STATE OF MONTANA
BUREAU OF MINES AND GEOLOGY
E. G. Koch, Director

BULLETIN 70

PROGRESS REPORT ON CLAYS AND SHALES OF MONTANA 1966 - 1967

by

R. B. Berg, D. C. Lawson, and F. P. Jones
Montana Bureau of Mines and Geology,
and
R. I. Smith, Montana College of Mineral Science and Technology

(Samples 502 - 635)

MONTANA COLLEGE OF MINERAL SCIENCE AND TECHNOLOGY
Butte, Montana
November 1968

CONTENTS

ILLUSTRATIONS

TABLES

PROGRESS REPORT ON CLAYS AND SHALES OF MONTANA 1966 - 1967 (SAMPLES 502 TO 635)

by

R. B. Berg, D. C. Lawson,. F. P. Jones, and R. I. Smith

ABSTRACT

This report is the sixth in a series of progress reports on a study of the clay and shale resources of Montana. Results of ceramic tests, expandability tests, x-ray diffraction analyses, and chemical analyses (including available alumina for selected samples) are given.

Fifty-four samples from the Helena area, 48 samples from the Great Falls area, and 32 samples from other localities in Montana were tested. Those samples collected from the Great Falls area appear most promising for use in ceramic products.

Results of tests are tabulated according to geologic age or formation for 419 of the samples tested to date.

INTRODUCTION

This bulletin is the sixth progress report on the survey of Montana's clay and shale resources, and is supplementary to the first five (Sahinen, U. M., Smith, R. I., and Lawson, D. C., 1958, 1960, and 1962; Chelini, J. M., Smith, R. I., and Lawson, D. C., 1965; Chelini, J. M., Smith, R. I., and Jones, F. P., 1966). The purpose of the project is to catalog the clay and shale deposits of the state. It is intended to sample likely clay and shale deposits and to determine possible uses, if any, of the material sampled. The clays are tested for possible use as ceramic raw materials or as possible sources of expanded shale (lightweight concrete aggregate), and analyzed as possible sources of alumina for the production of metallic aluminum.

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

A study of bentonite in Montana by the Montana Bureau of Mines and Geology is near completion. A separate report presenting the results of this investigation will be published.

It is a pleasure to acknowledge the helpful advice given by U. M. Sahinen. The help of numerous individuals who were kind enough to offer assistance in the field is sincerely appreciated. R. B. Berg was ably assisted in the field by M. E. Chapman.

EVALUATION OF CLAY OR SHALE DEPOSITS

The uses of clay are diverse and most of them depend on physical properties of the clay or shale. Clay as a source of alumina is an obvious exception, as the amount of alumina economically extractable from it is of prime concern.

The physical properties of clays are determined by mineralogy and texture. It would seem that by determining these two parameters, of which the mineralogy is more important, clays could be evaluated for use without extensive further testing. The Pennsylvania Geological Survey has completed a systematic study of clay and shale in that state (O'Neill and others, 1965). Their investigations show some correlation between mineral composition of a clay or shale and potential use. The correlation is best for refractory clays and considerably poorer for brick clays.

Although quantitative mineralogy shows promise as a rapid means of screening large numbers of clay samples for various uses, physical tests provide the best measure of a clay's potential. Because of the many uses of clay, a project such as this cannot hope to test samples for all possible uses. Here testing has been confined to two series--ceramic tests and expandability tests. Laboratory procedures employed in this testing are described in the following sections of this report.

The data on mineralogical and chemical composition are of assistance in evaluating samples for uses for which they were not specifically tested.

SAMPLING AND TESTING PROCEDURES

SAMPLING AND SAMPLE PREPARATION

Five-pound samples were obtained by using a 2-inch hand auger, by digging a small pit, or by cutting a channel across the entire bed where practicable. The method of sampling is noted for each sample in the section on "Sample Localities and Descriptions."

The entire sample was first dried at a temperature below 100°C, then several fragments of the clay or shale were picked out for reference and for the expandability tests. The sample was then crushed to about 3/8 inch and a 2-pound split was obtained, which was then crushed to pass a 20-mesh (U.S. Standard) sieve. A 200-gram split of this sample was pulverized to pass a 100-mesh (U.S. Standard) sieve. A split of 100 grams of this material was provided for the chemical analyses, and the other 100-gram portion was used in the x-ray diffraction analysis. The minus 20-mesh material was used in the ceramic testing.

Sample localities are reported in Table 1.

CERAMIC TESTS

Ceramic tests were performed by R. I. Smith, professor of metallurgy at Montana College of Mineral Science and Technology. A modified Atterberg test (Kinnison, 1915) is used to obtain the water-of-plasticity range and to indicate the plasticity. A 50-gram sample of the clay is mixed with water from a standard burette. The clay and water are worked with a spatula until the water is evenly distributed. Water is added until the clay-water mixture, when cut with a spatula, does not adhere to the spatula, and the clay on the sides of the cut remains standing. This is the lower plasticity limit. Water is again added in small amounts with mixing and working after each addition until the clay sticks to the spatula and the sides of the cut flow together immediately after the cut. This is the upper limit of plasticity. The amount of water used is expressed in percent, 1 gram being the weight of 1 cubic centimeter of water. The test shows the plasticity, working range, and roughly the type of clay mineral present. The best working range is found to be close to the lower plastic limit. The percentage of water used is a rough indication of the type of

Table 1. --Sample localities and geologic formations for clay and shale samples.

Sample no.	Formation	Location, collector	County	Location	Sec.	T.	R.
502	Unknown	S of Silver Star, W. M. Cocanougher	Madison		11	2 S	6 W
503	Unknown	NW of Kalispell, Dan Rovig	Flathead	NW$\frac{1}{4}$	15	30 N	23 W
504	Unknown	SW of Winnett, R. D. Geach	Petroleum	SW$\frac{1}{4}$	7	13 N	25 E
505	Unknown	SW of Winnett, R. D. Geach	Petroleum	SW$\frac{1}{4}$	7	13 N	25 E
506	Unknown	Winston area, Elmer Schye	Broadwater				
507	Probably Colorado Shale	Geyser area, Elmer Schye	Judith Basin				
508	Probably Bearpaw Shale	Vananda area, Elmer Schye	Treasure				
509	Probably Bearpaw Shale	Vananda area, Elmer Schye	Treasure				
510	Unknown	SE of Twin Bridges, Norman Rogers	Madison				
511	Oligocene tuff	N of Canyon Ferry dam, R. B. Berg	Lewis & Clark	NE$\frac{1}{4}$ SW$\frac{1}{4}$	3	10 N	1 W
512	Wolsey Shale	W of Canyon Ferry dam, R. B. Berg	Lewis & Clark	SE$\frac{1}{4}$ SW$\frac{1}{4}$	9	10 N	1 W
513	Wolsey Shale	W of Canyon Ferry dam, R. B. Berg	Lewis & Clark	SE$\frac{1}{4}$ SW$\frac{1}{4}$	9	10 N	1 W
514	Spokane Shale	W of Canyon Ferry dam, R. B. Berg	Lewis & Clark	NW$\frac{1}{4}$ NE$\frac{1}{4}$ NE$\frac{1}{4}$	8	10 N	1 W
515	Quaternary alluvium	W of Canyon Ferry dam, R. B. Berg	Lewis & Clark	NW$\frac{1}{4}$ NE$\frac{1}{4}$	8	10 N	1 W
516	Quaternary alluvium	W of Canyon Ferry dam, R. B. Berg	Lewis & Clark	NW$\frac{1}{4}$ NE$\frac{1}{4}$	8	10 N	1 W
517	Tertiary sediment	W of Lake Sewell, R. B. Berg	Lewis & Clark	NE$\frac{1}{4}$ NE$\frac{1}{4}$	25	10 N	2 W
518	Tertiary sediment	W of Lake Sewell, R. B. Berg	Lewis & Clark	NE$\frac{1}{4}$ NE$\frac{1}{4}$	25	10 N	2 W
519	Tertiary sediment	W of Lake Sewell, R. B. Berg	Lewis & Clark	NE$\frac{1}{4}$ NE$\frac{1}{4}$	25	10 N	2 W
520	Tertiary sediment	W of East Helena, R. B. Berg	Lewis & Clark	NW$\frac{1}{4}$ SE$\frac{1}{4}$	26	10 N	3 W
521	Tertiary sediment	W of East Helena, R. B. Berg	Lewis & Clark	NW$\frac{1}{4}$ SE$\frac{1}{4}$	26	10 N	3 W
522	Tertiary sediment	W of East Helena, R. B. Berg	Lewis & Clark	NW$\frac{1}{4}$ SE$\frac{1}{4}$	26	10 N	3 W
523	Skarn	NE of Unionville, R. B. Berg	Lewis & Clark	NE$\frac{1}{4}$ SW$\frac{1}{4}$	11	9 N	4 W
524	Quaternary alluvium	NE of Elliston, R. B. Berg	Powell	NE$\frac{1}{4}$ SW$\frac{1}{4}$	33	10 N	6 W
525	Quaternary alluvium	NE of Elliston, R. B. Berg	Powell	NE$\frac{1}{4}$ SW$\frac{1}{4}$	33	10 N	6 W
526	Quaternary alluvium	NE of Elliston, R. B. Berg	Powell	NE$\frac{1}{4}$ SW$\frac{1}{4}$	33	10 N	6 W

527	Tertiary rhyolite	NW of Blossburg, R. B. Berg	Powell	NE$\frac{1}{4}$ SW$\frac{1}{4}$	3	10 N	6 W
528	Tertiary sediment	NW of Blossburg, R. B. Berg	Powell	NE$\frac{1}{4}$ SW$\frac{1}{4}$	3	10 N	6 W
529	Tertiary sediment	NW of Blossburg, R. B. Berg	Powell	NE$\frac{1}{4}$ SW$\frac{1}{4}$	3	10 N	6 W
530	Tertiary sediment	NW of Blossburg, R. B. Berg	Powell	NE$\frac{1}{4}$ SW$\frac{1}{4}$	3	10 N	6 W
531	Mesozoic shale	NW of Blossburg, R. B. Berg	Powell	NE$\frac{1}{4}$ SW$\frac{1}{4}$	3	10 N	6 W
532	Mesozoic shale	NW of Blossburg, R. B. Berg	Powell	NE$\frac{1}{4}$ SW$\frac{1}{4}$	3	10 N	6 W
533	Tertiary(?) sediment	W of Blossburg, R. B. Berg	Powell	NE$\frac{1}{4}$ SE$\frac{1}{4}$	10	10 N	6 W
534	Quaternary alluvium	NE of Avon, R. B. Berg	Powell	NE$\frac{1}{4}$ SE$\frac{1}{4}$	19	10 N	7 W
535	Quaternary alluvium	NE of Avon, R. B. Berg	Powell	NW$\frac{1}{4}$ NE$\frac{1}{4}$	20	10 N	7 W
536	Tertiary sediment	NE of Avon, R. B. Berg	Powell	SE$\frac{1}{4}$ NE$\frac{1}{4}$	17	10 N	7 W
537	Tertiary sediment	NE of Avon, R. B. Berg	Powell	NE$\frac{1}{4}$ NW$\frac{1}{4}$	9	10 N	7 W
538	Tertiary sediment	NE of Avon, R. B. Berg	Powell	NE$\frac{1}{4}$ NW$\frac{1}{4}$	9	10 N	7 W
539	Tertiary sediment	NE of Avon, R. B. Berg	Powell	NE$\frac{1}{4}$ NW$\frac{1}{4}$	9	10 N	7 W
540	Quaternary alluvium	E of Marysville, R. B. Berg	Lewis & Clark	SW$\frac{1}{4}$ NE$\frac{1}{4}$	27	12 N	5 W
541	Quaternary alluvium(?)	E of Marysville, R. B. Berg	Lewis & Clark	NE$\frac{1}{4}$ SE$\frac{1}{4}$	27	12 N	5 W
542	Quaternary alluvium	E of Marysville, R. B. Berg	Lewis & Clark	NE$\frac{1}{4}$ NE$\frac{1}{4}$	35	12 N	5 W
543	Quaternary alluvium	NW of Helena, R. B. Berg	Lewis & Clark	NE$\frac{1}{4}$ SW$\frac{1}{4}$	6	11 N	4 W
544	Quaternary alluvium	NW of Helena, R. B. Berg	Lewis & Clark	NE$\frac{1}{4}$ SW$\frac{1}{4}$	6	11 N	4 W
545	Quaternary alluvium	NW of Helena, R. B. Berg	Lewis & Clark	NE$\frac{1}{4}$ SW$\frac{1}{4}$	6	11 N	4 W
546	Quaternary alluvium	NW of Helena, R. B. Berg	Lewis & Clark	NE$\frac{1}{4}$ NE$\frac{1}{4}$	7	11 N	4 W
547	Helena Dolomite	NW of Helena, R. B. Berg	Lewis & Clark	NW$\frac{1}{4}$ NE$\frac{1}{4}$	17	11 N	4 W
548	Helena Dolomite	NW of Helena, R. B. Berg	Lewis & Clark	SW$\frac{1}{4}$ NW$\frac{1}{4}$	16	11 N	4 W
549	Helena Dolomite	NW of Helena, R. B. Berg	Lewis & Clark	SW$\frac{1}{4}$ NW$\frac{1}{4}$	16	11 N	4 W
550	Empire or Spokane Shale	NW of Helena, R. B. Berg	Lewis & Clark	SW$\frac{1}{4}$ NE$\frac{1}{4}$	16	11 N	4 W
551	Belt Supergroup	N of Helena, R. B. Berg	Lewis & Clark	SE$\frac{1}{4}$ SW$\frac{1}{4}$	19	12 N	3 W
552	Belt Supergroup	N of Helena, R. B. Berg	Lewis & Clark	SW$\frac{1}{4}$ NW$\frac{1}{4}$	32	12 N	3 W
553	Tertiary sediment	NE of Lake Helena, R. B. Berg	Lewis & Clark	SE$\frac{1}{4}$ NW$\frac{1}{4}$	5	11 N	2 W
554	Tertiary sediment	NE of Lake Helena, R. B. Berg	Lewis & Clark	SW$\frac{1}{4}$ SE$\frac{1}{4}$	7	11 N	2 W
555	Tertiary sediment	W of Hauser Lake, R. B. Berg	Lewis & Clark	NE$\frac{1}{4}$ NW$\frac{1}{4}$	32	11 N	2 W
556	Greyson Shale	NE of Hauser Lake, R. B. Berg	Lewis & Clark	N$\frac{1}{2}$ SE$\frac{1}{4}$	25	12 N	1 W

No.	Formation	Location, collector	County	Location	Sec.	T.	R.
557	Greyson Shale	NE of Hauser Lake, R. B. Berg	Lewis & Clark	$N\frac{1}{2}$ $SE\frac{1}{4}$	25	12 N	1 W
558	Greyson Shale	NE of Hauser Lake, R. B. Berg	Lewis & Clark	$N\frac{1}{2}$ $SE\frac{1}{4}$	25	12 N	1 W
559	Quaternary alluvium	N of Hauser Lake, R. B. Berg	Lewis & Clark	$NW\frac{1}{4}$ $NE\frac{1}{4}$	23	11 N	2 W
560	Tertiary sediment	W of Hauser Lake, R. B. Berg	Lewis & Clark	$SW\frac{1}{4}$ $SE\frac{1}{4}$	27	11 N	2 W
561	Tertiary sediment	W of Hauser Lake, R. B. Berg	Lewis & Clark	$SE\frac{1}{4}$ $SE\frac{1}{4}$	33	11 N	2 W
562	Tertiary sediment	SW of Helena, R. B. Berg	Lewis & Clark	$NE\frac{1}{4}$ $SE\frac{1}{4}$	3	9 N	3 W
563	Tertiary sediment	SW of East Helena, R. B. Berg	Lewis & Clark	$SW\frac{1}{4}$ $NW\frac{1}{4}$	36	10 N	3 W
564	Oligocene tuff	N of Canyon Ferry dam, R. B. Berg	Lewis & Clark	$NE\frac{1}{4}$ $SW\frac{1}{4}$	3	10 N	1 W
565	LaHood Formation	N of Cardwell, R. B. Berg	Jefferson	$SE\frac{1}{4}$ $NE\frac{1}{4}$	35	2 N	3 W
566	LaHood Formation	N of Cardwell, R. B. Berg	Jefferson	$SE\frac{1}{4}$ $NE\frac{1}{4}$	35	2 N	3 W
567	LaHood Formation	N of Cardwell, R. B. Berg	Jefferson	$NW\frac{1}{4}$ $NW\frac{1}{4}$	36	2 N	3 W
568	LaHood Formation	N of Cardwell, R. B. Berg	Jefferson	$NW\frac{1}{4}$ $NW\frac{1}{4}$	36	2 N	3 W
569	Unknown	S of Belt, Kaiser Cement & Gypsum Corp.	Cascade			16 N	6 E
570	Unknown	W of Buffalo, G. B. Dover	Judith Basin			12 N	14 E
571	Tongue River Member Fort Union Formation	Knife River coal mine, D. W. Easton	Richland			20 N	57 E
572	Unknown	W of Miles City, Calvin Rice	Custer	$NW\frac{1}{4}$ $NW\frac{1}{4}$	33	7 N	46 E
573	Unknown	N of Terry, Calvin Rice	Prairie	$NW\frac{1}{4}$ $NW\frac{1}{4}$	9	12 N(?)	51 E
574	Unknown	NE of Epsie, Calvin Rice	Powder River	$SW\frac{1}{4}$ $SE\frac{1}{4}$	12	4 S	49 E
575	Unknown	N of Greenough, H. G. Nelson, Sr.	Missoula		36	14 N	15 W
576	Unknown	NW of Avon, Elmer Wagner	Powell		11	12 N	9 W
577	Unknown	SW of Philipsburg, Henry Hansen	Granite		21	6 N	14 W
578	Unknown	SW of Wise River, Frank Stagg	Beaverhead		5	1 S	11 W
579	Colorado Shale	East shore of Holter Lake, R. B. Berg	Lewis & Clark	$SE\frac{1}{4}$ $SW\frac{1}{4}$	14	14 N	3 W
580	Colorado Shale	East shore of Holter Lake, R. B. Berg	Lewis & Clark	$SE\frac{1}{4}$ $SW\frac{1}{4}$	14	14 N	3 W
581	Tertiary(?) sediment	East shore of Holter Lake, R. B. Berg	Lewis & Clark	$SE\frac{1}{4}$ $NW\frac{1}{4}$	15	14 N	3 W
582	Tertiary(?) sediment	East shore of Holter Lake, R. B. Berg	Lewis & Clark	$SE\frac{1}{4}$ $NW\frac{1}{4}$	15	14 N	3 W
583	Tertiary(?) sediment	East shore of Holter Lake, R. B. Berg	Lewis & Clark	$SE\frac{1}{4}$ $NW\frac{1}{4}$	15	14 N	3 W
584	Tertiary(?) sediment	East shore of Holter Lake, R. B. Berg	Lewis & Clark	$SE\frac{1}{4}$ $NW\frac{1}{4}$	15	14 N	3 W
585	Kootenai Formation	W of Raynesford, R. B. Berg	Judith Basin	$NW\frac{1}{4}$	8	17 N	9 E
586	Morrison Formation	S of Belt, R. B. Berg	Cascade	$NW\frac{1}{4}$ $SE\frac{1}{4}$	26	19 N	6 E

587	Morrison Formation	W of Belt, R. B. Berg	Cascade	$NW\frac{1}{4}$ $NW\frac{1}{4}$	26	19 N	6 E
588	Kootenai Formation	W of Belt, R. B. Berg	Cascade	$NW\frac{1}{4}$ $NW\frac{1}{4}$	26	19 N	6 E
589	Kootenai Formation	W of Belt, R. B. Berg	Cascade	$NW\frac{1}{4}$ $NE\frac{1}{4}$ $NW\frac{1}{4}$	26	19 N	6 E
590	Kootenai Formation	W of Belt, R. B. Berg	Cascade	$NE\frac{1}{4}$ $NE\frac{1}{4}$	27	19 N	6 E
591	Kootenai Formation	W of Belt, R. B. Berg	Cascade	$NE\frac{1}{4}$ $NE\frac{1}{4}$	27	19 N	6 E
592	Kootenai Formation	W of Belt, R. B. Berg	Cascade	$NE\frac{1}{4}$ $NE\frac{1}{4}$	27	19 N	6 E
593	Kootenai Formation	W of Belt, R. B. Berg	Cascade	$NW\frac{1}{4}$ $NE\frac{1}{4}$	27	19 N	6 E
594	Morrison Formation	SW of Stockett, R. B. Berg	Cascade	$NE\frac{1}{4}$ $NW\frac{1}{4}$	1	18 N	4 E
595	Morrison Formation	SW of Stockett, R. B. Berg	Cascade	$NE\frac{1}{4}$ $NW\frac{1}{4}$	1	18 N	4 E
596	Morrison Formation	SW of Stockett, R. B. Berg	Cascade	$NE\frac{1}{4}$ $NW\frac{1}{4}$	1	18 N	4 E
597	Kootenai Formation	SW of Stockett, R. B. Berg	Cascade	$SW\frac{1}{4}$ $NW\frac{1}{4}$	1	18 N	4 E
598	Kootenai Formation	SW of Stockett, R. B. Berg	Cascade	$SW\frac{1}{4}$ $NW\frac{1}{4}$	1	18 N	4 E
599	Morrison Formation	S of Armington junction, R. B. Berg	Cascade	$NE\frac{1}{4}$ $SE\frac{1}{4}$	12	18 N	6 E
600	Morrison Formation	S of Armington junction, R. B. Berg	Cascade	$NE\frac{1}{4}$ $SE\frac{1}{4}$	12	18 N	6 E
601	Morrison Formation	NW of Armington junction, R. B. Berg	Cascade	$SE\frac{1}{4}$ $NE\frac{1}{4}$	1	18 N	6 E
602	Kootenai Formation	N of Belt, R. B. Berg	Cascade	$NW\frac{1}{4}$ $NW\frac{1}{4}$	27	21 N	6 E
603	Flood Member Blackleaf Formation	E of Cascade, R. B. Berg	Cascade	$SW\frac{1}{4}$ $SE\frac{1}{4}$	1	18 N	2 E
604	Flood Member Blackleaf Formation	E of Cascade, R. B. Berg	Cascade	$SW\frac{1}{4}$ $SE\frac{1}{4}$	1	18 N	2 E
605	Flood Member Blackleaf Formation	E of Cascade, R. B. Berg	Cascade	$NW\frac{1}{4}$ $NE\frac{1}{4}$	12	18 N	2 E
606	Flood Member Blackleaf Formation	E of Cascade, R. B. Berg	Cascade	$NW\frac{1}{4}$ $NE\frac{1}{4}$	12	18 N	2 E
607	Kootenai Formation	E of Cascade, R. B. Berg	Cascade	$NE\frac{1}{4}$ $SW\frac{1}{4}$	36	18 N	2 E
608	Kootenai Formation	E of Cascade, R. B. Berg	Cascade	$SE\frac{1}{4}$ $NW\frac{1}{4}$	36	18 N	2 E
609	Kootenai Formation	E of Cascade, R. B. Berg	Cascade	$SW\frac{1}{4}$	1	17 N	2 E
610	Kootenai Formation	E of Cascade, R. B. Berg	Cascade	$SW\frac{1}{4}$	1	17 N	2 E
611	Kootenai Formation	E of Cascade, R. B. Berg	Cascade	$SW\frac{1}{4}$	1	17 N	2 E

No.	Formation	Location, collector	County	Location	Sec.	T.	R.
612	Kootenai Formation	SW of Eden, R. B. Berg	Cascade	NW$\frac{1}{4}$ SW$\frac{1}{4}$	31	18 N	4 E
613	Kootenai Formation	SW of Eden, R. B. Berg	Cascade	NW$\frac{1}{4}$ SW$\frac{1}{4}$	31	18 N	4 E
614	Kootenai Formation	NE of Eden, R. B. Berg	Cascade	SW$\frac{1}{4}$ NE$\frac{1}{4}$	20	18 N	4 E
615	Kootenai Formation	SE of Great Falls, R. B. Berg	Cascade	SE$\frac{1}{4}$ SE$\frac{1}{4}$	27	20 N	4 E
616	Kootenai Formation	SE of Great Falls, R. B. Berg	Cascade	SE$\frac{1}{4}$ SE$\frac{1}{4}$	27	20 N	4 E
617	Kootenai Formation	SE of Great Falls, R. B. Berg	Cascade	SE$\frac{1}{4}$ SE$\frac{1}{4}$	27	20 N	4 E
618	Kootenai Formation	SE of Great Falls, R. B. Berg	Cascade	SE$\frac{1}{4}$ SE$\frac{1}{4}$	27	20 N	4 E
619	Kootenai Formation	SE of Great Falls, R. B. Berg	Cascade	SE$\frac{1}{4}$ SE$\frac{1}{4}$	27	20 N	4 E
620	Morrison Formation	NE of Sand Coulee, R. B. Berg	Cascade	NE$\frac{1}{4}$ NE$\frac{1}{4}$	13	19 N	4 E
621	Morrison Formation	NE of Sand Coulee, R. B. Berg	Cascade	NE$\frac{1}{4}$ NE$\frac{1}{4}$	13	19 N	4 E
622	Morrison Formation	NE of Sand Coulee, R. B. Berg	Cascade	NE$\frac{1}{4}$ NE$\frac{1}{4}$	13	19 N	4 E
623	Kootenai Formation	SW of Great Falls, R. B. Berg	Cascade	NE$\frac{1}{4}$ SE$\frac{1}{4}$	16	20 N	3 E
624	Kootenai Formation	SW of Great Falls, R. B. Berg	Cascade	NE$\frac{1}{4}$ SE$\frac{1}{4}$	16	20 N	3 E
625	Kootenai Formation	SW of Great Falls, R. B. Berg	Cascade	NE$\frac{1}{4}$ SE$\frac{1}{4}$	16	20 N	3 E
626	Kootenai Formation	SW of Great Falls, R. B. Berg	Cascade	NE$\frac{1}{4}$ SE$\frac{1}{4}$	16	20 N	3 E
627	Kevin Shale Member Marias River Formation	N of Sun River, R. B. Berg	Cascade	SE$\frac{1}{4}$ SW$\frac{1}{4}$	11	21 N	1 W
628	Kevin Shale Member Marias River Formation	N of Sun River, R. B. Berg	Cascade	SE$\frac{1}{4}$ SW$\frac{1}{4}$	11	21 N	1 W
629	Kevin Shale Member Marias River Formation	N of Sun River, R. B. Berg	Cascade	SE$\frac{1}{4}$ SW$\frac{1}{4}$	11	21 N	1 W
630	Blackleaf Formation	NE of Manchester, R. B. Berg	Cascade	NE$\frac{1}{4}$ SW$\frac{1}{4}$	26	21 N	2 E
631	Blackleaf Formation	W of Great Falls, R. B. Berg	Cascade	SE$\frac{1}{4}$ SE$\frac{1}{4}$	32	21 N	3 E
632	Kootenai Formation	NE of Great Falls, R. B. Berg	Cascade	SE$\frac{1}{4}$ SE$\frac{1}{4}$	12	21 N	5 E
633	Tertiary volcanic	W of Painted Rocks Lake, R. B. Berg	Ravalli	SE$\frac{1}{4}$ NW$\frac{1}{4}$	33	1 S	22 W
634	Tertiary volcanic	E of Silverbow, R. B. Berg	Silver Bow	NE$\frac{1}{4}$ NE$\frac{1}{4}$	24	3 N	9 W
635	Tertiary volcanic	E of Silverbow, R. B. Berg	Silver Bow	NE$\frac{1}{4}$ NE$\frac{1}{4}$	24	3 N	9 W

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 Pryometric Cone Equivalent (P.C.E.). When the test cone fuses, the number of the standard cone that reaches the same state of fusion is noted. Firing at temperatures to 2400°F is done in a Hayes Glo-Bar electric furnace equipped with a thermocouple and pyrometer accurate to 5°C (9°F). Firing above 2400°F is done in a Denver Fire Clay cone furnace fired with natural gas. Fusing temperatures of pyrometric cones are given in Table 2.

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, the thermocouple pyrometer being used for temperature control. The bricks are removed from the furnace when the predetermined temperature has been reached and then placed in another furnace at 1200°F. When the firing is finished, the furnace is turned off and the test bricks allowed to cool overnight. For specimens requiring temperature greater than 2400°F the Denver Fire Clay furnace is used, and the temperature is measured with a standard cone. The specimens are left in the furnace until cool. Although the fast firing in the laboratory furnaces usually gives higher temperature values than would be obtained in the slower fired commercial furnaces, the tests permit a good estimate of the firing range and the firing characteristics of the materials.

All test bricks are measured before drying, after drying, and after firing. All shrinkage figures given in the tables are linear. Results of ceramic tests are given in Table 3.

Table 2. --Fusing points of pyrometric cones.

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

Table 3.--Ceramic properties of samples.

Sample no.	Water of plasticity %	Drying shrinkage%	P.C.E.	Firing temperature °F	Firing range °F	Firing shrinkage %	Fired color	Hardness	Suitability for ceramic use
a/	b/	c/	d/			e/	f/	g/	
502	L 18	4.1	12	1900	2100	0.0	gray	S	Common brick with plastic mix
	H 22			2100	to	4.3	gray	HS	
				2300	2300	4.5	gray	HS	
503	L 36	3.7	6	1700	none	1.7	tan	SS	Not suitable, poor firing characteristics
	H 40			1900		2.4	tan	SS	
				2100		42.0	tan	HS	
504	L 28	2.8	over 12	1900	2300	0.0	white	SS	Excellent ceramic material
	H 30			2100	and	0.0	white	SS	
				2300	up	0.6	white	S	
505	L 29	3.0	12	1900	2100	0.0	lt red	S	Common brick
	H 31			2100	to	1.1	lt red	HS	
				2300	2300	1.9	gray	HS	
506	L 42	5.4	6	1700	1900	0.0	tan	SS	Not suitable, poor firing characteristics
	H 64			1900	to	15.0	red	S	
				2100	1950	3.8	dk red	HS	
507	L 51			Not fired					Brick cracked on drying
	H 112								
508	L 76			Not fired					Brick cracked on drying
	H 140								
509	L 39	9.2	4	1650	none	0.0	red	SS	Not suitable, scum and poor firing characteristics
	H 48			1850		5.2	dk red	S	
				2050		OF	dk red	HS	
510	L 42	12.2	6	1700	none	1.0	red	SS	Not suitable, swelling and cracking of brick
	H 51			1900		1.3	dk red	S	
				2100		0.9	dk red	HS	

a/ Table 1.
b/ L, lower limit; H, upper limit.
c/ Drying shrinkage is linear.
d/ Pyrometric cone equivalent (Table 2).
e/ Firing shrinkage is linear; OF, over fired.
f/ lt, light; dk, dark.
g/ S, steel hard; HS, harder than steel; SS, softer than steel.

Table 3.--Ceramic properties of samples, contd.

Sample no.	Water of plasticity %	Drying shrinkage %	P.C.E.	Firing temperature °F	Firing range °F	Firing shrinkage %	Fired color	Hardness	Suitability for ceramic use
511	L 43 H 64	8.5	3	1600 1900 2000	1800 to 1950	2.3 7.2 0.6	tan red red	SS S HS	Possible for common brick with blending and careful handling
512	L 30 H 35	12.1	8	1750 1950 2150	none	0.0 5.7 7.9	tan red dk red	SS S HS	Not suitable, poor firing characteristics
513	L 26 H 31	3.1	5	1650 1850 2050	1950 to 2000	0.0 0.3 OF	lt red red red	SS SS HS	Not suitable, poor firing characteristics
514	L 28 H 31	3.4	8	1650 1850 2200	2100 to 2150	0.0 1.1 0.9	white white white	SS SS S	Not suitable, poor firing characteristics
515	L 23 H 26	4.0	6	1700 1900 2100	1950 to 2000	0.0 0.0 8.4	lt red lt red brown	SS SS HS	Possible use in common brick with plastic mix
516	L 25 H 29	4.0	5	1650 1850 2050	1950 to 2000	0.0 0.0 8.8	lt red lt red brown	SS SS HS	Possible use in common brick with plastic mix
517	L 33 H 40	7.6	5	1650 1850 2050	1850 to 2000	0.0 5.7 OF	lt red red dk red	SS HS HS	Possible common brick with blending material
518	L 23 H 30	6.6	6	1700 1900 2100	1900 to 2050	0.0 0.6 5.9	red dk red dk red	SS S HS	Possible common brick with blending material
519	L 22 H 26	2.1	6	1700 1900 2100	1900 to 2100	0.0 0.6 1.2	red red dk red	SS S HS	Possible common brick with plastic mix
520	L 26 H 27			Not fired					Not suitable, no plasticity

Sample no.	Water of plasticity %	Drying shrinkage%	P. C. E.	Firing temperature °F	Firing range °F	Firing shrinkage %	Fired color	Hardness	Suitability for ceramic use
521	L 39 H 41	1.8	6	1700 1900 2100	2000 to 2100	2.1 10.0 13.0	red red dk red	SS SS S	Unsuitable, poor firing characteristics
522	L 50 H 53	5.1	7	1700 1900 2100	1900 to 2000	4.5 13.0 14.2	red red dk red	SS S HS	Unsuitable, poor firing characteristics
523	L 24 H 27	2.6	8	1750 1950 2200	2100 to 2200	0.0 0.0 1.0	tan white white	SS SS HS	Blending material with plastic mix
524	L 23 H 27	3.6	4	1650 1850 2050	1950 to 2000	0.0 0.0 2.4	lt red lt red red	SS SS HS	Unsuitable, poor firing characteristics
525	L 23 H 26	3.3	5	1650 1850 2050	2000 to 2050	0.0 0.0 6.3	lt red lt red brown	SS SS HS	Unsuitable, poor firing characteristics
526	L 24 H 28	4.1	6	1700 1900 2100	2000 to 2050	0.0 0.0 8.5	red lt red brown	SS SS HS	Not suitable, low plasticity and poor firing characteristics
527	L 28 H 33	3.1	9	1750 1950 2150	2000 to 2050	0.0 3.0 5.0	tan white white	SS S HS	Possible common brick with blending material
528	L 22 H 26	4.8	over 12	1900 2100 2300	2100 to 2250	0.0 2.8 3.3	tan tan tan	S HS HS	Good ceramic material
529	L 26 H 30	6.9	12	1900 2100 2300	1900 to 2300	0.5 2.0 3.0	lt red red brown	S HS HS	Good ceramic material
530	L 18 H 22			Not fired					No plasticity

Table 3.--Ceramic properties of samples, contd.

Sample no.	Water of plasticity %	Drying shrinkage %	P.C.E.	Firing temperature °F	Firing range °F	Firing shrinkage %	Fired color	Hardness	Suitability for ceramic use
531	L 27 H 39	7.9	12	1900 2100 2300	1900 to 2300	0.0 3.0 5.6	lt red red brown	S HS HS	Good ceramic material with plastic mix
532	L 20 H 24	4.5	12	1900 2100 2300	1900 to 2300	0.0 0.0 3.5	lt red red brown	S HS HS	Good ceramic material
533	L 36 H 54	9.0	12	1900 2100 2300	1900 to 2250	0.6 3.4 4.0	lt red red red	S HS HS	Fair ceramic material with plastic mix
534	L 44 H 56	5.7	6	1700 1900 2100	2050 to 2100	1.7 4.0 12.0	lt red red dk red	SS SS HS	Not suitable, poor firing characteristics
535	L 37 H 46	10.4	5	1650 1850 2050	2000 to 2050	0.0 1.2 3.6	lt red red dk red	SS SS HS	Unsuitable, scum and poor firing characteristics
536	L 26 H 31	3.2	5	1650 1850 2050	2000 to 2050	0.0 0.0 1.0	white white tan	SS SS S	Not suitable, poor firing characteristics
537	L 25 H 31	3.3	7	1700 1900 2100	2000 to 2100	0.0 0.0 5.9	red dk red dk red	SS SS HS	Poor common brick material
538	L 46 H 49	4.2	7	1700 1900 2100	2000 to 2100	4.1 6.0 19.0	lt red red dk red	SS SS HS	Not suitable, high firing shrinkage
539	L 53 H 64	3.9	7	1700 1900 2100	none	3.5 9.3 12.3	lt red red dk red	SS SS HS	Not suitable, all brick cracked on firing
540	L 31 H 34	3.4	8	1700 1900 2100	2125 to 2150	0.0 0.0 9.4	tan tan green	SS SS HS	Not suitable, poor firing characteristics

Sample no.	Water of plasticity %	Drying shrinkage %	P. C. E.	Firing temperature °F	Firing range °F	Firing shrinkage %	Fired color	Hardness	Suitability for ceramic use
541	L 22 H 26	3.0	5	1650 1850 2050	2100 to 2150	0.0 0.0 0.2	tan white white	SS SS S	Not suitable, poor firing characteristics
542	L 22 H 26	3.1	8	1750 1950 2200	none	1.6 2.8 0.1	tan tan tan	SS SS SS	Not suitable, poor firing characteristics
543	L 21 H 23	4.8	8	1750 1950 2200	none	0.0 0.0 5.5	lt red brown brown	SS SS HS	Unsuitable, poor firing characteristics
544	L 24 H 28	4.5	6	1650 1850 2100	none	0.0 0.6 1.4	lt red red red	SS SS S	Unsuitable, brick cracked
545	L 21 H 26	4.8	4	1650 1850 2050	2000 to 2050	0.0 0.0 3.1	red red dk red	SS S HS	Possible use in common brick with plastic mix
546	L 22 H 28	3.3	5	1650 1850 2050	2000 to 2050	0.2 0.6 0.6	lt red lt red lt red	SS S S	Not suitable, scum and poor firing characteristics
547	L 22 H 25	1.5	8	1750 1950 2200	none	0.3 0.3 OF	tan tan green	SS SS HS	Not suitable, narrow firing range
548	L 32 H 38	3.5	8	1750 1950 2200	none	0.9 1.6 4.7	cream cream cream	SS SS S	Unsuitable, poor firing characteristics
549	L 32 H 38	2.9	6	1700 1900 2100	none	0.0 5.3 1.2	cream cream cream	SS SS SS	Unsuitable, poor firing characteristics
550	L 22 H 27	3.1	5	1650 1850 2050	1950 to 2050	0.9 0.0 2.3	red red red	SS S HS	Common brick

Table 3.--Ceramic properties of samples, contd.

Sample no.	Water of plasticity %		Drying shrinkage %	P. C. E.	Firing temperature °F	Firing range °F	Firing shrinkage %	Fired color	Hardness	Suitability for ceramic use
551	L	27	3.6	5	1650	2000	0.0	red	SS	Possible use in
	H	36			1850	to	0.0	red	SS	common brick
					2100	2050	3.4	red	HS	
552	L	26	3.5	9	1800	none	---	---	---	Unsuitable, brick
	H	30			2000					disintegrated when
					2200					fired
553	L	42	4.9	4	1650	2000	0.6	lt red	SS	Unsuitable, scum
	H	52			1850	to	0.7	lt red	S	and poor firing
					2050	2050	0.7	lt red	HS	characteristics
554	L	37	3.7	4	1650	1900	2.7	lt red	SS	Possible use in
	H	44			1850	to	3.7	red	S	common brick
					2050	2050	6.5	dk red	HS	
555	L	35	7.5	5	1650	1950	0.0	lt red	SS	Possible use in
	H	68			1850	to	0.0	red	S	common brick
					2050	2050	0.3	dk red	HS	
556	L	21	1.7	6	1700	none	0.0	white	SS	Not suitable, poor
	H	25			1900		0.0	white	SS	firing character-
					2150		0.2	white	S	istics
557	L	28	4.0	5	1650	2050	0.0	white	SS	Possible use in
	H	32			1850	to	0.0	white	SS	common brick
					2050	2100	0.0	white	S	
558	L	23	3.1	4	1650	2050	0.0	lt red	SS	Possible use in
	H	26			1850	to	0.0	cream	SS	common brick
					2050	2100	0.0	cream	S	
559	L	22	3.4	4	1650	2000	0.0	lt red	SS	Fair common brick
	H	24			1850	to	0.0	cream	SS	material
					2050	2050	1.0	cream	HS	
560	L	25	2.3	3	1600	2000	0.0	lt red	SS	Possible use in
	H	31			1800	to	0.3	lt red	SS	common brick
					2000	2050	0.3	cream	S	

Sample no.	Water of plasticity %	Drying shrinkage %	P. C. E.	Firing temperature °F	Firing range °F	Firing shrinkage %	Fired color	Hardness	Suitability for ceramic use
561	L 56 H 64	10.0	4	1600 1800 2050	1900 to 2000	2.8 10.3 11.5	lt red red dk red	S HS HS	Unsuitable, poor firing characteristics
562	L 42 H 46	5.7	4	1650 1850 2050	2000 to 2050	6.3 2.1 4.8	brown red dk red	SS SS HS	Poor common brick material
563	L 44 H 50	1.8	7	1700 1900 2100	1950 to 2050	2.2 5.4 18.7	lt red lt red brown	SS SS HS	Unsuitable, low plasticity and high firing shrinkage
564	L 39 H 45	4.5	5	1650 1850 2050	1850 to 2000	3.1 10.4 17.4	lt red red dk red	SS S HS	Unsuitable, high firing shrinkage
565	L 21 H 25	3.5	8	1750 1950 2150	2000 to 2100	0.0 0.2 6.8	red red dk red	SS S HS	Common brick material
566	L 21 H 25	1.6	over 12	1900 2100 2300	2100 to 2250	0.5 5.5 6.7	red red dk red	SS S HS	Good common brick material
567	L 29 H 34	4.5	over 12	1900 2100 2300	2000 to 2200	1.6 5.2 7.1	lt red red dk red	S HS HS	Good common brick material
568	L 23 H 27	3.7	7	1700 1900 2100	2000 to 2100	0.5 0.0 2.2	red red dk red	SS SS HS	Possible use as blend clay with a plastic clay
569	L 20 H 24	3.4	10	1850 2050 2250	2000 to 2250	0.0 2.5 2.5	lt red red red	SS	Fair common brick
570	L 24 H 27	3.0	10	1850 2050 2250	none	0.0 0.0 6.1	cream tan tan	SS SS SS	Not suitable

Table 3.--Ceramic properties of samples, contd.

Sample no.	Water of plasticity %	Drying shrinkage %	P. C. E.	Firing temperature °F	Firing range °F	Firing shrinkage %	Fired color	Hardness	Suitability for ceramic use
571	L 29 H 33	7.6	3	1600 1800 2000	2000 to 2050	0.0 0.0 0.4	lt red lt red cream	SS SS S	Fair common brick
572				Not fired					Not suitable, no plasticity; possible grog
573	L 46 H 57	12.1	9	1800 2000 2200	none	3.9 0.3 OF	red red red	S HS HS	Not suitable, brick cracked
574	L 38 H 48	10.4	10	1850 2050 2250	none	2.3 5.9 OF	lt red red red	S HS HS	Not suitable, brick swelled and cracked
575	L 47 H 59	17.4	10	1850 2050 2250	none	2.2 OF OF	lt red red red	S HS HS	Not suitable, brick cracked on firing
576				Not fired					Unsuitable
577				Not fired					Unsuitable
578				Not fired					Unsuitable
579	L 20 H 24	2.8	9	1800 2000 2200	2000 to 2100	0.0 0.7 9.0	lt red red red	SS S HS	Possible common brick with careful firing
580	L 34 H 36	8.5	12	1900 2100 2300	none	0.6 3.6 OF	lt red red gray	S HS HS	Not suitable, swelling and cracking
581	L 36 H 42	6.1	3	1600 1800 2000	very narrow	0.0 0.0 4.0	lt red lt red lt red	SS SS S	Not suitable, narrow firing range
582	L 35 H 40	6.5	01	1500 1700 1900	very narrow	0.0 0.0 0.3	lt red lt red lt red	SS SS S	Not suitable, narrow firing range; possible flux

Sample no.	Water of plasticity %		Drying shrinkage %	P. C. E.	Firing temperature °F	Firing range °F	Firing shrinkage %	Fired color	Hardness	Suitability for ceramic use
583	L	35	3.1	4	1650	very	0.0	lt red	SS	Not suitable;
	H	40			1850	narrow	0.0	lt red	SS	possible grog
					2050		3.2	red	S	or flux
584	L	37	4.0	3	1600	2000	0.0	lt red	SS	Possible grog or
	H	45			1800	to	1.2	lt red	SS	flux
					2000	2050	3.2	lt red	S	
585	L	25	7.1	4	1650	1900	0.0	red	SS	Fair common
	H	30			1850	to	0.4	red	S	brick
					2050	2050	5.3	lt red	HS	
586	L	22	6.2	over	1900	2000	0.0	lt red	S	Good common brick
	H	26		12	2100	to	4.6	red	HS	
					2300	2300	6.4	lt red	HS	
587	L	30	1.1	over	1900	over	2.7	white	SS	Good grog
	H	34		12	2100	2300	5.9	white	SS	material
					2300		7.6	white	S	
588	L	18	4.6	over	1900	2100	0.0	lt red	S	Good common
	H	24		12	2100	to	0.9	tan	HS	brick
					2300	2300	1.3	tan	HS	
589	L	18	3.3	over	1900	2100	0.0	lt red	SS	Good common
	H	21		12	2100	to	0.9	tan	S	brick
					2300	2300	0.9	tan	HS	
590	L	21	3.5	over	1900	2100	0.0	lt red	SS	Good common
	H	26		12	2100	to	2.6	red	S	brick
					2300	2250	6.3	lt red	HS	
591	L	19	4.2	over	1900	1900	0.0	lt red	S	Very good common
	H	24		12	2100	to	1.1	tan	HS	brick
					2300	2300	0.0	tan	HS	
592	L	20	4.1	12	1900	2100	0.0	lt red	SS	Good common
	H	24			2100	to	5.3	brown	HS	brick
					2300	2300	5.6	brown	HS	

Table 3.--Ceramic properties of samples, contd.

Sample no.	Water of plasticity %	Drying shrinkage %	P.C.E.	Firing temperature °F	Firing range °F	Firing shrinkage %	Fired color	Hardness	Suitability for ceramic use
593	L 20 H 25	4.3	12	1900 2100 2300	2100 to 2300	0.0 3.2 5.5	lt red red lt red	SS S HS	Good common brick
594	L 20 H 30	5.2	12	1900 2100 2300	2100 to 2250	6.9 4.6 2.7	lt red red brown	SS HS HS	Good common brick
595	L 22 H 34	5.7	11	1850 2050 2250	2050 to 2200	0.9 5.9 0.9	lt red red brown	SS HS HS	Good common brick
596	L 21 H 28	5.2	11	1850 2050 2250	2050 to 2250	0.0 3.4 5.5	lt red red brown	SS HS HS	Good common brick
597	L 20 H 28	4.6	8	1750 1950 2150	1950 to 2150	0.0 3.3 2.9	lt red red lt red	SS HS HS	Good common brick
598	L 24 H 30	0.6	4	1650 1850 2050	1850 to 2000	0.0 2.3 2.8	lt red lt red lt red	SS S HS	Fair common brick
599	L 21 H 24	5.1	12	1900 2100 2300	2000 to 2300	0.6 3.9 5.3	lt red red brown	S HS HS	Good common brick
600	L 20 H 28	5.2	over 12	1900 2100 2300	1950 to 2300	2.4 3.8 5.9	lt red tan brown	S HS HS	Good common brick
601	L 19 H 24	3.0	8	1750 1950 2150	1900 to 2150	0.0 1.8 3.1	lt red red lt red	SS HS HS	Good common brick
602	L 22 H 41	10.2	11	1850 2050 2250	1900 to 2250	0.6 2.8 3.9	lt red red lt red	S HS HS	Good common brick

Sample no.	Water of plasticity %	Drying shrinkage %	P. C. E.	Firing temperature °F	Firing range °F	Firing shrinkage %	Fired color	Hardness	Suitability for ceramic use
603	L 22 H 32	6.4	over 12	1900 2100 2300	1950 to 2300	0.6 2.4 5.0	lt red red red	S HS HS	Good common brick
604	L 26 H 40	7.1	over 12	1900 2100 2300	1900 to 2300	2.2 5.7 OF	lt red red red	S HS HS	Fair common brick with careful firing
605	L 28 H 42	6.8	over 12	1900 2100 2300	1900 to 2300	3.1 3.1 3.1	tan brown brown	S HS HS	Good common brick
606	L 24 H 42	6.8	over 12	1900 2100 2300	1900 to 2300	0.9 5.0 3.9	lt red red brown	S HS HS	Good common brick
607	L 18 H 22	4.3	7	1750 1950 2150	1950 to 2150	0.6 1.2 1.2	red red dk red	SS HS HS	Fair common brick
608	L 18 H 21	2.4	8	1750 1950 2150	1950 to 2150	0.0 5.3 4.6	red red dk red	SS HS HS	Good common brick
609	L 20 H 26	5.7	11	1850 2050 2250	1850 to 2250	1.8 6.1 3.1	lt red red dk red	S HS HS	Good common brick
610	L 20 H 24	5.4	over 12	1900 2100 2300	1900 to 2300	3.3 7.0 3.7	lt red red red	S HS HS	Good common brick
611	L 19 H 24	5.4	12	1900 2100 2300	1900 to 2300	1.1 4.5 4.5	lt red red dk red	SS HS HS	Good common brick
612	L 18 H 23	3.9	5	1650 1850 2050	1850 to 2050	0.0 1.8 3.2	lt red lt red red	SS S HS	Fair common brick

Table 3. --Ceramic properties of samples, contd.

Sample no.	Water of plasticity %		Drying shrinkage %	P. C. E.	Firing temperature °F	Firing range °F	Firing shrinkage %	Fired color	Hardness	Suitability for ceramic use
613	L	20	5.3	9	1800	1800	3.3	lt red	S	Fair common
	H	25			2000	to	6.6	red	HS	brick with
					2200	2000	4.9	brown	HS	careful firing
614	L	30	10.0	over	1900	none	3.5	red	S	Not suitable, poor
	H	40		12	2100		OF	dk red	HS	firing charac-
					2300		OF	dk red	HS	teristics
615	L	23	6.9	9	1800	1800	2.4	lt red	S	Fair common brick
	H	28			2000	to	6.7	red	HS	with careful
					2200	2100	3.2	dk red	HS	firing
616	L	24	7.1	9	1800	1800	1.2	lt red	S	Fair common brick
	H	34			2000	to	4.5	red	HS	with careful
					2200	2000	9.8	dk red	HS	firing
617	L	20	9.8	6	1700	1700	2.2	lt red	S	Fair common
	H	30			1900	to	5.5	red	HS	brick
					2100	2100	7.2	dk red	HS	
618	L	24	6.0	8	1750	1750	3.5	lt red	S	Fair common brick
	H	30			1950	to	4.6	red	HS	with careful
					2150	2100	4.7	dk red	HS	firing
619	L	22	5.7	over	1900	1900	5.0	lt red	S	Fair common brick
	H	28		12	2100	to	6.0	red	HS	
					2300	2300	6.6	dk red	HS	
620	L	20	5.6	over	1900	1900	1.5	tan	S	Good common brick
	H	32		12	2100	to	4.6	tan	HS	
					2300	2300	3.7	brown	HS	
621	L	20	5.7	over	1900	1900	3.5	tan	S	Fair common brick
	H	28		12	2100	to	6.0	tan	HS	with careful
					2300	2100	3.2	tan	HS	firing
622	L	22	6.6	12	1900	1900	2.0	tan	S	Good common brick
	H	34			2100	to	3.3	tan	HS	
					2300	2300	2.1	cream	HS	

Sample no.	Water of plasticity %	Drying shrinkage %	P.C.E.	Firing temperature °F	Firing range °F	Firing shrinkage %	Fired color	Hardness	Suitability for ceramic use
623	L 20 H 27	4.7	5	1650 1850 2050	1800 to 2050	0.0 0.6 4.7	tan lt red red	SS S HS	Fair common brick
624	L 24 H 31	5.9	5	1650 1850 2050	1850 to 2050	3.5 1.7 6.3	tan tan red	SS S HS	Good common brick
625	L 25 H 40	7.2	7	1750 1950 2150	none	2.5 OF OF	tan red dk red	S HS HS	Not suitable, poor firing charac-teristics
626	L 24 H 36	8.0	5	1650 1850 2050	1850 to 2050	0.0 1.2 7.3	red red dk red	SS S HS	Fair common brick
627	L 24 H 34	5.9	8	1750 1950 2150	1750 to 1950	1.5 4.5 OF	lt red red dk red	S HS HS	Fair common brick with careful firing
628	L 25 H 35	5.9	8	1750 1950 2150	1750 to 2000	0.0 8.0 8.4	lt red red dk red	S HS HS	Fair common brick with careful firing
629	L 24 H 32	5.6	8	1750 1950 2150	1750 to 2150	0.0 2.4 5.3	lt red red dk red	S HS HS	Good common brick
630	L 20 H 30	10.0	9	1800 2000 2200	none	1.3 3.3 OF	red dk red brown	S HS HS	Not suitable, drying and firing scum and swelling
631	L 26 H 42	8.2	over 12	1900 2100 2300	1900 to 2100	3.9 4.9 OF	tan tan tan	S HS HS	Fair common brick with careful firing
632	L 20 H 27	4.7	12	1900 2100 2300	2000 to 2250	0.9 4.2 3.8	tan tan brown	S HS HS	Good common brick

Table 3.--Ceramic properties of samples, contd.

Sample no.	Water of plasticity %	Drying shrinkage %	P.C.E.	Firing temperature °F	Firing range °F	Firing shrinkage %	Fired color	Hardness	Suitability for ceramic use
633	L 26 H 28	7	well over 12	1900 2100 2300	1900 to 2300	0.8 1.2 5.2	red brown dk red	S HS HS	Good common brick
634				Not fired					Unsuitable
635				Not fired					Unsuitable

EXPANDABILITY TESTS

Don C. Lawson of the Montana Bureau of Mines and Geology made all the expandability tests. Samples that on the basis of color, texture, and composition seemed unlikely to expand satisfactorily were not tested.

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

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

There seems to be no uniformity as to temperature scale used in expandability tests. Some authors use the Centigrade scale, others, the Fahrenheit. Ceramic data, on the other hand, are commonly given in degrees Fahrenheit. As this report covers both types of testing, the Fahrenheit scale will be used for sake of uniformity in this and future reports. Table 2 gives the Centigrade equivalent of various Fahrenheit values.

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.

Results of expandability testing are given in Table 4. Because of the known deposits of expandable shale in the Great Falls area (DeMunck, 1956; Sahinen, 1957), none of the samples collected in that area were tested for expandability.

Table 4. --Expandability test results.

Sample no.	County	Expansion range below 2400°F	Firing behavior	Suitability for lightweight aggregate
502	Madison	None	Slight glaze at 2400°	Not suitable
503	Flathead	None	Fused, but did not bloat at 2400°	Not suitable
504	Petroleum	100°	Fused and bloated at 2400°	Not suitable, narrow range
505	Petroleum	None	No change	Not suitable
506	Broadwater	None	No change	Not suitable
507	Judith Basin	None	Slight glaze at 2400°	Not suitable
511	Lewis & Clark	100°	Fused at 2300° ; bloated at 2400°	Not suitable, narrow range
512	Lewis & Clark	200°	Poor bloat at 2300° ; fused at 2400°	Not suitable, poor bloat
513	Lewis & Clark	300°	Bloated and fused at 2400°	Not suitable
514	Lewis & Clark	None	Slight glaze at 2400°	Not suitable
518	Lewis & Clark	None	Fused at 2200°	Not suitable
522	Lewis & Clark	None	Fused at 2400°	Not suitable
524	Powell	None	Fused at 2400°	Not suitable
525	Powell	200°	Fair bloat at 2300°	Not suitable, narrow range; not all of material bloated
526	Powell	200°	Minor bloating at 2300°	Not suitable
528	Powell	None	No change	Not suitable
529	Powell	None	Slight glaze at 2400°	Not suitable
531	Powell	None	Slight glaze at 2400°	Not suitable
534	Powell	None	Glazed at 2400°	Not suitable
535	Powell	None	Fused at 2400°	Not suitable
536	Powell	None	Fused at 2400°	Not suitable
539	Powell	None	Glaze at 2400°	Not suitable
540	Lewis & Clark	None	Glaze at 2400°	Not suitable
541	Lewis & Clark	None	Fused at 2400°	Not suitable
542	Lewis & Clark	None	Some material fused at 2400°	Not suitable

Table 4.--Expandability test results, contd.

Sample no.	County	Expansion range below 2400°F	Firing behavior	Suitability for lightweight aggregate
544	Lewis & Clark	None	Fused at 2400°	Not suitable
546	Lewis & Clark	None	Some material fused at 2400°	Not suitable
547	Lewis & Clark	None	Minor bloating at 2300° ; fusion at 2400°	Not suitable, poor bloating
548	Lewis & Clark	None	Fused at 2400°	Not suitable
549	Lewis & Clark	None	Fused at 2300°	Not suitable
550	Lewis & Clark	None	Glaze and minor bloat at 2400°	Not suitable, poor bloating
551	Lewis & Clark	100°	Poor bloat with fusion at 2400°	Not suitable, poor bloating
555	Lewis & Clark	None	Glaze at 2400°	Not suitable
556	Lewis & Clark	None	Fused at 2300°	Not suitable
559	Lewis & Clark	None	Fused at 2300°	Not suitable
566	Jefferson	None	Glaze at 2400°	Not suitable
567	Jefferson	300°	Fusion and minor bloating at 2100°	Not suitable, poor bloating
568	Jefferson	200°	Bloated and fused at 2400°	Not suitable
571	Richland	None	Fused at 2400°	Not suitable

X-RAY DIFFRACTION ANALYSES

Prof. R. I. Smith determined the mineralogy of each sample by x-ray diffraction. Time did not permit quantitative analyses, but the terms major, medium, minor, and trace are used to indicate the relative abundances of the minerals in each sample (Table 5).

A random-orientation mount prepared on an aluminum sample holder was first scanned at 2° two theta per minute on a Norelco diffractometer. Additional mounts of some samples were prepared by sucking a suspension of the clay through a filter, thus producing a basal orientation of the clay platelets. Clay minerals were identified according to procedures described in X-ray Identification and Crystal Structures of Clay Minerals (Brown, 1961).

Table 5.--X-ray diffraction data.

Sample no.	Kaolinite	Montmor-illonite	Illite	Quartz	Feldspar	Calcite	Other
502	---	---	med	maj	min	---	med chlorite
503	min	---	min	maj	min	med	med dolomite, min chlorite
504	maj	---	---	maj	---	---	---
505	min	---	min	maj	tr	---	---
506	---	maj	---	maj	med	---	---
507	---	maj	---	maj	min	---	---
508	---	maj	---	med	med	tr	min gypsum
509	---	maj	med	med	med	---	---
510	---	med	min	maj	maj	---	---
511	---	maj	---	min	min	---	min chlorite
512	---	maj	---	maj	maj	tr	min gypsum
513	min	min	med	maj	tr	---	maj dolomite, min hematite
514	---	---	---	maj	min	maj	med talc, min chlorite
515	---	tr	tr	maj	maj	med	med dolomite
516	min	---	min	maj	med	med	min dolomite, chlorite, and complex silicates
517	min	tr	med	maj	med	---	min mica, trace cristobalite
518	---	min	min	maj	min	---	min mica and mixed-layer clays
519	min	---	---	maj	maj	---	min mica
520	min	maj	min	min	min	min	---
521	---	maj	min	min	min	---	trace metahalloysite

Table 5.--X-ray diffraction data, contd.

Sample no.	Kaolinite	Montmor-illonite	Illite	Quartz	Feldspar	Calcite	Other
522	---	maj	---	min	min	---	min halloysite
523	---	tr	---	maj	min	---	maj white diopside
524	---	---	min	maj	med	min	---
525	tr	min	---	maj	min	tr	maj dolomite, min mica
526	---	min	tr	maj	med	tr	med dolomite, trace gypsum
527	---	---	---	---	med	---	maj cristobalite, min zeolite
528	med	---	med	maj	---	---	---
529	min	min	min	maj	tr	---	---
530	---	---	med	maj	maj	---	min metahalloysite, trace dolomite
531	min	min	min	maj	tr	tr	---
532	---	---	med	maj	min	---	---
533	---	---	med	maj	min	---	---
534	tr	maj	tr	med	med	min	---
535	---	maj	---	med	min	min	---
536	---	---	med	maj	min	---	maj dolomite, med chlorite
537	---	min	min	maj	maj	---	---
538	---	maj	---	min	min	---	trace metahalloysite
539	---	maj	---	min	min	---	---
540	min	min	min	maj	min	maj	med dolomite
541	med	min	min	maj	---	---	maj dolomite
542	tr	---	tr	med	---	med	maj dolomite
543	tr	---	min	maj	med	med	trace chlorite and complex silicate
544	tr	---	---	maj	med	med	min mica
545	tr	---	min	maj	min	min	min chlorite
546	min	---	med	maj	min	min	---
547	med	min	min	maj	min	min	med dolomite
548	---	---	min	maj	min	---	maj dolomite, min chlorite
549	---	---	tr	maj	min	med	maj dolomite, min chlorite
550	min	tr	maj	maj	min	---	min dolomite
551	min	min	med	maj	med	tr	min chlorite, trace dolomite
552	---	min	---	maj	maj	---	---
553	tr	---	min	maj	min	med	min dolomite
554	---	maj	---	min	min	---	min hydromica
555	---	min	tr	maj	maj	---	potash feldspar
556	---	---	med	maj	tr	---	maj dolomite and chlorapatite

Sample no.	Kaolinite	Montmor-illonite	Illite	Quartz	Feldspar	Calcite	Other
557	---	---	min	maj	tr	---	maj chlorite and dolomite
558	---	---	min	maj	tr	med	maj chlorite and dolomite
559	tr	---	tr	maj	maj	med	min dolomite, amphibole, and chlorite
560	tr	tr	---	maj	med	med	med dolomite, min mica
561	---	maj	---	min	min	---	---
562	---	maj	---	med	med	---	min mica
563	min	maj	min	min	min	tr	---
564	---	maj	---	min	min	---	min chlorite
565	min	---	med	maj	med	---	min chlorite
566	min	---	med	maj	tr	---	trace complex silicate
567	min	---	med	maj	tr	---	min hematite
568	tr	min	---	maj	maj	---	plagioclase feldspar
569	---	---	maj	maj	---	---	---
570	tr	---	---	min	---	maj	maj dolomite, trace cristobalite and complex silicate
571	med	tr	med	maj	min	maj	maj dolomite
572	---	---	---	---	---	---	glass and cristobalite
573	---	---	med	maj	min	min	---
574	---	med	---	maj	min	---	min gypsum and complex silicate
575	min	maj	---	med	med	---	min gypsum
576	---	maj	---	min	min	---	---
577	min	min	---	maj	min	maj	---
578	---	min	---	maj	min	maj	min chlorite
579	min	---	med	maj	min	---	med dolomite
580	min	---	---	maj	min	---	maj hydromica
581	min	min	min	maj	---	med	med dolomite
582	min	tr	min	maj	min	med	med dolomite
583	min	min	min	maj	maj	min	min dolomite
584	min	min	min	maj	med	maj	med dolomite
585	med	min	min	maj	med	med	---
586	med	---	med	maj	---	---	---
587	maj	tr	---	med	---	tr	---
588	med	---	tr	maj	---	---	min metahalloysite
589	med	---	---	maj	---	---	---

Table 5.--X-ray diffraction data, contd.

Sample no.	Kaolinite	Montmor-illonite	Illite	Quartz	Feldspar	Calcite	Other
590	maj	---	med	maj	min	---	---
591	maj	---	min	maj	---	tr	---
592	maj	---	med	maj	tr	---	min iron oxides
593	maj	tr	tr	maj	tr	tr	trace hydromica
594	med	---	med	maj	---	---	med hydromica, min complex silicate
595	med	min	med	maj	---	tr	---
596	med	---	med	maj	---	---	trace dolomite
597	med	---	med	maj	---	tr	trace dolomite
598	min	---	---	maj	---	maj	min complex silicate
599	min	---	med	maj	---	---	---
600	med	---	med	maj	tr	---	---
601	med	tr	min	maj	---	med	---
602	tr	---	med	maj	tr	min	min hydromica
603	med	---	min	maj	tr	---	min iron oxide
604	med	tr	med	maj	tr	---	---
605	med	---	med	maj	---	tr	---
606	maj	tr	med	maj	---	---	trace hydromica
607	med	tr	min	maj	---	min	---
608	tr	tr	med	maj	tr	min	trace iron oxide and complex silicate
609	min	---	min	maj	tr	min	min hydromica
610	---	tr	min	maj	med	min	trace chlorite
611	med	min	min	maj	tr	---	trace dolomite
612	med	tr	min	maj	---	maj	---
613	tr	tr	med	maj	tr	min	---
614	maj	---	med	maj	---	---	med hydromica
615	---	min	min	maj	---	---	min hydromica
616	min	---	min	maj	min	---	---
617	min	tr	min	maj	tr	---	---
618	tr	---	maj	maj	min	---	min complex silicate
619	med	tr	med	med	---	---	med hyrdomica
620	med	---	med	maj	tr	---	---
621	med	---	med	maj	min	tr	min hydromica
622	med	---	min	maj	---	med	min hydromica

Sample no.	Kaolinite	Montmor-illonite	Illite	Quartz	Feldspar	Calcite	Other
623	min	min	min	maj	med	tr	---
624	med	tr	min	maj	tr	---	---
625	med	med	min	maj	min	---	trace iron oxide
626	med	min	tr	maj	med	tr	trace iron oxide
627	tr	---	med	maj	tr	tr	maj gypsum
628	min	tr	med	maj	tr	---	maj gypsum
629	---	min	med	maj	med	min	---
630	min	min	tr	maj	tr	tr	---
631	med	tr	min	maj	tr	---	---
632	maj	---	min	maj	tr	---	trace complex silicate
633	maj	---	---	maj	min	---	min chlorite and hematite
634	---	maj	---	maj	min	min	---
635	---	maj	---	maj	---	---	---

CHEMICAL ANALYSES

Chemical analyses were performed in the Montana Bureau of Mines and Geology laboratory by F. P. Jones. A 100-gram split of the pulverized clay or shale sample was first dried at 140°C. Standard wet chemical methods were used in all determinations except those for sodium and potassium. A Beckman Model B flame photometer was used for these determinations.

Available alumina was determined on only those samples containing more than 18.0 percent Al_2O_3. The samples were first calcined at 625° to 650°C, and then a 0.5-gram split was treated with 50 ml of 1:1 hydrochloric acid. This mixture of sample and hydrochloric acid was maintained at a temperature slightly below its boiling point for 30 minutes. After this treatment the mixture was filtered and thoroughly washed. Analysis of the filtrate for aluminum was then completed according to standard methods.

The results of the chemical analyses are given in Table 6.

Table 6.--Chemical analyses (all figures are percent of total sample).

Sample no.	Total Al_2O_3	Available Al_2O_3	SiO_2	Fe	CaO	MgO	Na_2O	K_2O	TiO_2	Ign. loss at 625°-650°C
502	14.85	---	68.6	1.45	0.30	4.02	0.55	0.20	0.14	---
503	12.40	---	41.8	2.40	12.20	7.31	0.67	0.13	0.41	---
504	9.80	---	78.7	0.65	0.30	0.47	0.31	0.34	0.25	---
505	9.60	---	77.4	1.45	0.30	0.62	0.27	0.15	1.00	---
506	12.70	---	69.4	2.30	1.55	0.72	0.94	0.73	0.59	---
507	13.90	---	63.1	2.65	1.35	1.84	1.05	0.35	0.34	---
508	18.70	2.93	53.8	3.60	1.65	2.70	1.47	0.33	0.36	8.05
509	16.50	---	62.6	2.85	1.20	2.05	1.19	0.37	0.41	---
510	14.95	---	60.2	3.60	1.75	2.46	1.13	0.25	0.44	---
511	14.90	---	62.3	1.90	1.50	0.87	1.08	2.88	0.41	---
512	20.20	12.20	58.4	3.40	1.90	1.41	1.04	1.62	0.59	8.2
513	13.90	---	54.1	3.00	5.20	6.19	0.49	3.66	0.30	---
514	7.30	---	43.2	0.90	17.90	8.51	1.11	1.02	0.25	---
515	13.90	---	59.9	2.50	4.90	2.64	1.50	2.40	0.59	---
516	13.20	---	59.1	2.60	5.40	2.93	1.15	2.10	0.66	---
517	18.80	5.80	56.4	4.00	2.00	1.63	1.35	2.82	0.75	6.5
518	15.50	---	60.4	3.20	2.30	1.92	1.19	2.62	0.60	---
519	16.10	---	64.0	2.40	1.70	0.62	1.40	4.08	0.14	---
520	14.60	---	64.4	0.60	0.90	0.48	1.42	4.44	0.04	---
521	15.40	---	60.4	2.30	0.90	0.54	1.26	1.98	0.34	---
522	18.10	9.20	57.2	2.40	1.80	1.05	1.05	2.46	0.20	10.2
523	3.90	---	62.7	0.70	14.80	10.77	0.14	1.26	0.16	---
524	13.80	---	58.9	4.00	2.90	1.87	1.51	3.24	0.65	---
525	17.40	---	58.8	2.70	5.20	3.19	0.95	2.34	0.50	---
526	13.60	---	59.9	2.80	4.30	3.82	0.90	1.98	0.65	---

527	13.50	---	72.8	0.8	0.8	0.15	1.46	2.94	0.05	---
528	17.10	---	68.4	1.5	0.2	0.81	0.20	3.72	0.40	---
529	13.50	---	71.0	1.8	none	0.65	0.28	2.34	0.30	---
530	7.00	---	84.8	1.3	0.2	0.62	0.20	1.92	0.17	---
531	15.60	---	70.8	1.6	0.5	0.81	0.24	2.52	0.20	---
532	11.70	---	77.1	0.8	0.6	0.65	0.23	3.96	0.13	---
533	18.40	7.7	70.5	1.3	0.6	0.36	1.01	2.82	0.17	4.0
534	18.80	7.5	52.4	4.3	2.7	1.16	1.35	1.74	0.58	9.5
535	15.90	---	55.3	3.6	5.5	1.74	1.11	1.80	0.58	---
536	14.90	---	51.9	2.1	5.9	7.90	0.74	3.36	0.17	---
537	18.90	6.9	59.1	3.6	1.8	0.76	2.24	3.18	0.50	5.25
538	17.30	---	56.3	2.9	2.2	0.83	0.89	2.40	0.30	---
539	17.20	---	57.3	2.4	2.6	1.99	0.92	1.68	0.15	---
540	8.80	---	47.9	2.1	15.3	3.51	0.55	2.28	0.42	---
541	12.50	---	41.9	2.3	9.5	9.63	0.32	1.56	0.14	---
542	5.95	---	28.2	2.4	18.7	11.22	0.33	2.46	0.14	---
543	12.60	---	61.2	2.2	6.1	2.03	1.32	2.10	0.50	---
544	12.75	---	59.9	2.6	7.0	2.46	1.08	2.22	0.65	---
545	12.40	---	66.4	2.4	2.5	2.35	1.22	3.18	0.65	---
546	15.75	---	65.9	2.0	1.7	1.26	0.99	2.82	0.35	---
547	12.05	---	59.8	2.0	4.9	5.57	0.40	1.74	0.50	---
548	7.70	---	41.8	1.7	13.0	9.41	0.68	1.86	0.25	---
549	8.45	---	37.7	1.8	15.0	9.01	0.55	4.74	0.25	---
550	18.65	8.5	58.1	2.0	3.3	2.75	0.27	2.22	0.60	6.75
551	15.15	---	64.6	1.9	0.9	1.88	1.28	3.24	0.50	---
552	16.30	---	59.2	2.0	2.4	2.78	2.84	2.40	0.35	---
553	15.75	---	54.4	2.6	5.6	2.89	1.28	2.58	0.60	---
554	14.40	---	62.1	0.7	1.3	1.30	1.43	3.66	0.14	---
555	14.45	---	67.7	2.0	1.6	1.30	1.08	2.46	0.30	---
556	9.20	---	44.0	2.8	9.0	8.94	0.27	1.99	0.14	---

Table 6.--Chemical analyses, contd.

Sample no.	Total Al_2O_3	Available Al_2O_3	SiO_2	Fe	CaO	MgO	Na_2O	K_2O	TiO_2	Ign. loss at 625°-650°C
557	12.45	---	49.9	2.8	6.8	8.47	0.31	1.97	0.20	---
558	10.90	---	53.2	3.7	6.7	8.07	0.28	1.98	0.35	---
559	14.20	---	58.8	2.5	7.9	3.08	1.28	1.92	0.60	---
560	15.95	---	58.0	2.9	7.3	2.43	1.27	2.22	0.60	---
561	12.05	---	56.0	2.3	3.8	2.14	0.99	1.81	0.35	---
562	12.15	---	55.2	4.6	2.2	2.06	1.32	1.81	0.85	---
563	13.65	---	64.3	1.0	1.2	1.01	1.34	3.54	0.35	---
564	14.75	---	56.7	2.3	1.7	1.43	1.46	1.98	1.10	---
565	20.35	9.3	56.1	5.8	0.7	1.66	2.77	2.69	1.15	4.25
566	19.65	9.6	59.2	6.0	0.9	0.40	0.55	2.64	0.11	5.15
567	20.30	8.95	57.8	7.6	0.8	0.69	0.65	2.82	0.60	5.55
568	17.35	---	56.6	8.4	0.9	1.85	2.90	0.90	0.85	---
569	17.45	---	62.4	2.9	0.9	1.23	0.24	3.66	0.60	---
570	1.67	---	7.5	1.0	33.35	14.10	0.45	0.45	0.05	---
571	12.95	---	44.1	3.5	10.9	4.53	0.58	2.10	0.58	---
572	12.20	---	74.9	1.30	0.98	0.29	4.14	4.80	0.10	---
573	22.40	15.2	56.9	3.25	0.83	1.64	1.66	1.74	0.40	10.2
574	20.00	10.15	63.2	2.55	0.69	1.34	0.52	1.80	0.70	8.1
575	20.50	1.17	54.4	6.45	1.86	0.69	1.20	0.59	0.60	8.7
576	14.20	---	63.2	2.8	1.80	1.30	1.01	4.07	0.17	---
577	8.50	---	50.2	2.2	15.5	2.90	1.28	2.22	0.12	---
578	11.55	---	58.0	3.4	7.5	2.40	1.31	1.80	0.23	---
579	14.50	---	66.7	3.6	1.40	2.10	0.97	2.76	0.25	---
580	19.60	5.4	60.3	2.0	2.70	1.96	0.76	3.84	0.20	7.50
581	14.5	---	61.9	3.0	6.25	2.83	1.64	2.88	0.55	---

582	14.30	---	57.2	3.1	6.20	2.72	1.94	2.82	0.15	---
583	12.00	---	59.2	2.7	6.35	2.65	2.00	2.64	0.40	---
584	13.90	---	59.7	2.7	6.45	2.65	1.66	2.82	0.60	---
585	16.95	---	56.2	4.8	4.70	1.60	1.17	2.88	0.80	---
586	17.80	---	64.8	2.5	0.39	0.80	0.23	2.88	0.70	---
587	31.40	31.5	49.7	0.9	0.35	0.33	0.21	0.53	0.45	13.8
588	14.85	---	73.3	1.8	0.50	0.51	0.20	0.86	0.35	---
589	18.10	---	66.7	2.7	0.60	0.47	0.19	0.75	0.30	---
590	15.40	---	69.0	3.3	0.45	0.65	0.20	2.28	0.40	---
591	12.00	---	77.6	2.4	0.40	0.51	0.33	1.20	0.25	---
592	19.30	12.8	62.5	5.6	0.70	1.08	0.21	2.10	0.35	7.10
593	17.30	---	64.3	7.0	1.40	0.83	0.32	2.10	0.30	---
594	15.80	---	68.8	2.8	0.80	0.40	0.27	3.42	0.30	---
595	15.30	---	66.4	2.4	1.70	0.80	0.29	3.06	0.30	---
596	15.70	---	68.0	4.0	1.10	0.87	0.27	2.82	0.40	---
597	13.90	---	67.5	3.0	1.40	0.80	0.20	2.46	0.30	---
598	13.10	---	50.5	4.4	11.30	1.16	0.21	2.70	0.25	---
599	19.90	15.1	60.3	1.4	0.40	1.26	0.30	4.32	0.35	5.8
600	17.00	---	68.0	3.2	0.30	1.34	0.28	2.76	0.30	---
601	17.30	---	60.4	3.6	3.00	0.87	0.23	3.24	0.45	---
602	17.40	---	58.1	1.1	1.50	1.02	1.24	2.70	0.25	---
603	16.10	---	66.0	4.0	0.30	0.91	0.33	2.40	0.20	---
604	22.50	15.7	58.5	4.0	0.20	1.02	0.28	2.76	0.65	8.1
605	22.40	17.5	50.6	6.3	0.20	1.27	0.29	2.76	0.45	8.3
606	17.80	---	64.4	3.0	3.00	1.69	0.31	2.32	0.40	---
607	15.10	---	59.7	4.30	0.80	1.12	0.21	2.70	0.25	---
608	17.10	---	59.6	5.10	0.60	1.38	0.26	3.72	0.35	---
609	18.00	---	62.3	3.60	0.85	0.94	0.26	3.66	0.30	---
610	17.60	---	59.8	4.50	0.80	1.92	2.00	2.76	0.35	---
611	16.60	---	66.2	4.20	0.40	0.76	0.27	2.82	0.30	---

Table 6.--Chemical analyses, contd.

Sample no.	Total Al_2O_3	Available Al_2O_3	SiO_2	Fe	CaO	MgO	Na_2O	K_2O	TiO_2	Ign. loss at 625°-650°C
612	15.90	---	50.8	3.2	10.90	0.87	0.23	2.32	0.25	---
613	18.30	---	60.8	3.4	1.50	1.12	0.21	3.30	0.40	---
614	25.70	18.5	51.0	5.3	0.20	1.41	0.33	3.00	0.35	8.85
615	15.80	---	63.3	3.5	0.60	1.02	0.23	3.18	0.30	---
616	12.10	---	67.3	3.3	0.65	0.51	0.23	2.34	0.25	---
617	16.50	---	66.4	2.7	0.40	0.80	0.20	2.70	0.20	---
618	20.90	3.02	54.3	4.5	0.70	1.38	0.20	4.32	0.30	7.80
619	24.60	5.70	51.1	4.5	0.85	1.37	0.20	3.84	0.30	9.60
620	16.70	---	62.9	2.3	0.35	0.73	0.28	3.00	0.40	---
621	17.60	---	64.8	2.4	2.10	0.69	0.24	3.38	0.45	---
622	18.40	---	63.5	1.6	0.55	0.62	0.23	2.28	0.30	---
623	15.10	---	63.1	4.6	1.35	1.92	2.30	2.46	0.40	---
624	13.80	---	67.5	2.6	0.40	0.80	0.21	3.18	0.45	---
625	15.70	---	58.0	3.8	0.75	1.78	1.60	2.76	0.45	---
626	21.70	3.00	61.0	4.9	1.00	1.83	2.02	2.88	0.30	6.05
627	19.90	2.96	61.3	4.2	1.60	1.16	0.55	2.88	0.40	8.40
628	16.80	---	62.0	4.0	2.15	1.34	0.46	2.82	0.35	---
629	17.10	---	68.8	2.8	1.45	1.70	0.85	2.28	0.30	---
630	16.50	---	61.0	4.0	0.95	1.48	0.45	2.70	0.25	---
631	17.40	---	56.2	4.3	0.55	1.12	0.37	2.82	0.45	---
632	12.50	---	62.0	3.2	1.00	1.19	0.26	2.58	0.40	---
633	24.70	18.5	52.0	6.6	0.75	0.11	0.81	2.46	0.60	8.85
634	16.40	---	53.0	4.6	1.50	2.50	0.42	2.40	0.45	---
635	18.55	2.93	53.1	2.2	2.10	3.45	0.41	1.04	0.20	15.00

SAMPLE LOCALITIES AND DESCRIPTIONS

SAMPLE 502

(Submitted by W. M. Cocanougher, Twin Bridges)

Location: Two miles south of Silver Star, sec. 11, T. 2 S., R. 6 W., Madison County.

Geologic description: Not available.

Test results: The material is white illitic clay containing a small amount of chlorite. The plasticity is extremely low; drying and firing shrinkage are low. The material could be used for common ceramic products if combined with a plastic clay.

SAMPLE 503

(Submitted by Dan Rovig)

Location: Northwest of Kalispell near Tally Lake, NW$\frac{1}{4}$ sec. 15, T. 30 N., R. 23 W., Flathead County.

Geologic description: Not available

Test results: The material contains much quartz, calcite, and dolomite. Although the plasticity is fairly good, the carbonate content makes the material unsuitable for ceramic use.

SAMPLES 504 and 505

Location: Southwest of Winnett near Yellow Water Creek, SW$\frac{1}{4}$ sec. 7, T. 13 N., R. 25 E., Petroleum County.

Geologic description: Sample 504 is from a clay layer 1.5 ft. thick and exposed for a distance of 20 ft. in a bulldozer cut. The clay seems to be of hydrothermal origin. Sample 505 is from a 7-ft. bed of siltstone overlying the clay. Attitude of the bedding is N. 45° W. 6° NE.

Test results: Sample 504 is white-burning flint clay containing quartz. The plasticity is low and green strength is low. The firing characteristics are good. It is an excellent ceramic material, which could work more easily and better if blended with a small amount of plastic clay.

Sample 505 is mainly quartz but contains small amounts of illite and chlorite, which give it some plasticity. Working and firing characteristics are fair. It could be used for common brick and similar products by careful handling or if mixed with a more plastic clay.

SAMPLE 506

(Submitted by Elmer Schye, White Sulphur Springs)

Location: Winston area, Broadwater County.

Geologic description: Not available.

Test results: The large amount of montmorillonite in this illitic clay makes it unsuitable for ceramic use. The firing characteristics are poor; the brick swelled when fired at low temperature and shrank when fired at a temperature high enough to establish a good glassy bond.

SAMPLE 507

(Submitted by Elmer Schye, White Sulphur Springs)

Location: Geyser area, Judith Basin County.

Geologic description: Probably from Colorado Shale.

Test results: This is a montmorillonite clay containing a large percentage of quartz. The brick cracked on drying; the clay is not suitable for ceramic use.

SAMPLES 508 and 509

(Submitted by Elmer Schye, White Sulphur Springs)

Location: Vananda area, Treasure County.

Geologic description: Probably from the Bearpaw Shale.

Test results: Sample 508 is mainly montmorillonite. Although the plasticity is good, the brick cracked on drying. It is unsuitable for ceramic use.

Sample 509 is montmorillonite clay containing a large amount of quartz and a medium amount of feldspar. The dried brick has a heavy scum, and firing properties are poor. The clay is not suitable for ceramic use.

SAMPLE 510

(Submitted by Norman Rogers)

Location: Wet Georgia Gulch, Tobacco Root Mountains, Madison County.

Geologic description: Not available.

Test results: The material is bentonite containing a large amount of nonplastic substance. The plasticity is low, and the brick swelled and cracked on firing. The clay is unsuitable for ceramic use.

HELENA AREA

Samples 511 to 564 were collected in the Helena area during July 1966. The localities of these samples are shown on Figure 1. Extensive use was made of published reports on the geology of this area by Knopf (1963), Lorenz and Swenson (1951), Pardee and Schrader (1933), and Mertie, Fischer, and Hobbs (1951).

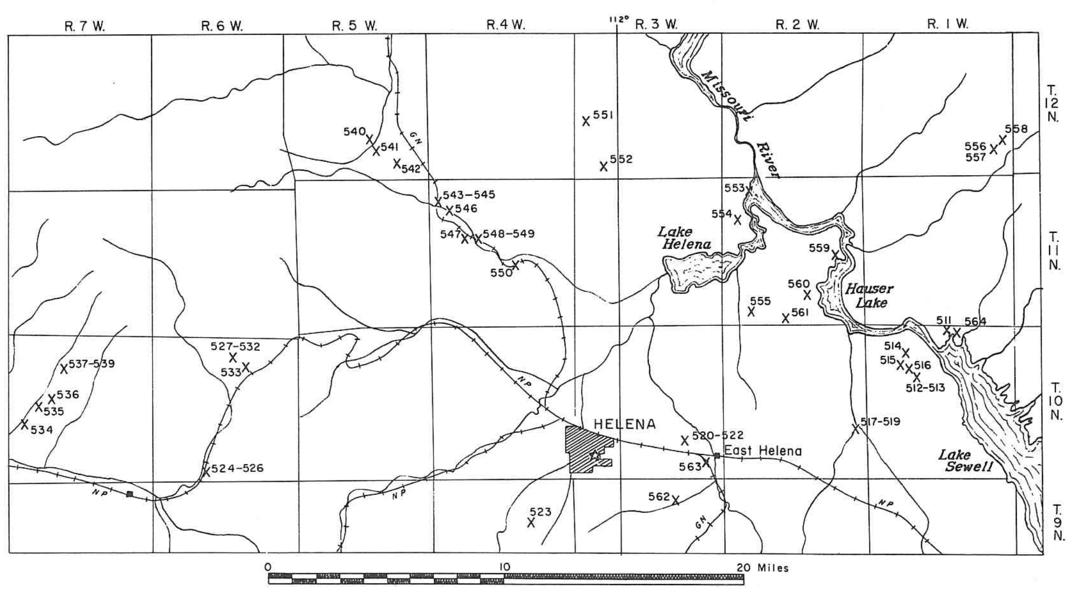

Figure 1. --Map showing localities of samples 511 to 564 from the Helena area.

Four of the ten samples collected from the Belt Supergroup were found to be suitable for use in ceramic products. Two samples of the Wolsey Shale were unsuitable for ceramic use, but two samples of a Mesozoic shale were suitable for such use. Eleven out of 25 samples of Tertiary sediments were judged suitable for ceramic use, and 4 of 15 samples of Quaternary alluvium were also found to be of possible use in the manufacture of ceramic products.

None of the samples tested for expandibility produced a product suitable for use in the manufacture of lightweight aggregate.

SAMPLE 511

Location: Exposure along road between Missouri River and Canyon Ferry, NE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 3, T. 10 N., R. 1 W., Lewis and Clark County.

Geologic description: Oligocene tuff; grab sample of white-weathering clay. Exposures of this tuff can be seen along the northeast shore of Lake Sewell.

Test results: Although this montmorillonite clay is low in plasticity and P.C.E., it could, with careful handling and blending, be used in making common brick and similar products.

SAMPLES 512 and 513

Location: Road cut at top of hill 1$\frac{1}{4}$ miles west of Canyon Ferry dam, SE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 9, T. 10 N., R. 1 W., Lewis and Clark County.

Geologic description: Wolsey Shale (Cambrian). The shale is exposed here only in the road cut and dips 45°. Sample 512 is from a white-weathering bed about 25 feet thick, and sample 513 is of red-weathering shale.

Test results: Sample 512 is composed of montmorillonite, quartz, feldspar, and minor amounts of calcite and gypsum. The firing characteristics are not good; the brick cracked. The material is not suitable for ceramic use.

Sample 513 is mainly quartz and dolomite but contains minor amounts of clay minerals and hematite. The firing characteristics are poor; the firing range is narrow. The material is unsuitable for ceramic use.

SAMPLE 514

Location: About 1 mile south of Missouri River in road cut in the Spokane Hills, NW$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 8, T. 10 N., R. 1 W., Lewis and Clark County.

Geologic description: Spokane Shale (Precambrian). White, earthy bed 1.5 ft. thick in road cut. Attitude of bedding, N. 60° E. 25° SE.

Test results: The material is a mixture, mainly quartz and calcite. The firing characteristics are poor, the firing range narrow. It is not suitable for ceramic use.

SAMPLES 515 and 516

Location: Road cut about 1 mile south of Missouri River in the Spokane Hills, NW$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 8, T. 10 N., R. 1 W., Lewis and Clark County.

Geologic description: Quaternary alluvium. Sample 515 is from the lower zone (7 ft. thick) of the soil profile exposed in this road cut. Sample 516 is from the 6-ft. zone overlying the zone sampled by sample 515. This upper zone is overlain by 0.2 ft. of soil containing much organic matter.

Test results: Sample 515 is mostly quartz and feldspar, of extremely low plasticity, but contains enough calcite and dolomite to act as a flux. It possibly could be used as a blending material with other materials.

Sample 516 is similar to the foregoing sample in working and firing properties, is more complex, however, and has more plasticity. It possibly could be used as a blending material.

SAMPLES 517 to 519

Location: Road cut 0.7 mile south of the Spokane Creek School, NE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 25, T. 10 N., R. 2 W., Lewis and Clark County.

Geologic description: Tertiary sediment. This sediment evidently contains much clay from the weathering of the Spokane or Empire Shale to the east in the Spokane Hills. Sample 517 is from a bed of sandy clay 4 ft. thick exposed near the base of this road cut. A bed of silty clay 15 ft. thick overlies this bed. Sample 518 is from the upper 4 ft. of the silty clay, and sample 519 is from the lower part of this same bed.

Test results: Sample 517 is impure illitic clay of low plasticity. The working and firing characteristics are fair. The clay could be used as a blending or flux material with other, more plastic clays.

Sample 518 is made up of quartz, mixed-layer clays, and minor impurities. The plasticity is low; the firing characteristics are fair. It could be used as a blending or flux material with other, more plastic clays.

Sample 519 is tan gritty clay material having extremely low plasticity. Drying and firing shrinkage are low and firing properties fair. It could be good material for blending with more plastic clays.

SAMPLES 520 to 522

Location: Road cut along U.S. Highway 12, 0.3 mile east from power substation, NW$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 26, T. 10 N., R. 3 W., Lewis and Clark County.

Geologic description: Tertiary sediment. Sample 520 is of a bed 5 ft. thick consisting of thinly bedded altered tuff and is exposed near the top of this road cut. A bed of altered tuff 5 ft. thick near the base of road cut is represented by sample 521. Sample 522 is from a bed of buff-weathering altered tuff 8 ft. thick and lying between the beds from which samples 520 and 521 were obtained.

Test results: Sample 520 is montmorillonite containing a minor amount of impurity. It has no plasticity and is unsuitable for a ceramic material.

Sample 521 is montmorillonite clay containing a small amount of impurity. The plasticity is low and the firing properties poor. It is unsuitable for ceramic use.

Sample 522 is montmorillonite containing some impurities. The firing shrinkage is large. The material is unsuitable for ceramic use.

SAMPLE 523

Location: Road cut about $\frac{1}{2}$ mile northeast of Unionville in Orofino Gulch, NE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 11, T. 9 N., R. 4 W., Lewis and Clark County.

Geologic description: Diopside skarn near the northern contact of the Boulder batholith.

Test results: The material is white and is a mixture of quartz and white diopside. The plasticity is extremely low, therefore the material could not be used alone. It might be used as blend or flux with a plastic clay.

SAMPLES 524 to 526

Location: Railroad cut along Dog Creek 0.9 mile downstream from Latham Gulch, NE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 33, T. 10 N., R. 6 W., Powell County.

Geologic description: Quaternary alluvium. This deposit of silt and clay is exposed for a vertical distance of 40 ft. in the railroad cut and also for a distance of at least 500 ft. to the northwest of the cut. There are a few scattered pebbles and cobbles. Sample 524 was collected 6 ft. below the top of the cut, sample 525 about 25 ft. below top of cut, and sample 526 from a silty clay lens about 3 by 10 ft., also exposed in the cut.

Test results: Sample 524 is quartz and feldspar and contains just enough illite and calcite to give it some plasticity. The firing characteristics are poor and the firing range narrow. It is not suitable for ceramic use.

Sample 525 is composed of quartz and dolomite but contains minor amounts of other minerals. The firing properties are poor and the firing range is narrow. It is not suitable for ceramic use.

Sample 526 is quartz and dolomite but contains minor amounts of other minerals including gypsum. The plasticity is very low and the firing properties poor. It is not suitable for ceramic use.

SAMPLES 527 to 532

Location: Inactive clay pit 1.5 miles northwest of Blossburg, NE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 3, T. 10 N., R. 6 W., Powell County.

Geologic description: Strongly contorted Jurassic or Cretaceous shale exposed in the pit was evidently the source of the clay mined here. Relatively flat-lying Tertiary sediments consisting mainly of tan to white silty claystone overlie the contorted shale. Altered and silicified rhyolite of Tertiary age overlies the Tertiary sediments. Samples 531 and 532 are of the Mesozoic shale, samples 528, 529, and 530 are of the Tertiary sediments, and sample 527 is of the altered rhyolite. There seems to be a large amount of shale remaining in this pit.

Test results: Sample 527 is mainly feldspar and cristobalite but contains a minor amount of zeolite. The plasticity is too low to permit use of this clay alone, but the material could be used as blend or flux material with a plastic clay.

Sample 528 is a mixture of kaolinite, illite, and quartz. All of the properties are good. It could be used for a variety of ceramic products.

Sample 529 is mostly quartz but it contains enough kaolinite, montmorillonite, and illite to give it fair plasticity. Drying and firing properties are good. It could be used for common brick and similar products.

Sample 530 consists of quartz, feldspar, and a minor amount of illite. The plasticity is extremely low; the brick would not hold together so was not fired. Other than as possible flux, the material has no ceramic possibilities.

Sample 531. The clay portion is minor amounts of kaolinite, montmorillonite, and illite, mixed with quartz. The plasticity is too low for use of this clay alone, but the drying and firing characteristics are good. The material could be a good material for blending with more plastic clay.

Sample 532 is illitic clay containing quartz and some feldspar. Plasticity is low, but the material has good firing properties and could be used with a plastic clay for common brick and similar products.

SAMPLE 533

Location: Four-tenths mile west of Blossburg, NE$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 10, T. 10 N., R. 6 W., Powell County.

Geologic description: Tertiary sediment(?). Buff-weathering claystone overlying sandstone and conglomerate. This claystone is exposed for a vertical distance of 7 ft. in a small gully.

Test results: The material is illite clay containing quartz and feldspar. The plasticity is low, but the other ceramic properties are fair. The material could be used as a blend with a plastic clay.

SAMPLE 534

Location: Road cut along Snowshoe Creek road about 2.5 miles upstream from junction with U.S. Highway 10 N, NE$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 19, T. 10 N., R. 7 W., Powell County.

Geologic description: Quaternary alluvium. Pebbly silty clay is exposed in a shallow road cut at the crest of a slight hill.

Test results: The clay is montmorillonite containing minor impurities. The firing shrinkage is large and the firing range narrow. The clay is unsuitable for ceramic use.

SAMPLE 535

Location: Ditch next to Snowshoe Creek road about 3.4 miles upstream from junction with U.S. Highway 10 N, NW$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 20, T. 10 N., R. 7 W., Powell County.

Geologic description: Quaternary alluvium. This sample of brown silty clay was collected at a depth of 3 ft.

Test results: The montmorillonite clay contains calcite, which acts as a flux and causes a scum on the dried brick. The firing properties are poor; the clay is unsuitable for ceramic use.

SAMPLE 536

Location: Along Snowshoe Creek road at junction with road to Trout Creek, SE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 17, T. 10 N., R. 7 W., Powell County.

Geologic description: Tertiary sediment. The bed sampled here is 4 ft. thick and is underlain by 2 in. of conglomerate, which in turn is underlain by more clay.

Test results: The material is composed of illite, quartz, dolomite, and minor impurities. The firing characteristics are poor. The material is not suitable for ceramic use.

SAMPLES 537 to 539

Location: About 1 mile downstream from fish hatchery on Snowshoe Creek, NW$\frac{1}{4}$ sec. 9, T. 10 N., R. 7 W., Powell County.

Geologic description: Tertiary sediment. These sediments are well exposed along the west side of this valley for a distance of at least 0.6 mile and over a vertical distance of approximately 200 ft. Samples 537, 538, and 539 were obtained at widely spaced locations within this area.

Test results: Sample 537 is quartz and feldspar but contains small amounts of montmorillonite and illite. Drying and firing properties are fair. The material could be used as a blend for common brick.

Sample 538 is composed of montmorillonite and minor amounts of quartz, feldspar, and metahalloysite. The plasticity is low and the firing shrinkage high. The clay is not suitable for ceramic use.

Sample 539 is montmorillonite. It has very little plasticity but high firing shrinkage. All of the bricks cracked on firing. The material is unsuitable for ceramic use.

SAMPLE 540

Location: Borrow pit on Montana Highway 279 near Trinity Creek, SW$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 27, T. 12 N., R. 5 W., Lewis and Clark County.

Geologic description: Quaternary alluvium. Sample 540 is from a layer of clay 2 ft. thick, which is underlain by gravel.

Test results: The material is composed of quartz, calcite, dolomite, and minor impurities. The plasticity is low and the properties poor. The material is unsuitable for ceramic use.

SAMPLE 541

Location: Road cut along Montana Highway 279, 1/3 mile southeast of Trinity Creek crossing, NE$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 27, T. 12 N., R. 5 W., Lewis and Clark County.

Geologic description: Quaternary alluvium(?). This pebbly clay is exposed in a shallow road cut about 5 ft. deep.

Test results: Although the clay mineral in this material is kaolinite, the dolomite content is great enough to control the firing properties. The brick cracked on firing. The clay is unsuitable for ceramic use.

SAMPLE 542

Location: Road cut along Montana Highway 279, 0.7 mile northwest of junction with road to Marysville, NE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 35, T. 12 N., R. 5 W., Lewis and Clark County.

Geologic description: Quaternary alluvium. This clay contains numerous angular fragments of the underlying argillaceous limestone. The maximum thickness is 3 ft. here.

Test results: The material is mainly dolomite and calcite but contains some quartz and feldspar. The firing properties are poor. It is unsuitable for ceramic use.

SAMPLES 543 to 545

Location: Road cut along Montana Highway 279 about $\frac{1}{2}$ mile southeast of railroad crossing, NE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 6, T. 11 N., R. 4 W., Lewis and Clark County.

Geologic description: Quaternary alluvium. Sample 543 is silty clay and was collected about 3 ft. below the top of this road cut. Samples 544 and 545 were obtained from an auger hole at the base of this road cut. Sample 544 was obtained from a depth of 8$\frac{1}{2}$ to 9$\frac{1}{2}$ ft. below road level. Sample 545 is from a depth of 9$\frac{1}{2}$ to 10 ft. and contains numerous angular rock fragments, indicating that perhaps the alluvium is here about 13 ft. thick.

Test results: Sample 543 is mainly quartz and calcite but contains a mixture of minor impurities. The firing properties are poor. It is unsuitable for ceramic use.

Sample 544 is mainly quartz, feldspar, and calcite. The firing characteristics are poor; the brick cracked on firing. The material is not suitable for ceramic use.

Sample 545 is mostly quartz but contains enough chlorite and montmorillonite to give it some plasticity. The firing characteristics are fair. The material could be used for blending with a plastic clay.

SAMPLE 546

Location: Road cut along Montana Highway 279 about $1\frac{1}{4}$ miles southeast of railroad crossing, NE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 7, T. 11 N., R. 4 W., Lewis and Clark County.

Geologic description: Quaternary alluvium. Tan pebbly clay is exposed to a depth of about 10 ft. in this road cut.

Test results: This illitic clay contains enough impurity to cause the brick to scum and then swell during firing. The clay is unsuitable for ceramic use.

SAMPLE 547

Location: Road cut along Montana Highway 279 north of Gearing siding, NW$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 17, T. 11 N., R. 4 W., Lewis and Clark County.

Geologic description: Helena Dolomite of Belt Supergroup (Precambrian) according to Knopf (1963). Shale is exposed throughout this road cut of about 15 ft. vertical extent.

Test results: The material is dolomitic kaolin clay. The firing characteristics are poor. The material is not suitable for ceramic use.

SAMPLES 548 and 549

Location: Road cut along Montana Highway 279 about $\frac{1}{2}$ mile east of Gearing siding, SW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 16, T. 11 N., R. 4 W., Lewis and Clark County.

Geologic description: Helena Dolomite of Belt Supergroup (Precambrian) according to Knopf (1963). The presence of numerous angular argillite fragments in this clay suggests that it has been produced by the alteration of Belt argillite. This zone of alteration extends intermittently along the highway for 1,100 ft. and contains numerous zones of more intense alteration 1 to 10 ft. thick. Samples 548 and 549 are from two of these more intensely altered zones.

Test results: Samples 548 and 549. The material is mainly quartz and dolomite but contains a small amount of impurities. The plasticity is low and firing properties poor; the brick swelled and cracked on firing. The material is unsuitable for ceramic use.

SAMPLE 550

Location: Railroad cut adjacent to Silver Creek at the north end of the Scratch Gravel Hills, SW$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 22, T. 11 N., R. 4 W., Lewis and Clark County.

Geologic description: Empire Shale or Spokane Shale of Belt Supergroup (Precambrian) according to Knopf (1963). Tan clay and slightly altered argillite are exposed in this railroad cut.

Test results: This impure illitic clay has fair working and firing properties. Although the plasticity is low, the clay could be used alone or with others as a blend for common brick.

SAMPLE 551

Location: Road cut along Interstate Highway 15, 5.5 miles north of Lincoln road exit, SE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 19, T. 12 N., R. 3 W., Lewis and Clark County.

Geologic description: Argillite of the Belt Supergroup (Precambrian). Sheared and somewhat altered argillite is exposed over an area of approximately 10 by 10 ft. in this road cut.

Test results: The material is a mixture of quartz, illite, and various impurities. The firing characteristics are fair, although the firing range is narrow. The material possibly could be used as a blend for common brick.

SAMPLE 552

Location: Road cut along Interstate Highway 15, 3.6 miles north of the Lincoln road exit, SW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 32, T. 12 N., R. 3 W., Lewis and Clark County.

Geologic description: Argillite of the Belt Supergroup (Precambrian). A white zone (hydrothermally altered?) 20 ft. thick is exposed in road cuts on both sides of the highway and is surrounded by maroon argillite. On the east side of the highway this zone is concordant to the bedding (N. 5° W., 16° SW), but on the west side a concordant relationship could not be established. The white argillite is somewhat softer than the maroon argillite.

Test results: The material is mainly quartz and feldspar but contains a small amount of montmorillonite. It has enough plasticity to hold a dried brick together. The brick disintegrated on firing; the sandy material did fuse or vitrify at the highest firing temperature used. The material reacts like freshly decomposed granite. It is not suitable for ceramic use.

SAMPLE 553

Location: West bank of Missouri River just below entrance of Prickly Pear Creek, SE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 5, T. 11 N., R. 2 W., Lewis and Clark County.

Geologic description: Tertiary sediment. Sample 553 is claystone from a road cut in which beds of siltstone and conglomerate are also exposed.

Test results: The material is mostly quartz and calcite but includes a minor amount of impurities. The firing range is narrow and the fired brick has a scum. The material is unsuitable for ceramic use.

SAMPLE 554

Location: In low hills north of dam at Lake Helena, SW$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 7, T. 11 N., R. 2 W., Lewis and Clark County.

Geologic description: Tertiary sediment. White clay containing numerous angular fragments of partly altered tuff is exposed for a vertical distance of 10 ft. in this road cut.

Test results: This montmorillonite clay has low plasticity but fairly good drying and firing properties. It possibly could be used as a blend for common brick.

SAMPLE 555

Location: Along road between Harmony School and Hauser Lake, NE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 32, T. 11 N., R. 2 W., Lewis and Clark County.

Geologic description: Tertiary sediment. A sandy greenish clay is exposed in this road cut to a depth of 5 ft.

Test results: The material is mostly quartz and feldspar but contains enough montmorillonite to give it good plasticity. Drying and firing properties are fair. The material could be used as a blend clay for common brick.

SAMPLES 556 to 558

Location: Along Trout Creek from $\frac{1}{2}$ to 1 mile downstream from Vigilante Campground, N$\frac{1}{2}$ SE$\frac{1}{4}$ sec. 25, T. 12 N., R. 1 W., Lewis and Clark County.

Geologic description: Greyson Shale of Belt Supergroup (Precambrian). This highly sheared shale is exposed for over 2,000 ft. along the northwest side of Trout Creek valley. Here the Greyson Shale has been thrust to the northeast over Paleozoic sediments (Pardee and Schrader, 1933, Pl. 15). Sample 556 was collected near the southernmost exposure of this sheared zone, sample 557 was collected upstream about 500 ft., and sample 558 is from a road cut just upstream from Beartrap Gulch, also in the sheared zone.

Test results: Sample 556. This illitic clay contains a large amount of dolomite, quartz, and ferromagnesium minerals. The firing properties are poor. The material is unsuitable for ceramic use.

Sample 557. This chloritic clay contains an appreciable amount of quartz and dolomite. Drying and firing characteristics are fair; the plasticity is low. It could be used as a blend in common brick.

Sample 558. The clay is a mixture of chlorite, quartz, dolomite, and calcite, and minor impurities. The plasticity is low, drying and firing properties fair. It could be used as a blend in common brick.

SAMPLE 559

Location: West bank of Missouri River about $\frac{1}{2}$ mile upstream from Trout Creek bridge, NW$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 23, T. 11 N., R. 2 W., Lewis and Clark County.

Geologic description: Quaternary alluvium. This silty clay contains numerous argillite fragments derived from the Greyson Shale adjacent to the west. The Quaternary alluvium covers an area of about a quarter square mile (Pardee and Schrader, 1933, Pl. 15).

Test results: The material is mainly quartz and feldspar but contains many minor impurity minerals. Plasticity is low, drying and firing properties fair. It could be used a blend in common brick.

SAMPLE 560

Location: West shore of Hauser Lake near resort, SW$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 27, T. 11 N., R. 2 W., Lewis and Clark County.

Geologic description: Tertiary sediment. Thinly bedded tan silty claystone is exposed in a small pit cut into the side of the hill.

Test results: The material is quartz, feldspar, calcite, dolomite, and a minor amount of clay minerals. Plasticity is low, drying and firing shrinkage low, fired color fair. The material could be used as a blend in common brick.

SAMPLE 561

Location: About 1$\frac{1}{2}$ miles west from Hauser Lake on northeast-trending road between East Helena and Hauser Lake, SE$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 33, T. 11 N., R. 2 W., Lewis and Clark County.

Geologic description: Tertiary sediment. This sample is from an exposure in a small gully about 300 ft. north of the road.

Test results: This montmorillonite clay has good plasticity, but the brick cracked and shrank on firing. The material is unsuitable for ceramic use.

SAMPLE 562

Location: Road cut along Interstate Highway 15, 2.6 miles southeast of Helena city limits, NE$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 3, T. 9 N., R. 3 W., Lewis and Clark County.

Geologic description: Tertiary sediment. Sample 562 is tan-weathering clay exposed in a road cut.

Test results: This material is mainly montmorillonite but contains minor amounts of quartz and feldspar. Plasticity is low, drying and firing shrinkage low. The clay could be used as a blend in common brick.

SAMPLE 563

Location: Seven-tenths mile southwest of East Helena along Montana Highway 518, NW$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 36, T. 10 N., R. 3 W., Lewis and Clark County.

Geologic description: Tertiary sediment. This white crumbly clay is seemingly altered tuff and is exposed in a road cut.

Test results: This montmorillonite clay has just enough plasticity to hold a brick together. Working characteristics are poor, the firing shrinkage is high. The clay is unsuitable for ceramic use.

SAMPLE 564

Location: Exposure along road between Missouri River and Canyon Ferry, NE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 3, T. 10 N., R. 1 W., Lewis and Clark County.

Geologic description: Oligocene tuff. This sample is a grab sample from a bed 3 ft. thick composed mainly of clay but containing scattered angular fragments of partly altered tuff. (Sample 511 was collected about 15 ft. above this bed.) Exposures of tuff can be seen along the northeast shore of Lake Sewell.

Test results: The impure montmorillonite clay has low plasticity and high firing shrinkage. It is not suitable for ceramic use.

SAMPLES 565 to 568

Location: Northeast of Whitehall along the east side of the Boulder River valley. Samples 565 and 566 from SE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 36, T. 2 N., R. 3 W.; samples 567 and 568 from NW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 36, T. 2 N., R. 3 W., Jefferson County.

Geologic description: LaHood Formation of Belt Supergroup (Precambrian) In this area the LaHood Formation has undergone extensive alteration, which McMannis (1963, p. 413) attributed to deep weathering before deposition of Cenozoic sediments. Samples 482 to 487 (Chelini and others, 1966, p. 13) are from an inactive clay pit in this altered sediment. Samples 565 and 566 are from exposures of altered LaHood Formation west of the clay pit; 567 and 568 were collected north of the pit. Sample 568 is from an arkosic bed that seemingly has not been altered to as great an extent as the adjacent beds. On the basis of these samples it seems likely that alteration extends well beyond the pit boundaries.

Test results: Sample 565. The material is illitic clay containing much quartz and a small amount of kaolinite. Plasticity is low, drying and firing properties are fair. It could be used for common brick.

Sample 566. This illitic clay contains a small amount of kaolinite and a large amount of quartz. Plasticity is low, firing and drying shrinkage good. It is a good material for common brick.

Sample 567. This illitic clay contains much quartz. It has fair plasticity, fair drying and firing properties, and a good fired color. It is a fairly good material for common brick.

Sample 568. The material is mainly quartz and feldspar. It has extremely low plasticity, but drying and firing shrinkage are low. It could be used in common brick if blended with a more plastic clay.

SAMPLE 569

(Sample submitted by Kaiser Cement and Gypsum Corp.)

Location: Thirteen miles south of Belt in the vicinity of Tiger Butte, T. 16 N., R. 6 E., Cascade County.

Geologic description: Not available.

Test results: The material is siliceous illitic clay. Drying and firing shrinkage are low, and the plasticity is extremely low. Combined with a more plastic clay it could be used for common brick.

SAMPLE 570

(Submitted by G. B. Dover, Buffalo)

Location: West of Buffalo Canyon in the Little Belt Mountains, Judith Basin County.

Geologic description: Not available.

Test results: The material is dominantly calcite and dolomite but contains some cristobalite and a complex silicate. Firing calcines the carbonates. On standing, the brick dehydrated and disintegrated. There is not enough silica present to form stable silicates. The material is not suitable for ceramic use.

SAMPLE 571

(Submitted by D. W. Easton, Knife River Coal Company, Savage)

Location: Knife River coal mine west of Savage, Montana, T. 20 N., R. 57 E., Richland County.

Geologic Description: Sample from the Tongue River Member of the Fort Union Formation.

Test results: Although this clay contains large amounts of calcite and dolomite, the plasticity is good and the drying and firing shrinkage are low. The brick fired at the higher temperatures has a pleasing cream color. By careful handling and firing the clay could be used for common brick, or it could be blended with other clays.

SAMPLE 572

(Submitted by Calvin Rice, Southeastern Montana Opportunity Center, Dawson County Courthouse, Glendive)

Location: Highway cut at Radar Base Interchange of Interstate Highway 90 west of Miles City, NW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 33, T. 7 N., R. 46 E., Custer County.

Geologic description: Not available.

Test results: The material is mostly glass but contains a small amount of cristobalite. It has no plasticity. It is unsuitable alone, but could be used as a grog.

SAMPLE 573

(Submitted by Calvin Rice, Southeastern Montana Opportunity Center, Dawson County Courthouse, Glendive)

Location: Across the Yellowstone River from Terry, NW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 9, T. 12 N., R. 51 E., Prairie County.

Geologic description: Not available.

Test results: This illitic clay, containing much quartz, has good plasticity, but the drying shrinkage is great and the brick fused and swelled on firing. The clay is not suitable for ceramic products.

SAMPLE 574

(Submitted by Calvin Rice, Southeastern Montana Opportunity Center, Dawson County Courthouse, Glendive)

Location: Rice Bros. ranch near Epsie, $SW\frac{1}{4}$ $SE\frac{1}{4}$ sec. 12, T. 4 S., R. 49 E., Powder River County.

Geologic description: Not available.

Test results: The material is montmorillonite clay containing gypsum. All of the bricks cracked when dried and swelled on firing. The clay is not suitable for ceramic use.

SAMPLE 575

(Submitted by Harold G. Nelson, Sr., Greenough)

Location: North of Greenough, sec. 36, T. 14 N., R. 15 W., Missoula County.

Geologic description: Not available.

Test results: This montmorillonite clay is not suitable for ceramic use; the brick cracked on firing.

SAMPLE 576

(Submitted by Elmer Wagner, P. O. Box 294, Avon)

Location: Northwest of Avon, sec. 11, T. 12 N., R. 9 W., Powell County.

Geologic description: Not available.

Test results: The material is mostly montmorillonite (a bentonitic clay) and is not suitable for ceramic use.

SAMPLE 577

(Submitted by Henry Hansen, Anaconda)

Location: Southwest of Philipsburg in the Flint Creek valley, sec. 21, T. 6 N., R. 14 W., Granite County.

Geologic description: Not available.

Test results: The material is mostly quartz and has extremely low plasticity; it is unsuitable for ceramic use.

SAMPLE 578

(Submitted by Frank Stagg, Butte)

Location: Southwest of Wise River, sec. 5, T. 1 S., R. 11 W., Beaverhead County.

Geologic description: Not available.

Test results: The material is mostly quartz and calcite but contains a minor amount of clay. It is unsuitable for ceramic use.

SAMPLES 579 and 580

Location: Road cut on Beartooth road along east shore of Holter Lake, SE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 14, T. 14 N., R. 3 W., Lewis and Clark County.

Geologic description: Colorado Shale (Cretaceous). Sample 579 is from the middle of a bed of black shale about 35 ft. thick. Sample 580 is from a bed of soft brown shale about 3 ft. thick. Interbedded sandstone and shale of variable attitude are exposed in several road cuts along the Beartooth road.

Test results: Sample 579. The material is illitic clay containing much quartz. The plasticity and drying shrinkage are low. The firing range is narrow; at the higher firing temperatures the brick cracked and swelled rapidly. The clay possibly could be used if blended with other clays.

Sample 580. The large amount of hydromica in this sample caused overfiring and swelling. The material is not suitable for ceramic use.

SAMPLES 581 to 584

Location: East shore of Holter Lake, SE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 15, T. 14 N., R. 3 W., Lewis and Clark County.

Geologic description: Tertiary(?) sediment. Tan silty to sandy claystone is exposed along the shore of Holter Lake. Sample 581 is from a 7.6-ft. layer exposed in a road cut. Sample 582 is from an 8.6-ft. layer just below this, and 583 is from a 5-ft. layer in turn below this. Sample 584 is from the lowest 2.5 ft. of this section.

Test results: Samples 581, 582, 583, and 584. These clays contain much quartz. Although they have good plasticity, they do not contain enough clay to make good brick. The firing range is very narrow. They are unsuitable alone, but possibly could be used as flux or grog.

GREAT FALLS AREA

Samples 585 to 632 were collected from the Great Falls area during the latter part of June 1967. Their localities are given in Figure 2. Further information on clay within this area, particularly those deposits that have been mined, is given by Warde (1937). Fisher (1908) presented information on the occurrence of clay in the Kootenai Formation southeast of Belt.

Thirty-eight samples were collected from the Kootenai and Morrison Formations in the Great Falls area. Of these samples, only two were entirely unsuitable for ceramic use. Of the four samples collected from the Flood Member of the Blackleaf Formation, three were found to be of possible ceramic value. Two of the three samples collected from the Kevin Shale Member of the Marias River Formation were not suitable for ceramic use.

Because of the previous work done by DeMunck (1956) and Sahinen (1957) on expandable shale in the Great Falls area, none of the samples collected during 1967 were tested for expandability.

SAMPLE 585

Location: Road cut on U.S. Highway 87, 5.7 miles east of Raynesford, $NW\frac{1}{4}$ sec. 8, T. 17 N., R. 9 E., Judith Basin County.

Geologic description: Kootenai Formation (Cretaceous) gray and maroon shale containing numerous calcareous concretions is exposed in this road cut over a vertical distance of about 15 ft.

Test results: The material is kaolin clay containing much quartz and fluxed by calcite. Although the firing range is narrow, the clay could be used for common brick if well ground and carefully fired, or possibly for grog or flux.

SAMPLE 586

Location: Road cut 0.5 mile south of Belt, $NW\frac{1}{4}$ $SE\frac{1}{4}$ sec. 26, T. 19 N., R. 6 E., Cascade County.

Geologic description: Morrison Formation (Jurassic). Silverman and Harris (1967, p. 18) reported a thickness of 35 ft. for this gray shale, of which sample 586 represents an 8-ft. section.

Test results: The clay is composed of kaolinite, illite, and quartz. The plasticity is low, drying and firing shrinkage average. The firing characteristics and firing range are good. The clay is good material for common brick.

SAMPLE 587

Location: Road cut along U.S. Highway 87 and 89, 0.3 mile west of Belt, $NW\frac{1}{4}$ $NW\frac{1}{4}$ sec. 26, T. 19 N., R. 6 E., Cascade County.

Geologic description. Morrison Formation (Jurassic). Silverman and Harris (1967, p. 19) indicated a thickness of 1 ft. 2 in. for this gray shale, but where sampled the bed is only 0.5 ft. thick.

Test results: The material is kaolin flint clay of extremely low plasticity. All other characteristics are good. It is an excellent white-burning ceramic material. It could be used for refractory brick and other ceramic products.

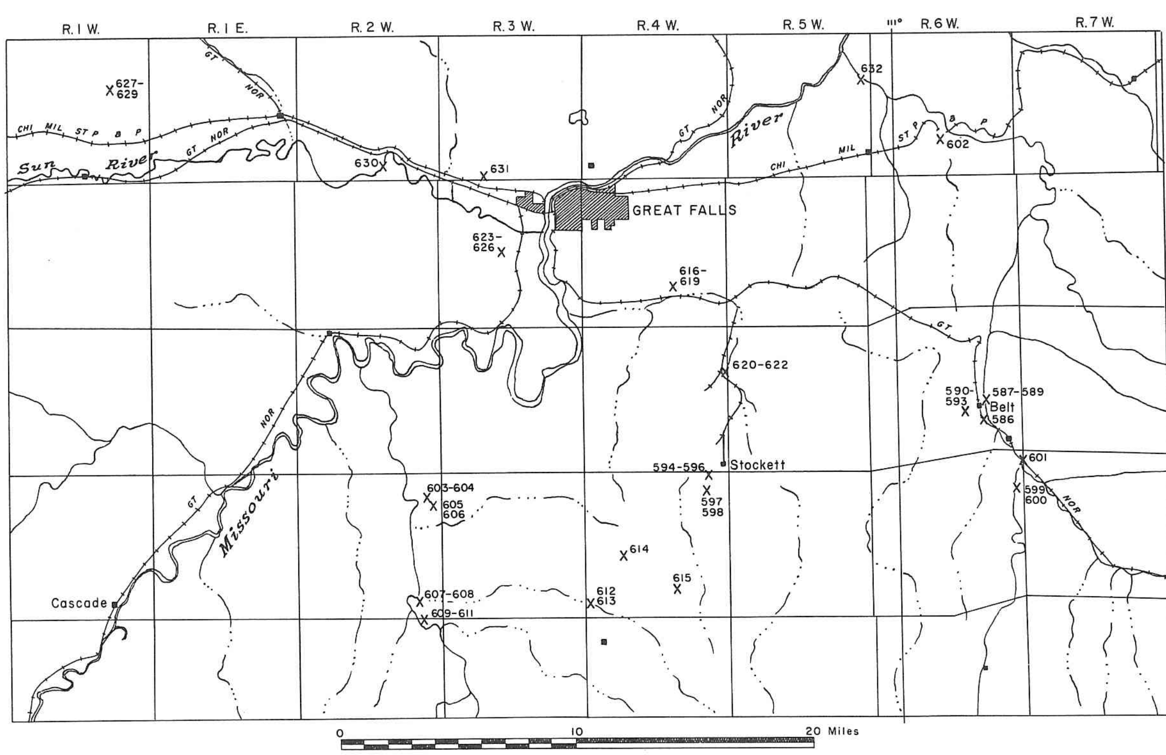

Figure 2.--Map showing sample localities of samples 585 to 632 from the Great Falls area.

SAMPLES 588 and 589

Location: Same as for sample 587.

Geologic description: Kootenai Formation (Cretaceous). Samples 588 to 593 are from a section of the Kootenai Formation described by Silverman and Harris (1967, p. 19). Sample 588 is from 6 ft. of orange- to yellow-weathering mudstone. The 4 ft. represented by sample 589 is directly above this unit and is a gray mudstone.

Test results: Samples 588 and 589. These are siliceous kaolin flint clays. The plasticity is fair, the drying and firing characteristics good. They are good refractory, common brick, flux, and grog clays.

SAMPLES 590 to 592

Location: Road cuts along U.S. Highway 87 and 89, 0.7 mile west of Belt, NE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 27, T. 19 N., R. 6 E., Cascade County.

Geologic description: Kootenai Formation (Cretaceous). Sample 590 is shale that ranges from yellow to maroon to gray and lies above the bed of purple-weathei ing limestone described by Silverman and Harris (1967, p. 19) as 30 ft. 4 in. thick. The sampled section is 7 ft. Sample 591 is from a gray to yellow shale bed 1.6 ft. thick and overlain by sandstone, at the base of which flute casts are abundant. Sample 592 is from red-weathering mudstone and represents a thickness of 2.8 ft. This mudstone is stratigraphically lower than the gray to yellow shale (sample 591), and is separated from it by a bed of red-weathering sandstone 7.5 ft. thick. Because of extensive lateral lithologic variation, it was not possible to identify the latter two beds sampled with any in the section measured by Silverman and Harris.

Test results: Samples 590 and 591. These are siliceous kaolin flint clays. The plasticity is fair, the drying and firing characteristics good. They are good refractory, common brick, flux, and grog clays.

Sample 592. This is good kaolin clay. The plasticity is good, the drying and firing characteristics are good. It is a good ceramic material.

SAMPLE 593

Location: Road cut along U.S. Highway 87 and 89, 0.8 mile west of Belt, NW$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 27, T. 19 N., R. 6 E., Cascade County.

Geologic description: Kootenai Formation (Cretaceous). This red-weathering mudstone was sampled over a thickness of 4.6 ft. It is stratigraphically above the beds from which samples 588 to 592 were collected.

Test results: The material is impure kaolin clay. The plasticity is fair, drying and firing characteristics are good. It is good material for common brick and similar products.

SAMPLES 594 to 596

Location: Road cut 0.4 mile southwest of Stockett, NE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 1, T. 18 N., R. 4 E., Cascade County.

Geologic description: Morrison Formation (Jurassic). These three samples were collected from the greenish-gray mudstone described by Silverman and Harris (1967, p. 18) as 26 ft. 7 in. thick. Sample 594 is from 4.4-ft. section near the base of the mudstone. A 4-ft. section just above this is represented by sample 595, and 596 was collected higher in the mudstone unit.

Test results: Sample 594. The clay matter in this sample is diluted with hydromica, which acts as a flux. The plasticity is fair. With careful handling and firing, it could be used for common brick.

Sample 595. The material is kaolinitic illitic clay. The plasticity is low, drying and firing characteristics are fair. With careful handling and firing, it could be used for common brick.

Sample 596. The material is kaolinitic illitic clay fluxed by dolomite. The plasticity is low; the working, drying, and firing characteristics are fair. It could be used for common brick.

SAMPLES 597 and 598

Location: Road cut 0.6 mile southwest of Stockett, SW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 1, T. 18 N., R. 4 E., Cascade County.

Geologic description: Kootenai Formation (Cretaceous). Both of these samples were obtained from the shale that overlies the basal sandstone of the Kootenai Formation (Silverman and Harris, 1967, p. 18, Stockett section 2). Sample 597, of gray shale, represents a thickness of 1.6 ft. beginning at the top of the sandstone. Sample 598 is yellow to gray shale overlying that previously sampled. This sample represents a thickness of 3.3 ft.

Test results: Sample 597. The material is kaolinitic illitic clay fluxed by dolomite. The plasticity is low; the working, drying, and firing characteristics are fair. It could be used for common brick.

Sample 598. The clay matter is a minor constituent in this sample. The plasticity is low, working and firing characteristics are fair. With careful handling and firing or blending with other clays, it could be used for common brick.

SAMPLES 599 and 600

Location: Road cut along U.S. Highway 89, 0.9 mile south of Armington junction, NE$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 12, T. 18 N., R. 6 E., Cascade County.

Geologic description: Morrison Formation (Jurassic). Sample 599 is from 3.8 ft. of greenish-gray shale overlain by tan sandstone. Sample 600 is of the shale overlying this sandstone. Both of these samples are from approximately the upper 25 ft. of the Morrison Formation.

Test results: These illitic clays are low in plasticity but have good working and firing characteristics. They are good material for common brick.

SAMPLE 601

Location: Roadside park 0.4 mile northwest of Armington junction, SE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 1, T. 18 N., R. 6 E., Cascade County.

Geologic description: Morrison Formation (Jurassic). The bottom of this sample section (0.7 ft.) is 2.6 ft. above the base of the Morrison Formation.

Test results: This illitic clay is low in plasticity but has good working and firing characteristics. It is good material for common brick.

SAMPLE 602

Location: Exposure along Red Coulee about 0.5 mile south of Belt Creek, NW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 27, T. 21 N., R. 6 E., Cascade County.

Geologic description: Kootenai Formation (Cretaceous). Greenish-gray and red mudstone are well exposed along Red Coulee near its junction with Belt Creek. This sample is of the greenish-gray mudstone.

Test results: This illitic clay contains hydromica, which acts as a flux. The plasticity is good, working and firing properties fair. It could be used for common brick and similar products.

SAMPLES 603 and 604

Location: Road cut along road from Smith River to Truly Bench, SW$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 1, T. 18 N., R. 2 E., Cascade County.

Geologic description: Flood Member of Blackleaf Formation (Cretaceous). Sample 603 is dark-gray hematite-stained shale, unit 15 in a section measured by Fox (1966, p. 62). Sample 604 is gray to tan shale lower in Fox's measured section (unit 9).

Test results: Sample 603. This kaolin clay has good plasticity and good working and firing properties. It could be used for common brick and similar products.

Sample 604. The material is kaolinitic illitic clay. Plasticity is good, as are working characteristics. Careful firing is necessary; the brick tends to swell and crack on high firing. The material could be used for common brick.

SAMPLES 605 and 606

Location: Road cut along road from Smith River to Truly Bench, NW$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 12, T. 18 N., R. 2 E., Cascade County.

Geologic description: Flood Member of Blackleaf Formation (Cretaceous). Sample 605 is gray shale from unit 6 of a section measured by Fox (1966, p. 62). Sample 606 is grayish-brown shale, unit 2 of Fox's measured section.

Test results: Sample 605. The clay is composed of kaolinite and illite. Plasticity is good; working and firing characteristics are good. It is suitable for common brick and similar products.

Sample 606. The material is kaolin clay containing some illite. The plasticity is good, as are the working and firing characteristics. It is suitable for common brick and similar products.

SAMPLE 607

Location: Road cut along Montana Highway 330 about 1 mile north of Orr School, NE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 36, T. 18 N., R. 2 E., Cascade County.

Geologic description: Kootenai Formation (Cretaceous). This sample represents 8.1 ft. of variegated purple, red, and green shale that is overlain by nodular-weathering limestone. The sampled shale is unit 5 of Fox's measured section (1966, p. 60).

Test results: The material contains much quartz but also enough kaolinite to give it fair plasticity. Drying and firing shrinkage are low. It is suitable for common brick.

SAMPLE 608

Location: Road cut along Montana Highway 330 about 1.1 miles north of Orr School, SE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 36, T. 18 N., R. 2 E., Cascade County.

Geologic description: Kootenai Formation (Cretaceous). Well-indurated shale lying above nodular-weathering limestone was sampled over a thickness of 2.5 ft. This is unit 7 of Fox's measured section (1966, p. 60).

Test results: This is an impure illitic clay. The plasticity is low, as are the drying and firing shrinkage. It could be used for common brick.

SAMPLES 609 to 611

Location: Road cut about 1 mile south of Orr School on road to Cascade, $SW\frac{1}{4}$ sec. 1, T. 17 N., R. 2 E., Cascade County.

Geologic description: Kootenai Formation (Cretaceous). Sample 609 was collected from grayish-tan shale that overlies a bed of massive sandstone. The sampled thickness is 5.6 ft. Sample 610 is grayish-green mudstone exposed in another road cut. It seems to be lower stratigraphically than the grayish-tan shale; a thickness of 2.2 ft. was sampled here. Sample 611 represents 1.8 ft. of variegated tan and gray mudstone, the top of which is 1.8 ft. below the base of the bed from which sample 610 was obtained.

Test results: Sample 609. The material is kaolinitic illitic clay containing much quartz. The plasticity is low; drying and firing shrinkage are medium. It is suitable for common brick.

Sample 610. The clay matter in this sample is illite, chlorite, and montmorillonite. The plasticity is low, as are the drying and firing shrinkage. The material could be used for common brick.

Sample 611. This is kaolinitic illitic clay. The plasticity is low; firing and drying shrinkage are also low. It could be used for common brick.

SAMPLES 612 and 613

Location: Road cut 0.4 mile southwest of Eden, $NW\frac{1}{4}$ $SW\frac{1}{4}$ sec. 31, T. 18 N., R. 4 E., Cascade County.

Geologic description: Kootenai Formation (Cretaceous). Sample 612 is gray shale from a section between 10.1 and 6.5 ft. below the base of nodular-weathering limestone. Sample 613 is gray shale from a section between 6.5 and 3.1 ft. below the base of the limestone bed.

Test results: Sample 612. This kaolin clay is fluxed by abundant calcite. The plasticity and the drying and firing shrinkage are low. With proper grinding and mixing, it could be used for common brick.

Sample 613. The material is impure illitic clay. It shows a tendency to swell when fired at high temperature. With careful firing, it could be used for common brick.

SAMPLE 614

Location: Road cut along Montana Highway 226, 3.9 miles south of Red Butte School, SW$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 20, T. 18 N., R. 4 E., Cascade County.

Geologic description: Kootenai Formation (Cretaceous). Interbedded black and tan shale is exposed in this shallow road cut. Because of slumping, thickness could not be estimated.

Test results: This kaolin clay contains both illite and hydromica, which cause swelling of the brick when fired at the higher temperatures. The clay is unsuitable for ceramic use.

SAMPLES 615 to 619

Location: Small pit near Sand Coulee Creek southeast of Great Falls, SE$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 27, T. 20 N., R. 4 E., Cascade County.

Geologic description: Kootenai Formation (Cretaceous). The following section was sampled here:

Sample 619	greenish-gray shale		1.6 ft.
618	greenish-gray shale		2.2 ft.
--	covered		3.9 ft.
617	greenish-gray shale		4.1 ft.
615, 616	greenish-gray shale	about	7.0 ft.
--	white thin-bedded fine-grained sandstone		1.1 ft.

Test results: Sample 615. The material is impure illitic clay containing much quartz. The plasticity is low, drying shrinkage medium, and firing shrinkage low. With careful handling and firing, it could be used for common brick.

Sample 616. The material is siliceous kaolin illitic clay. The plasticity is low; drying shrinkage is medium. The brick fired at the highest temperature swelled appreciably. With careful firing, the material could be used for common brick.

Sample 617. The material is siliceous illitic clay containing enough montmorillonite and kaolinite to produce good plasticity. The drying and firing shrinkage are medium. It is a fairly good clay for common brick.

Sample 618. The clay mineral is illite. The material has very little plasticity, and drying and firing shrinkage are low. It could be used for common brick or could be blended with a more plastic clay.

Sample 619. The clay is a mixture of kaolinite, illite, and hydromica. The plasticity is low, drying and firing shrinkage are medium. It is a fairly good clay for ceramic use.

SAMPLES 620 to 622

Location: Road cut 0.7 mile northeast of Sand Coulee on road to Centerville, $NE\frac{1}{4}$ $NE\frac{1}{4}$ sec. 13, T. 19 N., R. 4 E., Cascade County.

Geologic description: Morrison Formation (Jurassic). The following section was sampled here:

Sample	622	brownish-gray shale	>3.5 ft.
	--	tan ferruginous sandstone	1.5 ft.
	621	gray shale	1.3 ft.
	620	greenish-gray shale containing 1-in. siltstone bed	1.3 ft.
	--	light-gray fine-grained sandstone	>0.5 ft.

Test results: Sample 620. The material is siliceous kaolinitic illitic clay. The plasticity is good, drying and firing shrinkage are low. It is suitable for common brick and similar products.

Sample 621. The clay has fair plasticity and medium drying and firing shrinkage, but shows a tendency to swell when fired in the high portion of the firing range. With careful handling and firing, it could be used for common brick.

Sample 622. The clay has fair plasticity and medium drying and firing shrinkage. With thorough grinding and careful firing, it could be used for common brick and similar products.

SAMPLES 623 and 626

Location: Road cut along Interstate Highway 15 below Great Falls International Airport, $NE\frac{1}{4}$ $SE\frac{1}{4}$ sec. 16, T. 20 N., R. 3 E., Cascade County.

Geologic description: Kootenai Formation (Cretaceous). The following section was sampled here:

Sample	--	gray fine-grained sandstone	>10.0 ft.
	626	greenish-gray mudstone	9.1 ft.
	625	dark-gray shale containing numerous carbonaceous fragments	1.7 ft.
	--	gray sandy siltstone	1.5 ft.
	624	bluish-gray mudstone	5.5 ft.
	623	gray silty mudstone	2.1 ft.
	--	gray medium-grained sandstone	8.8 ft.

Test results: Sample 623. Although this sample has only a minor amount of clay matter, the firing characteristics are good. The material could be used for common brick.

Sample 624. The material is kaolin clay containing a large amount of quartz and a small amount of illite. Drying and firing shrinkage are medium, plasticity is low. It is a fairly good clay for common brick.

Sample 625. The clay matter is montmorillonite and kaolinite, which give good plasticity. The brick overfired at low temperature and swelled. The material is unsuitable for ceramic use.

Sample 626. The material is impure kaolin clay. The plasticity is fair, drying and firing shrinkage are medium. It is a fairly good clay for common brick.

SAMPLES 627 to 629

Location: Road cut on secondary road north of Sun River approximately 3 miles north of the junction of this road and U.S. Highway 89, SE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 11, T. 21 N., R. 1 W., Cascade County.

Geologic description: Kevin Shale Member of Marias River Formation (Cretaceous). The geology of the Vaughn quadrangle is described by Maughan (1961). The following section was sampled here:

Section	629	black shale	1.4 ft.
	--	black shale containing several yellow-orange bentonite layers <4 in. thick	21.0 ft.
	628	black shale containing numerous selenite crystals	5.6 ft.
	--	tan sandstone	0.8 ft.
	627	black shale containing numerous selenite crystals	8.6 ft.

Test results: Samples 627 and 628. These illitic clays contain appreciable gypsum. The gypsum calcined, and the calcium oxide combined chemically with the other ingredients; no scum was evident. With careful handling and firing, the material could be used for common brick.

Sample 629. Although the clay matter is illite and montmorillonite, the firing characteristics are good. The plasticity is good. The material could be used for common brick.

SAMPLE 630

Location: Road cut along Interstate Highway 15, 0.1 mile east of Manchester exit, NE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 26, T. 21 N., R. 2 E., Cascade County.

Geologic description: Blackleaf Formation (Cretaceous). Very fissile black shale is exposed for a vertical distance of about 20 ft. in road cut. Three thin bentonite layers are also exposed in this road cut.

Test results: The material is siliceous and contains only a small amount of montmorillonite and kaolinite. The dried brick had a scum, which remained after firing. Also the brick overfired and swelled in the higher firing range. The material is unsuitable for ceramic use.

SAMPLE 631

Location: Borrow pit north of Interstate Highway 15 about 4 miles east of Manchester exit, SE$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 32, T. 21 N., R. 3 E., Cascade County.

Geologic description: Blackleaf Formation (Cretaceous). This sample is from a dark-gray shale bed 2.2 ft. thick underlain and overlain by tan sandstone.

Test results: The material is impure kaolin clay. It has good plasticity. Drying shrinkage is medium, firing shrinkage is low in the lower firing range. The brick overfired and swelled in the higher firing range. With careful handling and firing, it could be used for common brick, or blended with other clays.

SAMPLE 632

Location: Exposure along Belt Creek northeast of Morony dam about 1.3 miles, SE$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 12, T. 21 N., R. 5 E., Cascade County.

Geologic description: Kootenai Formation (Cretaceous). This sample is maroon to dark-brown shale, which is interbedded with fine-grained sandstone.

Test results: The clay matter in this sample is kaolinite and a small amount of illite. Drying and firing shrinkage and plasticity are low. The material could be used for common brick.

SAMPLE 633

Location: Road cut along logging road west of Painted Rocks Lake near Took Creek, SE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 33, T. 1 S., R. 22 W., Ravalli County.

Geologic description: Altered Tertiary volcanic. Sample 633 is from a small mass of red clay exposed in a road cut. This clay contains numerous fragments of less-altered volcanic rock. Tertiary extrusive rocks cover an area of approximately 4 square miles (Fisk, in prepration), and throughout this area alteration is evident. A careful search of the area might disclose other clay deposits of greater extent.

Test results: The clay is a good grade of kaolinite and quartz. The plasticity, green strength, and firing properties are good. It is suitable for common brick and similar products.

SAMPLES 634 and 635

Location: Clay pit about 0.5 mile east of Silverbow, NE¼ NE¼ sec. 24, T. 3 N., R. 9 W., Silver Bow County.

Geologic description: Altered tertiary basalt(?). Both samples were collected from a clay pit owned by Thomas Helehan. This clay deposit covers an area of approximately a quarter square mile and is well exposed in a road cut along Interstate Highway 15 in the NE¼ SE¼ sec. 13, T. 3 N., R. 9 W.

Test results: These are bentonitic clays containing much montmorillonite and quartz and a minor amount of calcite. They are unsuitable for ceramic use.

SUMMARY OF TEST RESULTS TO DATE

The Montana Bureau of Mines and Geology has now analyzed 635 samples of clay or shale from Montana. The age of sampled sedimentary rock formations ranges from Precambrian to Quaternary. Also several samples represent deposits of hydrothermal origin. The results of tests aimed at evaluating samples for either ceramic uses or use in lightweight aggregate are given in Table 7. Only those samples for which definite information on geologic formation or age is known are included in this tabulation. Locations for samples 1 to 421 are given on Figure 3; those for samples 422 to 635 on Figure 4. From these maps and Table 7 it can be seen that coverage, either stratigraphic or geographic, is far from complete.

Of the tabulated formations, several stand out as containing a larger percentage of samples potentially useful in ceramic products. These are the glacial lake deposits (Pleistocene), Kootenai Formation (Cretaceous), and Morrison Formation (Jurassic). Although several of the other Cretaceous shales also show a large percentage of samples possibly useful in ceramic products, the number of samples tested is too small to justify definite conclusions.

Table 7. --Tabulation of test results by geologic formation or age.

Formation	Age	Ceramic products					Lightweight aggregate			
		Fair for brick	Good for brick	Other uses in ceramic products	Total number of samples tested	Percent having potential use in ceramic products	Fair quality aggregate	Good quality aggregate	Total number of samples tested	Percent having potential use in lightweight aggregate
Alluvium	Quaternary	4			15	27			11	0
Glacial lake deposits	Quaternary	2	42		61	72	2		10	20
Fort Union Formation	Tertiary	12	16		63	44	8	16	45	53
Undifferentiated Tertiary sediments	Tertiary	11	2		53	25	2	5	35	20
Total Tertiary		23	18		116	35	10	21	80	26
Hell Creek Formation	Cretaceous		1		14	7		9	13	69
Bearpaw Shale	Cretaceous		1		17	6	6	5	14	79
Judith River Formation	Cretaceous		3		11	37	2	6	11	73
Pierre Shale	Cretaceous				2	0		2	2	100
Claggett Formation	Cretaceous				6	0	1	2	6	50
Eagle Sandstone	Cretaceous		1		1	100	1		1	100
Telegraph Creek Formation	Cretaceous		1		1	100				
Cody Shale	Cretaceous		1		5	20	2		4	50
Niobrara Formation	Cretaceous		4		5	80			1	0
Kevin Shale member Marias River Formation	Cretaceous	1	2		3	100				
Jens Formation	Cretaceous	1			1	100			1	0
Frontier Formation	Cretaceous		1		1	100				
Blackleaf Formation	Cretaceous	6	3		12	75	2		6	33
Colorado Group undifferentiated	Cretaceous	1	3		13	31	4	3	9	78

	Kootenai Formation	Cretaceous	17	22		42	93				
	Cretaceous undifferentiated	Cretaceous	1	3		16	25	5	3	16	50
	Total Cretaceous		27	46		150	49	23	30	93	57
	Morrison Formation	Jurassic	1	10		11	100				
	Jurassic undifferentiated	Jurassic	1			1	100			1	0
	Total Jurassic		2	10		12	100			1	0
Paleozoic	Amsden Formation	Pennsylvanian	1			1	100			1	0
Paleozoic	Big Snowy Group	Mississippian		1		3	33				
Paleozoic	Three Forks Formation	Devonian	3	1		5	80		2	4	50
Paleozoic	Wolsey Shale	Cambrian		1		3	33			2	0
Belt	Helena Limestone	Precambrian				3	0			3	0
Belt	Spokane Shale	Precambrian		2		3	67			1	0
Belt	Greyson Shale	Precambrian	3	1		5	80			2	0
Belt	LaHood Formation	Precambrian	1	9		13	69			12	0
Belt	Belt Supergroup undifferentiated	Precambrian	6	1		15	47	1		7	14
	Total Precambrian (Belt Supergroup)		10	13		39	59	1		25	4
	Hydrothermally altered rock	Various	3	6	1	14	71			8	0
	Total		75	138	1	419	53	36	53	228	23

Also significant is the fairly large percentage of good clays of hydrothermal origin. Unfortunately, because of the nature of their formation, such deposits are likely to be small and irregular.

Of the samples tested for expandability, the greatest percent found suitable for use in lightweight aggregate were from Upper Cretaceous shales. The Hell Creek Formation, Bearpaw Shale, and Judith River Formation all showed large percentages of samples suitable for use in lightweight aggregate.

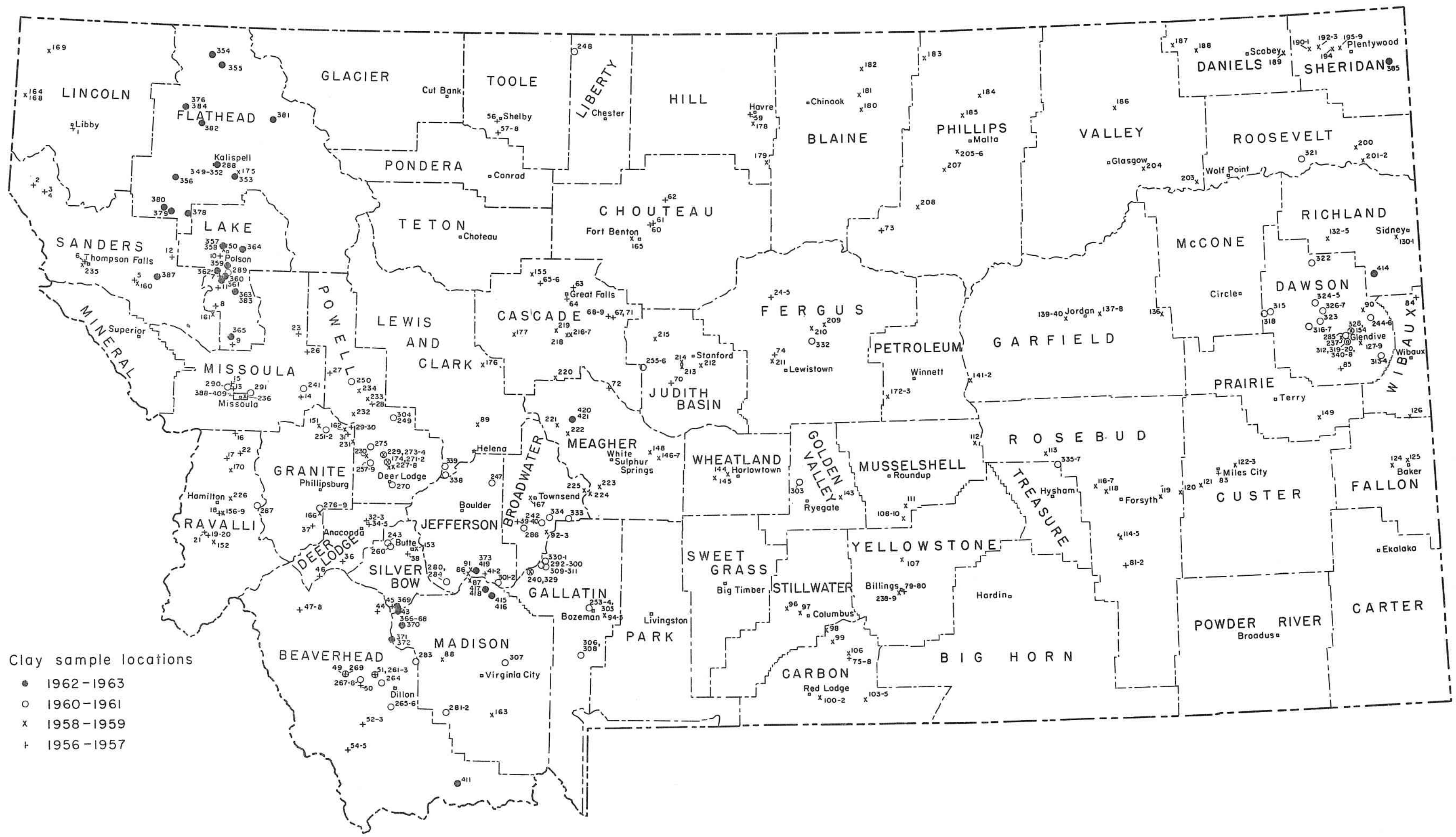

Figure 3. --Index map of Montana showing localities for samples 1 through 421.

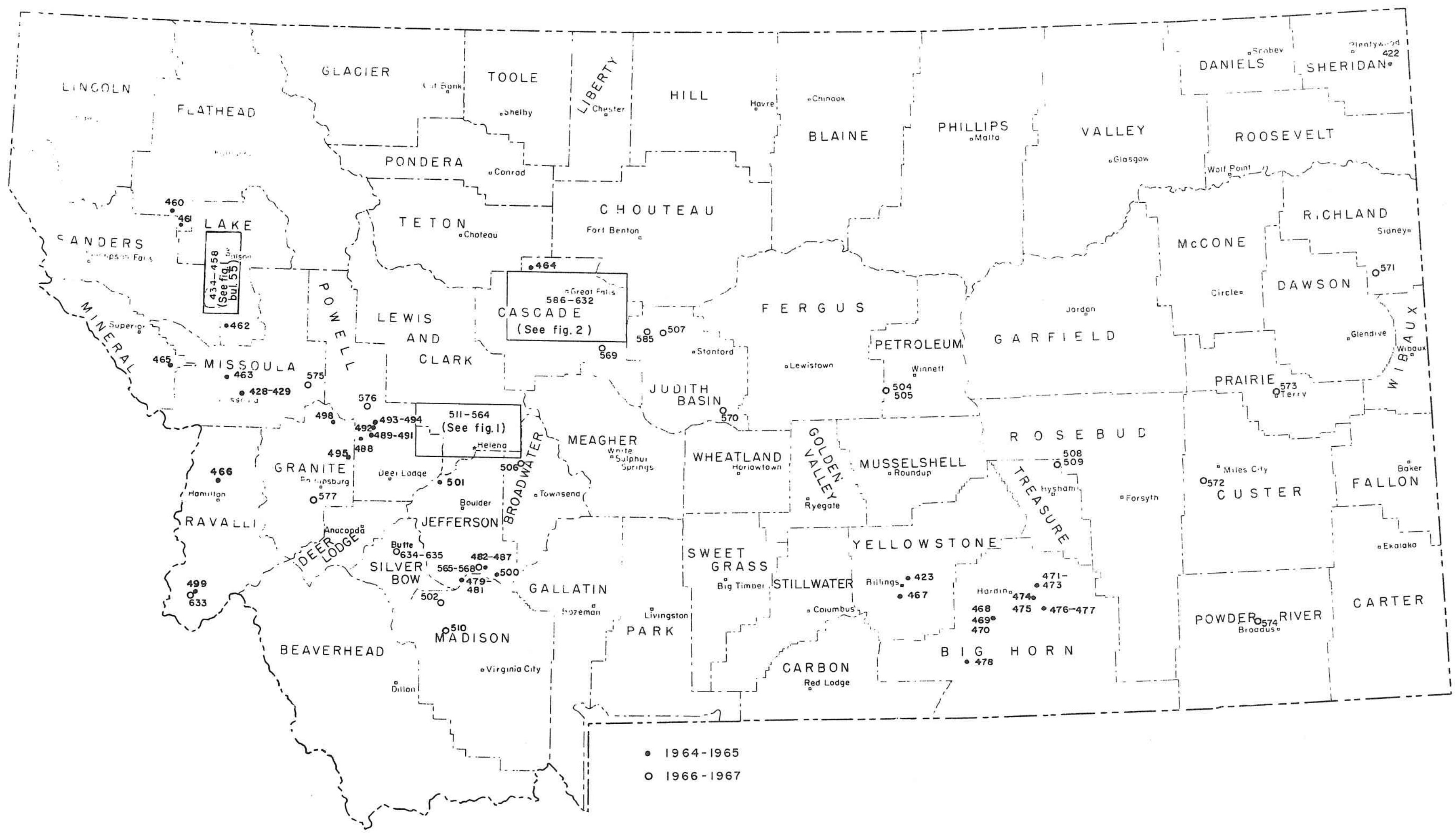

Figure 4. --Index map of Montana showing localities for samples 422 through 635.

REFERENCES

Brown, G., 1961, X-ray identification and crystal structures of clay minerals, 2d ed.: London, Mineralogical Society, 544 p.

Chelini, J. M., Smith, R. I., and Lawson, D. C., 1965, Progress report on clays and shales of Montana, 1962-64: Montana Bur. Mines and Geology Bull. 45, 43 p.

Chelini, J. M., Smith, R. I., and Jones, F. P., 1966, Progress report on clays and shales of Montana, 1964-65: Montana Bur. Mines and Geology Bull. 55, 38 p.

DeMunck, V. C., 1956, Possibilities for lightweight aggregate for concrete near Great Falls, Montana: Montana Bur. Mines and Geology Inf. Circ. 12, 11 p.

Fisk, H. G. (in preparation), Reconnaissance geologic map of a portion of Ravalli County, Montana: parts of Townships 1 and 2 S., Ranges 20-22 W.: Montana Bur. Mines and Geology.

Fisher, C. A., 1908, Clays in the Kootenai Formation near Belt, Montana, in Contributions to economic geology, 1907: U.S. Geol. Survey Bull. 340-I, p. 417-423.

Fox, R. D., 1966, Geology and ground-water resources of the Cascade-Ulm area, Montana: Montana Bur. Mines and Geology Bull. 52, 64 p.

Kinnison, C. S., 1915, A study of the Atterberg plasticity method: Natl. Bur. Standards Tech. Paper 46, 18 p.

Knopf, Adolph, 1963, Geology of the northern part of the Boulder bathylith and adjacent area, Montana: U.S. Geol. Survey Misc. Geol. Inv. Map I-381.

Lorenz, A. W., and Swenson, F. A., 1951, Geology and ground-water resources of the Helena Valley, Montana: U.S. Geol. Survey Circ. 83, 68 p.

Maughan, E. K., 1961, Geology of the Vaughn quadrangle, Montana: U.S. Geol. Survey Quad. Map GQ-135.

McMannis, W. J., 1963, LaHood Formation--a coarse facies of the Belt Series in southwestern Montana: Geol. Soc. America Bull., v. 74, p. 407-436.

Mertie, J. B., Jr., Fischer, R. P., and Hobbs, W. S., 1951, Geology of the Canyon Ferry quadrangle, Montana: U.S. Geol. Survey Bull. 972, 97 p.

O'Neill, B. J., Jr., and others, 1965, Properties and uses of Pennsylvania shales and clays: Pennsylvania Geol. Survey Bull. M-51, 448 p.

Pardee, J. T., and Schrader, F. C., 1933, Metalliferous deposits of the greater Helena mining region, Montana: U.S. Geol. Survey Bull. 842, 318 p.

Sahinen, U. M., 1957, Expandable shale in the Great Falls area, Montana: Montana Bur. Mines and Geology Inf. Circ. 18, 14 p.

Sahinen, U. M., Smith, R. I., and Lawson, D. C., 1958, Progress report on clays of Montana, 1956-57: Montana Bur. Mines and Geology Inf. Circ. 23, 41 p.

Sahinen, U. M., Smith, R. I., and Lawson, D. C., 1960, Progress report on clays and shales of Montana, 1958-59: Montana Bur. Mines and Geology Bull. 13, 83 p.

_______, 1962, Progress report on clays and shales of Montana, 1960-61: Montana Bur. Mines and Geology Bull. 27, 61 p.

Silverman, A. J., and Harris, W. L., 1967, Stratigraphy and economic geology of the Great Falls-Lewistown coal field, central Montana: Montana Bur. Mines and Geology Bull. 56, 20 p.

Skinner, K. G., and Kelly, H. G., 1949, Preliminary ceramic tests of clays from seven Pacific Northwest deposits: U.S. Bur. Mines Rept. Inv. 4449, 59 p.

Warde, J. M., 1937, Geology and clays of the Kootenai Formation of Montana--clay industry of Montana: Montana School of Mines unpub. M.S. thesis (Montana College of Mineral Science and Technology).