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U. M. Sahinen, Director

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PROGRESS REPORT ON

CLAYS AND SHALES OF MONTANA

1968 - 1969

(SAMPLES 636 - 727)

by

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MONTANA COLLEGE OF MINERAL SCIENCE AND TECHNOLOGY
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ABSTRACT

This report, seventh in the series, presents results of ceramic tests, bloating tests, x-ray diffraction analyses, and chemical analyses (including available alumina for selected samples).

Of 34 samples from sedimentary rocks surrounding the Pryor Mountains, one was judged suitable for good quality common brick, and six others would be capable of producing fair quality brick. Generally the better clays for ceramic use were those collected from the Cloverly Formation (Cretaceous). Of 45 samples from the Tongue River Member of the Fort Union Formation (Paleocene) obtained from holes drilled for the evaluation of the coal resources of eastern Montana, one was judged suitable for a fair grade of common brick, and 22 others might find some ceramic use. Four samples produced bloated material suitable for use as lightweight aggregate.

INTRODUCTION

This bulletin is the seventh progress report on the survey of Montana's clay and shale resources and is supplementary to the first six (Sahinen and others, 1958, 1960, and 1962; Chelini and others, 1965 and 1966; Berg and others, 1968). More than 700 samples have been tested, and a tabulation of the test results for 419 of these samples arranged by geologic formation or age is given by Berg and others (1968, Table 7). Clay samples are tested for possible use as ceramic raw materials and as possible raw material for lightweight aggregate, and selected samples are analyzed as possible sources of alumina for the production of metallic aluminum. Additional publications of the Montana Bureau of Mines and Geology deal with specific types of clay or shale deposits such as kaolinite, expandable shale, and bentonite.

This survey of clay and shale deposits was begun in 1956 and will be continued until the readily accessible deposits are sampled. Because of financial limitations, the project was temporarily suspended during the 1961-1963 biennium. Because it will be many years before the clay resources of a state as large as Montana can be adequately evaluated, progress reports such as this will be published as frequently as conditions warrant, rather than withholding the results until the entire survey is completed.

The assistance of Dariel McDonald with field work and of Michael Chapman with sample preparation is appreciated. Suggestions made by U. M. Sahinen and R. E. Matson have benefited this study.

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.

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 generally been confined to two series–ceramic tests and bloating tests. Laboratory procedures employed in this testing are described in the following sections of this report. The chemical and mineralogical analyses may be of assistance in evaluating these clay samples for uses for which they were not specifically tested.

SAMPLING AND TESTING PROCEDURES

SAMPLING AND SAMPLE PREPARATION

Five-pound samples were obtained 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 bloating 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, and plotted on Figures 1, 2, and 3.

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 and working range, and may suggest the type of clay mineral present. The best working range is found to be close to the lower plastic limit. The percentage of water used is a rough indication of the type of clay, as shown in the following tabulation (Skinner and Kelly, 1949):

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

Test cones, made of the raw clay mixed with water, are molded, dried at 105°C (221°F), and fired with standard cones to obtain the Pyrometric Cone Equivalent (P.C.E.). When the test cone fuses, the number of the standard cone 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.

BLOATING TESTS

After the ceramic tests are run and tabulated, the clays are tested for bloating properties to determine whether they could be used as raw materials for expanded-shale lightweight aggregate for concrete. The material used for bloating is minus ¾ inch plus ½ 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 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.

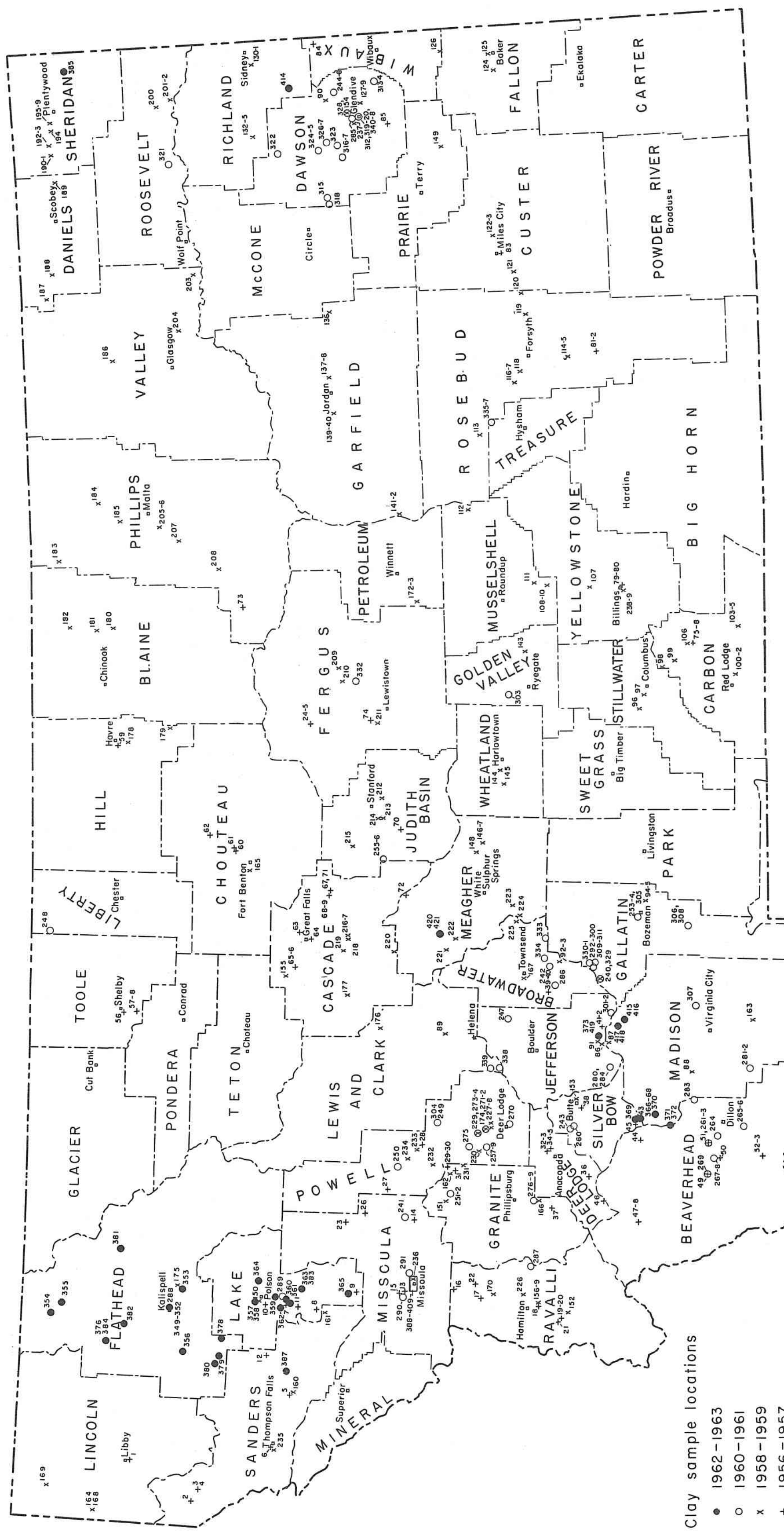

Figure 1.–Index map of Montana showing localities of samples 1 to 421.

Table 1.–Sample localities and geologic formations of clay and shale samples.

Sample no.	Formation	Location, collector, or drill hole	County	Location		Sec.	T.	R.	(See Botz, 1969, for explanation of this designation)
636	Climbing Arrow Formation	S of Three Forks, R. B. Berg	Gallatin		NW¼	12	1 N	1 E	01N01E12B
637	Climbing Arrow Formation	S of Three Forks, R. B. Berg	Gallatin		NW¼	12	1 N	1 E	01N01E12B
638	Climbing Arrow Formation	S of Three Forks, R. B. Berg	Gallatin	SE¼	NW¼	12	1 N	1 E	01N01E12BD
639	Climbing Arrow Formation	S of Three Forks, R. B. Berg	Gallatin	SE¼	NW¼	12	1 N	1 E	01N01E12BD
640	Not known	S of Anaconda, Norman Lesh	Deer Lodge			11	4 N	11 W	04N11W11
641	Probably of Mississippian age	NE of Warren, R. B. Berg	Carbon	Land divisions not shown for this area					
642	Probably of Mississippian age	NE of Warren, R. B. Berg	Carbon	Land divisions not shown for this area					
643	Chugwater Formation(?)	E of Warren, R. B. Berg	Carbon	NW¼	NW¼	15	9 S	27 E	09S27E15BB
644	Probably of Jurassic age	E of Warren, R. B. Berg	Carbon	SE¼	NE¼	16	9 S	27 E	09S27E16AD
645	Probably of Jurassic age	E of Warren, R. B. Berg	Carbon	SE¼	NE¼	16	9 S	27 E	09S27E16AD
646	Probably of Jurassic age	E of Warren, R. B. Berg	Carbon	SE¼	NE¼	16	9 S	27 E	09S27E16AD
647	Sundance Formation	SE of Warren, R. B. Berg	Carbon	SE¼	SW¼	28	9 S	27 E	09S27E28CD
648	Sundance Formation	SE of Warren, R. B. Berg	Carbon	SE¼	SW¼	28	9 S	27 E	09S27E28CD
649	Sundance Formation	SE of Bridger, R. B. Berg	Carbon		SW¼	17	7 S	24 E	07S24E17C
650	Sundance Formation	SE of Bridger, R. B. Berg	Carbon		SW¼	17	7 S	24 E	07S24E17C
651	Chugwater Formation	SE of Bridger, R. B. Berg	Carbon		SW¼	17	7 S	24 E	07S24E17C
652	Chugwater Formation	SE of Bridger, R. B. Berg	Carbon		NW¼	20	7 S	24 E	07S24E20B
653	Chugwater Formation	SE of Bridger, R. B. Berg	Carbon		NW¼	20	7 S	24 E	07S24E20B
654	Sundance Formation	SE of Bridger, R. B. Berg	Carbon		SE¼	20	7 S	24 E	07S24E20D
655	Sundance Formation	SE of Bridger, R. B. Berg	Carbon		SW¼	20	7 S	24 E	07S24E20C
656	Sundance Formation	SE of Bridger, R. B. Berg	Carbon		SW¼	20	7 S	24 E	07S24E20C
657	Morrison Formation	SE of Bridger, R. B. Berg	Carbon		NE¼	19	7 S	24 E	07S24E19A
658	Cloverly Formation	SE of Bridger, R. B. Berg	Carbon		SW¼	18	7 S	24 E	07S24E18C
659	Cloverly Formation	SE of Bridger, R. B. Berg	Carbon		SW¼	18	7 S	24 E	07S24E18C
660	Cloverly Formation	N of Yellowtail Dam, R. B. Berg	Big Horn		NE¼	6	6 S	31 E	06S31E06A
661	Cloverly Formation	N of Yellowtail Dam, R. B. Berg	Big Horn		NE¼	6	6 S	31 E	06S31E06A
662	Cloverly Formation	N of Yellowtail Dam, R. B. Berg	Big Horn		NE¼	6	6 S	31 E	06S31E06A
663	Thermopolis Formation	N of Yellowtail Dam, R. B. Berg	Big Horn	SE¼	SE¼	6	6 S	31 E	06S31E06DD
664	Of Cretaceous age	W of St. Xavier, R. B. Berg	Big Horn		SW¼	18	4 S	30 E	04S30E18C
665	Kootenai Formation	W of St. Xavier, R. B. Berg	Big Horn		NW¼	23	4 S	29 E	04S29E23B
666	Kootenai Formation	W of St. Xavier, R. B. Berg	Big Horn		NW¼	23	4 S	29 E	04S29E23B
667	Morrison Formation	NW of Pryor, R. B. Berg	Big Horn		NE¼	25	4 S	25 E	04S25E25A
668	Morrison Formation	NW of Pryor, R. B. Berg	Big Horn		NE¼	25	4 S	25 E	04S25E25A
669	Morrison Formation	NW of Pryor, R. B. Berg	Big Horn		NE¼	25	4 S	25 E	04S25E25A
670	Morrison Formation	NW of Pryor, R. B. Berg	Big Horn		NE¼	25	4 S	25 E	04S25E25A
671	Morrison Formation	NW of Pryor, R. B. Berg	Big Horn		NE¼	25	4 S	25 E	04S25E25A
672	Morrison Formation	NW of Pryor, R. B. Berg	Big Horn		NE¼	25	4 S	25 E	04S25E25A
673	Morrison Formation	NW of Pryor, R. B. Berg	Big Horn		NE¼	25	4 S	25 E	04S25E25A
674	Morrison Formation	NW of Pryor, R. B. Berg	Big Horn		NE¼	25	4 S	25 E	04S25E25A
675	Not known	S of Ennis, Pete Womack	Madison			3	7 S	1 W	07S01W03
676	Not known	NE of Winnett, Charles Allen	Petroleum			28	18 N	27 E	18N27E28
677	Not known	N of Winnett, Charles Allen	Fergus			30	19 N	27 E	19N27E30
678	Not known	SE of Winnett, Charles Allen	Petroleum			4	13 N	28 E	13N28E04
679	Not known	SE of Winnett, Charles Allen	Petroleum			4	13 N	28 E	13N28E04
680	Not known	SE of Winnett, Charles Allen	Petroleum			8	13 N	28 E	13N28E08

681	Not known	SW of Grassrange, Charles Allen	Fergus				19	14 N	21 E	14N21E19
682	Not known	SW of Grassrange, Charles Allen	Fergus				19	14 N	21 E	14N21E19
683	Fort Union Formation	W of Moorhead, drill hole Sm-11	Powder River	NW¼	NW¼	NW¼	11	9 S	46 E	09S46E11BBB
684	Fort Union Formation	W of Moorhead, drill hole Sm-11	Powder River	NW¼	NW¼	NW¼	11	9 S	46 E	09S46E11BBB
685	Fort Union Formation	W of Moorhead, drill hole Sm-11	Powder River	NW¼	NW¼	NW¼	11	9 S	46 E	09S46E11BBB
686	Fort Union Formation	W of Moorhead, drill hole Sm-11	Powder River	NW¼	NW¼	NW¼	11	9 S	46 E	09S46E11BBB
687	Fort Union Formation	W of Moorhead, drill hole Sm-11	Powder River	NW¼	NW¼	NW¼	11	9 S	46 E	09S46E11BBB
688	Fort Union Formation	W of Moorhead, drill hole Sm-14A	Powder River		SW¼	NE¼	5	5 S	46 E	05S46E05AC
689	Fort Union Formation	W of Moorhead, drill hole Sm-14A	Powder River		SW¼	NE¼	5	5 S	46 E	05S46E05AC
690	Fort Union Formation	W of Moorhead, drill hole Sm-14A	Powder River		SW¼	NE¼	5	5 S	46 E	05S46E05AC
691	Fort Union Formation	W of Moorhead, drill hole Sm-14A	Powder River		SW¼	NE¼	5	5 S	46 E	05S46E05AC
692	Fort Union Formation	W of Moorhead, drill hole Sm-17	Powder River		NE¼	SW¼	3	9 S	45 E	09S45E03CA
693	Fort Union Formation	W of Moorhead, drill hole Sm-17	Powder River		NE¼	SW¼	3	9 S	45 E	09S45E03CA
694	Fort Union Formation	W of Moorhead, drill hole Sm-17	Powder River		NE¼	SW¼	3	9 S	45 E	09S45E03CA
695	Fort Union Formation	NW of Moorhead, drill hole Sm-7	Powder River		NE¼	NW¼	8	8 S	47 E	08S47E08BA
696	Fort Union Formation	NW of Moorhead, drill hole Sm-7	Powder River		NE¼	NW¼	8	8 S	47 E	08S47E08BA
697	Fort Union Formation	NW of Moorhead, drill hole Sm-7	Powder River		NE¼	NW¼	8	8 S	47 E	08S47E08BA
698	Fort Union Formation	NW of Broadus, drill hole Br-6	Powder River	NE¼	NE¼	NE¼	7	3 S	50 E	03S50E07AAAB
699	Fort Union Formation	NW of Brandenberg, drill hole S-S-1	Rosebud				29	2 N	44 E	02N44E29
700	Fort Union Formation	NW of Brandenberg, drill hole S-S-1	Rosebud				29	2 N	44E	02N44E29
701	Fort Union Formation	NW of Brandenberg, drill hole S-S-1	Rosebud				29	2 N	44 E	02N44E29
702	Fort Union Formation	NW of Brandenberg, drill hole S-S-1	Rosebud				29	2 N	44 E	02N44E29
703	Fort Union Formation	NW of Brandenberg, drill hole S-S-1	Rosebud				29	2 N	44 E	02N44E29
704	Fort Union Formation	N of Brandenberg, drill hole S-S-5	Rosebud				3	3 N	44 E	03N44E03
705	Fort Union Formation	N of Brandenberg, drill hole S-S-5	Rosebud				3	3 N	44 E	03N44E03
706	Fort Union Formation	N of Brandenberg, drill hole S-S-5	Rosebud				3	3 N	44 E	03N44E03
707	Fort Union Formation	N of Brandenberg, drill hole S-S-5	Rosebud				3	3 N	44 E	03N44E03
708	Fort Union Formation	N of Brandenberg, drill hole S-S-5	Rosebud				3	3 N	44 E	03N44E03
709	Fort Union Formation	N of Brandenberg, drill hole S-S-5	Rosebud				3	3 N	44 E	03N44E03
710	Fort Union Formation	N of Brandenberg, drill hole S-S-5	Rosebud				3	3 N	44 E	03N44E03
711	Fort Union Formation	SE of Miles City, drill hole Ph-1	Custer				29	7 N	50 E	07N50E29
712	Fort Union Formation	SE of Miles City, drill hole Ph-1	Custer				29	7 N	50 E	07N50E29
713	Fort Union Formation	SE of Miles City, drill hole Ph-1	Custer				29	7 N	50 E	07N50E29
714	Fort Union Formation	NE of Circle, drill hole Mc-1	McCone		SW¼	SE¼	36	21 N	49 E	21N49E36DC
715	Fort Union Formation	NE of Circle, drill hole Mc-1	McCone		SW¼	SE¼	36	21 N	49 E	21N49E36DC
716	Fort Union Formation	NE of Circle, drill hole Mc-1	McCone		SW¼	SE¼	36	21 N	49 E	21N49E36DC
717	Fort Union Formation	NE of Circle, drill hole Mc-1	McCone		SW¼	SE¼	36	21 N	49 E	21N49E36DC
718	Fort Union Formation	NE of Circle, drill hole Mc-1	McCone		SW¼	SE¼	36	21 N	49 E	21N49E36DC
719	Fort Union Formation	NE of Circle, drill hole Mc-1	McCone		SW¼	SE¼	36	21 N	49 E	21N49E36DC
720	Fort Union Formation	NE of Circle, drill hole Mc-1	McCone		SW¼	SE¼	36	21 N	49 E	21N49E36DC
721	Fort Union Formation	NW of Circle, drill hole Mc-8	McCone		NW¼	NE¼	16	21 N	46 E	21N46E16AB
722	Fort Union Formation	NW of Circle, drill hole Mc-8	McCone		NW¼	NE¼	16	21 N	46 E	21N46E16AB
723	Fort Union Formation	NW of Circle, drill hole Mc-8	McCone		NW¼	NE¼	16	21 N	46 E	21N46E16AB
724	Fort Union Formation	NE of Brockway, drill hole Mc-14	McCone	NW¼	SW¼	SW¼	16	18 N	47 E	18N47E16CCB
725	Fort Union Formation	NE of Brockway, drill hole Mc-14	McCone	NW¼	SW¼	SW¼	16	18 N	47 E	18N47E16CCB
726	Fort Union Formation	NE of Brockway, drill hole Mc-14	McCone	NW¼	SW¼	SW¼	16	18 N	47 E	18N47E16CCB
727	Fort Union Formation	NE of Brockway, drill hole Mc-14	McCone	NW¼	SW¼	SW¼	16	18 N	47 E	18N47E16CCB

Table 2.–Fusing points of pyrometric cones.

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

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 bloating tests are given in Table 4. D. C. Lawson of the Montana Bureau of Mines and Geology made all bloating tests.

DETERMINATION OF MINERALOGY

The mineralogy of all samples was determined by x-ray diffraction. Although the composition of the samples was not determined quantitatively, the relative abundance of the various minerals in each sample is indicated in Table 5 by the notation major, medium, minor, and trace. Prof. R. I. Smith performed all analyses.

The pulverized sample was packed into an aluminum sample holder to produce a mount in which the orientation of individual grains shows a fair degree of randomness. The samples were scanned at 2° 2Θ on a Norelco diffractometer using 1° divergence and scatter slits. The identification of clay minerals was based mainly on basal spacings as given in *X-ray Identification and Crystal Structures of Clay Minerals (Brown, 1961).*

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 3.–Ceramic properties of samples.

Sample no. [1]	Water of plasticity, % [2]	Drying shrinkage, % [3]	P.C.E. [4]	Firing range °F	Firing temperature °F	Firing shrinkage, % [5]	Fired color	Hardness [6]	Suitability for various uses
636 637 638 639	Because of large montmorillonite content, the ceramic properties of these samples were not determined.								
640	L 43	- - -	7		not fired		red	SS	not suitable, brick cracked on drying
641	L 27 H 30	4.8	5	none	1650 1850 2050	0.0 0.0 1.2	red red buff	SS SS SS	not suitable, narrow firing range
642	L 30 H 36	8.1	9	2000 to 2150	1800 2000 2200	2.0 2.5 2.3	red red dark red	SS S HS	fair common brick
643	L 19 H 20	2.5	9	none	1800 2000 2200	0.6 0.7 o.f.	light red buff buff	SS SS S	not suitable, lack of plasticity and narrow firing range
644	L 23 H 29	5.5	1	1950 to 2000	1550 1750 2150	0.0 1.1 3.2	red red red	SS SS	not suitable, narrow firing range
645	L 28 H 34	8.8	1	1800 to 1950	1550 1750 1950	0.0 1.5 2.4	red red red	SS SS SS	poor common brick
646	L 22 H 26	4.4	8	2150 to 2200	1750 1950 2150	-1.1 -1.1 -1.8	buff buff buff	SS SS S	not suitable alone, possible grog
647	L 29 H 36	7.6	5	2050 to 2100	1650 1850 2050	1.1 0.6 2.9	red red red	SS SS S	poor common, narrow firing range
648	L 33 H 40	8.3	1	1800 to 2000	1550 1750 1950	0.0 0.0 0.9	red red red	SS S S	fair common brick
649	L 24 H 30	7.4	6	1900 to 2050	1700 1900 2100	0.0 0.6 2.8	red red tan	S S HS	fair common brick
650	L 25 H 30	5.2	7	none	1700 1900 2100	0.0 0.0 10.9	buff buff buff	SS SS SS	not suitable
651	L 25 H 28	5.8	2	2000 to 2050	1600 1800 2000	0.0 0.6 2.1	red red red	SS SS S	not suitable, scum on fired brick, narrow firing range
652	L 23 H 28	2.9	3	none	1600 1800 2000	0.0 0.0 0.0	red red red	SS SS SS	not suitable
653	L 23 H 27	3.5	3	none	1600 1800 2000	0.0 0.0 0.0	red red red	SS SS SS	not suitable
654	L 27 H 39	9.3	6	2100 to 2150	1700 1900 2100	0.0 0.0 0.5	red red buff	SS SS S	not suitable

[1] Table 1.
[2] L, lower limit; H, upper limit.
[3] Drying shrinkage is linear.
[4] Pyrometric cone equivalent (Table 2).
[5] Firing shrinkage is linear; o.f., over fired.
[6] S, steel hard; HS, harder than steel; SS, softer than steel.

Table 3.–Ceramic properties of samples–Continued

Sample no.	Water of plasticity, %	Drying shrinkage, %	P.C.E.	Firing range °F	Firing temperature °F	Firing shrinkage, %	Fired color	Hardness	Suitability for various uses
655	L 28	8.5	6	2050	1700	1.1	red	S	poor common brick
	H 34			to	1900	1.4	red	S	
				2100	2100	2.7	light red	S	
656	L 30	7.7	6	2075	1700	0.9	red	SS	poor common brick
	H 34			to	1900	2.4	red	S	
				2125	2100	2.4	red	S	
657	L 21	6.0	6	1800	1700	0.6	red	S	poor common with
	H 26			to	1900	0.9	red	S	careful firing
				2000	2100	o.f.	red	HS	
658	L 33		6	not fired, brick cracked on drying, not suitable					
	H 48								
659	L 22	5.0	7	2000	1700	0.0	red	SS	fair common brick
	H 29			to	1900	0.6	red	SS	
				2100	2100	7.0	dark red	HS	
660	L 29	4.5	11	2000	1850	0.0	red	SS	fair common brick
	H 33			to	2050	3.1	red	S	
				2100	2250	7.5	dark red	HS	
661	L 29	5.5	12	2000	1900	0.0	red	SS	fair common brick
	H 35			to	2100	5.2	red	S	
				2200	2300	7.0	dark red	HS	
662	L 30	11.0	12	2150	1900	1.9	buff	S	good common brick
	H 37			to	2100	6.2	buff	S	
				2300	2300	7.0	buff	HS	
663	L 27	7.2	11	none	1850	2.3	red	SS	not suitable
	H 32				2050	o.f.	red	HS	
					2250	o.f.	red	HS	
664	L 38	6.9	12	none	1900	0.6	red	SS	not suitable
	H 45				2100	9.8	red	HS	
					2300	9.4	dark red	HS	
665	L 41	10.0	12	2000	1900	0.0	red	S	poor common brick
	H 52			to	2100	7.4	red	HS	
				2200	2300	7.5	chocolate	HS	
666	L 44		10	none	not fired, brick cracked on drying				
	H 54								
667	L 22	3.9	4	none	1650	0.0	light red	SS	not suitable
	H 26				1850	0.0	light red	SS	
					2050	0.0	light red	SS	
668	L 21	3.0	3	none	1600	0.0	light red	SS	not suitable
	H 24				1800	0.0	light red	SS	
					2000	0.0	light red	SS	
669	L 24	4.0	3	1950	1600	0.0	red	SS	poor common brick
	H 27			to	1800	0.6	red	SS	
				2000	2000	2.0	red	S	
670	L 21	4.2	2	none	1600	0.0	red	SS	not suitable
	H 24				1800	0.0	red	SS	
					2000	0.0	red	SS	
671	L 27	5.1	4	1950	1650	0.6	tan	SS	poor common brick
	H 30			to	1850	2.5	tan	SS	
				2050	2050	9.6	brown	S	
672	L 20	4.8	4	1900	1650	0.0	red	SS	unsuitable
	H 23			to	1850	0.0	red	S	
				2050	2050	1.8	red	HS	

Table 3.–Ceramic properties of samples–Continued

Sample no.	Water of plasticity, %	Drying shrinkage, %	P.C.E.	Firing range °F	Firing temperature °F	Firing shrinkage, %	Fired color	Hardness	Suitability for various uses
673	L 30	11.0	3	1850	1600	0.0	red	S	poor common brick
	H 37			to	1800	6.1	red	S	
				2000	2000	9.4	red	HS	
674	L 26	7.1	6	1900	1700	0.0	red	S	poor common brick
	H 31			to	1900	0.0	red	S	
				2000	2100	o.f.	red	HS	
675	L 26	5.3	4	1900	1650	0.0	red	SS	fair common brick
	H 32			to	1850	2.1	light red	S	
				2050	2050	1.2	light red	HS	
676	L 19	3.6	over	2100	1900	2.3	white	SS	good ceramic material
	H 22		12	to	2100	0.0	white	S	
				2300	2300	0.0	white	HS	
677	L 18	2.3	over	2100	1900	0.0	white	SS	good ceramic material
	H 21		12	to	2100	0.0	white	S	
				2300	2300	0.0	white	HS	
678	L 34	11.0	6	none	1700	0.9	light red	S	unsuitable
	H 44				1900	2.1	brown	HS	
					2100	o.f.	brown	HS	
679	L 59	brick cracked on drying							unsuitable
	H 98								
680	L 75	brick cracked on drying							unsuitable
	H 94								
681	L 20	3.6	12	none	1900	3.6	white	SS	unsuitable, high
	H 26				2100	3.9	white	SS	lime
					2300	6.2	white	SS	
682	L 20	2.5	over	none	1900	-2.5	cream	SS	unsuitable, high
	H 24		12		2100	3.8	cream	SS	lime
					2300	2.9	mottled	SS	
683	L 31	8.2	4	none	1650	0.0	light red	SS	unsuitable, narrow
	H 39				1850	0.0	light red	SS	firing range
					2050	0.0	brown	HS	
684	L 31	10.6	5	1850	1650	-0.9	light red	SS	poor common brick
	H 38			to	1850	0.6	light red	S	
				2050	2000	o.f.	brown	HS	
685	L 39	11.0	5	1850	1650	0.0	light red	SS	poor common brick
	H 49			to	1850	1.4	light red	S	
				1950	2000	o.f.	red	S	
686	L 27	7.0	12	2000	1900	0.3	light red	S	fair common brick
	H 32			to	2100	4.0	light red	HS	
				2200	2300	o.f.	light red	HS	
687	L 29	9.2	8	none	1750	0.5	light red	S	unsuitable, poor
	H 35				1950	o.f.	light red	HS	firing characteristic
					2150	o.f.	red	HS	
688	L 30	8.2	9	none	1800	0.5	light red	SS	unsuitable, brick
	H 41				2000	6.5	light red	S	swell on firing
					2200	o.f.	red	HS	
689	L 32	9.0	9	none	1800	1.3	light red	S	poor common brick
	H 40				2000	3.0	light red	HS	
					2200	o.f.	brown	HS	
690	L 24	4.8	4	1900	1650	0.0	light red	SS	unsuitable, narrow
	H 29			to	1850	0.0	light red	S	firing range
				2050	2050	0.0	light red	S	

Table 3.–Ceramic properties of samples–Continued

Sample no.	Water of plasticity, %	Drying shrinkage, %	P.C.E.	Firing range °F	Firing temperature °F	Firing shrinkage, %	Fired color	Hardness	Suitability for various uses
691	L 26	5.0	4	none	1650	−1.1	light red	SS	unsuitable, narrow
	H 29				1850	0.0	light red	SS	firing range
					2050	1.2	light red	S	
692	L 28	9.8	4	1850	1650	−1.4	light red	SS	unsuitable, scum on
	H 48			to	1850	0.0	light red	S	brick
				2000	2050	o.f.	light red	HS	
693	L 31	7.8	over	2000	1900	2.2	gray	SS	unsuitable, poor
	H 38		12	to	2100	4.1	red	S	firing characteristics
				2200	2300	5.7	brown	HS	
694	L 32	8.9	7	1800	1700	0.0	light red	S	possible common brick
	H 40			to	1900	2.6	light red	S	
				2000	2100	o.f.	red	HS	
695	L 27	7.2	5	none	1650	−0.6	light red	SS	unsuitable, poor
	H 33				1850	−0.6	light red	SS	firing characteristic
					2050	o.f.	red	S	
696	L 22	3.2	8	2100	1750	−1.3	light red	SS	possible common brick
	H 28			to	1950	0.0	red	SS	
				2150	2150	0.0	red	S	
697	L 28	5.6	1	none	1550	0.0	red	SS	unsuitable, poor
	H 34				1750	0.0	light red	SS	firing characteristic
					1950	4.5	light red	S	
698	L 26	4.2	4	none	1650	0.0	light red	SS	unsuitable, narrow
	H 31				1850	0.0	light red	SS	firing range
					2050	5.6	light red	S	
699	L 27	5.6	4	1950	1650	0.0	tan	SS	possible common brick
	H 31			to	1850	0.0	tan	SS	
				2050	2050	2.7	tan	S	
700	L 22	4.9	4	1950	1650	−0.9	tan	SS	possible common brick
	H 28			to	1850	−0.5	tan	SS	
				2050	2050	1.4	tan	S	
701	L 23	5.9	4	1950	1650	0.0	tan	SS	possible common brick
	H 26			to	1850	0.0	tan	SS	
				2050	2050	0.5	tan	S	
702	L 26	4.7	4	1950	1650	0.0	tan	SS	possible common brick
	H 29			to	1850	0.0	tan	SS	
				2050	2050	1.3	tan	S	
703	L 31	not fired, brick cracked on drying							
	H 44								
704	L 23	4.4	4	none	1650	0.0	tan	SS	possible blending
	H 27				1850	0.0	tan	SS	material
					2050	2.7	tan	S	
705	L 24	5.4	4	none	1650	0.0	tan	SS	possible blending
	H 27				1850	0.0	tan	SS	material
					2050	0.0	tan	S	
706	L 22	5.5	4	none	1650	0.0	tan	SS	possible blending
	H 25				1850	0.0	tan	SS	material
					2050	0.0	tan	S	
707	L 22	6.0	4	none	1650	−0.2	tan	SS	possible blending
	H 30				1850	0.0	tan	SS	material
					2050	0.5	tan	S	
708	L 24	5.5	4	none	1650	0.0	tan	SS	possible blending
	H 29				1850	0.0	tan	SS	material
					2050	0.0	tan	S	

Table 3.–Ceramic properties of samples–Continued

Sample no.	Water of plasticity, %	Drying shrinkage, %	P.C.E.	Firing range °F	Firing temperature °F	Firing shrinkage, %	Fired color	Hardness	Suitability for various uses
709	L 26 H 32	7.5	4	none	1650 1850 2050	0.8 0.0 1.0	tan tan tan	SS SS S	possible blending material
710	L 27 H 32	6.5	4	none	1650 1850 2050	0.0 0.8 1.5	tan tan tan	SS SS S	possible blending material
711	L 24 H 28	7.1	4	none	1650 1850 2050	0.0 0.0 0.3	light red light red light red	SS SS SS	unsuitable, narrow firing range
712	L 28 H 34	7.1	4	none	1650 1850 2050	−1.4 1.1 1.2	tan tan tan	SS S HS	unsuitable, narrow firing range
713	L 22 H 28	7.3	11	none	1850 2050 2250	0.0 0.0 o.f.	tan tan green	SS S HS	unsuitable, poor firing characteristic
714	L 25 H 29	6.0	3	none	1650 1850 2050	0.0 0.0 4.2	tan tan tan	SS SS S	unsuitable, scum on dried and fired brick
715	L 28 H 33	5.7	3	none	1650 1850 2050	0.0 0.0 4.1	tan tan tan	SS S HS	unsuitable, scum on dried and fired brick
716	L 29 H 36	6.8	3	none	1650 1850 2050	−0.8 0.0 2.0	tan tan tan	SS SS S	possible blending material
717	L 25 H 30	4.9	4	none	1650 1850 2050	0.0 0.0 0.0	tan tan tan	SS SS SS	unsuitable, narrow firing range
718	L 21 H 25	2.6	4	none	1650 1850 2050	0.0 0.0 0.8	tan tan tan	SS SS SS	possible blending material
719	L 23 H 27	4.0	4	1950 to 2050	1650 1850 2050	0.0 0.0 1.4	tan light red brown	SS SS HS	poor common brick
720	L 24 H 29	7.5	11	2000 to 2150	1850 2050 2250	0.0 2.8 o.f.	light red green green	S HS HS	poor common brick
721	L 23 H 30	4.7	4	none	1650 1850 2050	0.0 0.0 1.3	cream cream cream	SS SS S	possible mixing material
722	L 25 H 31	7.7	3	1850 to 2050	1650 1850 2050	0.0 0.5 1.4	tan light red brown	SS S HS	poor common brick
723	L 26 H 32	7.1	3	1850 to 2050	1650 1850 2050	0.0 0.0 2.4	tan tan brown	SS S HS	poor common brick
724	L 28 H 34	5.1	3	none	1650 1850 2050	0.8 0.8 1.1	tan tan tan	SS S HS	unsuitable, scum on dried and fired brick
725	L 29 H 33	5.5	4	none	1650 1850 2050	0.0 0.0 1.6	tan tan tan	SS SS S	unsuitable, scum on dried and fired brick
726	L 28 H 34	4.0	5	none	1650 1850 2050	0.0 1.4 0.0	tan tan white	SS SS S	unsuitable, high lime, narrow firing range
727	L 25 H 30	3.6	4	none	1650 1850 2050	0.0 1.1 1.1	tan tan tan	SS SS S	unsuitable, scum and narrow firing range

Table 4.—Bloating test results

Sample no.	County	Expansion range below 2400°F	Firing behavior	Suitability for lightweight aggregate
636	Gallatin	2200-2300°F	Minor bloat at 2200°F, good bloat with glazed surface at 2300°F	Fair bloated product over narrow range
637	Gallatin	None	Fused at 2200°F	Not suitable
638	Gallatin	None	Fused with minor bloat at 2200°F	Not suitable
639	Gallatin	None	Fused at 2200°F	Not suitable
676	Petroleum	None	No fusion or bloating	Not suitable
677	Fergus	None	Poor bloat and fusion at 2300°F	Not suitable
678	Petroleum	None	Spalled at 2300°F	Not suitable
679	Petroleum	None	Very brittle bloat with fusion at 2400°F	Not suitable
680	Petroleum	None	Glazed with minor bloat at 2300°F	Not suitable
681	Fergus	None	Fused with brittle bloat at 2300°F	Not suitable
682	Fergus	None	No fusion or bloating	Not suitable
683	Powder River	None	No fusion or bloating	Not suitable
684	Powder River	None	No fusion or bloating	Not suitable
685	Powder River	None	No fusion or bloating	Not suitable
686	Powder River	2100-2400°F	Good bloat at 2200°F	Good product, specific gravity <1.0
687	Powder River	2100-2400°F	Good bloat at 2100°-2400°F	Excellent product, specific gravity <1.0
688	Powder River	2100-2400°F	Good bloat at 2300°F	Good bloat, specific gravity <1.0
689	Powder River	None	Fused at 2400°F	Not suitable
690	Powder River	None	Fused at 2400°F	Not suitable
691	Powder River	None	No fusion or bloating	Not suitable
692	Powder River	2100-2400°F	Excellent bloat, rounded and glazed	Excellent product produced over wide temperature range, specific gravity <1.0
693	Powder River	None	No fusion or bloating	Not suitable
694	Powder River	None	Fused at 2200°F	Not suitable
695	Powder River	None	Fused at 2300°F	Not suitable
696	Powder River	Narrow <100°F	Fair bloat with fusion at 2400°F	Possibly suitable
697	Powder River	None	Fused at 2400°F	Not suitable
698	Powder River	None	No fusion or bloating	Not suitable
699	Rosebud	None	Glaze produced at 2300°F	Not suitable
700	Rosebud	None	Fused at 2300°F	Not suitable
701	Rosebud	None	Fused at 2300°F	Not suitable
702	Rosebud	None	Fused at 2300°F	Not suitable
703	Rosebud	Insufficient sample for expandibility tests		
704	Rosebud	None	Glaze produced at 2300°F	Not suitable
705	Rosebud	None	Fused at 2300°F	Not suitable
706	Rosebud	None	Fused at 2300°F	Not suitable
707	Rosebud	None	Glaze produced at 2200°F	Not suitable
708	Rosebud	Narrow	Glaze and bloat produced at 2200°F	Poor product over narrow range
709	Rosebud	None	Glaze produced at 2200°F	Not suitable
710	Rosebud	Narrow <100°F	Poor bloat with fusion at 2200°F	Not suitable
711	Custer	None	Fused at 2300°F	Not suitable
712	Custer	None	Fused at 2300°F	Not suitable
713	Custer	None	No fusion or bloating	Not suitable
714	McCone	None	Fused at 2400°F	Not suitable
715	McCone	None	Fused at 2300°F	Not suitable
716	McCone	None	Fused at 2300°F	Not suitable
717	McCone	None	Fused at 2300°F	Not suitable
718	McCone	None	Fused at 2300°F	Not suitable
719	McCone	None	Fused with minor bloat at 2300°F	Not suitable
720	McCone	None	Fused at 2300°F	Not suitable
721	McCone	None	Minor bloat with glaze at 2200°F, fusion at 2300°F	Not suitable
722	McCone	None	Fused at 2200°F	Not suitable
723	McCone	None	Fused at 2200°F	Not suitable
724	McCone	None	Fused at 2400°F	Not suitable
725	McCone	None	Fused at 2400°F	Not suitable
726	McCone	None	Fused at 2400°F	Not suitable
727	McCone	None	Fused at 2300°F	Not suitable

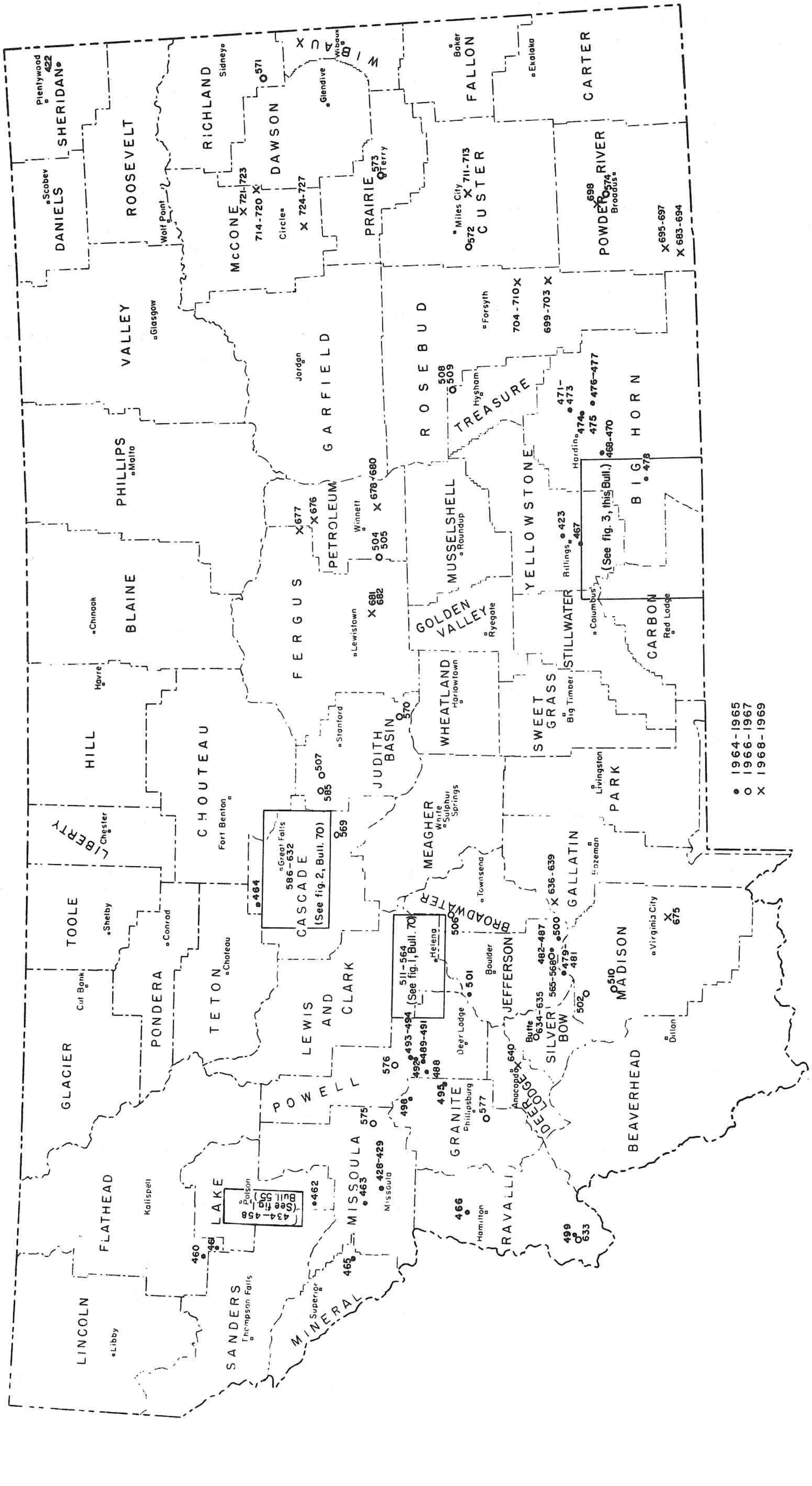

Figure 2.–Index map of Montana showing localities of samples 422 to 727.

Table 5.–Mineralogy of samples

Sample no.	Kaolinite	Montmor-illonite	Illite	Quartz	Feldspar	Calcite	Other
636	---	maj	---	min	min	---	tr cristobalite
637	---	maj	---	min	min	---	tr cristobalite
638	min	maj	---	min	tr	---	---
639	---	maj	---	tr	tr	---	---
640	min	maj	min	maj	min	---	min talc
641	---	---	min	maj	tr	---	maj ferroan dolomite, min complex silicates
642	---	---	min	maj	---	min	min metahalloysite and hydromica
643	min	---	min	maj	tr	maj	maj hemihydrate of calcium sulfate
644	---	min	min	maj	min	med	min dolomite and complex silicate
645	---	med	min	maj	min	---	min dolomite and amphibole
646	min	tr	min	maj	min	maj	---
647	med	min	min	maj	min	med	med dolomite, min complex silicate
648	---	---	min	maj	tr	min	min dolomite and amphibole and hydromica
649	min	tr	min	maj	min	maj	min hydromica
650	tr	---	min	med	min	maj	min chlorite
651	tr	---	min	maj	---	min	maj dolomite, min hydromica
652	min	tr	min	maj	min	---	med ankerite
653	min	---	min	maj	tr	tr	min dolomite
654	min	---	min	med	tr	maj	min dolomite
655	med	tr	min	med	---	maj	med metahalloysite
656	min	tr	min	maj	---	maj	---
657	med	---	min	maj	tr	med	---
658	tr	---	med	maj	tr	---	min gypsum, tr of cristobalite
659	med	---	min	maj	min	---	min hydromica
660	med	---	med	maj	min	---	---
661	---	min	min	maj	---	---	med matahalloysite
662	maj	---	min	maj	---	---	---
663	med	---	min	maj	---	---	tr hydromica
664	min	tr	min	maj	tr	---	tr chlorite
665	min	---	min	maj	tr	tr	---
666	min	maj	min	min	min	min	min metahalloysite
667	min	tr	min	maj	min	maj	tr dolomite
668	min	tr	min	maj	min	maj	min complex silicate, tr chlorite
669	min	---	min	maj	min	min	tr of cristobalite
670	---	tr	min	maj	min	med	min metahalloysite and complex silicate
671	---	---	min	maj	tr	tr	min metahalloysite and tr of chlorite
672	min	---	tr	maj	tr	med	tr of chlorite and hydromica
673	tr	---	med	maj	tr	tr	min gypsum and tr of hydromica
674	tr	---	min	maj	tr	---	min gypsum
675	---	---	med	maj	med	tr	med dolomite
676	med	---	min	maj	min	tr	---
677	med	---	min	maj	min	tr	---
678	---	min	tr	maj	min	min	tr chlorite
679	---	maj	---	tr	min	---	med gypsum, min chlorite
680	---	maj	---	min	---	maj	---
681	---	min	---	min	---	maj	---
682	---	min	tr	min	---	maj	---
683	---	med	---	maj	min	min	min dolomite and chlorite
684	---	tr	tr	maj	tr	min	tr dolomite, min mixed-layer clay
685	med	tr	min	maj	tr	tr	tr dolomite, min gypsum and complex silicate
686	---	min	min	maj	tr	---	metahalloysite and min complex silicate
687	min	tr	min	maj	min	---	min gypsum
688	min	tr	min	maj	min	---	min gypsum
689	min	tr	min	maj	tr	---	---
690	min	---	min	maj	min	tr	med dolomite
691	min	---	min	maj	min	min	med dolomite
692	min	min	min	maj	min	min	min dolomite and mixed-layer clay
693	min	---	min	maj	tr	---	---
694	min	---	min	maj	---	min	min dolomite and mixed-layer clay
695	min	---	min	maj	min	tr	min dolomite, complex silicate

Table 5.–Mineralogy of samples–Continued

Sample no.	Kaolinite	Montmor-illonite	Illite	Quartz	Feldspar	Calcite	Other
696	tr	- - -	min	maj	maj	- - -	tr dolomite and complex silicate
697	min	tr	min	maj	tr	min	med dolomite
698	min	tr	min	maj	min	med	med dolomite
699	med	- - -	min	maj	min	min	med dolomite
700	med	- - -	min	maj	min	min	med dolomite
701	med	- - -	min	maj	tr	min	med dolomite
702	med	tr	min	maj	tr	med	med dolomite, tr cristobalite
703	min	- - -	min	maj	tr	min	med dolomite, min hydromica
704	min	min	min	maj	min	med	med dolomite, tr chlorite
705	- - -	min	- - -	maj	med	min	med dolomite and metahalloysite
706	min	min	min	maj	min	med	med dolomite
707	min	tr	min	maj	med	min	med dolomite
708	med	tr	min	maj	min	min	maj dolomite, tr cristobalite
709	min	- - -	min	maj	min	min	maj dolomite
710	min	- - -	min	maj	tr	tr	med dolomite, tr cristobalite
711	min	min	min	maj	tr	med	med dolomite, min gypsum
712	min	min	min	maj	tr	tr	min dolomite
713	- - -	- - -	min	maj	min	min	min gypsum
714	- - -	- - -	min	maj	min	- - -	maj dolomite, med gypsum
715	- - -	- - -	min	maj	min	- - -	med dolomite, min gypsum
716	min	tr	min	maj	tr	tr	med dolomite, min gypsum
717	- - -	- - -	min	maj	tr	min	med dolomite, min gypsum
718	- - -	tr	tr	maj	tr	min	med dolomite, tr gypsum
719	min	- - -	min	maj	min	tr	min dolomite, tr cristobalite
720	min	tr	min	maj	tr	tr	- - -
721	min	- - -	min	maj	min	med	maj dolomite, tr gypsum
722	min	tr	min	maj	min	med	maj dolomite
723	min	tr	min	maj	tr	med	maj dolomite
724	min	- - -	min	maj	tr	min	med dolomite, tr cristobalite
725	min	- - -	min	maj	min	med	med dolomite, min gypsum
726	min	- - -	min	maj	min	med	med dolomite, tr gypsum and cristobalite
727	min	- - -	- - -	maj	med	med	med dolomite

Table 6.–Chemical analyses of clay samples (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
636	18.8	4.0	53.1	5.4	2.40	1.66	0.49	1.26	0.35	10.75
637	18.3	3.72	53.4	3.5	2.00	1.88	0.49	0.84	0.30	9.30
638	19.1	1.63	54.8	4.7	1.80	1.77	0.79	1.27	0.40	11.15
639	17.9	2.85	54.4	4.7	3.80	2.06	0.56	1.23	0.35	13.9
640	17.10	- - -	61.0	3.8	2.95	1.60	0.37	3.72	0.20	- - -
641	12.65	- - -	42.0	4.8	9.95	6.90	1.36	1.07	0.25	- - -
642	15.60	- - -	52.4	5.0	4.35	0.36	0.05	4.56	0.30	- - -
643	5.20	- - -	30.0	3.4	21.0	4.67	0.35	1.11	0.15	- - -
644	12.7	- - -	49.4	4.2	8.95	4.20	0.74	0.84	0.25	- - -
645	14.2	- - -	51.6	3.8	4.95	4.06	1.00	2.82	0.25	- - -
646	6.05	- - -	38.2	1.80	23.6	2.79	0.37	0.71	0.20	- - -
647	11.8	- - -	51.4	3.4	8.35	2.93	0.88	1.26	0.30	- - -
648	11.7	- - -	52.8	3.50	7.75	2.90	0.88	1.30	0.25	- - -
649	11.2	- - -	52.0	4.20	8.75	3.19	0.26	1.24	0.30	- - -
650	8.05	- - -	30.8	1.80	27.0	2.32	0.32	1.12	0.20	- - -
651	11.3	- - -	41.4	4.20	8.95	5.40	0.36	2.45	0.25	- - -
652	14.25	- - -	55.0	4.00	5.10	3.76	1.18	2.50	0.30	- - -
653	10.85	- - -	52.7	5.50	6.35	4.09	1.09	2.45	0.30	- - -
654	10.20	- - -	24.0	3.20	25.5	2.38	0.39	1.28	0.25	- - -
655	11.90	- - -	32.8	4.60	19.6	1.95	0.23	1.30	0.25	- - -

Table 6.–Chemical analyses of clay samples–Continued

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
656	12.80	---	36.2	2.30	20.4	2.35	0.30	1.27	0.25	---
657	16.00	---	51.8	4.80	7.40	1.74	0.53	1.31	0.25	---
658	20.00	15.2	56.3	7.00	1.25	1.30	1.15	1.22	0.30	8.25
659	20.15	9.4	54.7	4.30	0.85	1.37	1.36	1.24	0.35	5.65
660	16.7	---	66.6	2.50	0.45	0.51	0.39	1.24	0.40	---
661	15.05	---	64.5	3.80	0.25	0.18	0.30	1.22	0.40	---
662	29.15	24.9	51.5	1.30	0.70	0.58	0.09	0.51	0.20	11.5
663	20.8	9.75	60.2	2.60	0.50	0.94	0.51	1.28	0.45	7.6
664	19.4	9.7	58.6	4.60	0.31	0.92	0.34	1.29	0.35	10.15
665	18.3	---	63.5	2.80	0.57	0.93	0.30	1.27	0.35	---
666	15.45	---	66.6	3.30	0.52	1.03	0.96	0.57	0.30	---
667	10.10	---	58.2	2.50	11.35	1.99	1.08	1.24	0.20	---
668	9.10	---	57.3	2.40	12.70	0.84	0.85	1.20	0.17	---
669	14.90	---	58.4	4.4	4.35	1.42	0.53	1.24	0.18	---
670	8.8	---	43.8	3.10	16.7	1.53	0.30	1.31	0.13	---
671	17.45	---	59.9	4.30	2.35	2.03	0.53	1.21	0.35	---
672	14.05	---	52.9	3.40	10.85	1.53	0.60	1.31	0.25	---
673	18.80	---	55.0	6.00	2.05	2.14	0.34	2.42	0.35	---
674	13.15	---	60.5	4.80	1.85	1.72	0.57	2.50	0.30	---
675	19.6	12.1	49.3	4.70	3.15	2.75	0.09	7.20	0.25	7.80
676	12.10	---	79.1	1.20	0.58	0.65	0.15	1.25	0.20	---
677	11.45	---	74.8	1.20	0.95	0.65	0.18	1.23	0.15	---
678	16.0	---	50.9	4.10	4.80	1.60	0.63	1.26	0.30	---
679	17.75	---	46.2	3.80	4.00	3.32	2.43	0.20	0.30	---
680	17.7	---	49.3	3.20	2.95	4.35	0.80	0.18	0.15	---
681	1.77	---	21.6	1.60	40.2	1.45	0.09	0.47	0.10	---
682	1.80	---	18.4	1.70	43.4	1.56	0.06	0.42	0.10	---
683	18.75	4.85	54.0	5.20	3.90	3.36	0.69	1.31	0.30	8.15
684	13.4	---	59.7	3.80	2.40	1.68	0.60	1.30	0.25	---
685	17.4	---	49.4	6.40	1.65	2.63	0.49	2.46	0.30	---
686	13.8	---	67.4	2.40	0.70	1.11	0.35	1.28	0.25	---
687	16.95	---	56.7	4.80	1.00	1.91	0.61	1.31	0.30	---
688	16.9	---	59.4	4.70	1.35	1.91	0.59	1.32	0.33	---
689	16.45	---	60.5	3.60	0.78	1.57	0.53	1.30	0.35	---
690	10.95	---	59.6	3.20	6.3	3.55	0.78	1.29	0.25	---
691	12.1	---	59.6	3.60	5.15	3.15	0.78	1.30	0.25	---
692	14.8	---	57.0	4.60	5.00	2.42	0.65	1.29	0.25	---
693	17.25	---	57.5	2.70	0.78	1.85	0.54	1.28	0.30	---
694	11.6	---	53.5	4.70	2.10	1.92	0.61	1.29	0.35	---
695	10.45	---	70.3	3.10	2.15	1.70	0.80	1.30	0.25	---
696	12.45	---	64.1	6.40	1.30	1.16	0.80	1.25	0.35	---
697	15.85	---	55.6	4.30	5.45	2.64	0.72	1.29	0.27	---
698	11.35	---	43.7	4.00	13.55	4.35	0.81	1.30	0.26	---
699	13.75	---	48.5	3.70	8.95	4.23	0.61	1.31	0.28	---
700	15.00	---	56.3	2.80	5.30	3.40	0.57	1.30	0.25	---
701	12.75	---	55.3	2.80	7.10	3.80	0.53	1.27	0.26	---
702	13.2	---	48.0	3.20	7.55	4.15	0.60	1.28	0.27	---
703	18.1	7.75	55.1	3.40	4.10	2.53	0.67	1.30	0.28	10.85
704	12.8	---	51.2	3.00	9.05	4.37	0.78	1.29	0.23	---
705	12.0	---	53.5	2.90	7.70	3.86	0.81	1.26	0.23	---
706	11.55	---	55.7	3.20	8.15	3.65	0.78	1.24	0.24	---
707	12.7	---	57.8	3.40	5.75	3.28	0.72	1.25	0.30	---
708	10.6	---	50.0	2.50	9.80	4.80	0.78	1.27	0.20	---
709	12.9	---	50.0	2.80	8.85	4.74	0.61	1.27	0.25	---
710	14.0	---	55.6	2.90	4.90	2.60	0.57	1.28	0.25	---

Table 6.—Chemical analyses of clay samples—Continued

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
711	11.35	---	51.0	4.30	9.45	3.62	0.78	1.24	0.20	---
712	11.15	---	52.7	3.50	3.30	2.28	0.66	1.27	0.20	---
713	8.75	---	73.6	2.30	0.95	0.76	0.61	1.25	0.25	---
714	10.95	---	46.5	3.60	8.75	4.95	0.99	1.28	0.20	---
715	12.0	---	53.5	3.20	5.85	3.75	0.90	1.30	0.20	---
716	12.4	---	52.2	3.80	10.35	3.97	0.68	1.31	0.25	---
717	9.70	---	49.0	3.40	8.45	4.95	0.81	1.26	0.20	---
718	7.90	---	46.0	4.00	10.75	5.10	0.78	1.21	0.15	---
719	11.5	---	55.9	4.20	5.75	3.47	0.88	1.25	0.20	---
720	7.8	---	68.4	2.3	1.3	1.12	0.68	1.24	0.25	---
721	10.0	---	45.0	2.1	11.05	4.85	0.66	1.25	0.20	---
722	12.15	---	51.0	3.5	7.65	3.80	0.61	1.26	0.25	---
723	12.4	---	52.2	3.6	7.55	3.75	0.57	1.27	0.25	---
724	12.4	---	44.7	3.2	6.85	4.55	0.92	1.26	0.20	---
725	12.9	---	44.8	3.3	10.95	3.50	0.68	1.28	0.20	---
726	12.1	---	44.2	3.2	8.65	4.36	0.58	1.26	0.20	---
727	10.4	---	44.8	2.8	10.05	4.34	0.88	1.23	0.20	---

SAMPLE LOCALITIES AND DESCRIPTIONS

SAMPLES 636 and 637

Location.—Three miles south of Three Forks, in the NW¼ sec. 12, T. 1 N., R. 1 E., Gallatin County.

Geologic description.—The two samples are from bentonitic beds within the Climbing Arrow Formation reported by Robinson (1963, p. 74) to range in age from late Eocene to early Oligocene. Robinson showed these beds to dip 1° here and to be overlain to the east by Quaternary eolian silt and find sand. Sample 636 is a channel sample from a bed of pale-olive (10Y6/2) bentonitic clay 2.4 feet thick underlain and overlain by sandy clay. Sample 637 is a channel sample from a bed of yellowish-gray (5Y7/2) silty bentonitic clay 3.5 feet thick, which is stratigraphically above the bed from which sample 636 was collected.

Test results.— Because of the large amount of montmorillonite in these samples, ceramic tests were not performed. Bloating tests showed that sample 636 would produce a fair bloated product within the temperature range of 2200 to 2400°F. Sample 637 was judged not suitable for use as lightweight aggregate. Sample 636 did not swell significantly when slowly added to water, and sample 637 swelled to approximately twice its dry volume. Both of these samples would be regarded as very low swelling bentonite.

SAMPLES 638 and 639

Location.—Three miles south of Three Forks, in the SE¼ NW¼ sec. 12, T. 1 N., R. 1 E., Gallatin County.

Geologic description.—These two samples, also from the Climbing Arrow Formation, were collected approximately 150 feet higher in the section than samples 636 and 637. Sample 638 is from a bed of pale-olive (10Y6/2) silty bentonite 1.2 feet thick, which is approximately 60 feet below the top of the section exposed at this locality. It grades into underlying and overlying beds of sandy bentonite. Sample 639 was collected from a 4-inch layer about 35 feet below the position of sample 638. This sample is yellowish-gray (5Y7/2) bentonite.

Test results.—Because of the abundance of montmorillonite in these samples, ceramic tests were not performed. Neither sample was judged suitable for use as lightweight aggregate. Both samples swelled to less than twice dry volume when slowly added to water, and would therefore be regarded as low swelling bentonite.

SAMPLE 640

(Submitted by Norman Lesh, Anaconda)

Location.—Within 1 mile south of Anaconda, in sec. 11, T. 4 N., R. 11 W., Deer Lodge County.

Geologic description.—Not available.

Test results.—This sample contains a large amount of montmorillonite, which caused cracking of the brick on drying. The clay is unsuitable for ceramic use.

PRYOR MOUNTAINS AND SURROUNDING AREA

Samples 641 through 674 were collected from the Pryor Mountains and surrounding area during June 1968. Shale units in the Colorado and Montana Groups generally contain abundant montmorillonite, which is detrimental to their use in most ceramic applications. For this reason emphasis was placed on the sampling of beds in the Kootenai Formation or in older formations. Rocks ranging in age from Precambrian to Paleocene (Fort Union Formation) are exposed in the Pryor Mountains and surrounding area (Blackstone, 1940; Knappen and Moulton, 1930; Richards, 1955; Stewart, 1959).

SAMPLE 641

Location.—In Carbon County approximately 13 miles northeast of Warren, on Sage Creek road opposite the turnoff to the Schwend ranch. Land divisions are not shown on maps of this area (Big Ice Cave 7½-minute quadrangle).

Geologic description.—This sample is of terra rossa (10R4/6) exposed in a road cut and thought to extend over a large area in this vicinity.

Test results.—This material consists mainly of ferroan dolomite, quartz, and less abundant illite; it is unsuitable for ceramic use.

SAMPLE 642

Location.—Road cut along crooked Creek road about 12 miles northeast of Warren in Carbon County. This sample was collected from the north side of the road in Gooseberry Hollow, which is shown near the southern boundary of the Big Ice Cave 7¼-minute quadrangle. No land divisions are shown on maps of this area.

Geologic description.— Terra rossa (10R4/6) layer about 5 feet thick where exposed in road cut.

Test results.— This sample consists of illite, metahalloysite, quartz, and minor calcite. Plasticity and drying and firing characteristics are fair. With careful handling it could be used for common brick and similar products.

SAMPLE 643

Location.—Approximately 12 miles east of Warren, in the NW¼ NW¼ sec. 15, T. 9 S., R. 27 E. This sample was collected from an exposure about 0.1 mile east of the road to Cowley, Wyoming.

Geologic description.—Reddish-brown (10R4/6) silty shale, probably from the Chugwater Formation. This bed is at least 15 feet thick, and is overlain by 0 to 30 feet of siltstone containing some gypsum. Dip of bedding is 5° here.

Test results.—The large amounts of calcium sulfate (hemihydrate), calcite, and quartz and the small amount of clay in this sample render it unsuitable for ceramic use.

SAMPLES 644, 645, and 646

Location.—Approximately 12 miles east of Warren, in the SE¼ NE¼ sec. 16, T. 9 S., R. 27 E., Carbon County.

Geologic description.— These three samples were collected from exposures of a bed of grayish-brown (5YR3/2) to moderate-orange-pink (5YR8/4) shale 17 feet thick and thought to be in the Sundance Formation. Sample 644 was collected about 5 feet above the base of this bed, sample 645 higher in the bed, and sample 646 only 0.5 foot below the top. Bedding is nearly horizontal and overburden ranges from nil to somewhat more than 10 feet.

Test results.—Sample 644: The small amount of clay minerals fluxed by calcite, quartz, and complex silicates make this clay unsuitable for ceramic use. Sample 645: Although the main clay minerals are montmorillonite and illite, this material fires well and could possibly be used for common brick. Sample 646: The large amount of calcite and quartz in the clay act as a flux and give a narrow firing range. The brick fired to a light buff, but it cracked during firing. This clay could possibly be used as a blending material for buff- or white-firing products.

SAMPLES 647 and 648

Location.—About 12 miles southeast of Warren, in the SE¼ SW¼ sec. 28, T. 9 S., R. 27 E., Carbon County.

Geologic description.—Sample 647 is a channel sample from the lower 2.5 feet of a 5-foot bed of yellowish-gray (5Y7/2) shale. Sample 648 is a channel sample of the upper 2.5 feet of the same bed, which is thought to be in the Sundance Formation. The attitude of bedding is nearly horizontal.

Test results.—Sample 647 is an impure kaolin clay containing enough carbonate to act as a flux and restrict the firing range. With careful firing it could be used for common brick. Although there is only a minor amount of clay mineral in sample 648, the plasticity and drying and firing properties are fair. The fired brick has a nice light-red color. It is a fairly good clay for common brick, or could be used as blending clay.

SAMPLES 649, 650, and 651

Location.—Seven miles southeast of Bridger, in the SW¼ sec. 17, T. 7 S., R. 24 E., Carbon County.

Geologic description.—Samples 649 and 650 are from two gray to grayish-red shale beds probably included in the 18-foot shale bed described by Knappen and Moulton (1930, p. 19) as occurring at the base of the Sundance Formation. These beds are exposed on the northwest flank of Red Dome and dip 10°NE. They are overlain by 20 feet of limestone and shale. Sample 649 is a channel sample from a greenish-gray (5GY6/1) bed 2 feet

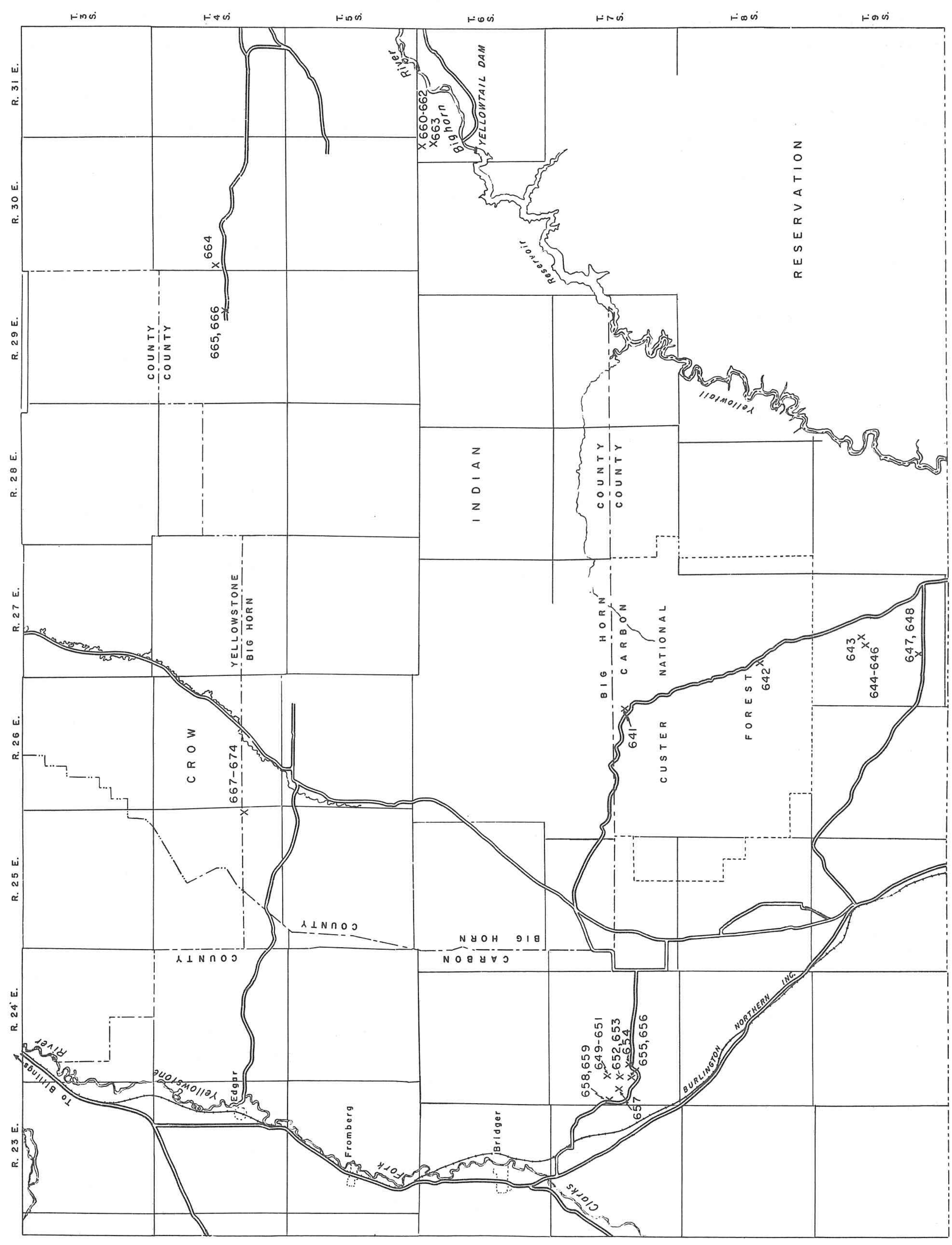

Figure 3.–Map showing localities of samples 641 to 674 from the Pryor Mountains and surrounding area.

thick, and sample 650 is a channel sample of a light-gray (N-8) bed 0.8 foot thick. Sample 651 is a channel sample of a bed of grayish-red (10R4/2) shale 2.8 feet thick near the top of the Chugwater Formation. The overburden, about 25 feet thick, consists of shale and limestone.

Test results.—Sample 649 is quartz and calcite and only a minor amount of clay. The plasticity is low, drying and firing properties are fair. With careful handling it could be used for common brick. Sample 650 is an impure limestone. The firing characteristics are poor, and it is not suitable for ceramic use. The large amount of dolomite in sample 651 results in poor firing properties. The fired brick had a scum. This sample is not suitable for ceramic use.

SAMPLES 652 and 653

Location.—Seven miles southeast of Bridger, in the NW¼ sec. 20, T. 7 S., R. 24 E., Carbon County.

Geologic description.— Sample 652 is reddish-brown (10R4/6) silty shale underlying the sandstone that Knappen and Moulton (1930, p. 15) describe as forming the Chugwater cuesta. Sample 653 is reddish-brown (10R4/6) silty shale in the Chugwater Formation, about 20 feet below the "prominent middle sandstone" described by Knappen and Moulton. Both samples were collected from exposures on the east flank of Red Dome.

Test results.—Sample 652 contains ankerite. The firing characteristics are poor; it is unsuitable for ceramic use. The firing properties of sample 653 are poor; it is unsuitable for ceramic use.

SAMPLE 654

Location.—Seven miles southeast of Bridger, in the SE¼ sec. 20, T. 7 S., R. 24 E., Carbon County.

Geologic description.—This sample was collected from a bed of dusky-yellow (5Y6/4) shale of the Sundance Formation, which is exposed in a road cut. The bed is more than 20 feet thick and contains some siliceous concretions.

Test results.—The firing properties of this dominantly calcitic clay are poor; it is unsuitable for ceramic products.

SAMPLES 655 and 656

Location.—Seven miles southeast of Bridger, in the SW¼ sec. 20, T. 7 S., R. 24 E., Carbon County.

Geologic description.—Both samples were collected from the Sundance Formation where exposed in a road cut on the east flank of Red Dome. Sample 655 is yellowish-gray (5Y7/2) shale 24 feet above a bed of fossiliferous limestone reported by Knappen and Moulton (1930, p. 19) to be 3 feet thick and 18 feet above the base of the Sundance Formation. Sample 656 is yellowish-gray (5Y7/2) shale sampled 4 feet above the limestone. Sandstone and shale more than 100 feet thick overlie the sampled beds at this locality.

Test results.—The clays in sample 655 are metahalloysite and kaolinite; calcite is the main impurity. The plasticity is fair, the firing properties poor, and the firing range narrow. With careful firing and handling, it could be used for common brick. Sample 656 contains only a small amount of clay, but large amounts of calcite and quartz. The test brick cracked on firing, consequently this sample is unsuitable for ceramic use.

SAMPLE 657

Location.—Seven miles southeast of Bridger, in the NE¼ sec. 19, T. 7 S., R. 24 E., Carbon County.

Geologic description.—The sample is brown (5YR3/4) shale about 30 feet above the base of the Morrison Formation. Because of poor exposures the thickness of this shale bed could not be determined.

Test results.—This kaolinitic, illitic clay contains enough calcite for good glass formation, but at higher firing temperatures the brick tends to swell and become vesicular. With careful firing it could be used for common brick.

SAMPLES 658 and 659

Location.—Six miles southeast of Bridger, in the SW¼ sec. 18, T. 7 S., R. 24 E., Carbon County.

Geologic description.—Sample 658 is dusky-yellowish-brown (10YR2/2) shale of the Cloverly Formation, which is poorly exposed. Sample 659 is from a bed of grayish-red (10R4/2) shale at least 10 feet thick and about 40 feet stratigraphically below sample 658. Thickness of overburden is variable, as erosion of the Cloverly Formation has produced a badlands topography.

Test results.—Sample 658, cracked on drying; this sample is unsuitable for ceramic use. Sample 659 has low plasticity but fair drying and firing properties. The clay could be used for several varieties of ceramic products.

SAMPLES 660, 661, and 662

Location.—Two miles north of Yellowtail Dam, in the NE¼ sec. 6, T. 6 S., R. 31 E., Big Horn County.

Geologic description.—Samples 660, 661, and 662 are of shale units within the Cloverly Formation, which is exposed on the east flank of Grapevine Dome where the bedding dips 60°NE. Sample 661 is from a bed of fissile black shale 1.5 feet thick. Sample 660 is from a bed of medium-gray (N-5) shale 4 feet thick and about 15 feet higher stratigraphically than sample 661. Sample 662 is from a poorly exposed bed of yellowish-gray (5Y8/1) shale, perhaps as much as 15 feet thick. This bed lies about 50 feet above the medium-gray shale.

Test results.—Samples 660 and 661 have low plasticity but fair drying and firing characteristics. With careful firing they could be used for common brick. Sample 662 is good buff-burning kaolin clay. Although the plasticity is low, the drying and firing properties are good, and this clay could be used for a variety of ceramic products.

SAMPLE 663

Location.—Two miles north of Yellowtail Dam, in the SE¼ SE¼ sec. 6, T. 6 S., R. 31 E., Big Horn County.

Geologic description.—This sample is from a poorly exposed bed of olive-gray (5Y4/1) shale perhaps as much as 20 feet thick and occurring in the Thermopolis Formation. At this locality, on the east flank of Grapevine Dome, bedding dips 55° NE.

Test results.— This sample is unsuitable for ceramic use; the brick cracked and swelled on firing.

SAMPLE 664

Location.—Outcrop along Beauvais Creek, 17 miles west of St. Xavier, in the SW¼ sec. 18, T. 4 S., R. 30 E., Big Horn County.

Geologic description.—This sample is of very fissile medium-dark-gray (N-4) shale of Cretaceous age. The bed sampled is at least 27 feet thick, is horizontal, and at this locality erosion has removed all overlying beds.

Test results.—The excessive firing shrinkage of this clay makes it unsuitable for ceramic use.

SAMPLES 665 and 666

Location.—Exposures north of Beauvais Creek, 19 miles west of St. Xavier, in the NW¼ sec. 23, T. 4 S., R. 29 E., Big Horn County.

Geologic description.—Sample 665 is from a bed of medium-light-gray (N-6) shale 1.7 feet thick of unknown stratigraphic position in the Kootenai Shale. Bedding is horizontal, and the sampled bed is overlain by about 30 feet of overburden, most of which is sandstone. Sample 666 is a channel sample of a bed of very light gray (N-8) shale 3 feet thick and 18 feet below the stratigraphic position of sample 665.

Test results.—Sample 665 consists mainly of quartz. The fired brick is mottled brown, and the brick fired at the highest temperature, 2400°F, was glazed. This clay could best be used as a blending material with other, more plastic clays. Sample 666 is unsuitable for ceramic use, as the brick cracked on drying.

SAMPLES 667 through 674

Location.—North bank of Plum Creek, 2 miles northwest of Pryor, in the NE¼ sec. 25, T. 4 S., R. 25 E., Big Horn County.

Geologic description.—This sequence of eight samples was collected from a section of the Morrison Formation that was measured and described by Knappen and Moulton (1930, p. 22). Those authors described this section as being exposed on the north bank of Poplar Creek, but more recent maps designate this creek as Plum Creek. All samples were collected from the "lower clay" reported by Knappen and Moulton to be 70 feet thick and to consist of clay (yellow, pale red, blue, green, and dull purple) and a very minor amount of interbedded sandstone. The relative stratigraphic positions of the samples are given below.

Sample no.	Color	Distance above base of exposure (feet)
674	light olive gray (5Y5/2)	65
673	grayish red (10R4/2)	59
672	pale yellowish brown (10YR6/2)	52
671	greenish gray (5GY6/1)	41
670	pale brown (5YR5/2)	31
669	moderate brown (5YR3/4)	21
668	yellowish gray (5Y8/1)	6
667	very light gray (N-8)	0

Above the position of sample 674 there is a covered sequence 18 feet thick, above which thin-bedded sandstone crops out. The attitude of bedding is very close to horizontal.

Test results.—The firing range of samples 667 and 668 is too narrow for their use in ceramic products. The material in sample 669 is an impure kaolin clay containing much quartz and a small amount of calcite. The plasticity is low, but the drying and firing properties are fair. The firing range is narrow. With careful firing it could be used for common brick or for blending with more plastic clay. Sample 670—this brick cracked on firing; this clay is unsuitable for ceramic use. Sample 671 consists mainly of quartz and contains only a minor amount of clay. The plasticity is very low but drying and firing properties are fair. With careful handling this clay could be used for common brick, but is more suitable for use as a blending clay. Sample 672—the brick cracked after firing, indicating that this clay is not suitable for ceramic use. Sample 673 is illitic clay containing abundant quartz. The plasticity is good; drying and firing properties are fair. With careful handling it could be used for common brick. Sample 674 is illitic clay but it contains a large amount of quartz and a small amount of gypsum. The plasticity is low, drying and firing properties are fair. The firing range is narrow, but with careful firing it could be used for common brick.

SAMPLE 675

Location.—Seven miles south of Ennis, in sec. 3, T. 7 S., R. 1 W., Madison County (sample submitted by Mr. Pete Womack).

Geologic description.–Not available.

Test results.–This material is illitic clay containing a large amount of quartz and dolomite. The plasticity is fair, drying and firing characteristics are good. It could be used either with other clays or alone for common brick.

SAMPLE 676

Location.–Twenty-two miles northeast of Winnett, in sec. 28, T. 18 N., R. 27 E., Petroleum County (sample submitted by Charles Allen).

Geologic description.–Not available.

Test results.–This sample is a flint clay containing much quartz, but with low plasticity. This clay could best be used with a more plastic clay for white and buff products. Bloating tests showed this material to be unsuitable for use as lightweight aggregate.

SAMPLE 677

Location.–Twenty-six miles north of Winnett, in sec. 30, T. 19 N., R. 27 E., Fergus County (sample submitted by Charles Allen).

Geologic description.–Not available.

Test results.–This sample is a flint clay containing much quartz, but with low plasticity. This clay could best be used with a more plastic clay for white and buff products. Bloating tests showed this material to be unsuitable for use as lightweight aggregate.

SAMPLES 678 and 679

Location.–Ten miles southeast of Winnett, in sec. 4, T. 13 N., R. 28 E., Petroleum County (sample submitted by Charles Allen).

Geologic description.–These samples are from either the Claggett Shale or Eagle Sandstone. (See Johnson and Smith, 1964, for the geology of this area.)

Test results.–The small amount of montmorillonite and illite in sample 678, which contains a large amount of quartz, gives this clay good plasticity. Drying and firing properties are poor, the drying shrinkage is high, and the brick cracked on firing. The clay is unsuitable for ceramic use, and bloating tests showed it to be unsuitable for use as lightweight aggregate. Sample 679, a montmorillonitic clay, also contains a large amount of calcite. The brick disintegrated on drying. The sample is unsuitable for ceramic use, and bloating tests showed it to be unsuitable for use as lightweight aggregate.

SAMPLE 680

Location.–Eleven miles southeast of Winnett, in sec. 8, T. 13 N., R. 28 E., Petroleum County (sample submitted by Charles Allen).

Geologic description.–This sample is from either the Claggett Shale or the Eagle Sandstone. (See Johnson and Smith, 1964, for the geology of this area.)

Test results.–This montmorillonitic clay contains much calcite. As the brick disintegrated on drying, the clay is not suitable for ceramic use. Bloating tests showed this material to be unsuitable for use as lightweight aggregate.

SAMPLES 681 and 682

Location.–Sixteen miles southwest of Grassrange, in sec. 19, T. 14 N., R. 21 E., Fergus County (samples submitted by Charles Allen).

Geologic description.–These samples are probably from the Heath Shale. (See Gardner, 1950, for the geology of this area.)

Test results.–Both of these samples contain much calcite and are probably impure limestone. They are unsuitable for ceramic use. Bloating tests showed them to be unsuitable for use as lightweight aggregate.

SAMPLES from the FORT UNION FORMATION

Samples 683 through 727 are from the Tongue River Member of the Fort Union Formation (Paleocene). These samples consist of cuttings obtained from holes drilled by the Montana Bureau of Mines and Geology during the evaluation of coal deposits in eastern Montana. Information on the coal deposits of McCone County (samples 714 - 727 are from this area) is given by Matson (1970). Matson and others (1968) provide information on the coal deposits and Tertiary stratigraphy of Powder River County. Reports on other coal deposits are in preparation and will be published by the Montana Bureau of Mines and Geology.

SAMPLES 683 through 687

Location.–These samples are from drill hole SM-11 10 miles west of Moorhead, in the NW¼ NW¼ NW¼ sec. 11, T. 9 S., R. 46 E., Powder River County.

Geologic description.–The stratigraphic units represented by these samples from the Tongue River Member of the Fort Union Formation are shown below:

Sample no.	Depth (ft.)	Description
	0 - 25	sandy yellow clay
683	25 - 40	light-brown (5Y6/4) sandy clay
684	40 - 55	olive-gray (5Y4/1) silty clay
685	55 - 65	olive-black (5Y2/1) clay
	65 - 71	brownish-gray clay
	71 - 100	coal
	100 - 110	gray clay
686	110 - 120	dusky-yellowish-brown (10YR2/2) silty clay
687	120 - 145	dusky-yellowish-brown (10YR2/2) clay
	145 - 146	clay
	146 - 157	coal
	157 - 159	gray clay

Test results.—Sample 683 is an impure montmorillonitic clay, which has fair plasticity. The abundance of impurities restricts the firing range, making this sample unsuitable for ceramic use. Bloating tests showed that this material is not suitable for use as lightweight aggregate. Sample 684 contains illite and a mixed-layered clay. The plasticity is fair, but the drying and firing shrinkage are excessive. With careful handling it could be used alone or blended with other clays for common brick and similar products. Bloating tests showed this sample to be unsuitable for use as lightweight aggregate. Sample 685 is impure kaolinitic clay. Plasticity and firing and drying properties are fair. It could be used for common brick if blended with other clays. Bloating tests showed this sample to be unsuitable for use as lightweight aggregate. Sample 686 is kaolin flint clay exhibiting low plasticity, but fair drying and firing properties. The brick fired at a high temperature has a glazed surface. With careful handling this clay could be blended with other clay and used for common brick. Bloating tests showed that this sample was suitable for the manufacture of lightweight aggregate. Sample 687 is an impure kaolin clay, which contains much quartz. The brick fused and swelled on firing; this material is unsuitable for ceramic use.

SAMPLES 688 through 691

Location.—These samples are from drill hole SM-14A 11 miles west of Moorhead, in the SW¼ NE¼ sec. 5, T. 5 S., R. 46 E., Powder River County.

Geologic description.—The stratigraphic units represented by these samples from the Tongue River Member of the Fort Union Formation are given below:

Sample no.	Depth (ft.)	Description
	0 - 8	yellow sandy clay
	8 - 11	coal
	11 - 24	gray sand
	24 - 25	gray clay
688	25 - 40	dusky-yellowish-brown (10YR2/2) silty clay
689	40 - 50	olive-gray (5Y4/1) silty clay
	50 - 53	gray clay
	53 - 62	coal
	62 - 73	gray clay
	73 - 77	sandstone
	77 - 109	gray sandy clay
	109 - 114	sandstone
690	114 - 140	light-olive-gray (5Y6/1)sandy clay
691	140 - 160	olive-gray (5Y5/2) sandy clay
	160 - 165	gray clay
	165 - 170	coal
	170 - 175	brown clay
	175 - 195	coal
	195 - 197	gray clay

Test results.—Sample 688 is kaolinitic clay and contains a major amount of quartz. The brick fused and swelled on firing, and therefore this material is unsuitable for ceramic use. Bloating tests indicate that it may be suitable for use as lightweight aggregate. Sample 689 is kaolinitic clay also containing a major amount of quartz. Plasticity and firing and drying properties are fair. With careful handling and firing or blended it could be used for common brick. Bloating tests indicate that this sample is not suitable for use as lightweight aggregate. Samples 690 and 691 contain dolomite and calcite, which act as fluxes. The firing properties are poor, and these samples are judged unsuitable for ceramic use. Bloating tests showed them to be also unsuitable for use as lightweight aggregate.

SAMPLES 692 through 694

Location.—These samples are from drill hole SM-17 15 miles west of Moorhead, in the NE¼ SW¼ sec. 3, T. 9 S., R. 45 E., Powder River County.

Geologic description.—The stratigraphic units represented by these samples from the Tongue River Member of the Fort Union Formation are given below:

Sample no.	Depth (ft.)	Description
	0 - 12	sandstone
	12 - 15	yellow clay
692	15 - 30	olive-gray (5Y4/1) silty clay
	30 - 43	gray clay
	43 - 62	coal
	62 - 64	brown clay
	64 - 68	coal
693	68 - 79	olive-black (5Y2/1) sandy clay
	79 - 81	coal
	81 - 85	brown clay
694	85 - 100	olive-black (5Y2/1) silty clay

Test results.—Sample 692: The dried and fired brick had scum on the surface; this clay is unsuitable for ceramic use. Bloating tests indicated that this material is well suited for the manufacture of lightweight aggregate. Sample 693: The dried and fired brick had a scum on the surface, and the brick fired at the highest temperature had a rough glazed surface. This sample is unsuitable for ceramic use. Bloating tests showed this material to be unsuitable for use as lightweight aggregate. Sample 694 has fair plasticity and fair drying and firing properties. With blending and careful handling it could be used for common brick. It is not suitable for lightweight aggregate.

SAMPLES 695 through 697

Location.—These samples are from drill hole SM-7 8 miles northwest of Moorhead, in the NE¼ NW¼ sec. 8, T. 8 S., R. 47 E., Powder River County.

Geologic description.—The stratigraphic units represented by these samples from the Tongue River Member of the Fort Union Formation are shown below:

Sample no.	Depth (ft.)	Description
	0 - 29	yellow sandy clay
	29 - 30	gray clay
695	30 - 55	brownish-gray (5YR4/1) sandy clay
696	55 - 70	olive-gray (5Y4/1) sandy clay
697	70 - 85	light-olive-gray (5Y6/1) sandy clay
	85 - 88	gray sandy clay
	88 - 91	coal
	91 - 99	brown clay
	99 - 119	coal
	119 - 130	gray clay

Test results.—Sample 695 is impure kaolin clay. Because of poor firing characteristics the clay is unsuitable for ceramic use. Bloating tests indicate that this sample is unsuitable for use as lightweight aggregate. Sample 696: Although this illitic clay consists mainly of quartz, and shows low plasticity, the drying and firing properties are fair. If blended with other clays it could be used for ceramic products. Bloating tests produced material satisfactory for use as lightweight aggregate, but within a very narrow temperature range. The firing range of sample 697 is too narrow for its use in ceramic products. Bloating tests showed it unsuitable for use as lightweight aggregate.

SAMPLE 698

Location.—This sample is from drill hole Br-6 14 miles northwest of Broadus, in the NE¼ NE¼ NE¼ sec. 7, T. 3 S., R. 50 E., Powder River County.

Geologic description.—The stratigraphic unit represented by this sample from the Tongue River Member of the Fort Union Formation is shown below:

Sample no.	Depth (ft.)	Description
	0 - 22	yellow sand
	22 - 33	soft sandstone
	33 - 39	yellow clay
	39 - 47	gray clay
	47 - 57	yellow sandy clay
	57 - 60	gray clay
698	60 - 65	olive-gray (5Y5/2) silty clay
	65 - 72	gray clay
	72 - 85	gray sand
	85 - 90	gray clay
	90 - 92	brown clay
	92 - 117	Broadus coal bed
	117 - 133	gray clay
	133 - 134	trace of coal
	134 - 160	gray clay

Test results.—The narrow firing range of this clay makes it unsuitable for ceramic use. Bloating tests indicate that it is unsuitable for use as lightweight aggregate.

SAMPLES 699 through 703

Location.—These samples are from drill hole S-S-1 5 miles northwest of Brandenberg, in sec. 29, T. 2 N., R. 44 E., Rosebud County.

Geologic description.—The stratigraphic units represented by these samples from the Tongue River Member of the Fort Union Formation are given below:

Sample no.	Depth (ft.)	Description
	0 - 17	yellow sandy clay
	17 - 20	yellow and gray clay
699	20 - 35	olive-gray (5Y5/2) silty clay
700	35 - 50	pale-olive (10Y6/2) silty clay
	50 - 67	coal (Terrett bed)
	67 - 70	gray clay
701	70 - 80	light-olive-gray (5Y6/1) silty clay
	80 - 85	gray clay, traces of coal
702	85 - 95	olive-gray (5Y3/2) silty clay
703	95 - 100	olive-gray (5Y3/2) silty clay
	100 - 107	gray clay
	107 - 111	coal
	111 - 120	gray clay

Test results.—Sample 699: Although this kaolin clay contains a large amount of dolomite, the firing properties are fair. Blended with other clays it could be used for ceramic products. Bloating tests showed that this sample is not suitable for use as lightweight aggregate. Samples 700 - 702: Although these impure kaolin clays are not identical, their firing characteristics are similar. Their firing range is narrow, but with blending and careful handling they could be used for ceramic products. These samples are not suitable for use as lightweight aggregate. The test brick made from sample 703 cracked on drying. This material is unsuitable for ceramic use. Bloating tests were not performed on this sample.

SAMPLES 704 through 710

Location.—These samples are from drill hole S-S-5 14 miles north of Brandenberg, in sec. 3, T. 3 N., R. 44 E., Rosebud County.

Geologic description.—The stratigraphic units represented by these samples from the Tongue River Member of the Fort Union Formation are given below:

Sample no.	Depth (ft.)	Description
	0 - 5	clay
704	5 - 15	light-olive-gray (5Y5/2) silty clay
705	15 - 25	dusky-yellow (5Y6/4) sandy clay
706	25 - 35	dusky-yellow (5Y6/4) sandy clay

	35 - 40	clay
707	40 - 55	olive-gray (5Y4/1) silty clay
	55 - 56	soft sandstone
	56 - 64	gray clay
	64 - 65	trace of coal
	65 - 69	gray clay
	69 - 70	trace of coal
	70 - 80	gray clay
708	80 - 95	yellowish-gray (5Y7/2) silty clay
709	95 - 109	light-olive-gray (5Y6/1) silty clay
	109 - 127	coal
	127 - 135	gray clay
710	135 - 150	light-olive-gray (5Y5/2) silty clay
	150 - 167	gray clay
	167 - 169	sandstone
	169 - 184	gray clay
	184 - 187	coal
	187 - 200	brown to gray clay

Test results.–These seven samples are all impure kaolin clays, which contain relatively large amounts of dolomite. Their firing range is narrow. Any one of these clays could be used as an additive fluxing material to other good clays. With the exception of sample 708, none was found suitable for use as lightweight aggregate. Sample 708 might be suitable for this use, but it bloated over a very narrow temperature range.

SAMPLES 711 through 713

Location.–These samples are from drill hole Ph-1 17 miles southeast of Miles City, in sec. 29, T. 7 N., R. 50 E., Custer County.

Geologic description.–The stratigraphic units represented by these samples from the Tongue River Member of the Fort Union Formation are given below:

Sample no.	Depth (ft.)	Description
	0 - 21	yellow sandy clay
	21 - 26	gravel
	26 - 45	gray and yellow sand
711	45 - 55	light-olive-gray (5Y5/2) silty clay
	55 - 85	gray sand
	85 - 87	gray clay
	87 - 90	coal
712	90 - 95	olive-gray (5Y4/1) silty clay (some coal in sample)
	95 - 112	coal
	112 - 120	gray clay
713	120 - 130	olive-gray (5Y4/1) sandy clay

Test results.–Samples 711 and 712 are impure kaolin clays, which contain relatively large amounts of dolomite. Their firing range is narrow, but either of these clays could be used as an additive fluxing material to other good clays. Bloating tests showed that neither of these samples is suitable for use as lightweight aggregate. Sample 713 is impure illitic clay, which contains much quartz. The firing range is narrow, but with careful handling and firing, the clay could be used for common brick. It is not suitable for use as lightweight aggregate.

SAMPLES 714 through 720

Location.–These seven samples are from drill hole McCone 1, 14 miles northeast of Circle, in the SW¼ SE¼ sec. 36, T. 21 N., R. 49 E., McCone County.

Geologic description.–These samples are from the Tongue River Member of the Fort Union Formation and their positions in this hole are shown below: (See Matson, 1970, for further information on the geology of this area.)

Sample no.	Depth (ft.)	Description
	0 - 5	yellow clay
714	5 - 10	dusky-yellow (5Y6/4) silty clay
715	10 - 15	dusky-yellow (5Y6/4) silty clay
	15 - 19	yellow clay
	19 - 26	coal
	26 - 35	gray clay
716	35 - 45	greenish-gray (5GY6/1) clay
717	45 - 55	light-gray (N7) silty clay
718	55 - 65	light-olive-gray (5Y5/2) silty clay
	65 - 75	gray clay
719	75 - 85	olive-gray (5Y4/1) silty clay
	85 - 88	gray clay
	88 - 97	coal (S bed)
	97 - 105	gray clay
720	105 - 110	olive-gray (5Y4/1) silty clay

Test results.–Samples 714 and 715: The dried and fired brick had scum on the surface; the material is unsuitable for ceramic use. Bloating tests showed it also to be unsuitable for use as lightweight aggregate. Sample 716 consists of kaolinite, illite, quartz, and dolomite. Plasticity is fair, but the firing range is narrow. With blending and careful firing it could be used for ceramic products. Bloating tests showed it to be unsuitable for use as lightweight aggregate. Sample 717 is impure illitic clay containing much dolomite. The low plasticity and poor firing properties indicate that it is unsuitable for ceramic use. Bloating tests showed it to be unsuitable for use as lightweight aggregate. Sample 718 is impure kaolinitic, illitic clay containing much dolomite. The plasticity is very low, but the firing properties are fair. It could be used as an additive fluxing material with other, more plastic clays. Bloating tests showed this material to be unsuitable for use as lightweight aggregate. Sample 719 is impure kaolinitic clay, containing much quartz, exhibits fair plasticity, and fair drying and firing characteristics. The firing range is narrow, but with careful handling the clay could be used for common brick or blending. Bloating tests showed this material to be unsuitable for use as lightweight aggregate. Sample 720, a kaolinitic, illitic clay, contains much quartz, is of low plasticity, but has fair drying and firing properties. With blending and careful handling it could be used for common brick. Bloating tests showed this material to be unsuitable for lightweight aggregate.

SAMPLES 721 through 723

Location.–These three samples are from drill hole McCone 8, 16 miles northwest of Circle, in the NW¼ NE¼ sec. 16, T. 21 N., R. 46 E., McCone County.

Geologic description.–These samples are all from the Tongue River Member of the Fort Union Formation. (See Matson, 1970, for further information on the geology of this area.) The beds represented by these samples are shown below:

Sample no.	Depth (ft.)	Description
	0 - 45	yellow clay
721	45 - 65	dusky-yellow (5Y6/4) silty clay
722	65 - 90	light-olive-gray (5Y5/2) silty clay
723	90 - 110	light-olive-gray (5Y5/2) silty clay
	110 - 114	gray clay
	114 - 126	coal (S bed)
	126 - 130	gray clay

Test results.–Kaolinite and illite are the clay minerals in sample 721. The clay is fluxed by a large amount of dolomite, causing a narrow firing range. This material could be used as an additive clay with other, more plastic clays. Bloating tests indicated that it is not suitable for use as lightweight aggregate. Samples 722 and 723 are kaolinitic, illitic clays similar in mineral content and properties. Drying and firing properties are good, the plasticity is fair. With careful handling, blending, and firing they could be used for common brick. Bloating tests showed that neither sample is suitable for use as lightweight aggregate.

SAMPLES 724 through 727

Location.–These samples are from drill hole McCone 14, slightly more than 1 mile northeast of Brockway, in the NW¼ SW¼ SW¼ sec. 16, T. 18 N., R. 47 E., McCone County.

Geologic description.–These samples are from the Tongue River Member of the Fort Union Formation. (See Matson, 1970, for further information on the geology of this area.) The beds represented by these samples are given below:

Sample no.	Depth (ft.)	Description
	0 - 16	yellow clay
	16 - 20	coal
	20 - 25	yellow clay
724	25 - 35	yellowish-gray (5Y7/2) silty clay
	35 - 38	sandstone
	38 - 40	gray clay
725	40 - 55	olive-gray (5Y4/1) silty clay
	55 - 62	sandstone
	62 - 78	sandy gray clay
	78 - 81	coal
	81 - 82	brown clay
	82 - 83	coal
	83 - 85	clay, trace of coal
726	85 - 100	olive-gray (5Y4/1) silty clay
	100 - 130	gray clay, trace of coal
727	130 - 150	olive-gray (5Y4/1) sandy clay
	150 - 160	gray clay

Test results.–Samples 724 and 725 are kaolinitic, illitic clay, which also contains quartz, dolomite, and calcite. The bricks developed a scum on firing; this material is unsuitable for ceramic use. Bloating tests showed this material to be also unsuitable for use as lightweight aggregate. Sample 726 is kaolinitic, illitic clay, which also contains quartz, dolomite, and calcite. The fluxing action of the carbonates gives this material a very narrow firing range, making it unsuitable for ceramic use. Bloating tests indicate that this sample is unsuitable for use as lightweight aggregate. A brick made from sample 727 developed a scum, therefore this material is judged to be unsuitable for ceramic use. Bloating tests showed it to be unsuitable for use as lightweight aggregate.

SUMMARY

The ceramic properties of 34 samples from the Pryor Mountains and surrounding area were determined. One of these samples (no. 662, from the Cloverly Formation) was judged to be a good brick clay, six other samples were judged to be of fair quality for common brick, and ten samples were of poor quality for common brick. The other 17 samples were not satisfactory for ceramic use. On the basis of these results, in this area the Cloverly Formation seems to offer the best possibility as a source of brick clay. Four of the five samples collected from the Cloverly Formation would be suitable for fair to good common brick. Most of the samples judged fair or only poor are from the Morrison and Sundance Formations.

Of the 45 samples from the Tongue River Member of the Fort Union Formation, only one was judged capable of producing a fair grade of common brick (sample 686), 13 other samples were judged to be capable of producing only poor common brick, and nine samples could possibly be used as blending material. The other 21 samples are unsuitable for ceramic use.

Bloating tests were performed on all but one of the samples from the Fort Union Formation. Samples 686, 687, 688, and 689 produced a satisfactory bloated product and would be suitable for the manufacture of lightweight aggregate. Samples 696 and 708 produced a satisfactory bloated product, but the temperature range at which bloating occurred was too narrow for the commercial production of lightweight aggregate from these samples.

REFERENCES

BERG, R. B., LAWSON, D. C., JONES, F. P., and SMITH, R. I., 1968, Progress report on clays and shales of Montana, 1966-1967: Montana Bur. Mines and Geology Bull. 70, 74 p.

BLACKSTONE, D. L., JR., 1940, Structure of the Pryor Mountains, Montana: Jour. Geology, v. 48, p. 590-618.

BOTZ, M. K., 1969, Conversion of section-township-range to latitude-longitude–A computer technique: Montana Bur. Mines and Geology Spec. Pub. 48, 15 p.

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, 1962-1964: 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, 1964-1965: Montana Bur. Mines and Geology Bull 55, 38 p.

GARDNER, L. S., 1950, Geology of the Button Butte-Forestgrove area, Fergus County, Montana: U. S. Geol. Survey Oil and Gas Inv. Map 106.

JOHNSON, W. D., JR., and SMITH, H. R., 1964, Geology of the Winnett-Mosby area, Petroleum, Garfield, Rosebud, and Fergus Counties, Montana: U. S. Geol. Survey Bull. 1149, 91 p.

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

KNAPPEN, R. S., and MOULTON, G. F., 1930, Geology and mineral resources of parts of Carbon, Big Horn, Yellowstone, and Stillwater Counties, Montana: U. S. Geol. Survey Bull. 822-A, 70 p.

MATSON, R. E., 1970, Preliminary report, strippable coal resources, McCone County, Montana: Montana Bur. Mines and Geology Bull. 78, 13 p.

MATSON, R. E., DAHL, G. G., JR., and BLUMER, J. W., 1968, Strippable coal deposits on state land, Powder River County, Montana: Montana Bur. Mines and Geology Bull. 69, 81 p.

RICHARDS, P. W., 1955, Geology of the Bighorn Canyon–Hardin area, Montana and Wyoming: U. S. Geol. Survey Bull. 1026, 93 p.

ROBINSON, G. D., 1963, Geology of the Three Forks quadrangle, Montana: U. S. Geol. Survey Prof. Paper 370, 143 p.

SAHINEN, U. M., SMITH, R. I., and LAWSON, D. C., 1958, Progress report on clays of Montana, 1956-1957: Montana Bur. Mines and Geology Inf. Circ. 23, 41 p.

1960, Progress report on clays and shales of Montana, 1958-1959: Montana Bur. Mines and Geology Bull. 13, 83 p.

1962, Progress report on clays and shales of Montana, 1960-1961: Montana Bur. Mines and Geology Bull. 27, 61 p.

STEWART, J. C., 1959, Geology of the Dryhead-Garvin Basin, Big Horn, and Carbon Counties, Montana: Montana Bur. Mines and Geology Spec. Pub. 17.