalli	Missoula	SW$\frac{1}{4}$ SE$\frac{1}{4}$	8	17 N.	20 W.
463	Cl-30-64	Glacial Lake Missoula	S. of Evaro	Missoula	---	19	14 N.	20 W.
464	64-41	Bootlegger	S. L. Groff	Cascade	SE$\frac{1}{4}$	28	22 N.	1 E.
465	65-1	Unknown	W. of Alberton, I. E. Schmidt	Mineral	---	2	14 N.	24 W.
466	65-2	Unknown	N. of Hamilton, D. E. Bennett	Ravalli	S$\frac{1}{2}$	11	6 N.	21 W.
467	Cl-1-65	---	Stockpile, Lovell Clay Products, Billings	Unknown	---	11	1 S.	26 E.
468	Cl-2-65	Cody	SW of Hardin	Big Horn	SE$\frac{1}{4}$	19	3 S.	32 E.
469	Cl-2a-65	Cody	SW of Hardin	Big Horn	SE$\frac{1}{4}$	19	3 S.	32 E.
470	Cl-3-65	Cody	SW of Hardin	Big Horn	NE$\frac{1}{4}$	19	3 S.	32 E.
471	Cl-4-65	Bearpaw	E. of Hardin	Big Horn	SE$\frac{1}{2}$	8	1 S.	35 E.
472	Cl-5-65	Bearpaw	E. of Hardin	Big Horn	SE$\frac{1}{4}$	8	1 S.	35 E.
473	Cl-5a-65	Bearpaw	E. of Hardin	Big Horn	SE$\frac{1}{4}$	8	1 S.	35 E.
474	Cl-6-65	Bearpaw	E. of Hardin	Big Horn	NE$\frac{1}{4}$ SW$\frac{1}{4}$	20	1 S.	35 E.
475	Cl-7-65	Bearpaw	E. of Hardin	Big Horn	NE$\frac{1}{4}$ SW$\frac{1}{4}$	20	1 S.	35 E.
476	Cl-8-65	Bearpaw	SE of Hardin	Big Horn	Center	4	3 S.	35 E.
477	Cl-8a-65	Bearpaw	SE of Hardin	Big Horn	Center	4	3 S.	35 E.
478	Cl-9-65	Amsden	Yellowtail dam	Big Horn	SE$\frac{1}{4}$	18	6 S.	31 E.
479	S-65-1	Spokane(?)	E. of Whitehall	Jefferson	SE$\frac{1}{4}$	32	1 N.	4 W.
480	S-65-2	Spokane(?)	E. of Whitehall	Jefferson	SE corner	32	1 N.	4 W.

TABLE 1. --Sample locations, Montana clay and shale, contd.

Sample no.	Field no.	Formation	Location, collector	County	Location	Sec.	T.	R.
481	S-65-3	Spokane(?)	E. of Whitehall	Jefferson	SE corner	32	1 N.	4 W.
482	S-65-4	Spokane(?)	Western Clay Products pit, N. of Cardwell, U.M. Sahinen	Jefferson	NW$\frac{1}{4}$	36	2 N.	3 W.
483	S-65-5	Spokane(?)	Western Clay Products pit	Jefferson	NW$\frac{1}{4}$	36	2 N.	3 W.
484	S-65-6	Spokane(?)	Western Clay Products pit	Jefferson	NW$\frac{1}{4}$	36	2 N.	3 W.
485	S-65-7	Spokane(?)	Western Clay Products pit	Jefferson	NW$\frac{1}{4}$	36	2 N.	3 W.
486	S-65-8	Spokane(?)	Western Clay Products pit	Jefferson	NW$\frac{1}{4}$	36	2 N.	3 W.
487	S-65-9	Spokane(?)	Western Clay Products pit	Jefferson	NW$\frac{1}{4}$	36	2 N.	3 W.
488	Cl-10-65	Jens	N. of Jens	Powell	NE$\frac{1}{4}$ SE$\frac{1}{4}$	17	10 N.	11 W.
489	Cl-11a-65	Blackleaf	N. of Jens	Powell	Center	9	10 N.	11 W.
490	Cl-11b-65	Blackleaf	N. of Jens	Powell	Center	9	10 N.	11 W.
491	Cl-11c-65	Blackleaf	N. of Jens	Powell	Center	9	10 N.	11 W.
492	Cl-12-65	Blackleaf	N. of Jens	Powell	---	33	11 N.	11 W.
493	Cl-13-65	Kootenai	N. of Jens	Powell	---	28	11 N.	11 W.
494	Cl-14-65	Kootenai	N. of Jens	Powell	---	28	11 N.	11 W.
495	Cl-15-65	Blackleaf	S. of Jens	Granite	NE$\frac{1}{4}$	22	9 N.	12 W.
496) 497)	Dalys Spur slide area, samples voided.							
498	Cl-18-65	Jurassic undifferentiated	1.4 miles up Rattler Gulch	Missoula	NW$\frac{1}{4}$	15	11 N.	13 W.
499	Cl-19-65	(Fissure)	Mud Creek road cut	Ravalli	NW$\frac{1}{4}$ NE$\frac{1}{4}$	33	1 S.	22 W.
500	Cl-20-65	Unknown	$\frac{1}{2}$ mile N. of Limespur	Jefferson	Center	18	1 N.	2 W.
501	Cl-21-65	(Fissure)	Josephine mine	Jefferson	SE$\frac{1}{4}$ NE$\frac{1}{4}$	26	8 N.	6 W.

TABLE 2.--Ceramic properties of clay and shale samples.

Sample no.	Water of plasticity %	Drying shrinkage %	P. C. E.	Firing range °F	Firing temperature °F	Firing shrinkage %	Fired color	Hardness	Remarks
a/	b/	c/	d/			e/	f/	g/	
422	L 27 H 42	5.5	2	1900 to 2000	1600 1800 2000	0.0 0.0 4.5	tan tan brown	SS SS HS	Fair common brick.
423	L 42 H 75	Not fired, brick cracked on drying.							Not suitable.
424	L 79 H 172	Not fired, brick cracked on drying.							Not suitable.
425	L 86 H 190	Not fired, brick cracked on drying.							Not suitable.
426	L 88 H 190	Not fired, brick cracked on drying.							Not suitable.
427	L 78 H 190	Not fired, brick cracked on drying.							Not suitable.
428	None	Sandy, not enough plasticity to form brick.							Not suitable.
429	L 70 H 73	10.2	4	1900 to 2050	1650 1850 2050	0.0 11.0 12.0	tan tan red	SS SS HS	Low plasticity, could be used as grog.
430	L 24 H 31	3.5	12	2100 to 2300	1900 2100 2300	1.9 2.8 3.7	tan red red	SS HS HS	Low plasticity, could mixed with other clays for common brick.
431	L 25 H 29	3.3	4	1900 to 2050	1650 1850 2050	0.0 2.2 2.4	tan lt. red red	SS S HS	Low plasticity, could be used as grog.

a/ See Table 1.

b/ L, lower limit; H, upper limit.

c/ Drying shrinkage is lineal.

d/ Pyrometric cone equivalent in standard Segar cones.

e/ Firing shrinkage is lineal; OF, over fired.

f/ lt, light; dk, dark.

g/ S, steel hard; HS, harder than steel; SS, softer than steel.

TABLE 2.--Ceramic properties of clay and shale samples, contd.

Sample no.	Water of plasticity %	Drying shrinkage %	P. C. E.	Firing range °F	Firing temperature °F	Firing shrinkage %	Fired color	Hardness	Remarks
432	L 24	5.3	4	1900	1650	0.0	tan	SS	Common brick.
	H 32			to	1850	1.0	lt. red	S	
				2050	2050	3.0	red	HS	
433	L 23	2.0	6	1900	1650	0.0	red	SS	Low plasticity, could be used as grog.
	H 25			to	1850	2.1	red	S	
				2050	2050	2.3	red	HS	
434	L 27	3.4	2	1900	1600	0.0	tan	SS	Common brick.
	H 38			to	1800	2.8	tan	S	
				2000	2000	7.2	brown	HS	
435	L 32	5.5	3	1900	1600	0.0	tan	SS	Common brick.
	H 44			to	1800	0.0	tan	SS	
				2000	2000	8.8	brown	HS	
436	L 34	5.4	4	1950	1650	0.0	tan	SS	Common brick.
	H 44			to	1850	0.0	tan	SS	
				2050	2050	8.5	red	HS	
437	L 32	6.0	4	1900	1650	0.0	tan	SS	Common brick.
	H 38			to	1850	0.0	tan	SS	
				2000	2050	10.3	brown	HS	
438	L 27	2.0	4	1900	1650	0.0	tan	SS	Common brick.
	H 38			to	1850	0.0	tan	SS	
				2050	2050	8.8	brown	HS	
439	L 27	0.9	4	1950	1650	0.0	tan	SS	Common brick.
	H 34			to	1850	0.0	tan	SS	
				2050	2050	8.7	brown	HS	
440	L 33	1.1	3	1900	1600	0.0	tan	SS	Common brick.
	H 40			to	1800	0.0	tan	SS	
				2000	2000	10.0	brown	HS	
441	L 32	2.6	4	1900	1650	0.0	tan	SS	Common brick.
	H 40			to	1850	0.0	tan	SS	
				2050	2050	10.6	brown	HS	
442	L 35	4.5	3	1900	1600	0.0	tan	SS	Common brick.
	H 44			to	1800	0.5	tan	SS	
				2000	2000	10.7	brown	HS	

TABLE 2.--Ceramic properties of clay and shale samples, contd.

Sample no.	Water of plasticity %	Drying shrinkage %	P. C. E.	Firing range °F	Firing temperature °F	Firing shrinkage %	Fired color	Hardness	Remarks
443	L 34	5.5	2	1900	1600	0.0	tan	SS	Common brick.
	H 45			to	1800	0.0	tan	SS	
				2000	2000	10.0	brown	HS	
444	L 35	9.2	02	1800	1550	0.0	tan	SS	Scum on fired brick,
	H 49			to	1750	1.5	tan	SS	not suitable.
				1900	1950	8.1	lt. red	HS	
445	L 37	7.6	01	1800	1550	0.0	tan	SS	Scum on fired brick,
	H 53			to	1750	0.0	tan	SS	not suitable.
				1850	1950	9.1	lt. red	HS	
446	L 39	15.0	01	1800	1550	0.0	tan	SS	Scum on fired brick,
	H 47			to	1750	0.0	tan	SS	not suitable.
				1950	1950	3.8	lt. red	HS	
447	L 27	5.0	2	1900	1600	0.0	tan	SS	Common brick.
	H 33			to	1800	0.0	tan	S	
				2000	2000	7.2	brown	HS	
448	L 35	6.5	2	1900	1600	0.0	tan	SS	Common brick.
	H 46			to	1800	1.0	tan	SS	
				2000	2000	8.5	brown	HS	
449	L 38	5.5	01	1800	1550	0.0	tan	SS	Common brick.
	H 53			to	1750	2.9	lt. red	S	
				1900	1950	9.7	red	HS	
450	L 34	7.5	2	1850	1600	0.0	tan	SS	Brick swelled and
	H 52			to	1800	3.1	tan	S	cracked, not suitable.
				1900	2000	-8.6	brown	HS	
451	L 34	6.0	2	1850	1600	0.0	tan	SS	Scum on fired brick,
	H 48			to	1800	0.0	tan	S	not suitable.
				1900	2000	10.2	brown	HS	
452	L 22	2.2	5	1900	1650	0.0	tan	SS	Common brick
	H 29			to	1850	0.0	tan	S	
				2050	2050	7.3	lt. red	HS	
453	L 30	1.0	4	1900	1650	0.0	tan	SS	Common brick.
	H 37			to	1850	0.0	tan	SS	
				2050	2050	8.6	brown	HS	

TABLE 2.--Ceramic properties of clay and shale samples, contd.

Sample no.	Water of plasticity %	Drying shrinkage %	P.C.E.	Firing range %	Firing temperature °F	Firing shrinkage %	Fired color	Hardness	Remarks
454	L 32 H 38	2.0	2	1900 to 2000	1600 1800 2000	0.0 0.0 9.4	tan tan red	SS SS HS	Common brick.
455	L 28 H 32	1.7	4	1900 to 2000	1650 1850 2050	0.0 0.0 8.5	tan tan brown	SS SS HS	Low plasticity, could be used as grog.
456	L 32 H 40	4.9	1	1950 to 2000	1550 1750 1950	0.0 0.0 3.0	tan tan brown	SS S HS	Common brick.
457	L 31 H 33	2.0	4	1950 to 2000	1550 1750 1950	0.0 0.0 3.2	tan tan brown	SS S HS	Common brick.
458	L 30 H 43	5.4	3	1900 to 2000	1600 1800 2000	0.0 0.0 5.2	tan tan brown	SS S HS	Scum on fired brick, not suitable.
459	Sample voided								
460	Sandy, not enough plasticity to form brick.								
461	L 28 H 38	2.3	4	1900 to 2050	1650 1850 2050	0.0 0.0 8.5	tan tan brown	SS SS HS	Common brick.
462	Sandy, not enough plasticity to form brick.								
463	L 44 H 62	Not fired, brick cracked on drying.							
464	L 30 H 114	Not fired, brick cracked on drying.							
465	L 27 H 32	9.5	9	2000 to 2100	1800 2000 2200	0.0 11.3 OF	tan brown brown	SS S HS	Fair common brick.

TABLE 2. --Ceramic properties of clay and shale samples, contd.

Sample no.	Water of plasticity %	Drying shrinkage %	P. C. E.	Firing range %	Firing temperature °F	Firing shrinkage %	Fired color	Hardness	Remarks
466	L 35 H 48	8.8	11	none	1850 2050 2250	2.5 6.5 6.7	tan red brown	SS S HS	Unsuitable, brick cracked when fired.
467	L 20 H 25	9.5	9	2100 to 2150	1800 2000 2200	1.5 1.5 OF	buff buff lt. green	SS SS HS	Poor common brick, high lime content and narrow firing range.
468	L 46 H 118		2	Brick cracked when dried.					Unsuitable.
469	L 50 H 118		3	Brick cracked when dried.					Unsuitable.
470	L 25 H 36	9.3	01	1850 to 1900	1600 1800 1950	1.3 1.7 5.5	tan lt. red brown	SS S HS	Poor common brick, narrow firing range.
471	L 38 H 65		2	Brick cracked when dried.					Unsuitable.
472	L 32 H 70		2	Brick cracked when dried.					Unsuitable.
473	L 62 H 102		3	Brick cracked when dried.					Unsuitable.
474	L 43 H 78		2	Brick cracked when dried.					Unsuitable.
475	L 65 H 112		2	Brick cracked when dried.					Unsuitable.
476	L 37 H 55		2	Brick cracked when dried.					Unsuitable.
477	L 36 H 60	8.8	2	1850 to 1900	1600 1800 2000	0.0 1.7 OF	lt. red lt. red red	SS S HS	Poor common brick, narrow firing range.
478	L 20 H 24	9.2	9	1900 to 2150	1800 2000 2200	0.3 1.2 2.6	lt. red red red	S HS HS	Fair common brick.

TABLE 2.--Ceramic properties of clay and shale samples, contd.

Sample no.	Water of plasticity %	Drying shrinkage %	P. C. E.	Firing range %	Firing temperature °F	Firing shrinkage %	Fired color	Hardness	Remarks
479	L 22 H 25	9.6	10	2000 to 2200	1800 2000 2200	0.5 1.5 2.5	lt. red lt. red lt. red	SS HS HS	Fair common brick.
480	L 52 H 57	9.4	02	none	1600 1750 1950	1.9 4.4 18.3	buff buff red	SS SS HS	Unsuitable, high firing shrinkage.
481	L 60 H 63	9.5	3	none	1600 1800 2000	4.7 11.2 OF	tan red red	SS SS HS	Unsuitable, poor firing characteristics.
482	L 22 H 28	9.5	10	2000 to 2150	1800 2000 2200	1.1 8.0 10.0	lt. red gray gray	SS HS HS	Good common brick.
483	L 24 H 30	9.5	10	1900 to 2150	1800 2000 2200	2.2 6.8 2.3	red dk. red dk. red	S HS HS	Good common brick.
484	L 22 H 28	9.6	10	1900 to 2150	1800 2000 2200	0.8 7.2 10.3	red dk. red dk. red	S HS HS	Good common brick.
485	L 24 H 29	9.6	11	1900 to 2200	1850 1050 2250	2.2 8.3 7.3	red dk. red dk. red	S HS HS	Good common brick.
486	L 22 H 27	9.6	12	1950 to 2250	1900 2100 2300	4.1 8.3 7.1	red dk. red brown	HS HS HS	Good common brick.
487	L 24 H 29	9.6	12	1950 to 2200	1900 2100 2300	4.5 8.3 4.7	lt. red lt. red brown	S HS HS	Good common brick.
488	L 20 H 28	5.8	3	1900 to 2000	1600 1800 2000	0.0 0.0 0.6	tan tan dk. red	SS S HS	Fair common brick.
489	L 17 H 22	3.2	3	1900 to 2000	1600 1800 2000	0.0 0.0 2.5	red red dk. red	SS SS HS	Fair common brick

TABLE 2. --Ceramic properties of clay and shale samples, contd.

Sample no.	Water of plasticity %	Drying shrinkage %	P. C. E.	Firing range %	Firing temperature °F	Firing shrinkage %	Fired color	Hardness	Remarks
490	L 19	3.2	5	none	1700	0.5	lt. red	SS	Not suitable, brick cracked when fired, narrow firing range.
	H 22				1900	0.2	lt. red	SS	
					2100	OF	brown	HS	
491	L 18	3.6	5	1950 to 2050	1700	0.0	lt. red	SS	Fair common brick.
	H 21				1900	0.4	red	S	
					2100	0.0	dk. red	HS	
492	L 20	4.5	over 12	1900 to 2150	1900	4.3	lt. red	S	Fair common brick
	H 26				2100	3.7	dk. red	HS	
					2300	3.3	brown	HS	
493	L 18	2.5	5	none	1700	0.0	lt. red	SS	Unsuitable, swelling when fired.
	H 21				1900	0.0	red	S	
					2100	-3.5	dk. red	HS	
494	L 18	2.5	9	1950 to 2050	1800	0.6	red	SS	Poor common brick, careful firing required.
	H 22				2000	3.5	dk. red	HS	
					2200	-1.2	dk. red	HS	
495	L 18	3.5	over 12	2000 to 2200	1900	2.2	lt. red	SS	Fair common brick.
	H 25				2100	10.0	dk. red	S	
					2300	3.3	dk. red	HS	
496	L 49		10	Brick cracked when dried.					Unsuitable.
	H 66								
497	L 55		4	Brick cracked when dried.					Unsuitable.
	H 70								
498	L 22	3.6	3	1800 to 1950	1600	3.1	lt. red	SS	Fair common brick.
	H 26				1800	1.6	lt. red	S	
					2000	3.5	brown	HS	
499	L 24	7.0	over 12	1950 to 2300	1900	2.0	lt. red	S	Good common brick with careful firing
	H 32				2100	8.4	lt. red	HS	
					2300	11.2	dk. red	HS	
500	L 25	3.8	9	2100 to 2150	1800	0.0	buff	SS	Unsuitable alone, could be used as blending material.
	H 28				2000	-1.5	buff	SS	
					2200	OF	brown	HS	
501	L 38	3.0	over 12	2100 to 2300	1900	2.4	buff	SS	Mottled color, fair common brick.
	H 42				2100	3.6	tan	HS	
					2300	6.7	brown	HS	

TABLE 3. --Results of expandability tests made on samples of clay and shale described in this report.

Sample no.	Location, county	Expansion range °F	Sp. gr. after firing	Firing behavior	Remarks
422	Sheridan	None	---	Fused at +2400	Not suitable
423	Yellowstone	2100 to 2300	1.0	Minor fusion at 2400	Excellent product; wide range
424	Unknown	None	---	Slight glaze at 2400	Not suitable
425	Unknown	2400 to 2500	---	Medium bloat at 2400	Severe decrepitation at 700°F; not suitable
426	Unknown	None	---	Slight bloat at 2400 with fusion	Not suitable
427	Unknown	2300 to 2400	1.0	Incipient fusion at 2400	Good round bloat, narrow range
428	Missoula	None	---	Partially fused at 2400	Not suitable
429	Missoula	None	---	Fused at 2400	Not suitable
430	Unknown	2400 to 2500	---	Good bloat at 2500	Not economical at this temperature
431	Unknown	None	---	Fused at 2500	Not suitable
432	Unknown	None	---	Fused at 2400	Not suitable
433	Unknown	None	---	Fused at 2400	Not suitable
434 to 463	Not suitable to expansion tests				
464	Cascade	2300 to 2400	1.0	Fused at 2400	Narrow bloating range
465	Mineral	None	---	Fused at 2300	Not suitable
466	Ravalli	2400 to 2450	1.4	Fair bloat at 2400	Narrow range; not suitable
467	Unknown	None	---	Fused at 2200	Not suitable
468	Big Horn	2200 to 2300	0.70	Fair bloat at 2200	Narrow range; not suitable
469	Big Horn	2100 to 2300	1.1	Fused at 2400	Fair bloat, but narrow range
470	Big Horn	None	---	Fused at 2300	Not suitable
471	Big Horn	2000 to 2100	1.3	Fused at 2300	Fair bloat, but narrow range
472	Big Horn	None	---	Fused at 2200	Not suitable
473	Big Horn	2200 to 2400	-1.0	Fused at 2400	Fair bloat
474	Big Horn	2000 to 2300	-1.0	Fused at 2400	Good bloat, medium range
475	Big Horn	2200 to 2300	-1.0	Fused at 2300	Fair bloat, but narrow range
476	Big Horn	2000 to 2300	1.0	Fused at 2300	Fair bloat, medium range
477	Big Horn	None	---	Fused at 2300	Not suitable
478	Big Horn	2200 to 2400	---	Slight bloat	Not suitable

479	Jefferson	2300 to 2400	---	Slight bloat	Not suitable
480	Jefferson	None	---	Fused at 2100	Not suitable
481	Jefferson	None	---	Fused at 2400	Not suitable
482	Jefferson	2300 to 2400	-1.0	Fair bloat	Not suitable, narrow range
483	Jefferson	2300 to 2400	-1.0	Fair bloat	Not suitable, narrow range
484	Jefferson	None	---	No change	Not suitable
485	Jefferson	None	---	No change	Not suitable
486	Jefferson	None	---	No change	Not suitable
487	Jefferson	None	---	Fused at 2400	Not suitable
488	Powell	None	---	Fused at 2400	Not suitable
489	Powell	2100 to 2400	---	Fused at 2400	Poor bloat; not suitable
490	Powell	2000 to 2300	---	Fused at 2300	Poor bloat; not suitable
491	Powell	2000 to 2400	---	Fused at 2400	Poor bloat; not suitable
492	Powell	2000 to 2400	---	Considerable spalling	Not suitable
493	Powell	2000 to 2400	---	Considerable spalling	Not suitable
494	Powell	2000 to 2400	---	Considerable spalling	Not suitable
495	Granite	2300 to 2400	-1.0	Some spalling	Fair bloat, narrow range
496	Sample voided				
497	Sample voided				
498	Missoula	None	---	No change	Not suitable
499	Ravalli	2200 to 2300	---	Fused at 2300	Poor bloat; not suitable
500	Jefferson	None	---	Fused at 2400	Not suitable
501	Jefferson	None	---	No change	Not suitable

TABLE 4.--X-ray diffraction data on Montana clay and shale.

Sample no.	Kaolin	Montmor-illonite	Quartz	Feldspar	Illite	Calcite	Other
422	med	---	maj	min	maj	tr	---
423	min	med	maj	min	med	min	med. chlorite, min. dolomite
424	---	---	min	---	---	---	maj. nontronite and cristobalite
425	---	---	min	---	---	---	maj. nontronite and cristobalite
426	---	---	min	---	---	---	maj. nontronite and cristobalite
427	---	---	min	---	---	---	maj. nontronite and cristobalite
428	---	maj	---	min	---	tr	---
429	---	maj	---	min	---	---	---
430	---	---	min	tr	---	---	maj. hydromica, min. complex silicates
431	min	---	maj	---	maj	min	min. chlorite
432	min	---	maj	---	maj	maj	min. chlorite and sulfates
433	min	tr	maj	min	maj	---	tr. chlorite
434	min	tr	maj	min	maj	min	min. hydromica and iron oxides
435	min	---	maj	min	maj	min	min. chlorite
436	min	---	maj	min	maj	med	min. chlorite and hydromica
437	---	---	maj	min	maj	min	min. dolomite and chlorite
438	tr	---	maj	min	med	med	min. chlorite and cristobalite
439	---	---	maj	min	med	min	min. chlorite and cristobalite
440	min	---	maj	min	maj	med	min. dolomite and chlorite
441	min	tr	maj	min	maj	med	min. dolomite, chlorite, and hydromica
442	min	---	maj	min	maj	med	min. chlorite
443	med	---	maj	min	med	min	min. dolomite and chlorite
444	med	---	maj	min	med	tr	tr. dolomite
445	med	---	maj	min	med	min	min. dolomite and chlorite
446	min	---	maj	min	maj	min	min. dolomite and chlorite
447	min	---	maj	min	min	min	min. dolomite and chlorite
448	med	---	maj	min	med	med	min. chlorite
449	min	tr	maj	min	maj	min	---
450	med	tr	maj	min	med	min	min. chlorite
451	med	---	maj	min	med	min	min. chlorite
452	med	---	maj	min	maj	med	min. dolomite and chlorite
453	med	---	maj	min	maj	med	min. dolomite and chlorite
454	med	---	maj	min	maj	min	min. dolomite and chlorite
455	med	---	maj	min	med	med	min. dolomite, chlorite, and meta-halloysite
456	med	---	maj	min	maj	min	min. dolomite and chlorite

TABLE 4.--X-ray diffraction data on Montana clay and shale, contd.

Sample no.	Kaolin	Montmor-illonite	Quartz	Feldspar	Illite	Calcite	Other
457	min	tr	maj	min	maj	min	min. dolomite and chlorite
458	med	---	maj	min	med	min	min. chlorite
459	Sample voided						
460	maj	---	min	min	---	min	maj. cristobalite
461	min	---	maj	min	maj	med	min. dolomite, chlorite, cristobalite, and complex silicates
462	---	---	maj	min	min	min	min. chlorite
463	min	tr	min	---	min	tr	maj. hydromica
464	---	maj	maj	---	---	---	min. mixed sulfates
465	min	med	maj	min	med	min	min. dolomite
466	min	med	maj	med	---	---	med. gypsum, min. cristobalite
467	min	---	maj	tr	min	maj	min. dolomite
468	min	---	maj	med	---	---	maj. hydromica, min. gypsum
469	---	---	maj	med	---	min	maj. hydromica, min. gypsum
470	min	---	maj	min	min	maj	min. dolomite and gypsum in several stages of hydration
471	---	---	maj	min	maj	min	min. gypsum subhydrate
472	---	---	med	maj	min	tr	maj. hydromica, min. gypsum and dolomite
473	---	---	med	maj	min	tr	maj. hydromica
474	min	---	maj	med	maj	min	min. gypsum
475	---	med	med	med	med	---	cristobalite
476	---	---	maj	med	min	tr	med. hydromica, min. gypsum
477	---	---	maj	med	maj	---	med. hydromica, min. dolomite and hematite
478	med	---	maj	---	---	min	min. hydromica
479	med	---	maj	tr	med	---	---
480	---	maj	min	tr	---	---	tr. cristobalite
481	---	maj	min	maj	min	---	tr. cristobalite
482	med	---	maj	tr	maj	---	tr. hydromica
483	min	---	maj	tr	maj	---	min. hematite
484	med	---	maj	tr	maj	---	min. hematite
485	min	---	maj	tr	maj	---	min. hematite
486	med	---	maj	tr	maj	---	min. hematite

TABLE 4.--X-ray diffraction data on Montana clay and shale, contd.

Sample no.	Kaolin	Montmor-illonite	Quartz	Feldspar	Illite	Calcite	Other
487	med	---	maj	tr	maj	---	min. hematite
488	min	med	maj	tr	min	med	---
489	med	---	maj	min	med	tr	min. hematite
490	med	min	maj	med	---	maj	min. hematite
491	med	---	maj	min	min	min	min. chlorite
492	maj	---	maj	---	med	---	---
493	---	---	maj	---	med	---	med. chlorite
494	med	---	maj	tr	med	med	med. chlorite
495	---	---	maj	---	min	med	maj. chlorite, min. talc
496	---	maj	tr	min	min	---	maj. cristobalite
497	---	maj	tr	---	---	---	maj. cristobalite
498	min	min	maj	med	min	---	min. hematite
499	maj	tr	min	---	---	---	min. hematite
500	---	---	tr	min	---	maj	med. vermiculite, min. dolomite
501	min	---	maj	min	med	---	tr. dolomite

TABLE 5. --Chemical analyses of high-alumina clay samples giving available alumina for those exceeding 20 percent total alumina.

Sample no.	Total Al_2O_3	Available Al_2O_3	SiO_2	Fe	CaO	MgO	Na_2O	K_2O	TiO_2	H_2O -140°C	Ign. loss 650°C
422	14.65	---	53.5	2.80	5.90	5.10	2.42	1.39	0.10	0.50	---
423	16.75	---	59.1	4.40	1.31	2.32	1.68	1.59	0.15	3.65	---
424	16.15	---	60.1	2.60	2.32	2.43	1.88	0.32	0.04	7.80	---
425	16.30	---	63.5	2.45	1.26	2.39	1.83	1.30	0.03	7.20	---
426	15.50	---	63.4	2.35	1.16	2.32	2.15	0.07	0.06	6.70	---
427	17.75	---	62.2	2.25	1.01	2.61	3.90	0.07	0.02	7.20	---
428	18.90	---	57.1	4.00	2.02	1.12	1.90	0.13	0.40	6.80	---
429	18.35	---	57.0	4.10	3.18	1.41	2.34	0.53	0.35	7.60	---
430	20.80	17.1	57.8	3.60	0.91	1.01	3.72	1.17	0.40	3.85	7.90
431	18.05	---	53.4	4.40	2.12	2.50	0.95	3.43	0.30	2.65	---
432	18.60	---	46.4	4.20	8.10	2.36	1.20	3.65	0.40	2.50	---
433	20.10	18.9	58.0	5.60	0.35	1.63	1.51	2.44	0.43	1.30	4.85
434	13.40	---	59.7	2.70	3.33	2.86	1.88	1.50	0.15	2.25	---
435	13.15	---	59.4	2.85	5.20	2.90	1.57	1.08	0.18	4.30	---
436	10.80	---	67.4	2.30	3.03	2.17	1.74	0.93	0.18	2.70	---
437	13.90	---	64.0	3.10	4.29	3.19	1.48	0.59	0.20	1.60	---
438	16.05	---	56.3	3.60	2.58	3.51	1.42	1.66	0.22	2.15	---
439	15.95	---	55.4	3.45	2.02	3.55	1.28	0.75	0.22	1.30	---
440	14.75	---	60.2	3.10	3.33	3.40	1.42	1.56	0.15	3.15	---
441	14.85	---	60.2	3.10	3.33	3.16	1.67	2.65	0.20	1.50	---
442	16.65	---	56.2	3.35	4.39	3.48	1.74	1.57	0.12	3.00	---
443	17.85	---	54.3	3.85	3.13	3.77	1.23	2.31	0.17	3.15	---
444	19.10	---	51.7	4.50	1.11	3.84	1.10	2.72	0.18	7.65	---
445	19.10	---	51.3	4.40	2.07	4.05	1.51	2.42	0.22	5.45	---
446	16.15	---	57.8	5.05	3.08	3.62	1.62	2.18	0.20	3.95	---

TABLE 5. --Chemical analyses of high-alumina clay samples giving available alumina for those exceeding 20 percent total alumina, contd.

Sample no.	Total Al_2O_3	Available Al_2O_3	SiO_2	Fe	CaO	MgO	Na_2O	K_2O	TiO_2	H_2O -140°C	Ign. loss 650°C
447	12.40	---	63.3	4.05	4.00	2.68	1.81	1.96	0.13	1.40	---
448	14.80	---	56.1	5.05	3.02	3.55	1.34	0.57	0.10	2.70	---
449	17.75	---	51.4	5.45	2.73	4.34	1.50	2.80	0.12	2.80	---
450	16.75	---	49.4	4.85	3.08	4.56	0.93	0.26	0.08	3.60	---
451	15.70	---	52.7	4.40	3.54	4.09	2.29	1.54	0.10	4.20	---
452	11.10	---	67.3	3.20	3.54	2.32	1.54	1.64	0.12	0.65	---
453	11.05	---	61.4	3.40	5.18	3.11	1.78	0.69	0.10	0.40	---
454	13.30	---	61.2	3.50	3.95	3.19	2.02	1.81	0.15	0.60	---
455	10.05	---	67.7	2.70	3.29	3.98	1.97	1.29	0.11	0.45	---
456	14.90	---	55.7	4.15	4.27	1.99	1.76	1.78	0.18	1.55	---
457	13.25	---	62.5	3.40	2.43	2.93	2.16	1.97	0.16	1.30	---
458	14.75	---	60.2	3.40	2.53	3.33	0.76	1.79	0.14	0.75	---
459	Sample voided										
460	17.05	---	65.6	1.50	0.71	0.33	2.50	1.95	0.10	1.20	---
461	10.40	---	63.4	2.90	4.05	2.53	2.49	2.08	0.10	0.75	---
462	7.85	---	69.6	2.40	3.14	2.03	2.34	1.55	0.08	0.25	---
463	18.55	---	52.1	4.65	0.91	2.74	1.53	0.43	0.35	12.85	---
464	11.85	---	62.6	2.20	1.92	1.45	3.81	0.54	0.05	4.15	---
465	17.70	---	65.7	2.60	2.82	1.27	2.25	1.11	0.41	1.17	---
466	18.40	---	62.1	2.30	0.91	0.62	2.76	0.95	1.16	1.72	---
467	18.70	---	41.0	2.90	18.60	0.87	3.06	2.24	0.26	2.50	---
468	19.70	---	63.3	1.40	1.72	1.47	1.70	2.34	0.07	17.30	---
469	19.60	---	64.0	1.50	2.37	1.29	2.90	0.22	0.03	21.20	---
470	13.90	---	49.0	2.10	11.90	0.94	3.35	1.31	0.46	7.55	---
471	16.75	---	61.0	2.70	1.92	1.15	3.82	0.79	0.80	17.90	---
472	14.95	---	64.3	2.00	2.02	1.51	4.47	1.26	0.25	15.75	---
473	15.00	---	63.2	1.10	2.32	1.70	0.69	0.54	0.16	22.35	---
474	16.55	---	56.3	3.20	2.68	1.12	3.13	0.50	0.50	28.00	---

475	14.30	---	65.5	1.90	1.62	1.47	5.06	0.84	0.34	17.75	---
476	13.85	---	62.8	2.50	2.27	1.10	4.72	0.88	0.75	12.15	---
477	13.95	---	63.4	2.80	3.64	0.69	4.03	0.98	0.57	11.85	---
478	14.75	---	60.8	5.50	2.27	1.12	1.69	0.46	0.33	3.35	---
479	10.00	---	75.7	2.90	0.90	1.16	1.18	0.22	0.41	0.45	---
480	12.70	---	64.3	1.15	1.60	2.39	4.46	2.67	0.20	2.50	---
481	12.80	---	60.0	2.65	2.70	3.26	1.88	1.45	1.09	4.55	---
482	23.40	10.80	52.0	4.50	0.80	0.80	1.82	1.64	1.41	0.25	6.75
483	21.80	11.05	53.0	6.60	0.60	0.54	3.83	0.61	0.84	0.50	7.95
484	21.90	8.80	54.8	9.00	0.70	0.54	1.23	1.23	0.33	0.25	9.15
485	22.30	8.75	54.6	5.10	0.50	0.51	1.96	0.32	1.09	0.50	6.30
486	21.80	9.15	52.4	7.50	0.65	0.36	1.00	1.40	1.00	0.25	6.00
487	21.50	9.70	52.7	7.40	0.70	0.25	1.13	0.19	0.83	0.30	5.75
488	16.20	---	56.5	2.75	4.20	2.50	0.86	0.19	0.75	1.70	---
489	18.65	---	55.8	5.65	1.40	3.22	0.54	0.49	0.84	0.85	---
490	13.10	---	52.6	3.55	8.00	2.97	2.77	0.70	0.25	2.50	---
491	16.95	---	57.2	4.80	1.60	2.39	2.13	0.54	0.34	1.35	---
492	24.30	7.95	52.3	5.60	0.40	1.34	0.21	0.41	0.56	3.35	9.55
493	15.00	---	61.2	3.60	3.60	2.06	1.93	1.36	0.66	2.35	---
494	18.75	---	58.2	5.15	1.20	2.57	2.98	1.50	0.75	0.45	---
495	25.95	6.50	51.5	5.40	0.50	1.30	1.79	1.23	0.58	1.15	7.45
496	Sample voided										
497	Sample voided										
498	26.05	1.90	60.9	4.60	2.40	2.50	0.24	0.33	0.80	0.75	5.25
499	20.25	15.30	38.8	9.15	0.30	0.13	0.92	0.19	1.66	1.25	12.55
500	7.25	---	28.7	1.85	19.20	14.25	2.95	1.81	0.25	0.65	---
501	13.25	---	70.0	1.60	0.50	0.33	1.28	0.92	0.14	1.10	---

TABLE 6.--Fusing points of Seger cones.

	When fired slowly 20°C per hr.		When fired rapidly 150°C per hr.	
Cone no.	°C	°F	°C	°F
022	585	1085	605	1121
021	595	1103	615	1139
020	625	1157	650	1202
019	630	1166	660	1220
018	670	1238	720	1328
017	720	1328	770	1418
016	735	1355	795	1463
015	770	1418	805	1481
014	795	1463	830	1526
013	825	1517	860	1580
012	840	1544	875	1607
011	875	1607	895	1643
010	890	1634	905	1661
09	930	1706	930	1706
08	945	1733	950	1742
07	974	1787	990	1814
06	1005	1841	1015	1859
05	1030	1886	1040	1904
04	1050	1922	1060	1940
03	1080	1976	1115	2039
02	1095	2003	1125	2037
01	1110	2030	1145	2093
1	1125	2057	1160	2120
2	1135	2075	1165	2129
3	1145	2093	1170	2138
4	1165	2129	1190	2174
5	1180	2156	1205	2201
6	1190	2174	1230	2246
7	1210	2210	1250	2282
8	1225	2237	1260	2300
9	1250	2282	1285	2345
10	1260	2300	1305	2381
11	1285	2345	1325	2417
12	1310	2390	1335	2435
13	1350	2462	1350	2462
14	1390	2534	1400	2552
15	1410	2570	1435	2615
16	1450	2642	1465	2669
17	1465	2669	1475	2687
18	1485	2705	1490	2714
19	1515	2759	1520	2768
20	1520	2768	1530	2786
23			1580	2876
26			1595	2903
27			1605	2921
28			1615	2939
29			1640	2984
30			1650	3002
31			1680	3056
32			1700	3092
33			1745	3173