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PROGRESS REPORT ON CLAYS AND SHALES OF MONTANA 1960 - 1961

by

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PROGRESS REPORT ON THE CLAYS AND SHALES OF MONTANA, 1960-1961

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ABSTRACT

This report is the third in a series of progress reports on a survey of Montana's clay resources. The first two reports were issued as Information Circular 23 (June 1958) and Bulletin 13 (January 1960). The survey is intended to catalog the clay (and shale) deposits of the State and to determine possible uses, if any, of the raw materials sampled. 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. This report contains a description of 108 samples.

INTRODUCTION

This bulletin is the third progress report on the survey of Montana's clay and shale resources. The first progress report was issued as Information Circular 23 in June 1958, and the second, as Bulletin 13 in January 1960. This report is supplementary to the first two. (Sahinen, U. M., Smith, R. I., and Lawson, D. C., 1958, 1960.)

The purpose of this project is to catalog the clay (and shale) deposits of the State and to make this information available to all concerned. It is intended to sample likely clay (and shale) deposits and to determine possible uses, if any, of the material sampled. The clays are examined for possible use as ceramic raw materials, as possible sources of expanded shale lightweight concrete aggregate, and as possible sources of alumina for the production of metallic alluminum.

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 1961-1963 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 withhold the results until the entire survey is completed.

Acknowledgments

The geological examinations for this report were made by Uuno M. Sahinen. X-ray analyses and all ceramic tests were made by Ralph I. Smith. Chemical analyses were made by Clem J. Bartzen and Don C. Lawson. Bloating tests were made by Don C. Lawson. The Ideal Cement Co., Trident, Montana, made flame-photometer analyses for sodium and potassium on the clays. The Anaconda Company furnished the analyses for available alumina.

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 these are acknowledged in the descriptions.

CLAY AND SHALE FOR CERAMIC USE

Field trips are conducted each summer to gather samples and to get sufficient geologic data to determine if the deposit would warrant further examination if preliminary tests showed evidence of a clay or shale of special economic value. No field trips were made in 1961 because of lack of funds. However, 37 clay samples sent in by residents of the State are included as survey work for that year. So far all work has been of a preliminary nature.

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 if they are suitable for the manufacture of expanded shale lightweight aggregate for concrete.

All of the 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 (Kinneson, 1915) is used to obtain the water of plasticity range and indicate the plasticity as follows: 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 the 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 following the cut. This is the upper limit of plasticity. The amount of water used is measured in percent, using 1 gram as 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 up to 2,400° F. is done in a Hayes Glo-Bar electric furnace equipped with a thermocouple and Pyrometer accurate to 5° C. (9° F.). Firing above 2,400° F. is done in a Denver Fire Clay cone furnace fired with natural gas.

Test bricks 1 by 1 by 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, using the thermocouple pyrometer for temperature control. The bricks are removed from the furnace when the predetermined temperature has been reached and then placed in another furnace at 1,200° F. When the firing is finished, the furnace is turned off and the test bricks allowed to cool overnight. For specimens taking over 2,400° F. the DFC cone furnace is used, and the temperature 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 (Table 7), the tests give a good estimation 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 and shale as a lightweight aggregate for use 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 a very slow increase in use of expanded clay and shale for lightweight aggregate took place. 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 partially 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 sound-proofing qualities when used in ceilings and partitions.

Considerable research has been done on lightweight aggregate material in the past 19 years by many people with the following generalized conclusions:

1. That in order to be classified as a lightweight aggregate, it must weigh not more than 55 pounds per cubic foot for fine material and 70 pounds per cubic foot for coarse material.

2. That the bloating characteristics of a material are determined not 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 2 necessary conditions to bring about bloating in shales:

1. When the bloating temperature is reached, the general clay mass must be in a semi-molten condition;

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

If the above stated conditions exist, the developed gases are entrapped in the fusion and cause the bloating.

In California and North Dakota pH* tests on a mud slurry of different clays and shales were found to be 90 percent accurate in determining the bloating and non-bloating clays. If the slurry had a pH

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*pH is a measure of acidity or alkalinity. Materials with a pH below 7 are acidic, those above 7 are alkaline.

above 5, the clay would bloat, but if it was under 5, it would not. This was found not to apply in all areas as tests run on Indiana shales by Murray and Smith (1958) showed no connection between pH and bloating ability. Tests run on water slurries of 27 Montana clay and shale samples by the Montana Bureau of Mines and Geology also showed no connection between bloating ability and pH.

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 testing should be made. The work done by the Bureau as described in this report is necessarily of a preliminary nature, and testing is done on many clays and shales to establish which ones are most favorable for bloating.

The bloated clay or shale produced by the expanding procedure show which clays or shales are most favorable for use as lightweight aggregate. In general, expanded clay or shale in well-rounded pellets, partly glazed, and with a uniform fine cell structure is considered 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 aggregates must weigh not over 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 using 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. The 8 x 8 x 16 inch blocks can range between 24 and 40 pounds in weight.

Laboratory Procedure in Expanding Tests

After the ceramic tests are run and tabulated, the clays that show P.C.E. values of less than cone 6 are tested for bloating properties to determine if they could be used as raw materials for expanded shale lightweight aggregate for concrete building masonry units.

The material used for bloating is minus 3/4 inch plus 1/2 inch except in such cases where the original sample fragments are of a smaller size.

The firing is done in a heavy-duty Glo-Bar electric muffle furnace with an automatic temperature control thermostat which allows only a 5° C. (9° F.) drop in temperature. The samples require preheating. The firing is done at ranges from 2,000° F. to 2,400° 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, is 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 subtacting 32° from the Fahrenheit reading and multiplying the remainder by 5/9.

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. Cobalt and copper radiations were tried. Copper was selected as the more suitable, and it is used for all the 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 fifteen minutes and a new trace made. If necessary, further treatments are made, such as saturation with glycerene 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 in the Appendix. Those which show high alumina content (20% or over) are reanalyzed for available alumina.

DESCRIPTION OF CLAYS AND DEPOSITS

Sample 241

This clay is from a deposit on the Blackfoot River sampled by Norman Rogers of Helena. It is a soft clay greyish-orange pink (5 YR 7/2)* in color. The material appears to be a Pleistocene clay from Glacial Lake Missoula deposits. The clay is highly calcareous, slightly bentonitic, and disintegrates readily in water. (Sahinen,

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*Color names and designations from "Rock Color Chart" distributed by the Geological Society of America.

U. M., Smith, R. I., and Lawson, D. C., 1958, p. 5, pl. 1.) The size of the deposit in unknown to the writers, but similar clay is very plentiful in northwestern Montana wherever Glacial Lake Missoula sediments are found.

Ceramically, the clay is sticky, has medium plasticity, and has good green strength. The P.C.E. is cone 3 (2,093° F.), and the firing range is 1,850° to 1,950° F. With careful handling and firing, it could be used for common brick.

When tested as a possible source of lightweight aggregate, the material yielded an expanded product, but only at a high temperature and over a very narrow range. It is doubtful if it could be used commercially for this purpose.

Sample 242

This sample was collected by Norman Rogers from the Toston area. It is a firm, compact clay of a moderate red-orange (10 R 6/6) color. It is noncalcareous and disintegrates slowly in water. The geologic formation from whence it came and the size of the deposit are unknown to this writer.

The clay has medium plasticity, good working properties, and good green strength. The P.C.E. is cone 9 (2,282° F.), and the firing range is 1,800° to 2,000° F. It is a good material for common brick and like products.

When tested for lightweight aggregate, it was found unsuitable. It glazed at 2,192° F. but did not expand.

Sample 243

Another clay sampled by Norman Rogers of Helena is from the Tuxedo mine in sec. 28, T. 4 N., R. 9 W., about 12 miles west of Butte. The clay is very light grey (N 8) or white (N 9), hard, noncalcareous, but highly bentonitic. It breaks down fairly readily in water to a suspension of clay and a residue of quartz and altered feldspar.

The ground material is gritty, but has medium plasticity and fair green strength. The P.C.E. is over cone 12, and it fires well from 1,950° to 2,400° F., the latter being the highest temperature available at the time of test firing. The fired color ranges from a buff at lower temperatures to a delicate pink at the higher temperatures. It is a good ceramic material and could be used for brick, other ceramic products, and grog.

The material is not suitable for the manufacture of lightweight aggregate.

Samples 244, 245, 246

These 3 samples were sent in by L. P. Holmes, Secretary of the Glendive Chamber of Commerce. They were collected by J. T. Kasper of the Montana-Dakota Utility Co. from sec. 18, T. 17 N., R. 57 E. They are clay-shale and sandstone from the Fort Union Formation of early Tertiary age. The main outcrop is along the south bank of a fork of Box Elder Creek. The main seam is 10 to 15 feet thick and about 75 feet wide and lies between 2 thin coal beds under about 50 feet of overburden. Below the lower coal bed is another seam of clay of unknown thickness. Sample 244 was taken in the upper third of the main seam; sample 245, in the middle (sandy); and sample 246, at the top of the lower seam. Some 300 yards upstream the same clay seam outcrops again. The beds are generally flat, and the formation seems to be widespread. Sample 244 is a light-grey (N 7), compact, noncalcareous, slightly bentonitic clay-shale. Sample 245 is a yellowish-grey (5 Y 7/2), fine-grained, calcareous, clayey sandstone. Sample 246 is very similar to 244, but is somewhat calcareous.

Sample 244 has good plasticity and working properties and high green strength. The P.C.E. is cone 8 (2,237° F.), and the firing range is 1,900° to 2,000° F. It is a fair ceramic raw material and could be used for common brick and as a bonding clay in blending. Sample 245 has low plasticity and only fair green strength. Its P.C.E. is cone 8 (2,237° F.), and the firing range is 1,800° to 2,050° F. It is a fair ceramic material for common brick. Sample 246 contains an appreciable amount of dolomite. Its P.C.E. is cone 5 (2,156° F.), and the firing range is 1,700° to 2,000° F. The test brick, fired to 2,050° F., was glazed. This clay would have to be carefully prepared so that the dolomite would be broken up and the calcium and magnesium oxides chemically bound to silicates by the firing; otherwise, the brick might spall after firing. Close control of the firing in the higher ranges would be necessary. Under such conditions it would be good material for common brick.

Sample 245 did not expand on firing. Sample 244 gave an excellent well-rounded glazed lightweight product over a wide temperature range (2,102° to 2,282° F.). The expanded product ranged in specific gravity from 1.5 at 2,102° F. to less than 1.0 as the firing temperature was raised. Sample 246 also yielded a good expanded product at 2,102° F., but fused at higher temperatures. The expanding range is too narrow for commercial use.

Sample 247

This sample was collected by F. A. Crowley of the Bureau off the dump of the White Pine mine in the Alhambra (Hot Springs) district in northern Jefferson County. The material is reported to have occurred as an intrusive dike (?) in the mine.

The material is perlite, a dark greenish-grey to black volcanic glass. It is not a clay, but was tested for expandability. It was fired to 2,000° F., yet showed no change.

Sample 248

This sample was submitted by a student of the Montana School of Mines, Russell Meech of Whitlash. The locality and character of the deposit is unknown to the writer.

The material is a soft very pale-orange (10 YR 8/2) calcareous nonbentonitic shale that slaked slowly in water. Although quite sticky when wet, the plasticity is low, and the firing characteristics are poor. It is unsuitable for ceramic use.

Although this material expanded at 2,102° F., the firing range is much too narrow for commercial practice.

Sample 249

This sample was taken from an exposure alongside of State Highway Montana 272, 0.7 mile east of Jefferson Creek bridge, 16 miles north of Avon in Powell County. The material is greyish-orange-pink (5 YR 7/2) thin-bedded shale of Tertiary age. It is noncalcareous, nonbentonitic, or only slightly so, and it does not disintegrate in water. No survey was made of the deposit, but is should be fairly extensive; it is readily accessible.

The plasticity is low, but the material can be molded and fired to a lightly bonded, light red-colored porous body when fired to 2,400° F. It could be used for grog with other clays. It has possibilities as a moderate silica refractory (P.C.E. is above cone 12). Further testing, beyond the limits of this project, are necessary to ascertain the potentialities of this material.

The shale is not suitable for the manufacture of lightweight aggregate; however, it is one of the few clays or shales of Tertiary age that merits additional investigation.

Sample 250

This sample was taken by the writer from a road cut on the south side of Highway Montana 20, just east of the bridge over the North Fork of the Blackfoot River. The clay slumps in the cut, but it appears to be over 10 feet thick. The deposit may be quite large.

The clay is greyish pink (5 R 8/2) in color, thin bedded, calcareous, but nonbentonitic. It is soft and slacks readily in water and resembles the Pleistocene Glacial Lake Missoula clays of Missoula Valley.

It has good plasticity and green strength. The P.C.E. is cone 2, and the firing range, 1,700°-1,900° F. It is usable for common brick.

Samples 251, 252

These 2 samples were taken by J. C. Maxwell in a gully 0.6 and 0.7 mile respectively north of the old Mullan road, 2.8 miles ESE of Bearmouth in northern Granite County. They are Tertiary clays.

Sample 251 is a firm light-grey (N 7), noncalcareous, slightly bentonitic clay. Sample 252 is white (N 9) in color, noncalcareous but very bentonitic. Neither is suitable for ceramic use or for lightweight aggregate.

Samples 253, 254

Samples 253 and 254 were submitted by O. A. Callantine of Bozeman. Both apparently are bentonitic clays of Tertiary age.

Sample 253 is soft pinkish-grey (5 YR 8/1), noncalcareous, swelling bentonite. Sample 254 is yellowish-grey (5 YR 8/1), noncalcareous, bentonite clay. It does not slack in water as does sample 253.

Samples 253 and 254 showed poor firing characteristics and high firing shrinkage; neither is suitable for ceramic use.

When tested for lightweight aggregate, sample 253 expanded to an excellent popcorn-like product at temperatures between 2,012° and 2,102° F. The product had a specific gravity less than 1, i.e., it floats on water. Sample 254 was not suitable for lightweight aggregate.

Samples 255, 256

Gwenlian Vaughn-Rhys collected sample 255 from the Blankenship mine and sample 256 from the Toliver placer, both in the Barker mining district, Hughesville, Judith Basin County.

Sample 255 is a firm white, calcareous, nonbentonitic clay that does not slack in water. Sample 256 is light olive-grey, noncalcareous and nonbentonitic and does not slack in water. It looks like Wolsey Shale of Cambrian age.

X-ray data indicates sample 255 to contain metahalloysite. The plasticity is low and the green strength, fair. The P.C.E. is over cone 12 (2,390° F), and the firing range from 2,100° to over 2,400° F. The fired color is white in the lower ranges and mottled white and black in the higher ranges. It is a good ceramic material. Sample 256, an illitic clay, has fair plasticity and green strength. The P.C.E. is cone 12 (2,390° F.), and the firing range is 1,900° to 2,200° F. The fired color is deep red. It is a fair ceramic material for common brick.

Neither clay is suitable for lightweight aggregate.

Samples 257, 258, 259

These 3 samples were collected by T. A. Mutch from Tertiary deposits in SW$\frac{1}{4}$ sec. 30, T. 9 N., R. 10 W., on Pike's Peak Creek about 6 miles south of Gold Creek station in Powell County. The samples represent grab samples from 3 distinct horizons in the deposit. Sample 258 was taken 50 feet below 257; and sample 259, 20 feet below 258. The deposit appears to be quite extensive and is readily accessible by country road from Gold Creek or Deer Lodge.

The clays are all yellowish grey in color, fairly firm, and although quite bentonitic, do not slack readily in water. Sample 257 is noncalcareous; sample 258, slightly so; and sample 259 is quite calcareous.

Test bricks of sample 259 crumbled on drying. Samples 257 and 258 showed poor firing characteristics, and the fired bricks were warped and cracked. All 3 clays are unsuited to ceramic use.

None of the material yielded a suitable product when tested for expandability to a lightweight aggregate.

Sample 260

This material is a sandy, calcareous, slightly bentonitic light olive-grey (5 Y 6/1) clay. The sample represents about 4 feet of clay in a road cut along old U.S. 10-91 Highway at its junction with the new highway at Buffalo Hump, 6 miles west of the Rocker turnoff (about 9 miles west of Butte) in sec. 15, T. 3 N., R. 9 W. Material was sampled by the writers.

The test bricks crumbled on drying; the material is not suitable for ceramic use.

When fired, this material furnished a good expanded product at a high temperature and narrow range (about 2,192° F.). The specific gravity of the expanded material is only 1.1, but it is doubtful if this clay could be used as a commercial source of lightweight aggregate.

Samples 261, 262, 263

These 3 samples were collected by R. M. (Robert) Fleming, R. I. Smith, and U. M. Sahinen on the Bell ranch in sec. 34, T. 6 S., R. 10 W., about 11 miles west of Dillon. The deposit is quite extensive, covering parts of secs. 34 and 35 and has been exposed in several widely scattered shallow pits and trenches. Sample 261 is pinkish grey (5 Y 8/1) and contains scattered black spots of manganese oxide. Sample 262 is a very pale orange (10 YR 8/2), and sample 263 is white (N 9). All slake readily in water, are noncalcareous, and all gave poor tests for bentonite with benzidine solution, although X-rays gave montmorillonite as a major constituent. These samples were taken from the same deposit, but from different locations, as sample 51 reported in the first progress report (Sahinen and others, 1958, p. 18).

All of the test bricks crumbled on drying; the clay is unsuited for ceramic purposes.

Sample 261 is not suitable as a source of lightweight aggregate. Samples 262 and 263 yielded a good product on bloating, but the firing range is so narrow as to render the clay of doubtful value for this purpose.

Sample 264

This sample was taken by R. M. Fleming, R. I. Smith, and U. M. Sahinen in a road cut along the Dillon-Argenta road at the south end of Fleming's 960-A claim, 6.5 miles west of Dillon. The deposit is in sec. 7, T. 7 S., R. 9 W. About 6 feet of clay overlain by gravel is exposed in the cut. The clay is greyish-orange pink (5 YR 7/2), slakes readily in water, is noncalcareous, and reacts poorly, if at all, to benzidine solution. It is quite similar to clays found on the Bell ranch (samples 261-263), 3 miles to the northwest.

It was found unsuited for either ceramic use or for lightweight aggregate.

Samples 265, 266

These samples were taken by the writers in Fleming's white clay prospect about 8 miles south of Dillon in sec. 35, T. 8 S., R. 9 W. The "deposit" consists of hydrothermally altered wall rock along some brown limonite-stained porous quartz vein matter. Because of its nature, the deposit is apt to be erratic and of small size.

In appearance both clays are much alike, being compact, very light-grey (N 8) clay with scattered blebs of bluish-white (5 B 9/1) to very pale-green (10 G 8/2) chlorite (?) clay. They crumble in water and give a good blue reaction with benzidine and are not calcareous.

Fleming reports the P.C.E. of clay 265 as cone 33. Firing tests to cone 12 did not fuse it. Clay 265 has good plasticity and working properties, but the firing shrinkage is high, and the bricks cracked when fired at temperatures from 1,700° to 2,300° F. Chemical analysis revealed the presence of phosphorous, which probably accounts for this poor firing characteristic of the clay. Further and more exhaustive test work, beyond the limits of the report, would be necessary to establish the value of this clay, but the character of the deposit does not seem to warrant it. Clay 266 had better firing characteristics than 265. With careful handling and proper blending, the material could be used for ceramic products. Both clays need further and more extensive test work, but it is doubtful if the size of the deposit would justify it.

Sample 267

This sample is from Fleming's "halloysite prospect" near Badger Pass in sec. 2, T. 7 S., R. 11 W., 14 miles west of Dillon. The deposit is opened by a 25-foot vertical shaft, at the bottom of which is a short drift. Sample 267, essentially halloysite, was taken in the drift. The halloysite was derived from the alteration of the light-colored trachyte and rhyolite lava flows or tuffs by hydrothermal solutions which also were responsible for the low-grade gold mineralization of the area. The lateral extent of this hydrothermal zone is not known.

In place the halloysite is soft and unctious, but in air it hardens to a firm white (N 9) to very pale-orange (10 YR 8/2) rock that shows slickensides due to fault movement. The hydrothermal solutions came up along faults or shear zones along which there was recurrent movement after the halloysite had been formed. The halloysite contains impurities of other white silicates and is locally stained with the blue-black manganese oxide; but is noncalcareous and nonbentonitic. It does not regain its softness in water after once drying.

The plasticity and green strength of the once dried material is extremely low; the test bricks will just hold together. The P.C.E. is over cone 12, and the upper limit of the firing range is over 2,400° F. Although the firing shrinkage within the range fired (1,900° to 2,300° F.) is high, the material could be used for ceramic products if a bonding clay were blended with it.

The high P.C.E. precluded testing for expandability.

Sample 268

This sample was taken in the 25-foot shaft mentioned under sample 267. It lies above the halloysite and is a bentonitic clay derived from the weathering of the trachyte-rhyolite lavas or tuffs. It is a very pale-orange (10 YR 8/2) to greyish-orange (10 YR 7/4) noncalcareous clay that slakes readily in water and give good blue color with benzidine solution.

The plasticity and green strength are low. The P.C.E. is over cone 12, and the firing range is from 2,000° to 2,200° F. With careful handling and use of a bonding clay, the material could be used for common brick.

The clay is not expandable to lightweight aggregate.

Sample 269

This sample was taken from the same deposit (but not the same location) as sample 49, previously reported (Sahinen and others, 1958, p. 17). Clay 49 was an excellent kaolin clay (P.C.E. cone 18), but clay 269 is entirely different in character and quality.

Clay 269 is moderate reddish brown (10 R 4/6), noncalcareous, and does not give a benzidine test for montmorillonite. It does, however, slake readily in water, and looks like a weathered and reworked version of clay 49. The test bricks crumbled on drying, so the clay was not fired.

The clay is not expandable.

Sample 270

Sample 270 is the most likely looking clay material from the pit just east across the road from the old prison brick plant at Deer Lodge. The bed from which it was taken is several feet thick, but is interbedded with silty and sandy sediments. It is of Tertiary age.

The clay is greyish orange (10 YR 7/4) in color, noncalcareous, and does not give a blue color with benzidine solution. X-ray analysis shows it to be a kaolin-illite clay. The plasticity and green strength are low, and 2 of the test bricks cracked on drying. The P.C.E. is cone 5, and the firing range is 1,700° to 1,950° F. This material alone is not suitable for ceramic use.

The material is not suitable for lightweight aggregate.

Sample 271

This sample was taken from a road cut in Colorado Shale along U.S. 10 in SW¼ sec. 28, T. 9 N., R. 9 W., 7.4 miles north of the Deer Lodge P.O. The material occurs in beds several feet thick interbedded with sandstone and sandy shale. The quantity present is very large, but it might prove difficult to mine a single bed because the strata dip steeply (as much as 45°) to the southeast. The shale varies physically stratigraphically up or down as is shown in the description of clay 271 taken 0.9 mile west and stratigraphically below clay 271.

The material is hard, indurated shale that would require grinding before use. It is greenish grey (5 GY 6/1) in color, does not break down in water, is only slightly calcareous, and gives a definite blue color with benzidine solution. The plasticity and green strength are low. The P.C.E. is cone 10 (2,300° F.); the firing range, 1,900° to 2,100° F. The material could be used for common brick or blended with other clays.

The shale is not suitable for manufacture of lightweight aggregate.

Sample 272

This sample was taken alongside Highway U.S. 10, 0.9 mile west of sample 271, about 8.3 miles north of Deer Lodge P.O. It is also a Colorado Group Shale that is interbedded with sandstone. The formation dips about 45° SE.

The shale is yellowish grey (5 Y 7/2) to light-olive grey (5 Y 5/2) in color. The lighter-colored material is calcareous. Both give positive blue tests for montmorillonite with benzidine solution.

The shale is hard enough to require grinding before use. The plasticity and green strength are low. The P.C.E. is cone 4 (2,129° F.); and the firing range, 1,700° to 2,000° F. The material could be used for common brick or blended with other clays.

When tested for expandability, the shale did give a lightweight product, but results were erratic, and the shale probably would not be suitable for commercial application.

Sample 273

This shale sample was taken from the road cut at the junction of Highways U.S. 10N and U.S. 10S, just east of Garrison. The sample was taken across about 20 feet of steeply dipping beds (55° W.) overlain by about 6 to 8 feet of gravel.

The shale is hard and would require grinding before use. It is light-olive grey (5 Y 6/1) in color, calcareous, and gives a decided blue color when tested with benzidine solution.

The plasticity and green strength are low. The P.C.E. is cone 2 (2,075° F.). The firing range is 1,700° to 1,900° F. The material could be used for common brick or blended with other clays.

Although a good expanded product was obtained from this material at 2,192° F., it is doubtful whether this material expands over a sufficiently wide temperature range to be used commercially as a source of lightweight aggregate.

Sample 274

This sample was taken just north of Highway U.S. 10 at the west end of the village of Garrison. The shale is not well exposed, and the sample represents a "grab" from several places. The shale is medium grey (N 5) in color; firm, but tends to slack in water; and quite calcareous. It is an Upper Cretaceous Shale (Golden Spike).

The plasticity and green strength are fair. The calcite and dolomite content of the shale necessitates fine grinding, complete mixing, and careful firing. Under these circumstances the material could be used for common brick or blended with other clays.

When fired for expansion, this shale behaved similarly to sample 273, q.v.

Sample 275

Sample 275 is of Carter Creek Shale. The Carter Creek Formation is the uppermost in the Colorado Group of Late Cretaceous age. The sample was taken on a steep back-slope of a road cut in bouldery clay along U. S. 10, 6 miles northwest of Garrison. The clay selected is greenish grey (5 GY 5/1) to medium-brownish grey (5 YR 5/1). It is calcareous and hard, does not slake in water or give a reaction with benzidine.

The material has low plasticity and green strength. Because of the calcite content (and hardness), it would require fine grinding, complete mixing, and careful firing. The firing range is narrow, and the shale could be used only for blending with other clays.

The expanded product was good, but was obtained only at one firing temperature, between 2,100° and 2,200° F. It is of doubtful commercial value because of this narrow temperature range.

Sample 276

This sample is Belt Shale (Missoula Group) of Precambrian age taken along a road cut along Highway U.S. 10A at the foot of Flint Creek hill in Granite County, in the west end of sec. 26, T. 6 N., R. 14 W. The clay is noncalcareous, white (N 9), and soft; but the softness may be due to weathering of a hydrothermally altered product. The clay gives a very slight, if any, reaction with benzidine solution.

The plasticity and green strength of this clay are low. The P.C.E. is cone 11 (2,345° F.); the firing range, 1,950° to 2,200° F. The burned bricks were light in weight, porous, and lightly bonded. Mixed with a bonding clay, the material could be used for common brick.

The clay is not suitable for manufacture of lightweight aggregate.

Sample 277

This sample is Precambrian Belt quartzitic argillite or very fine-grained argillaceous quartzite from a road cut along Highway U. S. 10A in the NW$\frac{1}{4}$ sec. 36, T. 6 N., R. 14 W. The rock is light-brownish grey (5 YR 6/1) to pale red (5 R 6/2) and very hard and noncalcareous. X-rays show the clay mineral to be illite.

The plasticity is extremely low, and the test bricks barely hold together. The firing characteristics are good. With grinding, the material could be used as a grog in common brick.

It is not suitable as a source of lightweight aggregate.

Sample 278

This sample was taken of Belt "shale" 0.6 mile farther up Flint Creek hill near the head of the "hairpin" turn in the NE$\frac{1}{4}$ sec. 36, T. 6 N., R. 14 W., in Granite County. The rock is a hard greyish-red (10 R 4/2) noncalcareous argillite.

The P.C.E. is cone 5 (2,156° F.); and the firing range, 1,850° to 2,000° F. The material alone is not suitable for ceramic bodies, but, if ground, it could be used for grog.

The material is not suitable for making lightweight aggregate because of the high temperature required for expansion.

Sample 279

This sample is a greyish-red (10 R 4/2), mud-cracked, indurated Belt Shale taken from a road cut on Highway U.S. 10A on Flint Creek hill 0.4 mile up-grade from sample 278. Like sample 278, it is not suitable for use alone in ceramic bodies, but could be used as a grog.

It is not suitable for the manufacture of lightweight aggregate.

Sample 280

This material is a Tertiary bentonitic clay taken from the deposits half a mile south of the Cactus Inn at the junction of Highways U. S. 10 and Montana 41. The clay is fairly soft, yellowish grey (5 Y 8/1) in color, noncalcareous, and bentonitic. It softens but does not break down in water.

Ceramically, the firing characteristics are poor, and the fired bricks were cracked and warped. The material is unsuited for ceramic use.

A good expanded product was secured from this material at 2,192° F., but it is doubtful if this could be used commercially because of the narrow firing range and the lack of strength in the product due to thin cell-walls.

Samples 281, 282

These 2 samples were taken from a deposit of Tertiary bentonitic clay in secs. 3 and 4, T. 9 S., R. 5 W., in Sweetwater Basin of southern Madison County. Sample 281 was from a low hill, and sample 282, from a cut bank a quarter of a mile east of 281.

Sample 281 is a yellowish-grey (5 Y 7/2), noncalcareous, gypsiferous and slightly bentonitic clay. Sample 282 is dark yellowish-orange (10 YR 6/6), gritty clay containing chlorite spots. Firing characteristics of both clays are poor, and neither one is suitable for ceramic use nor for use in making lightweight aggregate.

Sample 283

Sample 283 is bentonite from Tertiary sediments exposed in a road cut along Highway Montana 41 near Beaverhead Rock in sec. 28, T. 5 S., R. 7 W., Beaverhead County. It is a yellowish-grey (5 Y 7/2), noncalcareous, highly bentonitic clay.

The test bricks crumbled on drying, so the material was not fired for ceramic tests.

It did not expand on heat treatment.

Sample 284

This sample was taken from the Tertiary deposits half a mile south of the Cactus Inn Junction in the same area, but east of the road and stratigraphically below sample 280. The material is a pale yellowish-brown (10 YR 6/2), slightly calcareous, highly bentonitic clay that slakes readily in water.

The test bricks crumbled on drying. The clay is of no value as a ceramic raw material.

Although minor expansion was obtained on all firing tests on the raw clay, the material would not be suitable as a source of lightweight aggregate.

Sample 285

This sample was sent in by Ruth Olmstead of Glendive, Montana. The material is a pale-brown (5 YR 5/2), noncalcareous, and slightly bentonitic soft shale. X-rays showed it to be an illitic clay.

The dried test brick had a thin alkali scum. The firing characteristics of the clay are poor, the firing range narrow, and the alkali scum discolored the fired brick. It is not suitable for ceramic use.

An excellent expanded product was obtained from this material when the raw shale was fired. The expanding range is from 2,102° to 2,282° F., and the expanded material has a specific gravity of 1.0.

Sample 286

This sample was taken by Frank Crowley and Don Lawson of the Bureau staff 4 miles south of Radersburg and north of the road in S½ sec. 32, T. 5 N., R. 1 E. It is a pale yellowish-grey (5 Y 7/2), noncalcareous, bentonitic clay interbedded with Tertiary sediments.

The firing characteristics are poor; the test bricks fired at the higher temperatures were cracked and warped. The clay is not suitable for ceramic use.

No expansion was obtained when the raw clay was fired. It is unsuitable for lightweight aggregate.

Sample 287

This material is a hydrothermally altered Wallace Limestone from the Piegan Group of the Belt Series of Precambrian age. The sample was taken from a deposit found by Mr. McGruder of Darby, in the SW¼ sec. 34, T. 6 N., R. 18 W. The deposit lies across Daly Creek from Skalkaho road. The clay mineral in the rock is white (N 9) dickite. However, there was not enough clay material to hold the test bricks together after grinding. The material is unsuitable for ceramic use or for expanded lightweight aggregate.

Sample 288

This sample was taken in Kalispell at the east end of town near the junction of Highway U.S. 2 and Sunset Drive S. The material proved to be a very fine silt of glacial origin and is not suitable for ceramic ware or for expanded aggregate.

Sample 289

Sample 289 represents Glacial Lake Missoula clay (Pleistocene) and was taken near Pablo in northern Lake County, about 1.2 miles west of Highway U.S. 93 along the first county road south of the village. The material is a soft, very pale-orange (10 YR 8/2), nonbentonitic, but quite calcareous, silty laminated clay.

The P.C.E. is cone 3. The firing range is very narrow, 1,900° to 1,950° F. The material would be suitable for common brick with careful firing. During molding, the laminations in this clay must be thoroughly broken up; otherwise, the fired brick will spall badly on weathering.

The material is not suitable for the manufacture of lightweight aggregate.

Sample 290

This sample represents another Glacial Lake Missoula clay of Pleistocene age. It was taken from the back-slope of a road cut on Highway U.S. 10-93 in the NE$\frac{1}{4}$ sec. 34, T. 14 N., R. 20 W., about 7 miles west of Missoula. The sample is about 3 miles west of sample 13 taken in 1956. The material from both places is quite similar. At sample locality 290, only about 5 feet of clay are exposed in the cut, but it underlies a large field to the south of the highway.

The clay is laminated and greyish pink (5 R 8/2) in color. It is soft, calcareous, slightly bentonitic, and breaks down readily in water. It has a P.C.E. of cone 3, and the firing range is 1,800° to 1,950° F. It is suitable for common brick, if precautions mentioned under clay 289 are taken.

The clay is not suitable for making lightweight aggregate.

Sample 291

Sample 291 is from the Miller Peak Formation exposed in a deep road cut 3 miles east of Missoula, where the Clark Fork fault cuts the formation at the mouth of Marshall Creek. An attempt was made to sample the fault zone, but the sample turned out to be hard argillite and quartzite. The material, when ground, had no plasticity so was not fired for ceramic testing. Bloating tests were negative.

Samples 292 through 300

This series of samples is from the Colorado Shale in sec. 13, T. 2 N., R. 2 E., about 3 miles north of Logan. Samples 292 through 295 were taken by George Kanta in the NW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 13. Sample 296 is a composite of samples 292 through 295. Samples 297 through 300 were taken by U. M. Sahinen and George Kanta; 297 is about a quarter of a mile east of 295 and represents 8 feet of shale above a sandstone bed and igneous sill at the same stratigraphic horizon as Kanta's samples. Sample 298 was taken an eighth of a mile east of 297 and below the sill. Sample 299 was taken in the center SW$\frac{1}{4}$ sec. 13 and represents 10 feet of shale. Sample 300 represents the next 4 feet below sample 299.

All of the material is very much alike in physical appearances. It ranges in color from medium-dark grey (N 4) to dark-greenish grey (5 GY 4/1), fissile to slaty, noncalcareous.

For ceramic use, the shales would require fairly fine grinding to gain enough plasticity to give them good working qualities. The firing characteristics of these shales are poor, and the fired test bricks were crazed and warped. Although the P.C.E. is fairly high (cone 12-14), the outside of the test bricks fired at high temperatures (2,300° F.) were glazed. The shales are not suitable for ceramic use.

The primary purpose in taking these samples was to test them for expandability. The results are tabulated below:

Sample	Sp. Gr. aver. of 3 tests	Remarks
292	1.5	Poor product, brittle, considerable spalling
293	1.1	Poor product, brittle, considerable spalling
294	1.1	Good product, wide range, 2,000° to 2,200° F.
295	-1.0	Good product, wide range, 2,000° to 2,200° F.
296	1.2	Fair product, some spalling
297	1.4	Poor product, not suitable
298	1.8	Poor product, not suitable
299	1.6	Excellent product with wide firing range
300	1.4	Poor product, spalling, but wide firing range

Sample 301

Sample 301 is from an outcrop of Lower Cretaceous (?) Shale. The sample was taken about 100 yards south of Highway U.S. 10 in the NE corner sec. 26, T. 1 N., R. 2 W., in southeastern Jefferson County, 2-3/4 miles west of Sappington Junction. The material is olive-grey (5 Y 4/1) noncalcareous shale. X-rays show it to be composed of illitic and kaolinitic clay. Sample represents 20 feet of shale above a sandstone that strikes east and dips 40° N.

The material has fair plasticity, good green strength, and working properties. The firing range is good. The clay is a fairly good material for common brick and like products.

When tested for expansion the material spalled badly and yielded an unsatisfactory product.

Sample 302

This sample was taken on the back-slope of a road cut along Highway U.S. 10, 1.8 miles west of sample site 301. The material is pale olive-grey (5 Y 6/2), noncalcareous and bentonitic shale, Cretaceous age (Kootenai Formation ?). The shale slacks readily in water.

X-rays show the material to be a chloritic clay high in quartz, feldspar, calcite, and dolomite. The impurity minerals are predominant, and as a result the plasticity is low. The firing range is extremely narrow, and fusion takes place before a ceramic bond is established. The material is not suited to ceramic use or lightweight aggregate.

Sample 303

This sample was collected by T. P. Wollenzien, Great Northern Railway geologist, (No. GV-6006) from an exposure of Claggett Shale 8 miles north of Ryegate, Golden Valley County, in the SE,NW sec. 35, T. 8 N., R. 19 E. The sample was cut from 15 feet of clean grey-brown shale exposed at a stock tank dam. The base of the bed is not exposed. It is overlain by a 1-foot bed of tan calcareous concretions, then 10 more feet of grey shale to the surface. The Claggett strikes N. 70° E., and dips 4° N. at this location. The bed is perhaps 200 stratigraphic feet above the top of the Eagle and about 230 stratigraphic feet below the basal Judith River Sandstone, which forms a very prominent cliff a half a mile to the north. Much strippable tonnage is available immediately east and west of the location.

The material is medium-olive grey (5 Y 5/1), noncalcareous, but bentonitic. It breaks down partly in water. The plasticity and working properties are fair, but the firing characteristics are not good. The test bricks cracked and swelled on firing, so the material is unsuited for ceramic use.

When the raw shale was fired, it produced an excellent well-rounded and glazed lightweight product over a very wide temperature range. The average specific gravity of the expanded material was 1.1.

Sample 304

Sample 304 was sent in by S. R. Foot, Pittsburgh Building, Helena, and is reported to have come from Jefferson Gulch in Powell County. The material is a reddish-orange (10 R 5/6), noncalcareous and nonbentonitic, residual clay, and it contains many subangular pebbles and boulders of very hard Beltian quartzite and argillite. The clay matrix softens in water.

When ground the plasticity and working properties are fair. With careful firing a red to chocolate-brown brick was obtained. With careful handling and with blending, the material could be used for common brick and like products.

The material is not suitable as a source of lightweight aggregate.

Sample 305

This material was submitted by H. S. Kirk of Bozeman. It is pale-yellowish brown (10 YR 6/2) in color, highly calcareous, contains organic remains, and gives a positive reaction with benzidine (illite ?). The X-ray shows it to be composed principally of kaolin, quartz, illite, and dolomite. The clay breaks down in water.

The plasticity is good; the drying and firing shrinkages, low. The firing range is 1,900° to 2,000° F. With careful firing, it is a fairly good material for common brick and like products.

It is not suitable for making lightweight aggregate.

Samples 306, 307, 308

These 3 samples are feldspars sent in by H. S. Kirk of Bozeman. Sample 306 is a pegmatite from Squaw Creek, Gallatin County, containing essentially greyish-pink (5 R 8/2) microcline with some transparent glassy quartz. Sample 307 is pale-red (5 R 6/2) microcline from Ennis, Madison County, and sample 308 is white to very light-grey (N 9 to N 8) orthoclase with some microcline from Squaw Creek, Gallatin County.

Samples 309, 310, 311

These 3 samples were taken by George Kanta in sec. 13, T. 2 N., R. 2 E., where the best results were obtained in the previous series, 292 through 300. The samples were tested for expansion only. The clay is a light olive-grey color, noncalcareous, and gives a positive reaction with benzidine (illite).

Sample 309 spalled badly when fired. The expanded product was unsatisfactory.

Sample 310 also spalled considerably, but a fair to good expanded product was obtained. Expansion occurred over a temperature range of 2,012° to 2,372° F., and the average specific gravity of the expanded product was 1.1.

Sample 311 also yielded a good expanded product over a temperature range of 2,102° to 2,372° F. The average specific gravity of the expanded product was 1.1, the same as sample 310.

Sample 312

This sample was submitted by Ray Almstead of Glendive to the Glendive Chamber of Commerce clay content. It is reported to be from sec. 22, T. 16 N., R. 55 E. and is probably from the Hell Creek Formation of Late Cretaceous age. It is a yellowish-brown (10 YR 5/2) clay-shale containing abundant brown lignitic plant remains. It is noncalcareous but gives a reaction with benzidine, probably due mainly to the illite shown to be present by X ray.

The plasticity is medium, and the working properties are good. The firing characteristics are not good, and the test bricks cracked and swelled on firing. The material is not suitable for ceramic use.

When tested for expandability this shale gave a good glazed product over a very wide temperature range (2,012° to 2,372° F.). According to D. C. Lawson, who made the firing tests, this clay is the second best clay for expanded lightweight aggregate of those submitted by the Glendive Chamber of Commerce.

Samples 313, 314

These 2 samples were submitted by Elmond Anderson of Glendive to the Glendive Chamber of Commerce clay contest and are reported to have come from sec. 31, T. 15 N., R. 58 E. and are probably from the Fort Union Formation of Early Tertiary age.

Sample 313 is light olive-grey (5 Y 6/1), noncalcareous clay-shale with some brown lignitic plant remains. X rays show it to be an illitic clay, the plasticity and working properties of which are fair. The dried brick had a slight alkalic scum, and on firing the brick cracked and swelled. The material is not suitable for ceramic use but was the third best expandable clay for lightweight aggregate submitted in the Glendive clay contest. The clay yielded a good expanded product at a temperature range of 2,192° to 2,372° F.

Sample 314 is a pale-brown (5 YR 5/2), fissile clay-shale containing considerable organic matter from plant remains. The plasticity and working properties are fair, but the firing properties are only fair, and the material has a high firing shrinkage. With careful firing and preferably blending with other clays, it could be a common brick material.

Sample 314 ranked fourth as an expandable clay for lightweight aggregate in the Glendive Chamber of Commerce clay contest. It expanded to an excellent product but only at a narrow high temperature range around 2,372° F. The narrow high range may rule it out as a commercial source of lightweight aggregate.

Sample 315

Jack Reeves of Glendive submitted this sample to the Glendive Chamber of Commerce clay contest. It is reported to be from sec. 22, T. 18 N., R. 50 E. and is probably from the Fort Union Formation of Early Tertiary age.

The material is a light-grey (N 7), kaolinitic, and illitic clay-shale that softens readily in water. It is noncalcareous, has low plasticity, but fair working properties. With careful handling and firing, it is a fair common brick material but is not suitable for making lightweight aggregate. Of the clays submitted in the contest, this clay ranked first of the four that had possibilities for ceramic use.

Samples 316, 317

John Omdal contributed these 2 clays to the Glendive clay contest. He reported them as from sec. 30, T. 17 N., R. 53 E., and they are probably from the Fort Union Formation of Early Tertiary age.

This is a light olive-grey (5 Y 6/1) gumbo clay that softens readily in water. It is noncalcareous. Sample 317 is quite similar to sample 316. The 2 clays have low plasticity and poor working properties. The bricks crumbled on drying, and the materials are not suitable for ceramic use.

Neither clay, 316 nor 317, is suitable for lightweight aggregate.

Sample 318

This clay was submitted to the Glendive Chamber of Commerce clay contest by Don Gibson, is reported to be from sec. 29, T. 18 N., R. 50 E., and is probably from the Fort Union Formation of Early Tertiary age.

The material is a very light-grey (N 8), very slightly calcareous clay-shale that breaks down readily in water. The plasticity and working properties are fair. Although the test bricks have a tendency to swell when fired at the higher temperatures, with careful handling and firing it could be used for common brick.

When the raw clay was fired for expansion, it yielded an excellent strong well-rounded and glazed aggregate. The expansion range runs from 2,192° to 2,282° F.

In the Glendive clay contest, this clay ranked first as an expandable shale for lightweight aggregate and third as a clay for ceramic use. Of the 17 clays submitted, it is the only one that could be used commercially for both purposes.

Samples 319, 320

These 2 samples were submitted in the Glendive Chamber of Commerce clay contest by a Mr. Schwartz. No locality was mentioned for these clays. Clay 319 is greyish yellow (5 Y 7/4) and highly calcareous. Clay 320 is very light grey (N 8) and noncalcareous. Both clays break down readily in water and give a blue reaction with benzidine.

Clay 319 has a narrow firing range, and the test bricks cracked and swelled. Clay 320 has fair firing characteristics, but an alkali scum discolors the fired brick. Neither clay is suitable for ceramic ware nor for expanded lightweight aggregate.

Sample 321

Pete Boje collected this sample from sec. 22, T. 18 N., R. 53 E. It is probably from the Fort Union Formation of Early Tertiary age. The clay-shale is yellowish grey (5 Y 8/1), slightly calcareous, and breaks down with swelling in water.

A heavy scum of ferrous sulfate mono-hydrate ($FeO \cdot SO_3 \cdot H_2O$) forms on the dried brick. The firing characteristics are poor, and the test bricks cracked on firing. The material is unsuited for ceramic use.

A very poor product was obtained when the raw clay was tested for expansion. It is not suitable for lightweight aggregate.

Sample 322

John Boise submitted this sample to the Glendive Chamber of Commerce clay contest. It is reported to be from sec. 20, T. 21 N., R. 53 E. It is a highly calcareous, greyish-yellow (5 Y 8/4) clay-shale that breaks down readily in water.

X rays show the clay to contain considerable montmorillonite and dolomite. It has fair plasticity, working properties, and firing characteristics. A light scum forms on the dried brick, and discoloration of this scum in firing makes the clay unsuited for ceramic use.

It is unsuitable for making lightweight aggregate.

Sample 323

Ed Ekland submitted this sample to the Glendive Chamber of Commerce clay contest. It is reported to have come from sec. 13, T. 17 N., R. 53 E., an area underlain by the Fort Union Formation.

The material is a pale yellowish-brown (10 YR 6/2), noncalcareous, fissile clay-shale. The test bricks cracked on drying, and the fired bricks were swelled and cracked to a greater degree. The material is unsuited for ceramic use.

This clay is not suitable as a source of lightweight aggregate.

Samples 324 to 327

These 4 samples were submitted to the Glendive Chamber of Commerce clay contest by Bill Appleby of Glendive. The samples are from secs. 30 and 31, T. 18 N., R. 54 E. The bedrock of secs. 30 and 31 is the Fort Union Formation of Tertiary age, locally overlain by Flaxville Gravels.

Clay 324 is yellowish-grey (5 Y 7/2), highly calcareous, illitic clay containing much calcite and dolomite. Its narrow firing range and poor firing characteristics make it unsuitable for ceramic use, and lack of expansion at any temperature tried makes it unsuitable for manufacture of lightweight aggregate.

Clay 325 is pale yellowish-brown (10 YR 6/2), slightly calcareous, laminated clay-shale that breaks down readily in water. X rays show it to be illitic with a high percentage of dolomite. The working properties, plasticity, and firing characteristics are fair, but the dried brick has a light alkali scum. Discoloration from the scum makes the material unsuitable for ceramic use. The material is not expandable into lightweight aggregate.

Clay 326 is a light greenish-grey (5 GY 6/1), compact, noncalcareous clay that softens slowly in water. The plasticity and working properties are fair. The clay has a tendency to swell when fired at the higher temperatures. With careful firing, it could be used for common brick. This clay ranks second among the 4 found suitable for ceramic use in those submitted to the Glendive Chamber of Commerce clay contest. It is not expandable into lightweight aggregate.

Clay 327 is moderate-yellow (5 Y 8/6), compact, gritty, highly calcareous shale that softens in water. The firing range is narrow, the material is not suitable for ceramic products, and it is not expandable into lightweight aggregate.

Sample 328

This sample was submitted to the Glendive Chamber of Commerce clay contest by a Mr. Anderson, who did not report the locality from where it came. Presumably, it is from Dawson County.

The material is a pale-brown (5 YR 5/2), noncalcareous, slightly bentonitic clay-shale that also contains considerable brown organic matter from plant remains. The dried test bricks had a light alkali scum, and they cracked and swelled on firing. The discoloration due to scumming and the poor firing characteristics render the material unfit for ceramic use.

This material gave a good expanded product, but only at a very narrow and high temperature range. The high narrow range makes the material uncommercial.

Samples 329, 330, 331

Samples 329 (brown sample), 330 (lower half pit), and 331 (upper half pit) were sent in by George Kanta of Three Forks in his search for expandable shale for lightweight aggregate.

Sample 329 is a compact, light-brown, noncalcareous clay-shale that swells and slakes down in water. The drying shrinkage is very high, and the bricks crumble on drying. It is unsuited for ceramic use, but when fired raw gave a fair expanded product over a wide temperature range (2,012° to 2,372° F.). However, considerable spalling of fines occurred throughout the firing range.

Sample 330 (lower half pit) is a compact, light olive-grey, (5 Y 5/2), noncalcareous shale with just enough kaolin to control the ceramic properties. The plasticity is very low and the working properties poor, but the drying and firing shrinkages are low and the firing characteristics, good. The material is suitable for use in common brick and like products; but, when tested for expandability, it expanded only at the upper limit (2,372° F.) of what is considered the economic limit of expanding temperatures. Although the expanded product is a fair lightweight aggregate, the high and narrow firing range is unfavorable.

Sample 331 (upper half pit) is a compact, light olive-grey (5 Y 6/2), noncalcareous shale containing barely enough kaolin to hold it together while molding. The drying and firing shrinkages are low; and the firing characteristics are poor. With careful firing and blending, it could be used for common brick. When fired for expandability, this shale gave a good product over a wide temperature range (2,012° through 2,372° F.).

Sample 332

This sample was sent in by G. C. Morton, Box 597, Lewistown, at the request of H. S. Kirk of Bozeman as a possible ceramic material. The material proved to be a highly altered syenite composed essentially of feldspar altered to kaolin. It is no doubt derived from one of the many syenite intrusives in the Judith Mountains.

The material is essentially light-grey kaolin. The plasticity is very low, the drying and firing shrinkages are low, and the firing characteristics are good. It is a good ceramic material, which could be used for many ceramic products.

The material was not tested for expandability.

Samples 333 through 339

These 7 samples were collected by Randall Chew III, mining geologist, on the Northern Pacific Railway Co. clay project. The sample locations as described by Chew are as follows:

No. 33 (RTC-57-128): Sec. 16, T. 5 N., R. 4 E., Broadwater County, Montana. A 4-ft. sample of the overclay above the abandoned coal mine in this section.

No. 334 (RTC-2-60): Sec. 7, T. 5 N., R. 3 E., Broadwater County, Montana. A grab sample from the most bentonitic part of a green-brown montmorillonitic zone about 30 feet thick immediately above a prominent white siltstone bed on the hill north of the county road. The area sampled is about 10 feet above the bottom of the bed. The clay is not gritty and retains much water.

No. 335 (RTC-3-60): Sec. 24, T. 7 N., R. 37 E., Treasure County, Montana. A grab sample from the stockpile at an abandoned bentonite prospect.

No. 336 (RTC-4-60): Sec. 1, T. 7 N., R. 37 E., Treasure County, Montana. Interbedded clay, siltstone, and sandy siltstone from stockpile at bentonite prospect.

No. 337 (RTC-5-60): Sec. 1, T. 7 N., R. 37 E., Treasure County, Montana. Light-grey, non-gritty, bentonitic clay from a 2-foot thick bed near the top of the ridge.

No. 338 (RTC-59-53): NW$\frac{1}{4}$ sec. 29, T. 5 W., R. 8 S.(?), near Rimini, formerly the Woodrow Wilson mine. Altered quartz monzonite adjacent to vein. Archie Bray of Western Clay Products Company reports some of this material to be white burning.

No. 339 (RTC-59-55): Porphyry Dike mine in Tenmile Creek west of Rimini. Mill tailings. The country rock is altered rhyolite, and the tailings are very finely crushed.

Preliminary gelatinization tests were run on samples 333 through 337 to determine the suitability for oil well drilling muds. The preliminary tests did not give results encouraging enough to complete the tests.

Sample 333 is a very light-grey (N 8) to greyish-yellow (5 Y 8/4), noncalcareous clay-shale that breaks down readily in water. It is an impure kaolin clay. The plasticity is low; drying and firing shrinkages are low, and the firing characteristics are fair. It is a good material for common brick and like products. It is not expandable to lightweight aggregate.

Sample 334 is a yellowish-grey (5 Y 8/1), noncalcareous bentonite with excessive drying shrinkage. The test bricks crumble on drying, and the clay is unsuitable for ceramic use, nor is it suitable for making lightweight aggregate.

Sample 335 is a yellowish-grey (5 Y 8/1), noncalcareous bentonite that gels somewhat in water. It has excessive drying shrinkage. Test bricks crumbled on drying so were not fired. It is unsuited for ceramic use. It was not tested for expandability.

Sample 336 is a greenish-grey (5 GY 6/1), popcorn-like, noncalcareous, gritty clay that slacks, but does not gel as much as sample 335, in water. The drying shrinkage is excessive, and the test bricks cracked on drying. It is not suitable for ceramic use and was not tested for expandability.

Sample 337 is a yellowish-grey (5 Y 8/1) to light olive-grey (5 Y 6/1), calcareous bentonite. Test bricks crumbled on drying. It is not suitable for ceramic use and was not tested for expandability.

Sample 338 is a kaolinitic and illitic clay. The plasticity is low, drying and firing shrinkages are low, and the firing characteristics are good. This material could be used for many ceramic products.

Sample 339 is chloritic clay, the drying shrinkage of which is high. The test bricks crumbled on drying, and the material is not suitable for ceramic use. It was not tested for expandability.

Samples 340 through 348

These 9 samples were sent in by H. E. Bartram of 11 - 16th St. N., Great Falls, who collected them from Dawson County in the SE$\frac{1}{4}$ sec. 30, T. 16 N., R. 56 E., just east of Glendive, Montana. The samples were all taken at a single exposure. Samples 340, 341, and 342 each represent 4-foot beds, and sample 343 represents a 10-foot bed of shale all interbedded with sandy sediments and overlying a shale deposit 30 feet thick. Samples 344, 345, 346, 347, and 348 represent equal portions of the basal 30-foot bed.

Sample 340 is a light olive-grey, noncalcareous, gumbo clay that tends to gel in water because of its bentonite content. The drying shrinkage is high, and the briquette crumbled on drying. It is not suitable for ceramic use nor for making lightweight aggregate.

Sample 341 is a dusky-yellow (5 Y 5/4), gumbo clay that breaks down fairly easily in water. It is a kaolinitic clay. The plasticity is low as are the drying and firing shrinkages. The dried brick has an alkali scum, and the fired brick has a mottled uneven color. With washing and careful handling it could be used for common brick and similar material. It is not suitable for making lightweight aggregate.

Sample 342 is a light olive-grey (5 Y 6/1), noncalcareous and bentonitic clay that breaks down readily in water. The plasticity is fair, but the drying shrinkage is high. The firing characteristics are poor, and the test bricks cracked and swelled on firing. It is not suitable for ceramic ware, nor is the swelling on firing sufficient to make an expanded lightweight aggregate.

Sample 343 is a brownish-grey (5 Y 4/1), compact, noncalcareous clay that does not readily break down in water. The drying shrinkage is high, and the test bricks crumbled on drying. It is unsuitable for ceramic use, and it is not expandable into lightweight aggregate.

Sample 344 is a clay high in silica. The plasticity is low, and the drying shrinkage, medium high. The firing characteristics are poor, and the test bricks cracked badly at the higher temperatures. It is unsuitable for ceramic use, but when tested for expandability by firing the raw clay, the material yielded a good expanded product over a medium temperature range (2,192° to 2,372° F.).

Sample 345 is a pale yellowish-brown (10 YR 6/2), compact, noncalcareous, slightly bentonitic clay that does not readily break down in water. It is not suitable for ceramic use; but when fired to expandability, the clay furnished an excellent rounded and glazed lightweight aggregate over a very wide temperature range (2,012° to 2,372° F.). The average specific gravity of the expanded material was only 1.1, just slightly heavier than water.

Sample 346 is pale olive-grey (5 Y 6/1) to medium brownish-grey (5 YR 5/1), noncalcareous, bentonitic clay that breaks down readily in water. It is not suitable for ceramic use; but when fired for expandability, this shale gave a good lightweight aggregate over a medium temperature range (2,192° to 2,372° F.). The average specific gravity of the expanded material is 1.3 (about half the weight of ordinary granite or limestone aggregate).

Sample 347 is an olive-grey (5 Y 6/1), crumbly, weathered, noncalcareous, but bentonitic, clay that softens and tends to gel in water. It is unsuitable for ceramic use; but expandability firing tests produced a very good expanded and glazed lightweight aggregate over a medium temperature range. The average specific gravity of the expanded product is 1.2.

Sample 348 is a light olive-grey (5 Y 6/1), weathered shale with some unweathered light olive-grey siltstone. The material is not calcareous, but is bentonitic and breaks down readily in water. It is not suitable for ceramic use; but when fired for expandability, the clay gave an excellent expanded product over a wide temperature range (2,102° to 2,372° F.). This product is well-rounded and glazed and has an average specific gravity of 1.0. Some of the expanded material will actually float, especially that fired above 2,300° F.

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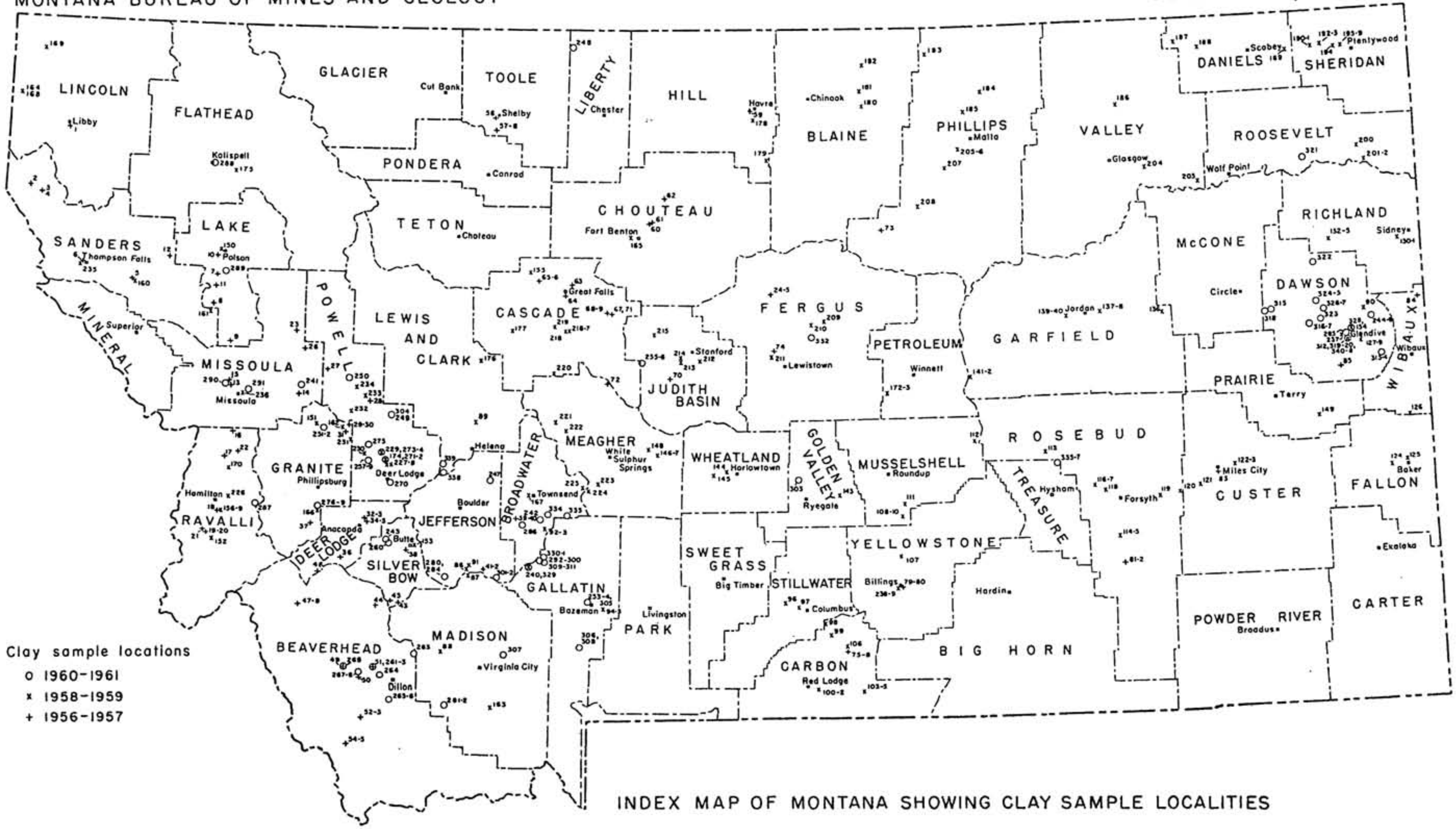

INDEX MAP OF MONTANA SHOWING CLAY SAMPLE LOCALITIES

TABLE 1.--Sample locations, Montana clays and shales.

Sample No.	Field No.	Formation	Location	County	Sec.	T.	R.
241	7-1	Pleistocene	Blackfoot R., N. Rogers	Missoula	--	--	--
242	7-2	Unknown	Toston area, N. Rogers	Broadwater		5N	2E
243	7-3	Fault clay	Tuxedo mine, N. Rogers	Silver Bow	28	4N	9W
244	7-4	Fort Union	J. Kasper, Glendive	Dawson	18	17N	57E
245	7-5	Fort Union	J. Kasper, Glendive	Dawson	18	17N	57E
246	7-6	Fort Union	J. Kasper, Glendive	Dawson	18	17N	57E
247	7-7	Mine dump	White Pine, M.F. Crowley	Jefferson	32	8N	2W
248	7-8	Unknown	Russel Meech, MSM	Jefferson	--	--	--
249	7-9	Tertiary	Mont-272, 16 mi. N. Avon	Powell	27	12N	9W
250	7-10	Pleistocene	E side N Fk. Blackfoot R.	Powell	11	14N	12W
251	7-11	Tertiary	Bearmouth, J. Maxwell	Granite	19	11N	13W
252	7-12	Tertiary	Bearmouth, J. Maxwell	Granite	19	11N	13W
253	7-13	Tertiary(?)	Bozeman, O.A. Callantine	Gallatin	--	--	--
254	7-14	Tertiary(?)	Bozeman, O.A. Callantine	Gallatin	--	--	--
255	7-15	Alt.syenite (?)	Blankenship mine, Barker, G. Vaughn-Rhys	Judith Basin	--	15N	9E
256	7-16	Cambrian(?)	Toliver Placer, Barker, G. Vaughn-Rhys	Judith Basin	--	15N	9E
257	7-17	Tertiary	Pikes Peak Cr., T. Mutch	Powell	30	9N	10W
258	7-18	Tertiary	50' below 257, T. Mutch	Powell	30	9N	10W
259	7-19	Tertiary	20' below 258, T. Mutch	Powell	30	9N	10W
260	7-20	Tertiary	West of Silver Bow	Silver Bow	15	3N	9W
261	7-21	Tertiary	Bell ranch	Beaverhead	34	6S	10W
262	7-22	Tertiary	E of 261, Bell ranch	Beaverhead	34	6S	10W
263	7-23	Tertiary	E of 262, Bell ranch	Beaverhead	34	6S	10W
264	7-24	Tertiary	Fleming's 960-A claim	Beaverhead	7	7S	9W
265	7-25	Mine pit	8 mi. S of Dillon	Beaverhead	35	8S	9W
266	7-26	Mine pit	8 mi. S of Dillon	Beaverhead	35	8S	9W
267	7-27	Mine pit	Badger Pass, Fleming	Beaverhead	2	7S	11W
268	7-28	Tertiary	Badger Pass, Fleming	Beaverhead	2	7S	11W
269	7-29	Unknown	Dyce Creek, Fleming	Beaverhead	35	6S	12W
270	7-30	Tertiary	Brick plant, St. Prison	Powell	4	7N	9W
271	7-31	Colorado	7.4 mi. N Deer Lodge P.O.	Powell	28	9N	9W
272	7-32	Colorado	8.3 mi. N Deer Lodge P.O.	Powell	29	9N	9W
273	7-33	Cretaceous	East of Garrison	Powell	24	9N	9W
274	7-34	Cretaceous	West end of Garrison	Powell	23	9N	10W
275	7-35	Cretaceous	NW of Garrison	Powell	30	10N	10W
276	7-36	Beltian	Foot of Flint Cr. hill	Granite	26	6N	14W
277	7-37	Beltian	On Flint Cr. hill	Granite	36	6N	14W
278	7-38	Beltian	On Flint Cr. hill	Granite	36	6N	14W
279	7-39	Beltian	On Flint Cr. hill	Granite	36	6N	14W
280	7-40	Tertiary	S jct. US 10 & Mont. 41	Jefferson	17	1N	5W
281	7-41	Tertiary	Sweetwater Basin	Madison	4	9S	5W
282	7-42	Tertiary	Sweetwater Basin	Madison	3	9S	5W
283	7-43	Tertiary	Mont.41 at Point of Rocks	Beaverhead	28	5S	7W
284	7-44	Tertiary	S jct. US 10 & Mont. 41	Jefferson	17	1N	5W
285	7-45	Unknown	Ruth Olmstead, Glendive	Dawson	--	--	--
286	7-46	Tertiary	S Radersburg, F. Crowley	Broadwater	32	5N	1E
287	7-47	Beltian	McGruder prosp. Daly Cr.	Ravalli	34	6N	18W

TABLE 1.--Sample locations, Montana clays and shales, cont'd.

Sample No.	Field No.	Formation	Location	County	Sec.	T.	R.
288	7-48	Pleistocene	Kalispell, US2, Sunset Dr.	Flathead	8	28N	21W
289	7-49	Pleistocene	S & 1.2 mi. W of Pablo	Lake	15	21N	20W
290	7-50	Pleistocene	7 mi. W of Missoula	Missoula	34	14N	20W
291	7-51	Beltian	3 mi. E of Missoula	Missoula	18	13N	18W
292	7-52	Cretaceous	N of Logan, G. Kanta	Gallatin	13	2N	2E
293	7-53	Cretaceous	N of Logan, G. Kanta	Gallatin	13	2N	2E
294	7-54	Cretaceous	N of Logan, G. Kanta	Gallatin	13	2N	2E
295	7-55	Cretaceous	N of Logan, G. Kanta	Gallatin	13	2N	2E
296	7-56	Cretaceous	Composite 292-295	Gallatin	13	2N	2E
297	7-57	Cretaceous	3 mi. N of Logan	Gallatin	13	2N	2E
298	7-58	Cretaceous	3 mi. N of Logan	Gallatin	13	2N	2E
299	7-59	Cretaceous	3 mi. N of Logan	Gallatin	13	2N	2E
300	7-60	Cretaceous	3 mi. N of Logan	Gallatin	13	2N	2E
301	7-61	L.Cretaceous	8 mi. W of Willow Cr.	Jefferson	26	1N	2W
302	7-62	L.Cretaceous	9 mi. W of Willow Cr.	Jefferson	22	1N	2W
303	7-63	Claggett	T. Wollenzien, G.N.R.R.	Golden Val.	35	8N	19E
304	7-64	Recent(?)	Jefferson Gulch, S. Foot	Powell	--	12N	9W
305	7-65	Tertiary	Bozeman, H. S. Kirk	Gallatin	--	2S	6W?
306	7-66	Igneous	Squaw Cr., H. S. Kirk	Gallatin	--	5S	5W
307	7-67	Igneous	Ennis, H. S. Kirk	Madison	--	5S	2W
308	7-68	Igneous	Squaw Cr., H. S. Kirk	Gallatin	--	5S	5W
309	7-69	Cretaceous	G. Kanta, Three Forks	Gallatin	13	2N	2E
310	7-70	Cretaceous	G. Kanta, Three Forks	Gallatin	13	2N	2E
311	7-71	Cretaceous	G. Kanta, Three Forks	Gallatin	13	2N	2E
312	8-1	Hell Creek	Glendive, R. Almstead	Dawson	22	16N	55E
313	8-2	Fort Union	Glendive, E. Anderson	Dawson	31	15N	58E
314	8-3	Fort Union	Glendive, E. Anderson	Dawson	31	15N	58E
315	8-4	Fort Union	Glendive, J. Reeves	Dawson	22	18N	50E
316	8-5	Fort Union	Glendive, J. Omdal	Dawson	30	17N	53E
317	8-6	Fort Union	Glendive, J. Omdal	Dawson	30	17N	53E
318	8-7	Fort Union	Glendive, D. Gibson	Dawson	29	18N	50E
319	8-8	--	Glendive, Schwartz	Dawson	--	--	--
320	8-9	--	Glendive, Schwartz	Dawson	--	--	--
321	8-10	Fort Union	Glendive, Pete Boje	Dawson	22	18N	52E
322	8-11	--	Glendive, John Boese	Dawson	20	21N	53E
323	8-12	Fort Union	Glendive, Ed Eklund	Dawson	13	17N	53E
324	8-13	Fort Union	Glendive, B. Appleby	Dawson	30	18N	54E
325	8-14	Fort Union	Glendive, B. Appleby	Dawson	31	18N	54E
326	8-15	Fort Union	Glendive, B. Appleby	Dawson	30	18N	54E
327	8-16	Fort Union	Glendive, B. Appleby	Dawson	30	18N	54E
328	8-17	--	Glendive, Anderson	Dawson	--	--	--
329	8-18	--	G. Kanta, brown sample	Gallatin	--	--	--
330	8-19	Cretaceous	Upper half pit, G. Kanta	Gallatin	13	2N	2E?
331	8-20	Cretaceous	Lower half pit, G. Kanta	Gallatin	13	2N	2E?
332	8-21	Syenite	Judith Mts., G. Morton	Fergus	--	--	--
333	8-22	Cretaceous?	R. Chew, N.P.Ry.	Broadwater	16	5N	4E
334	8-23	Tertiary(?)	R. Chew, N.P.Ry.	Broadwater	7	5N	3E
335	8-24	Cretaceous?	R. Chew, N.P.Ry.	Treasure	24	7N	37E
336	8-25	Cretaceous?	R. Chew, N.P.Ry.	Treasure	1	7N	37E

TABLE 1.--Sample locations, Montana clays and shales, cont'd.

Sample No.	Field No.	Formation	Location	County	Sec. T & R
337	8-26	Cretaceous?	R. Chew, N. P. Ry.	Treasure	1, 7N, 37E
338	8-27	Qtz. Monz.	Woodrow Wilson Mine, Rimini, R. Chew	Lewis & Clark	29, 8N, 5W
339	8-28	Tailings	Porphyry Dike Mine, Rimini, R. Chew	Lewis & Clark	9N, 5W
340	8-29	Hell Creek	Glendive, H. Bartram	Dawson	30, 16N, 56E
341	8-30	Hell Creek	Glendive, H. Bartram	Dawson	30, 16N, 56E
342	8-31	Hell Creek	Glendive, H. Bartram	Dawson	30, 16N, 56E
343	8-32	Hell Creek	Glendive, H. Bartram	Dawson	30, 16N, 56E
344	8-33	Hell Creek	Glendive, H. Bartram	Dawson	30, 16N, 56E
345	8-34	Hell Creek	Glendive, H. Bartram	Dawson	30, 16N, 56E
346	8-35	Hell Creek	Glendive, H. Bartram	Dawson	30, 16N, 56E
347	8-36	Hell Creek	Glendive, H. Bartram	Dawson	30, 16N, 56E
348	8-37	Hell Creek	Glendive, H. Bartram	Dawson	30, 16N, 56E

TABLE 2.--Ceramic properties of Montana clays and shales

Sample No.	Water of Plasticity Percent	Drying Shrinkage Percent	P.C.E.	Firing Range Degrees Fahrenheit	Firing Temperature Degrees Fahrenheit	Firing Shrinkage Percent	Fired Color	Hardness	Remarks
a	b	c	d			e	f	g	
241	L 44 H 54	6.2	3	1850 to 1950	1600 1800 2000	0.9 2.0 OF	lt. red lt. red dk. red	SS SS HS	Common brick with careful handling
242	L 34 H 52	9.4	9	1800 to 2000	1750 1950 2150	1.2 7.0 OF	dk. red dk. red dk. red	S HS HS	Common brick
243	L 34 H 44	4.8	over 12	1950 to 2300	1950 2150 2300	2.7 4.3 3.5	buff tan white	HS HS HS	Good common brick material

a. See table 1
b. L = Lower limit; H = Upper limit
c. Drying shrinkage is lineal.
d. Pyrometric Cone Equivalent in Standard Seger 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 Montana clays and shales, cont'd.

Sample No.	Water of Plasticity Percent	Drying Shrinkage Percent	P.C.E.	Firing Range Degrees Fahrenheit	Firing Temperature Degrees Fahrenheit	Firing Shrinkage Percent	Fired Color	Hardness	Remarks
244	L 30 H 45	8.5	8	1800 to 2000	1750 1950 2150	0.3 7.5 OF	tan dk. red brown	SS HS HS	Fair common brick material
245	L 22 H 27	4.7	8	1800 to 2050	1750 1950 2150	0.0 0.3 6.5	tan tan grey	SS S HS	Fair common brick material
246	L 32 H 44	5.6	5	1700 to 2000	1650 1850 2050	0.0 1.1 6.9	tan tan olive	S S HS	Good common brick material
247		Not tested for ceramic properties							
248	L 34 H 44	6.1	5	1900 to 1950	1650 1850 2050	0.0 0.3 OF	tan pink brown	SS SS HS	Not suitable
249	L 48 H 56	3.9	over 12	above 2400	1900 2100 2300	1.2 0.6 3.3	tan lt. red lt. red	SS SS SS	Not suitable alone, would make good lightweight grog
250	L 32 H 44	7.5	2	1650 to 1900	1600 1800 2000	0.6 0.9 OF	tan tan brown	S HS HS	Fair common brick material
251	L 60 H 110	Not fired, brick crumbled on drying							Not suitable
252	L 62 H 134	Not fired, bricks crumbled on drying							Not suitable
253	L 59 H 86	Not fired, bricks crumbled on drying							Not suitable
254	L 52 H 58	7.1	5	1750 to 1900	1650 1850 2050	7.9 15.6 OF	tan tan brown	SS S HS	Not suitable
255	L 25 H 30	4.2	over 12	2100 to 2400+	1900 2100 2300	0.0 0.0 0.6	all mottled white	SS S HS	Good ceramic material

TABLE 2.--Ceramic properties of Montana clays and shales, cont'd.

Sample No.	Water of Plasticity Percent	Drying Shrinkage Percent	P.C.E.	Firing Range Degrees Fahrenheit	Firing Temperature Degrees Fahrenheit	Firing Shrinkage Percent	Fired Color	Hardness	Remarks
256	L 22 H 29	3.6	over 12	1900 to 2200	1900 2100 2300	3.9 4.8 5.4	red dk. red brown	S HS HS	Fair common brick material
257	L 60 H 68	5.5	5	nil	1650 1850 2050	2.7 11.0 24.2	tan red dk. red	SS SS HS	Not suitable
258	L 72 H 84	5.3	1	nil	1600 1750 1950	0.6 18.0 29.0	tan red brown	SS SS HS	Not suitable
259	L 58 H 68	8.1	3	nil	1600 1800 2000	10.3 10.6 OF	tan tan brown	SS SS HS	Not suitable
260	L 68 H 140	Not fired, bricks crumbled on drying							Not suitable
261	L 84 H 160	Not fired, bricks crumbled on drying							Not suitable
262	L 60 H 90	Not fired, bricks crumbled on drying							Not suitable
263	L 68 H 120	Not fired, bricks crumbled on drying							Not suitable
264	L 50 H 100	Not fired, bricks crumbled on drying							Not suitable
265	L 36 H 58	5.9	over 12	2200 up	1900 2100 2300	4.5 12.3 15.3	white buff buff	SS HS HS	Not suitable alone, might be used as blending clay
266	L 34 H 57	6.0	over 12	2100 up	1900 2100 2300	4.9 11.6 12.0	buff buff brown	HS HS HS	Not suitable alone, might be used as blending clay
267	L 30 H 35	6.1	over 12	2400 up	1900 2100 2300	9.7 12.0 10.0	all mottled white	SS SS SS	Good ceramic material with binder added

TABLE 2.--Ceramic properties of Montana clays and shales, cont'd.

Sample No.	Water of Plasticity Percent	Drying Shrinkage Percent	P.C.E.	Firing Range Degrees Fahrenheit	Firing Temperature Degrees Fahrenheit	Firing Shrinkage Percent	Fired Color	Hardness	Remarks
268	L 34	11.3	over	1900	1900	4.3	pink	HS	Fair common
	H 60		13	to	2100	6.0	tan	HS	brick material
				2200	2300	5.5	brown	HS	
269	L 58	Not fired, bricks crumbled on drying							Not suitable
	H 132								
270	L 40	9.9	5	1700	1650	3.0	tan	HS	
	H 48			to	1850	10.5	red	HS	
				1950	2050	OF	brown	HS	
271	L 22	4.1	10	1900	1850	1.4	tan	S	Common brick
	H 26			to	2050	3.8	dk. red	HS	
				2100	2250	0.6	brown	HS	
272	L 21	3.1	4	1700	1650	0.0	tan	S	Common brick
	H 25			to	1850	0.0	red	HS	
				2050	2050	1.8	dk. red	HS	
273	L 22	3.1	2	1700	1600	0.0	tan	HS	Common brick
	H 26			to	1800	0.0	red	HS	
				1900	2000	OF	brown	HS	
274	L 20	5.9	5	1700	1650	0.3	tan	S	Fair common
	H 22			to	1850	0.3	red	HS	brick material
				1950	2050	1.3	grey	HS	
275	L 19	2.3	4	1950	1650	0.0	tan	SS	Not suitable
	H 23			to	1850	0.6	lt. red	SS	
				2000	2050	4.5	brown	HS	
276	L 51	4.2	11	1950	1850	5.2	tan	SS	Fair common
	H 54			to	2050	9.8	red	HS	brick material
				2200	2250	9.8	brown	HS	
277	L 18	2.7	9	2000	1750	+1.3	red	SS	Not suitable
	H 21			to	1950	0.3	red	SS	alone, could be
				2100	2150	2.9	brown	HS	used for grog
									with grinding

TABLE 2.--Ceramic properties of Montana clays and shales, cont'd.

Sample No.	Water of Plasticity Percent	Drying Shrinkage Percent	P.C.E.	Firing Range Degrees Fahrenheit	Firing Temperature Degrees Fahrenheit	Firing Shrinkage Percent	Fired Color	Hardness	Remarks
278	L 20 H 22	2.5	5	1850 to 2000	1650 1850 2050	0.0 0.9 1.0	red red brown	SS S HS	Not suitable alone, could be used for grog with grinding
279	L 18 H 21	2.5	9	nil	1750 1950 2150	1.2 2.4 +4.5	lt. red dk. red brown	SS S HS	Not suitable alone, could be used for grog with grinding
280	L 50 H 68	9.3	9	nil	1750 1950 2150	7.5 12.2 15.3	tan red dk. red	SS SS HS	Not suitable
281	L 52 H 62	8.7	7	1900 to 2050	1700 1900 2100	1.8 5.6 OF	lt. red red dk. red	SS S HS	Not suitable
282	L 36 H 45	7.5	5	2000	1650 1850 2050	2.1 0.3 11.0	lt. red dk. red dk. red	SS HS HS	Not suitable
283	L 56 H 110	Not fired, bricks crumbled on drying							Not suitable
284	L 56 H 120	Not fired, bricks crumbled on drying							Not suitable
285	L 42 H 48	4.9	10	1900 to 1950	1850 2050 2250	5.4 11.6 10.9	tan red dk. red	SS HS HS	Not suitable
286	L 42 H 76	15.1	11½	2000 to 2200	1850 2050 2250	0.7 7.0 +0.3	tan dk. red dk. red	SS HS HS	Not suitable
287	L 16 H 20	Not fired, no plasticity							Not suitable
288	L 23 H 28	4.5	4	1950 to 2000	1650 1850 2050	+0.5 1.9 8.3	lt. red lt. red tan	SS HS HS	Not suitable, silt, no plasticity

TABLE 2.--Ceramic properties of Montana clays and shales, cont'd.

Sample No.	Water of Plasticity Percent	Drying Shrinkage Percent	P.C.E	Firing Range Degrees Fahrenheit	Firing Temperature Degrees Fahrenheit	Firing Shrinkage Percent	Fired Color	Hardness	Remarks
289	L 29 H 34	3.1	3	1900 to 1950	1600 1800 2000	0.3 0.0 12.0	lt. red lt. red brown	SS SS HS	Suitable for common brick with careful handling
290	L 36 H 48	8.2	3	1800 to 1950	1600 1800 2000	0.6 1.1 OF	lt. red lt. red brown	S S HS	Suitable for common brick & like products
291	L 16 H 19	Not fired, no plasticity							Not suitable
292	L 23 H 33	4.5	12	nil	1900 2100 2300	3.9 1.9 2.9	lt. red lt. red dk. red	SS HS HS	Not suitable
293	L 23 H 35	4.3	14	nil	1900 2100 2300	6.3 13.0 OF	red dk. red brown	HS HS HS	Not suitable
294	L 22 H 32	3.5	12	nil	1900 2100 2300	+1.4 +9.3 +3.1	red dk. red dk. red	HS HS HS	Not suitable
295	L 22 H 28	4.5	12	nil	1900 2100 2300	+1.6 1.6 OF	red dk. red dk. red	HS HS HS	Not suitable
296	Composite (not tested ceramically)								
297	L 22 H 31	4.7	14	nil	1900 2100 2300	3.0 7.4 3.6	red dk. red dk. red	HS HS HS	Not suitable
298	L 24 H 34	4.4	14	nil	1900 2100 2300	3.0 6.2 3.0	red dk. red dk. red	HS HS HS	Not suitable
299	L 22 H 33	4.7	12	nil	1900 2100 2300	1.8 5.6 5.1	red dk. red dk. red	HS HS HS	Not suitable

TABLE 2.--Ceramic properties of Montana clays and shales, cont'd.

Sample No.	Water of Plasticity Percent	Drying Shrinkage Percent	P.C.E.	Firing Range Degrees Fahrenheit	Firing Temperature Degrees Fahrenheit	Firing Shrinkage Percent	Fired Color	Hardness	Remarks
300	L 25 H 33	4.7	14	nil	1900 2100 2300	2.0 5.2 2.3	red dk. red dk. red	HS HS HS	Not suitable
301	L 25 H 33	5.8	13	1900 to 2300	1900 2100 2300	3.5 5.2 2.4	red dk. red dk. red	HS HS HS	Common brick
302	L 20 H 24	4.0	7	nil	1650 1850 2100	0.0 0.0 OF	red red brown	SS SS HS	Not suitable, narrow firing range
303	L 28 H 48	7.3	3	1650 to 2050	1650 1850 1800	0.95 2.6 OF	lt. red dk. red brown	SS S HS	Not suitable
304	L 22 H 27	6.6	10	1800 to 2100	1800 2000 2200	0.0 2.4 2.9	lt. red dk. red dk. red	S HS HS	Good common brick material
305	L 29 H 40	3.0	7	1900 to 2000	1700 1900 2100	1.0 1.0 OF	lt. red cream brown	S S HS	Fair common brick material
306) 307) 308)	All feldspars, not tested for ceramic properties								
309) 310) 311)	Tested for expandability only								
312	L 40 H 50	8.6	8	1750 to 1800	1750 1950 2150	3.2 OF OF	lt. red brown brown	S HS HS	Not suitable
313	L 34 H 62	9.6	10	1800 to 1850	1800 2000 2200	2.9 OF OF	lt. red brown brown	S HS HS	Not suitable
314	L 42 H 50	6.7	8	1850 to 1950	1750 1950 2150	2.9 15.9 OF	lt. red mottled brown	SS HS HS	Possibly use as a common brick material with careful handling

TABLE 2.--Ceramic properties of Montana clays and shales, cont'd.

Sample No.	Water of Plasticity Percent	Drying Shrinkage Percent	P.C.E.	Firing Range Degrees Fahrenheit	Firing Temperature Degrees Fahrenheit	Firing Shrinkage Percent	Fired Color	Hardness	Remarks
315	L 34 H 50	7.3	5	1650 to 1850	1650 1850 2050	1.2 6.7 OF	lt. red dk. red brown	S HS HS	Fair common brick material
316	L 40 H 98	Not fired, brick crumbled on drying							Not suitable
317	L 39 H 88	Not fired, brick crumbled on drying							Not suitable
318	L 34 H 64	8.5	7	1700 to 1850	1700 1900 2100	1.5 OF OF	lt. red dk. red brown	S HS HS	Fair common brick material
319	L 30 H 56	6.1	5	nil	1650 1850 2050	0.3 -0.6 OF	lt. red cream brown		Not suitable
320	L 26	9.3	9½	1800 to 1900	1750 1950 2150	1.7 2.6 OF	mottled mottled brown	S HS HS	Not suitable
321	L 30 H 44	7.5	1	nil	1600 1750 1950	0.8 0.3 10.4	lt. red mottled mottled	SS SS S	Not suitable
322	L 27 H 44	6.5	1	1600 to 1800	1600 1750 1950	0.0 0.0 5.7	lt. red mottled mottled	S S HS	Not suitable
323	L 42 H 66	12.7	1	nil	1600 1750 1950	-1.2 - -	lt. red dk. red dk. red	S HS HS	Not suitable, all brick cracked on firing
324	L 31 H 42	7.5	4	1900 to 1950	1650 1850 2050	0.6 0.6 OF	lt. red cream brown	SS SS HS	Not suitable
325	L 30 H 48	8.4	4	2000 to 2050	1750 1950 2150	0.0 0.0 OF	lt. red cream brown	SS SS HS	Not suitable

TABLE 2.--Ceramic properties of Montana clays and shales, cont'd.

Sample No.	Water of Plasticity Percent	Drying Shrinkage Percent	P.C.E.	Firing Range Degrees Fahrenheit	Firing Temperature Degrees Fahrenheit	Firing Shrinkage Percent	Fired Color	Hardness	Remarks
326	L 29 H 47	8.4	8	1800 to 2000	1750 1950 2150	0.6 2.4 OF	tan dk. red dk. red	S HS HS	Fair common brick material with careful handling
327	L 29 H 35	3.6	5	1875 to 1925	1650 1850 2050	2.6 0.0 OF	lt. red cream brown	SS SS HS	Not suitable, narrow firing range
328	L 36 H 43	5.8	11	1850 to 1900	1850 2050 2250	5.6 - -	mottled brown brown	S HS HS	Not suitable, swelling & cracking of brick
329	L 46 H 80	Not fired, brick crumbled on drying							Not suitable
330	L 24 H 30	6.7	12	2100 to 2300	1900 2100 2300	0.0 5.1 3.6	lt. red lt. red dk. red	SS S HS	Common brick material
331	L 24 H 31	5.3	12	2050 to 2250	1900 2100 2300	1.7 4.6 5.2	lt. red red dk. red	S HS HS	Poor common brick material
332	L 24 H 27	0.0	12	2050 to 2300	1900 2100 2300	+1.6 0.9 3.3	lt. pink lt. pink grey	SS S HS	Good ceramic material
333	L 27 H 33	5.4	5	1800 to 2050	1650 1850 2050	+0.9 0.0 4.7	lt. red lt. red lt. red	SS S HS	Good common brick
334	L 54 H 112	Not fired, brick crumbled on drying							Not suitable
335	L 68 H 144	Not fired, brick crumbled on drying							Not suitable
336	L 80 H 140	Not fired, brick crumbled on drying							Not suitable
337	L 50 H 92	Not fired, brick crumbled on drying							Not suitable

TABLE 2.--Ceramic properties of Montana clays and shales, cont'd.

Sample No.	Water of Plasticity Percent	Drying Shrinkage Percent	P.C.E.	Firing Range Degrees Fahrenheit	Firing Temperature Degrees Fahrenheit	Firing Shrinkage Percent	Fired Color	Hardness	Remarks
338	L 22 H 25	4.2	over 12	2050 to 2300	1900 2100 2300	+1.3 1.4 4.3	pink pink grey	SS S HS	Very good ceramic material
339	L 24 H 28	3.2	11½	2150 to 2300	1900 2100 2300	+0.6 2.1 4.6	lt. red lt. red red	SS SS HS	Good ceramic material
340	L 56 H 124	Not fired, brick crumbled on drying							Not suitable
341	L 32 H 54	4.3	4	1850 to 2050	1650 1850 2050	0.0 0.6 3.5	lt. red lt. red dk. red	SS S S	Common brick, some stain from alkali scum
342	L 40 H 75	10.5	9	nil	1750 1950 2150	0.0 cracked OF	tan lt. red dk. red	SS S HS	Not suitable, brick cracked & swelled on firing
343	L 49 H 97	Not fired, brick crumbled on drying							Not suitable
344	L 40 H 48	10.4	3	nil	1600 1800 2000	0.0 cracked OF	lt. red lt. red dk. red	SS SS HS	Not suitable, brick cracked on firing
345	L 43 H 68	11.0	3	nil	1750 1950 2150	+0.9 cracked OF	lt. red lt. red dk. red	SS S HS	Not suitable, brick cracked & swelled on firing
346	L 39	Not fired, brick crumbled on drying							Not suitable
347	L 47 H 83	13.9	10	nil	1800 2000 2300	+0.6 cracked OF	lt. red lt. red dk. red	S HS HS	Not suitable, brick cracked & swelled on firing
348	L 44 H 81	14.8	10	nil	1800 2000 2200	0.0 cracked OF	lt. red lt. red brown	S HS HS	Not suitable brick cracked & swelled on firing

TABLE 3.--Expandability of Montana clays and shales.

Sample No.	Formation & Location	Expansion Range °F	Sp. Gr. after Firing	Grade of Product	Firing Behavior	Remarks
241	Pleistocene, Blackfoot R.	2282	1.1	fair	fused @ 2282° F	Fair product, narrow range
242	Toston, Montana	-	-	-	glazed @ 2192° F	Not suitable
243	Tuxedo mine, Silver Bow Co.	-	-	-	no change	Not suitable
244	Ft. Union, Dawson Co.	2102 to 2282	1.2	excel-lent	glazed @ 2282° F	Excellent, wide range
245	Fort Union, Dawson Co.	-	-	-	fused @ 2372° F	Not suitable
246	Fort Union, Dawson Co.	2102	-1.0	good	bloated & glazed @ 2102° F	Good product, narrow range
247	Perlite, White Pine, Jefferson Co.	-	-	-	-	Not suitable
248	Russel Meech, MSM	2102	-1.0	good	bloated & fused @ 2102° F	Good product, narrow range
249	Tertiary, Powell Co.	-	-	-	no change	Not suitable
250	Pleistocene, Powell Co.	-	-	-	fused @ 2192° F	Not suitable
251	Tertiary, Granite Co.	-	-	-	minor bloat @ 2372° F	Not suitable
252	Tertiary, Granite Co.	-	-	-	fused @ 2282° F	Not suitable
253	Tertiary ?, Gallatin Co.	2012 to 2102	-1.0	good	fused @ 2102° F	Good, low range
254	Tertiary ?, Gallatin Co.	-	-	-	glazed @ 2102° F	Not suitable

TABLE 3.--Expandability of Montana clays and shales, cont'd.

Sample No.	Formation & Location	Expansion Range °F	Sp. Gr. after Firing	Grade of Product	Firing Behavior	Remarks
255	Alt. syenite, Hughesville	-	-	-	fused @ 2282° F	Not suitable
256	Cambrian, Hughesville	-	-	-	spalled @ all temp.	Not suitable
257	Tertiary, Powell Co.	-	-	-	glazed @ 2372° F	Not suitable
258	Tertiary, Powell Co.	-	-	-	fused, minor bloat @ 2192° F	Not suitable
259	Tertiary, Powell Co.	-	-	-	fused @ 2192° F	Not suitable
260	Tertiary, Silver Bow Co.	-2192	1.1	good	fused @ 2192° F	Good product, narrow range
261	Tertiary, Beaverhead Co.	-	-	poor	glazed @ 2282° F	Not suitable
262	Tertiary, Beaverhead Co.	-	1.0	good	fused @ 2282° F	Good product, narrow range
263	Tertiary, Beaverhead Co.	-	-1.0	good	fused @ 2282° F	Good product, narrow range
264	Tertiary, Beaverhead Co.	-	-	-	fused @ 2282° F	Not suitable
265	Mine pit, Beaverhead Co.	-	-	-	no change	Not suitable
266	Mine pit, Beaverhead Co.	-	-	-	no change	Not suitable
267	Mine pit, Beaverhead Co.	-	-	-	fused @ 2282° F	Not suitable
268	Tertiary, Beaverhead Co.	-	-	-	no change	Not suitable

TABLE 3.--Expandability of Montana clays and shales, cont'd.

Sample No.	Formation & Location	Expansion Range °F	Sp. Gr. after Firing	Grade of Product	Firing Behavior	Remarks
269	Red clay, Dyce Cr., Beaverhead Co.	-	-	-	fusion @ 2372° F	Not suitable
270	Colorado, Powell Co.	-	-	-	nothing	Not suitable
271	Colorado, Powell Co.	-	-	-	fused @ 2372° F	Not suitable
272	Colorado, Powell Co.	2012 to 2192	1.2	fair	fused @ 2192° F	Fair product, erratic bloat
273	Cretaceous, Powell Co.	-	1.4	fair	fused @ 2282° F	Fair product, narrow range
274	Cretaceous, Powell Co.	-2282	1.6	poor	fused @ 2282° F	Poor product, narrow range
275	Cretaceous Powell Co.	-2192	1.2	good	fused @ 2282° F	Good product, narrow range
276	Beltian, Flint Cr. hill	-	-	-	fused @ 2282° F	Not suitable
277	Beltian, Flint Cr. hill	-	-	-	fused @ 2372° F	Not suitable
278	Beltian, Flint Cr. hill	-2282	1.4	fair	fused @ 2282° F	Not suitable
279	Beltian, Flint Cr. hill	-	-	-	glazed @ 2282° F	Not suitable
280	Tertiary, Jefferson Co.	-2192	1.0	good	fused @ 2192° F	Good product
281	Tertiary, Sweetwater Basin	-	-	-	glazed @ 2282° F	Not suitable
282	Tertiary, Sweetwater Basin	-	-	-	glazed @ 2282° F	Not suitable
283	Tertiary, Beaverhead Co.	-	1.4	-	fused @ 2282° F	Not suitable

TABLE 3.--Expandability of Montana clays and shales, cont'd.

Sample No.	Formation & Location	Expansion Range °F	Sp. Gr. after Firing	Grade of Product	Firing Behavior	Remarks
284	Tertiary, Jefferson Co.	-	1.0	-	fused @ 2282° F	Poor product
285	Glendive, Dawson Co.	2102 to 2282	1.0	-	fused @ 2282° F	Excellent product
286	Tertiary, Jefferson Co.	-	-	-	fused @ 2282° F	Not suitable
287	Beltian, Ravalli Co.	-	-	-	-	Not suitable
288	Pleistocene, Flathead Co.	-	-	-	fused @ 2282° F	Not suitable
289	Pleistocene, Lake Co.	-	-	-	fused @ 2282° F	Not suitable
290	Pleistocene, Missoula Co.	-	-	-	fused @ 2282° F	Not suitable
291	Beltian, Missoula Co.	-	1.0	-	fused @ 2282° F	Not suitable
292	Cretaceous, Gallatin Co.	2012 to 2192	1.5	poor	spalled all temp.	Poor product, brittle, flaky
293	Cretaceous, Gallatin Co.	2012 to 2192	1.1	poor	spalled all temp.	Poor product, brittle, flaky
294	Cretaceous, Gallatin Co.	2012 to 2192	1.1	fair	popcorn bloat	Fair product, wide range, flaky
295	Cretaceous Gallatin Co.	2012 to 2192	-1.0	fair	popcorn bloat	Fair product, wide range, some flakes
296	Cretaceous, composite, Gallatin Co.	2012 to 2192	1.2	fair	spalled	Fair product, spalling
297	Cretaceous, Gallatin Co.	-	1.4	-	fused @ 2192° F	Not suitable
298	Cretaceous, Gallatin Co.	-	1.9	-	spalled	Not suitable

TABLE 3.--Expandability of Montana clays and shales, cont'd.

Sample No.	Formation & Location	Expansion Range °F	Sp. Gr. after Firing	Grade of Product	Firing Behavior	Remarks
299	Cretaceous, Gallatin Co.	2102 to 2282	1.6	excel-lent	rounded fused @ 2282° F	Excellent product, wide range
300	Cretaceous, Gallatin Co.	2102 to 2282	1.4	poor	spalled	Poor product
301	Late Cretaceous, Jefferson Co.	-	1.2	poor	spalled	Poor product, brittle
302	Late Cretaceous, Jefferson Co.	-	1.7	-	spalled all temp.	Not suitable, crumbly
303	Claggett, Golden Valley Co.	2012 to 2372	1.1	excel-lent	glazed, bloated all temp.	Excellent, glazed & rounded
304	Recent ?, Powell Co.	-	2.4	-	fused @ 2282° F	Not suitable
305	Tertiary, Gallatin Co.	-	-	-	fused @ 2282° F	Not suitable
306	Igneous, Gallatin Co.	-	-	-	-	Not bloated
307	Igneous, Madison Co.	-	-	-	-	Not bloated
308	Igneous, Madison Co.	-	-	-	-	Not bloated
309	Cretaceous, Gallatin Co.	-	-	-	spalled all temp.	Not suitable
310	Cretaceous, Gallatin Co.	2012 to 2372	1.3	fair	glazed @ 2372° F	Fair product, wide range
311	Cretaceous, Gallatin Co.	2102 to 2372	1.1	good	glazed @ 2372° F	Good product, wide range
312	Hell Creek, Dawson Co.	2012 to 2372	1.0	good	glazed @ 2372° F	Good product, wide range

TABLE 3.--Expandability of Montana clays and shales, cont'd.

Sample No.	Formation & Location	Expansion Range °F	Sp. Gr. after Firing	Grade of Product	Firing Behavior	Remarks
313	Fort Union, Dawson Co.	2102 to 2372	1.2	good	glazed @ 2372° F	Good product, high range
314	Fort Union, Dawson Co.	±2372	-1.0	good	expanded 2372° F	Good product, but only @ 2372° F
315	Fort Union, Dawson Co.	-	-	-	fused @ 2372° F	Not suitable
316	Fort Union, Dawson Co.	-	-	-	fused @ 2372° F	Not suitable
317	Fort Union, Dawson Co.	-	-	-	fused @ 2372° F	Not suitable
318	Fort Union, Dawson Co.	2102 to 2282	1.3	excel-lent	fused @ 2282° F	Excellent product, rounded, glazed
319	Dawson Co.	-	-	-	fused @ 2372° F	Not suitable
320	Dawson Co.	-	-	-	minor fusion @ 2372° F	Not suitable
321	Fort Union, Dawson Co.	-	-	-	fused @ 2282° F	Not suitable
322	Dawson Co.	-	-	-	fused @ 2372° F	Not suitable
323	Fort Union, Dawson Co.	-	-	-	fused @ 2372° F	Not suitable
324	Fort Union, Dawson Co.	-	-	-	glazed @ 2372° F	Not suitable
325	Fort Union, Dawson Co.	-	-	-	no re-action	Not suitable
326	Fort Union, Dawson Co.	-	-	-	no re-action	Not suitable
327	Fort Union, Dawson Co.	-	-	-	fused @ 2282° F	Not suitable

TABLE 3.--Expandability of Montana clays and shales, cont'd.

Sample No.	Formation & Location	Expansion Range °F	Sp. Gr. after Firing	Grade of Product	Firing Behavior	Remarks
328	Dawson Co.	±2372	-1.0	fair	expanded fused @ 2372° F	Not suitable
329	Gallatin Co.	2012 to 2372	1.0	fair	spalled badly	Fair product, wide range, flaky
330	Gallatin Co.	2282 to 2372	1.2	good	expanded w/fusion @ 2372°F	Fair product, narrow high range
331	Gallatin Co.	2012 to 2372	1.5	good	fused @ 2372° F	Good product, very wide range
332	Syenite, Fergus Co.	-	-	-	-	Not fired
333	Cretaceous ?, Broadwater Co.	-	-	-	no re-action	Not suitable
334	Tertiary ?, Broadwater Co.	-	-	-	fused @ 2372° F	Not suitable
335	Cretaceous ?, Treasure Co.	-	-	-	-	Not fired
336	Cretaceous ?, Treasure Co.	-	-	-	-	Not fired
337	Cretaceous ?, Treasure Co.	-	-	-	-	Not fired
338	Qtz. monz., Lewis & Clark Co.	-	-	-	-	Not fired
339	Tailings, Lewis & Clark Co.	-	-	-	-	Not fired
340	Hell Creek, Dawson Co.	-	-	-	fused @ 2372° F	Not suitable
341	Hell Creek, Dawson Co.	-	-	-	minor change	Not suitable

TABLE 3.--Expandability of Montana clays and shales, cont'd.

Sample No.	Formation & Location	Expansion Range °F	Sp. Gr. after Firing	Grade of Product	Firing Behavior	Remarks
342	Hell Creek, Dawson Co.	-	-	-	minor change	Not suitable
343	Hell Creek, Dawson Co.	-	-	-	no reaction	Not suitable
344	Hell Creek, Dawson Co.	2192 to 2372	1.3	good	glazed @ 2372° F	Good product, semi-rounded, medium range
345	Hell Creek, Dawson Co.	2012 to 2372	1.1	excellent	expanded @ all ranges	Excellent product, very wide range
346	Hell Creek, Dawson Co.	2192 to 2372	1.3	good	glazed @ 2372° F	Good product, medium range
347	Hell Creek, Dawson Co.	2192 to 2372	1.2	very good	glazed from 2192° F on	Very good product, medium range
348	Hell Creek, Dawson Co.	2102 to 2372	1.0	excellent	glazed from 2192° F on	Excellent product, wide range

TABLE 4.--X-ray diffraction data on Montana clays and shales.

Sample No.	Kaolin	Montmorillonite	Quartz	Feldspar	Illite	Calcite	Other
241	-	Min*	Maj*	Min	Maj	Med*	Min. hydromica & amesite
242	-	-	Maj	Min	Med	-	Min. complex silicates
243	-	-	Maj	Min	Maj	-	Min. chlorite & complex silicates
244	-	-	Maj	Min	Maj	-	Maj. chamosite, min. chlorite
245	Med	-	Maj	Min	Med	Min	Maj. dolomite
246	Med	-	Maj	Min	Med	Min	Maj. dolomite, min. chlorite
247	-	-	-	-	-	-	Volcanic glass
248	-	-	Maj	Min	Maj	Med	Maj. chlorite
249	-	Min	Min	-	-	-	Maj. cristobalite
250	Tra*	-	Maj	Min	Maj	Med	Maj. chlorite, min. dolomite & iron oxide
251	Med	Maj	Tra	Min	-	-	Min. chlorite & pyrophyllite
252	-	Maj	Tra	Min	Tra	-	Maj. cristobalite, min. chlorite
253	-	Maj	Tra	-	-	-	Min. complex silicates
254	-	Maj	Tra	Min	Tra	-	Tra. cristobalite
255	-	Tra	Maj	-	Min	Med	Maj. metahalloysite
256	-	-	Med	-	Maj	Min	Min. metahalloysite
257	-	Maj	Med	Min	Min	-	Min. metahalloysite & palygorskite
258	-	Maj	Min	-	Tra	Maj	
259	-	Maj	Min	Min	-	Maj	
260	-	Maj	Med	Min	-	-	Min. pyrophyllite
261	-	Maj	Min	Min	-	-	
262	Min	Maj	-	Med	-	-	Min. talc
263	-	Maj	-	Tra	-	-	Tra. talc
264	Min	Maj	Min	Min	Med	-	Min. palygorskite & metahalloysite
265	Maj	Tra	-	-	-	-	Tra. chlorite

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*Min = minimum
Maj = major
Med = medium
Tra = trace

TABLE 4.--X-ray diffraction data on Montana clays and shales, cont'd.

Sample No.	Kaolin	Montmor-illonite	Quartz	Feld-spar	Illite	Calcite	Other
266	Maj	Min	Min	Min	-	-	
267	Min	-	-	-	Min	-	Maj. halloysite & complex silicate (alunite, high), min. iron oxide
268	Min	Maj	Med	Min	-	-	Min. complex silicate
269	Min	Maj	Min	Min	-	-	Med. iron oxide
270	Med	-	Maj	Min	Maj	-	Min. cristobalite
271	Min	Med	Maj	Min	Med	Min	Min. hydromica & palygorskite
272	Med	Min	Maj	Min	Med	Min	Min. chlorite & amphibole
273	Med	-	Maj	Min	Med	Min	Min. dolomite & pyrophyllite
274	-	Maj	-	-	Med	Maj	Med. dolomite, min. hydromica & metahalloysite
275	Med	Min	Maj	-	Med	Maj	Med. dolomite, min. chlorite & hematite
276	Maj	-	Min	Min	-	-	Maj. Halloysite
277	Min	-	Maj	Min	Maj	-	Min. chlorite, dolomite & hematite
278	Min	Min	Maj	Min	Maj	-	Min. cronstedtite
279	Min	-	Maj	Min	Maj	Min	Min. hematite
280	Med	Med	Min	Min	-	-	Maj. chlorite, min. cristobalite
281	Med	Maj	-	Min	-	-	Min. gypsum
282	Med	Maj	Min	Min	-	Maj	Min. chlorite, talc & vermiculite
283	-	Maj	Min	Min	-	Med	Min. cristobalite
284	-	Maj	Min	Min	-	Min	Med. chlorite, min. gypsum
285	Min	Min	Maj	Min	Med	-	Min. chlorite
286	Min	Maj	Maj	Min	Min	-	Min. chlorite & palygorskite
287	-	-	Maj	-	-	-	Maj. dolomite, min. dickite
288	Min	-	Maj	Min	Med	Med	Min. dolomite, tra. chlorite
289	Med	-	Maj	Min	Med	Med	Med. dolomite, min. chlorite
290	Min	-	Maj	Min	Med	Min	Min. dolomite, tra. chlorite

TABLE 4.--X-ray diffraction data on Montana clays and shales, cont'd.

Sample No.	Kaolin	Montmor- illonite	Quartz	Feld- spar	Illite	Calcite	Other
291	-	Tra	Maj	Min	Min	Med	Min. dolomite
292	-	-	Maj	Med	Med	Med	Med. hydromica, tra. dolomite
293	-	Tra	Maj	-	Med	Med	Med. hydromica, tra. chlorite
294	-	-	Maj	-	Med	Med	Med. hydromica, tra. chlorite
295	Tra	Tra	Maj	-	Med	Min	Tra. dolomite
296	composite sample						
297	-	-	Maj	Tra	Med	Min	Med. hydromica, tra. dolomite
298	Tra	-	Maj	Tra	Med	Tra	Med. hydromica
299	Med	-	Maj	-	Med	Tra	Min. chlorite
300	Min	Tra	Maj	-	Med	-	Med. hydromica, tra. chlorite & complex silicates
301	Min	-	Maj	Min	Med	-	Med. hydromica, min. hematite, amphibole & dolomite
302	-	-	Maj	Med	Min	Med	Med. hydromica & dolomite, min. chlorite, hematite & talc
303	Min	Tra	Maj	Min	Med	-	Med. hydromica, min. dolomite
304	Min	-	Maj	Tra	Min	-	Tra. chlorite
305	Maj	Tra	Maj	Tra	Maj	Med	Med. dolomite
306	-	-	-	All	-	-	Microcline orthoclase
307	-	-	-	All	-	-	Microcline
308	-	-	-	All	-	-	Orthoclase, some Microcline
309	tested for expandability only						
310	tested for expandability only						
311	tested for expandability only						
312	Min	Min	Maj	Tra	Med	-	Hydromica & min. cronstedtite
313	-	Min	Maj	Min	Maj	-	Hydromica, min. halloysite & gypsum
314	-	Tra	Maj	Min	Maj	-	Hydromica, min. halloysite & gypsum
315	Med	Maj	Maj	Min	Med	-	Hydromica, min. amphibole minera

TABLE 4.--X-ray diffraction data on Montana clays and shales, cont'd.

Sample No.	Kaolin	Montmor-illonite	Quartz	Feld-spar	Illite	Calcite	Other
316	-	Maj	Maj	Min	Maj	-	Maj. hydromica, min. amphibole mineral, cristobalite, & iron oxides
317	-	Tra	Maj	Min	Med	Tra	Compex silicate, halloysite
318	Med	Min	Maj	Min	Med	-	Min. chlorite
319	-	Min	Maj	-	Med	Maj	Dolomite, min chlorite & halloysite
320	-	Med	Maj	Min	Min	-	Hydromica, halloysite
321	Med	Min	Maj	Tra	Med	-	Maj. dolomite, min. chlorite. Heavy scum taken off; dried brick was ferrous sulphate monohydrate $FeO \cdot SO_3 \cdot H_2O$
322	-	Med	Maj	Min	Maj	Maj	Maj. dolomite, min. chlorite, halloysite & amphibole mineral
323	-	-	Med	Min	Min	-	Maj. chlorite, min. calcium aluminate hydrate
324	Med	Min	Maj	Min	Med	Maj	Maj. dolomite, min. chlorite, hydromica & iron oxides
325	-	Min	Maj	Min	Min	-	Maj. dolomite, min. hydromica & halloysite
326	-	Med	Maj	Min	Med	-	Med. halloysite, min. chlorite
327	Min	Min	Maj	Min	Med	Maj	Maj. dolomite, min. amphibole mineral
328	Med	Med	Maj	Min	Med	-	Min. gypsum & iron oxides.
329	-	Maj	Maj	Min	-	-	Min. metahalloysite & chlorite
330	Med	Med	Maj	-	Maj	-	Min chlorite & metahalloysite

TABLE 4.--X-ray diffraction data on Montana clays and shales, cont'd.

Sample No.	Kaolin	Montmor-illonite	Quartz	Feld-spar	Illite	Calcite	Other
331	Min	-	Maj	-	Maj	-	Min. chlorite, hydromica & iron oxides
332	Maj	-	Maj	Min	-	Min	Min. hydromica & cronstedtite
333	Maj	Min	Maj	Min	Min	Min	Min. chlorite & amphibole
334	-	Tra	Maj	Med	-	-	Maj. chlorite, min. compex silicates
335	-	Maj	Maj	Min	Maj	-	Min. complex silicates & pyrophyllite
336	-	Med	Min	Med	Maj	-	Min. cristobalite & talc
337	-	Maj	Min	-	-	Maj	Min. hydromica
338	Maj	-	Maj	-	Maj	-	Min. hydromica & chamosite
339	Med	-	Maj	Min	Maj	-	Min. hematite
340	Min	Min	Med	Min	Min	-	Maj. chlorite
341	Maj	Min	Maj	Min	Maj	-	Min. cristobalite & dolomite
342	Med	Maj	Maj	Min	Min	Min	Min. chlorite
343	Min	Maj	Maj	Min	Min	Min	Min. chlorite
344	Tra	Med	Maj	Med	-	-	Min. iron oxides
345	Min	Maj	Maj	Min	Min	-	Min. cristobalite & dolomite
346	-	Med	Maj	Min	Min	-	Min. chlorite, sepiolite & med. metahalloysite
347	Min	Med	Maj	Med	Min	-	
348	Min	Med	Maj	Min	Min	-	Min. hydromica & complex silicate

TABLE 5.--Partial chemical analyses of high-alumina clays giving available alumina on those over 20% total alumina.

Sample No.	Total Al_2O_3 (a)	Available Al_2O_3 (a)	Na_2O (b)	K_2O (b)	H_2O -140° C. (a)	Ign. loss +650° C. (a)
241	14.35		2.7	9.2	0.90	5.16
243	15.05		2.8	7.0	0.73	6.35
246	11.9		4.6	5.4	0.83	9.44
250	15.4		0.3	0.2	0.80	8.84
251(c)	27.0	18.2	0.5	0.2	6.80	6.67
256(d)	20.4	14.1	1.2	6.0	1.33	5.60
260	18.15		2.3	6.5	9.67	4.07
261(e)	21.3	8.8	3.5	2.2	12.30	0.13
262(e)	21.8	11.0	3.4	6.1	5.73	5.60
263	18.6		0.6	0.5	11.27	5.87
264(f)	23.9	21.9	1.5	1.8	5.93	7.38
266(g)	23.15	23.1	2.8	0.4	2.40	9.52
267(h)	37.5	36.8	2.9	0.4	2.27	15.00
268	19.6		4.0	4.0	2.83	5.65
269	19.7		2.4	2.0	7.90	5.62
270	17.9		3.5	5.3	3.70	5.14
271	17.4		2.1	6.5	0.87	4.17
280	15.9		3.0	2.6	6.13	3.83
282	19.0		3.1	8.2	3.70	5.66
286	18.0		3.5	4.1	4.10	4.62
290	15.7		2.8	7.5	1.57	5.51
292	19.5		2.7	4.3	2.67	4.91
293(i)	20.8	11.65	1.1	4.7	2.37	5.33
294(i)	20.1	12.60	1.7	4.4	2.50	5.39
295	16.9				2.28	
297	19.5		2.9	4.4	2.43	
298	19.6		1.0	4.2	2.23	
299	18.1		1.6	4.5	2.58	
300	18.8		0.9	4.4	2.58	
301(j)	20.1	15.35	0.9	4.7	2.63	6.00
312	17.4		1.8	6.2	2.35	
313	17.6		1.0	6.6	2.53	
314	13.6		0.5	4.9	3.50	
315	17.3		1.7	6.3	1.70	
318	16.7		0.3	8.3	1.73	
323	16.7		2.9	5.9	3.17	
325	11.6		2.2	3.5	1.40	
329(k)	20.8	15.0	0.7	5.1	6.60	4.42
330	18.3		1.0	5.0	3.13	
331	17.6		1.9	5.0	2.87	

TABLE 5.--Partial chemical analyses of high-alumina clays, cont'd.

Sample No.	Total Al_2O_3 (a)	Available Al_2O_3 (a)	Na_2O (b)	K_2O (b)	H_2O -140^o C. (a)	Ign. loss $+650^o$ C. (a)
332	17.3		0.7	15.6	.80	
335	18.3		5.5	0.5	3.60	
336	19.0		5.3	8.0	3.60	
337	13.4		1.3	0.2	3.30	
340	17.4		2.9	3.1	3.60	
342	17.0		3.3	5.1	2.33	
343	15.5		5.5	4.2	2.60	
346	15.5		3.5	4.7	1.83	

(a) Analyses by the Anaconda Co., General Laboratory, dry basis at 135^o-140^o C.
(b) Analyses by Ideal Cement Co., flame photometer.
(c) Sample 251, collected by Prof. J. C. Maxwell, Princeton University, of Tertiary sediments in a gully 0.6 mi. north of the old Mullan road, 2.8 mi. ESE of Bearmouth in sec. 19, T. 11 N., R. 13 W.
(d) Sample 256, collected by Gwenllian Vaughan-Rhys (G.N. Ry.) from Toliver placer, Barker mining district, Judith Basin County.
(e) Samples 261 & 262, Tertiary bentonitic clay-shale from R. M. Fleming's clay prospects on the Bell ranch in sec. 34, T. 6 S., R. 10 W., west of Dillon in Beaverhead County. Large deposit.
(f) Sample 264, Tertiary clay from R. M. Fleming's (Argenta, Mont.) 960-A claim along Dillon-Argenta road in sec. 7, T. 7 S., R. 9 W., in Beaverhead County. Quantity present probably very large.
(g) Sample 266, hydrothermally altered wall rock from R. M. Fleming's white clay prospect about 8 mi. south of Dillon in sec. 35, T. 7 S., R. 9 W. Exposed in pit. "Vein" not over 5 feet wide and quantity present may not be very large.
(h) Sample 267, halloysite and alunite, hydrothermally altered Tertiary clay from R. M. Fleming's halloysite prospect in sec. 2, T. 7 S., R. 11 W., Badger Pass area west of Dillon, Beaverhead County. Halloysite deposit overlain by bentonitic shale. Halloysite is exposed at the bottom of a 25-foot prospect shaft and short drift. Extent unknown, but could be large.
(i) Samples 293 & 294, taken by George Kanta, Builders Products, Inc., Three Forks, from an area 3 mi. north of Logan in sec. 13, T. 2 N., R. 2 E. Deposit could be very large.
(j) Sample 301, Lower Cretaceous shale from NE corner sec. 26, T. 1 N., R. 2 W., 2-3/4 mi. west of Sappington junction, southern Jefferson County. Bed 20 feet wide, strikes east and dips 40^o north.
(k) Sample 329, taken by George Kanta, Builders Products, Inc., Three Forks, Montana.

TABLE 6.--Fusing points of Seger cones.

Cone Number	When fired slowly 20° C. per hour		When fired rapidly 150° C. per hour	
	°Cent.	°Fahr.	°Cent.	°Fahr.
022	585	1,085	605	1,121
021	595	1,103	615	1,139
020	625	1,157	650	1,202
019	630	1,166	660	1,220
018	670	1,238	720	1,328
017	720	1,328	770	1,418
016	735	1,355	795	1,463
015	770	1,418	805	1,481
014	795	1,463	830	1,526
013	825	1,517	860	1,580
012	840	1,544	875	1,607
011	875	1,607	895	1,643
010	890	1,634	905	1,661
09	930	1,706	930	1,706
08	945	1,733	950	1,742
07	974	1,787	990	1,814
06	1,005	1,841	1,015	1,859
05	1,030	1,886	1,040	1,904
04	1,050	1,922	1,060	1,940
03	1,080	1,976	1,115	2,039
02	1,095	2,003	1,125	2,037
01	1,110	2,030	1,145	2,093
1	1,125	2,057	1,160	2,120
2	1,135	2,075	1,165	2,129
3	1,145	2,093	1,170	2.138
4	1,165	2,129	1,190	2,174
5	1,180	2,156	1,205	2,201
6	1,190	2,174	1,230	2,246
7	1,210	2,210	1,250	2,282
8	1,225	2,237	1,260	2,300
9	1,250	2,282	1,285	2,345
10	1,260	2,300	1,305	2,381
11	1,285	2,345	1,325	2,417
12	1,310	2,390	1,335	2,435
13	1,350	2,462	1,350	2,462
14	1,390	2,534	1,400	2,552
15	1,410	2,570	1,435	2,615
16	1,450	2,642	1,465	2,669
17	1,465	2,669	1,475	2,687
18	1,485	2,705	1,490	2,714

TABLE 6.--Fusing points of Seger cones, cont'd.

Cone Number	When fired slowly 20° C. per hour		When fired rapidly 150° C. per hour	
	°Cent.	°Fahr.	°Cent.	°Fahr.
19	1,515	2,759	1,520	2,768
20	1,520	2,768	1,530	2,786
23			1,580	2,876
26			1,595	2,903
27			1,605	2,921
28			1,615	2,939
29			1,640	2,984
30			1,650	3,002
31			1,680	3,056
32			1,700	3,092
33			1,745	3,173