MARYLAND GEOLOGICAL SURVEY
REPORT OF INVESTIGATIONS NO. 4

EXPANDABLE CLAY IN ST. MARYS FORMATION OF SOUTHERN MARYLAND

By
Maxwell M. Knechtel
Howard P. Hamlin
John W. Hosterman

Prepared in cooperation with

UNITED STATES DEPARTMENT OF THE INTERIOR
Geological Survey
Bureau of Mines

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Kenneth N. Weaver, *Director*

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Abstract

Firing tests were made on clay samples representing strata of the Chesapeake Group (Miocene) found in exposures and auger borings at 24 localities in Calvert and St. Marys Counties, Maryland. Results suggest that promising sources of raw material for production of bloated, rotary-kiln-fired lightweight aggregate occur in the St. Marys Formation. The deposits sampled include bodies of bloatable clay at sites within moderate distances of populous areas wherein this type of aggregate is in growing demand. At many such sites, excavation of open pits would be feasible. The bloatable materials are composed mainly of clay shown by X-ray analyses to be made up of kaolinite, montmorillonite, and illite in approximately equal amounts. The nonclay fractions, which vary in amount from sample to sample, comprise disseminated grains of quartz, muscovite, and various heavy minerals.

Introduction

The possibility that formations of Miocene age cropping out in southern Maryland (fig. 1) might include bodies of clay that could be used as raw material for production of expanded (bloated) lightweight aggregate was investigated in reconnaissance work performed intermittently by the authors from 1958 to 1960. The investigation was administered by the Maryland Geological Survey in cooperation with two agencies of the U.S. Department of the Interior: the Geological Survey and the Bureau of Mines. The fieldwork was supervised by Knechtel. Samples of clay from strategic localities were tested under Hamlin's supervision at the Norris (Tennessee) Metallurgy Research Laboratory of the Bureau of Mines, and the mineralogy of the sampled materials was studied by Hosterman at Beltsville, Maryland.

Most of the lightweight aggregate hitherto used in and around the Washington metropolitan area for construction of large buildings, bridges, and roads has come about 100 miles by rail from a plant near Bremo Bluff, Buckingham County, Virginia. It is a bloated, rotary-kiln-fired product prepared from raw material quarried from the Arvonia Slate (Ordovician). Supplies of lightweight aggregate for consumption in Baltimore and its environs have heretofore consisted mostly of expanded slag, a byproduct of steel making at Sparrows Point. Early in 1965, however, both metropolitan areas began receiving rotary-kiln-fired lightweight aggregate from a newly constructed plant approximately 40 miles northwest of Baltimore, near Woodsboro, Frederick County, Maryland, where supplies of bloatable shale occur in strata of the Frederick Limestone (Cambrian).

The present compilation of results of the investigation in southern Maryland comprises data heretofore unpublished, as well as information that has appeared in two earlier releases (Knechtel, Hamlin, and Hosterman, 1959; Knechtel and Hosterman, 1960). It includes information on lightweight aggregate in general and on the physical properties, stratigraphy, location, and outlook for exploitation of expandable clay found by the authors in Calvert and St. Marys Counties, Maryland.

Lightweight aggregate in general

Concrete of low bulk density is used for an ever-widening variety of purposes. As a consequence, annual production of the lightweight aggregates required for preparation of such concrete has been increasing in the United States for several decades more rapidly than has the output of aggregates in general. Materials commonly used for the purpose are expanded clay, shale, and slate; expanded perlite; expanded blast-furnace slag; cinders from industrial power plants; and certain rocks of low bulk density, notably pumice and scoria. Among the lightweight aggregates in greatest demand are those prepared from expandable clay, shale, and slate, annual production of which increased sixfold between 1953 and 1963 (fig. 2). Some argillaceous materials of this

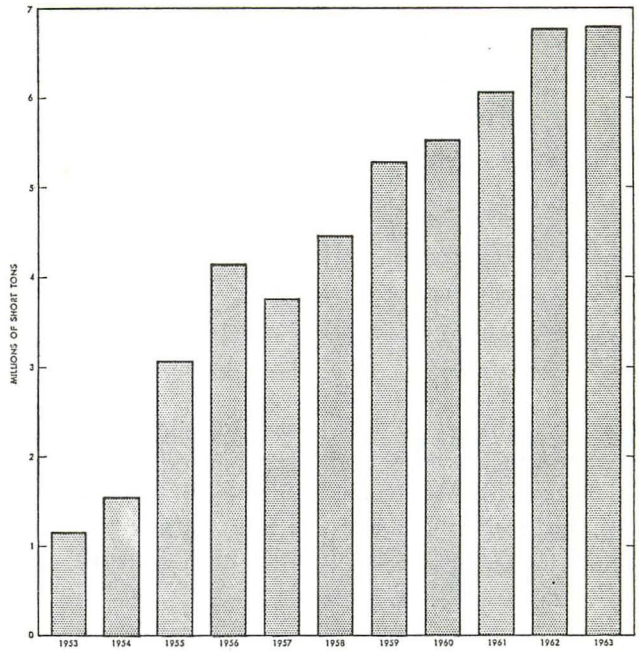
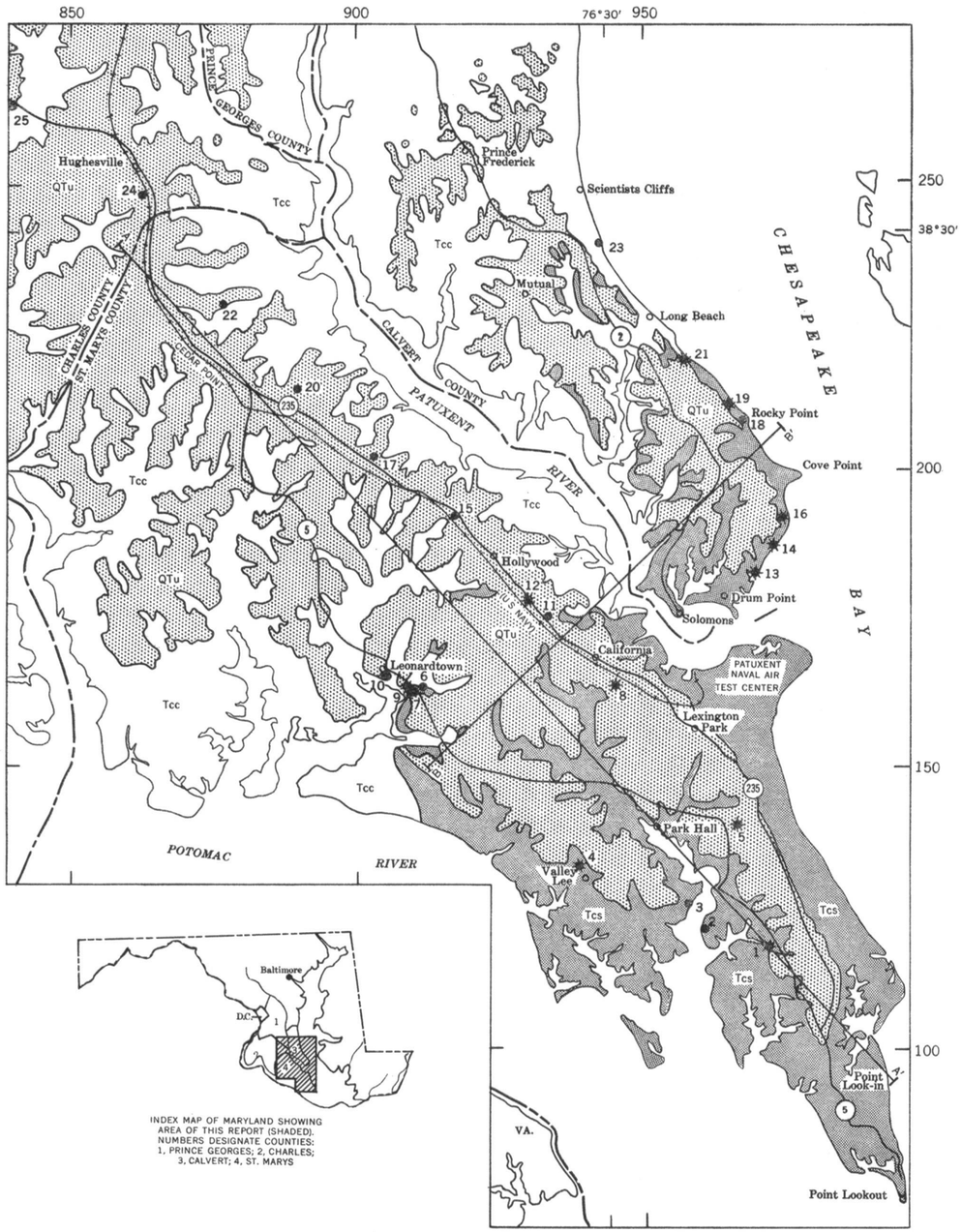
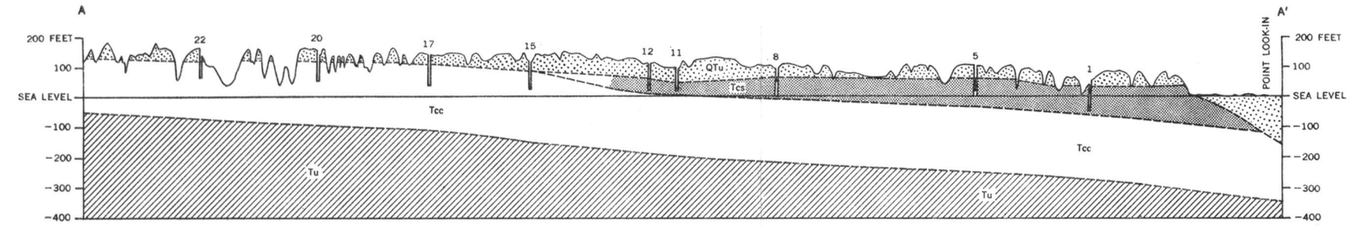


Figure 2—Clay and shale used in the United States during the period 1953-1963 for production of lightweight aggregates.

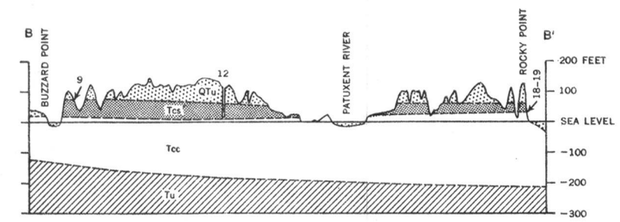
type are fired, and thereby converted into lightweight aggregate, in sintering machines and chain-grate furnaces (Myers, Pfeiffer, and Orning, 1964), but most lightweight aggregate manufactured in the United States from such raw materials is processed in plants using rotary kilns similar to those commonly used for manufacture of Portland cement (Hamlin and Templin, 1962, p. 2).

Concrete containing bloated, rotary-kiln-fired clay, shale, or slate as aggregate is increasingly used as building material for structures designed to take advantage of its low bulk density. Such material is especially favored for construction of the framework, roof, and exterior walls of large





Geologic profile showing positions, projected along line A-A′, of nine borings, in four of which expandable clay (black segments) occurs in St. Marys Formation. Vertical scale 50 times horizontal



Geologic profile showing positions, projected along line B–B′, of two exposures (arrows) of expandible clay in St. Marys Formation. Vertical scale 50 times horizontal

EXPLANATION

Miocene and younger	QTu — Sedimentary rocks, undivided	TERTIARY AND QUATERNARY	
Miocene, Chesapeake Group[1]	Tcs — St. Marys Formation	TERTIARY	
	Tcc — Calvert and Choptank Formations, undivided		
Eocene and older	Tu — Sedimentary rocks, undivided. Shown in section only	TERTIARY AND OLDER	

3 — Locality referred to in text

4 — Locality at which expandable argillaceous materials are present

[1]Covered in part by Pleistocene sand and gravel; for approximate altitudes of their contact with the Chesapeake Group in St. Marys County see Ferguson, 1953, pl. 5.

4 0 4 8 MILES

Horizontal scale of map and profiles

Figure 1—Map and profiles illustrating occurrence of expandable clay in St. Marys Formation (Miocene) of southern Maryland. (Numbered ticks at margins of map indicate the 10,000-foot State grid, omitting last three digits of numbers. Geology compiled from published maps and sections.)

buildings and for fabricating masonry units such as precast and prestressed beams, roof slabs, flooring, and firewalls. The most obviously critical property of a bloated aggregate is its lightness as compared with materials, most commonly sand and gravel, that are used in mixing conventional concrete. The unit weights (bulk densities) given in table 1 are more or less typical of materials

Table 1. Bulk densities of typical aggregates and of concretes prepared from them.

Material	Type of aggregate	Bulk density (lb/ft³)	
		Aggregate	Concrete
Gravel	Ordinary	120	150
Sand	Ordinary	90–100	150
Crushed stone	Ordinary	100	145
Slag (heavy)	Ordinary	80	110–130
Slag (expanded)	Lightweight	40–60	90–100
Clay and shale (expanded)	Lightweight	40–60	90–100
Cinders	Lightweight	40–50	110–115

used as ordinary and lightweight aggregates and of aged and cured concretes prepared from them. To be usable for mixing lightweight concrete, an aggregate should also have low water-absorption capacity, fairly uniform vesicular texture, and high compression strength.

The raw materials used for production of rotary-kiln-fired lightweight aggregate commonly differ little in their lithology from those used for manufacture of the sintered variety. But even slight mineralogical differences are apt to be critical factors in determining whether a given sampled material may be suitable for processing in rotary kilns or whether sintering can be considered a feasible alternative. Shales and clays that are used as raw materials for manufacture of sintered lightweight aggregate ordinarily do not form products of low bulk density when heated alone but must first be pulverized and mixed with coal or other fuel. When the mixture is fed to sintering devices, burning of the fuel agglutinates the incombustible particles to form a porous clinker having properties more or less comparable to those of rotary-kiln-fired lightweight aggregate. Clay, shale, or slate that will bloat satisfactorily in rotary kilns requires no such admixture of fuel. It already contains matter that volatilizes to steam or to such gases as CO_2, H_2S, SO_2, SO_3, and nitrogen oxide when the material is heated quickly to the temperature at which glass begins to form (White, 1960, p. 16). Formation of a surficial glass film or skin, enveloping each lump and confining the resulting evolution of minute bubbles within it, gives the hot, softened material its vesicular structure, thereby greatly reducing its bulk density and tending to increase its water-absorption capacity, after cooling, by an amount that depends on such factors as the average size of the vesicules and the extent to which they are interconnected.

The temperatures at which satisfactory bloated products form should, for efficient processing in rotary kilns, lie somewhere between 1800° and 2200° F. A fairly broad permissible temperature range, not less than 100°, is desirable because it tends to reduce the danger of over- or underfiring. Use of materials having smaller bloating ranges may nevertheless be feasible, provided a sufficiently constant kiln temperature can be maintained.

The time involved in "quick firing" to the temperature at which bloating occurs is ordinarily less than half an hour. It is thus only a small fraction of the average period required for "slow firing" of similar materials in stationary kilns to produce heavy ceramic wares such as common brick, drain tile, and pottery.

Tests that are performed in the Norris Metallurgy Research Laboratory for evaluation of clays, shales, and slates as prospective raw materials for production of rotary-kiln-fired lightweight aggregate have been described in detail by Hamlin and Templin (1962). A small sample of each crude material to be evaluated is subjected to preliminary experimentation, in which an electrically heated muffle kiln is used. Larger samples of materials judged to deserve further investigation are then fired in a pilot-sized rotary kiln.

The preliminary experimentation includes: investigation of such characteristics of each crude material as pH, oven-drying behavior and the effects of fragmentation with jaw and roll crushers; insertion and retention of a 20-gram specimen of each material for 15 or 20 minutes in a muffle kiln preheated to 2400° F.; repetition of this procedure for a second specimen at 2300° F. and for a sequence of five additional specimens of the same material at temperatures of

2200°, 2100°, 2000°, 1900°, and 1800° F., respectively; and determination of noteworthy acquired characteristics of each material fired, including the extent to which it may have expanded, its bulk density, and its water-absorption capacity.

Additional work on each crude material selected for further investigation includes: additional studies of physical properties; chemical and mineralogical analyses; observation of behavior in passing through a rotary kiln heated to a temperature at which the bulk density of the material was reduced, in the preliminary muffle-kiln firing, to a value somewhere between 45 and 60 pounds per cubic foot; determination of the bulk density and water-absorption capacity of the rotary-kiln-fired product, the effects of quenching immediately following discharge from the kiln, and the effects of crushing after the product has cooled; and measurement of the bulk density, water-absorption capacity, compression strength, and other noteworthy characteristics of a 2-inch steam-oven-cured or autoclave-cured cube of concrete prepared from the finished aggregate.

Geologic formations exposed in southern Maryland

The sedimentary rocks cropping out most extensively in southern Maryland belong to formations of Miocene, Pliocene (?), and Quaternary ages. They have been described by Clark and others (1904); Shattuck (1907), Miller (1907A; 1907B), Overbeck (1950; 1951), Ferguson (1953), Stephenson and MacNeil (1954), Hack (1955), and Vokes (1957).

Named in downward sequence, the formations of Miocene age are the St. Marys, Choptank, and Calvert. These three formations, which make up the Chesapeake Group as mapped and as represented in cross-section on figure 1, resemble one another lithologically and are differentiated largely on the basis of paleontological criteria. As exposed in Calvert and St. Marys Counties, they are made up of marine sand, silt, clay, and shell marl estimated to have a total thickness of 400 to 500 feet. Their geologic structure, which is broadly homoclinal, is discernible in the attitude of the strata of the lowermost formation, the Calvert, whose east-southeasterly dip ranges from about 4 feet to about 15 feet per mile (Otton, 1955, pl. 5)

In Calvert and St. Marys Counties the strata of the Chesapeake Group are exposed only where extensive overlying deposits of gravel and sand have been eroded, as in small areas along streams, in small man-made excavations such as road cuts; and in wave-cut cliffs along the Chesapeake Bay shore.

Expandable clay in the St. Marys Formation

Exploration and location

Exploration for expandable argillaceous material in strata of Miocene age cropping out in southern Maryland seemed warranted after Lodding (1956, p. 115) had reported occurrence of such material in the Kirkwood Formation (Miocene) of Salem County, New Jersey. Clay samples were accordingly obtained from the formations of the Chesapeake Group (Miocene), as exposed at 16 localities in Calvert and St. Marys Counties and as found in power-driven auger holes at 8 localities in St. Marys County and 2 localities in Charles County. The samples from all these localities (fig. 1, nos. 1-25) were investigated in the Norris (Tennessee) Metallurgy Research Laboratory of the Bureau of Mines. The clays were there evaluated with reference to the various physical properties they must possess to be usable as raw material for production of bloated, rotary-kiln-fired lightweight aggregate (Hamlin and Templin, 1962). The resulting data suggest that promising resources of such raw material occur in the St. Marys Formation. No evidence is afforded, however, of the presence of such material in the Choptank and Calvert, the two oldest formations of the Chesapeake Group of southern Maryland.

The bloatable clay deposits of Miocene age in southern Maryland all lie within 65 miles of the Capital Beltway (Interstate Highway 495) and within 100 miles of the Baltimore Beltway (Interstate Highway 695). These deposits appear to represent conveniently situated prospective sources of raw material for additional plants which will no doubt eventually be needed to satisfy the growing demand for lightweight aggregate in Baltimore, Washington, and adjacent populous areas. The product of any plant so situated could probably be delivered by truck at moderate cost to users in and near both cities. Water transport from some sites to more distant markets along the Atlantic seaboard might also be feasible.

Descriptions of deposits and experimental data

The St. Marys Formation, whose thickness ranges from about 30 to about 80 feet, crops out in the southeastern part of St. Marys County between Hollywood and Point Lookout and in the southeastern part of Calvert County between Mutual and Solomons. The formation is well exposed in the Calvert Cliffs from the neighborhood of Rocky Point southward to the mouth of the Patuxent River, but scattered exposures elsewhere in the two counties are mostly small and obscure.

The expandable material in the formation is in beds consisting largely of olive-gray silty clay or argillaceous silt, which generally has a coloration resembling, though distinctly darker than, that of similar materials abundantly present in the Choptank and Calvert Formations, most of which do not bloat appreciably in quick-fire tests. X-ray analyses of the clay fractions of numerous samples, including the analyses illustrated in figures 3 and 4, indicate that clay fractions of materials from the Choptank and Calvert Formations contain little or no kaolinite but are composed mainly of montmorillonite and illite, approximately in a 2:1 ratio. Clay fractions from the St. Marys Formation, however (fig. 3), contain kaolinite, montmorillonite, and illite approximately in a 1:1:1 ratio. In samples from all three formations of the Chesapeake Group, the nonclay fraction consists of silt- and sand-sized quartz grains, together with smaller amounts of muscovite and heavy minerals. According to Dorothy Carroll of the U.S. Geological Survey, the heavy minerals include ilmenite, tourmaline, zircon, staurolite, sillimanite, kyanite, garnet, amphiboles, epidote, chloritoid, sphene, and andalusite. Some samples contain much pyrite.

The mineralogical data suggest that the superior performance of clays from the St. Marys Formation, in the tests relating to their possible use as raw materials for production of rotary-kiln-fired lightweight aggregate, is largely due to their relatively high content of kaolinite as compared with samples from the Calvert and Choptank Formations. Because any clay consisting exclusively of montmorillonite and illite would melt at a temperature well below the range of temperatures (1800° to 2400° F.) within which the tests were performed, and because pure kaolinite would begin to melt only when heated to a temperature much higher than that range, there is reason to suppose that any material containing all three clay minerals intimately intermixed would begin melting at some temperature below the melting point of pure kaolinite but higher than that of either montmorillonite or illite. Softening within the test range, together with any possibility of satisfactory bloating, would presumably occur only in the presence of enough refractory matter to prevent melting before quick-firing has heated the clay to the lower limit of the range. The smaller proportion of kaolinite in samples from the Choptank and Calvert Formations may accordingly be largely responsible for their unsatisfactory firing behavior as compared with samples from the St. Marys Formation, which not only form products much better suited to use as lightweight aggregate, but also appear to be usable as raw materials for manufacture of common brick (table 2).

Muffle-kiln-test data

The data given in tables 3 and 4 include geologic sections of the materials observed at the source localities of samples giving favorable test results. The muffle-kiln-test data for specimens (weighing less than an ounce) of materials that expanded strongly are given in table 5. All these expandable materials occur in strata of the St. Marys Formation. At 6 of the 12 localities listed in the tables (localities 13, 14, 16, 18, 19, and 21), the expanders consist of clay in a virtually unweathered condition that is freshly exposed in wave-cut cliffs. Expanders sampled from boreholes at 4 other localities (1, 5, 8, and 12) represent comparatively fresh subsurface materials of the St. Marys Formation. Those from 2 localities (4 and 9) were obtained from small exposures of clay that has presumably been altered by weathering, with little or no damage to its capacity for expansion.

Sampled materials from the 12 localities not listed in the tables proved to be deficient in one or more of the properties tested. Those from 5 of these localities (2, 3, 6, 7, and 10) represent small exposures of the St. Marys Formation where alteration by weathering is believed sufficient to be the cause of their poor performance in the evaluation tests. Those from 6 of the 7 remaining unlisted localities (15, 17, 20, 22, 23, and 24), and possibly from the seventh (11), are materials from the Choptank and Calvert Formations. They consist of clay wherein the finely divided ($<2\mu$) fractions show a smaller content of kaolinite (fig. 4) than is indicated for clay samples from the St. Marys Formation (fig. 3).

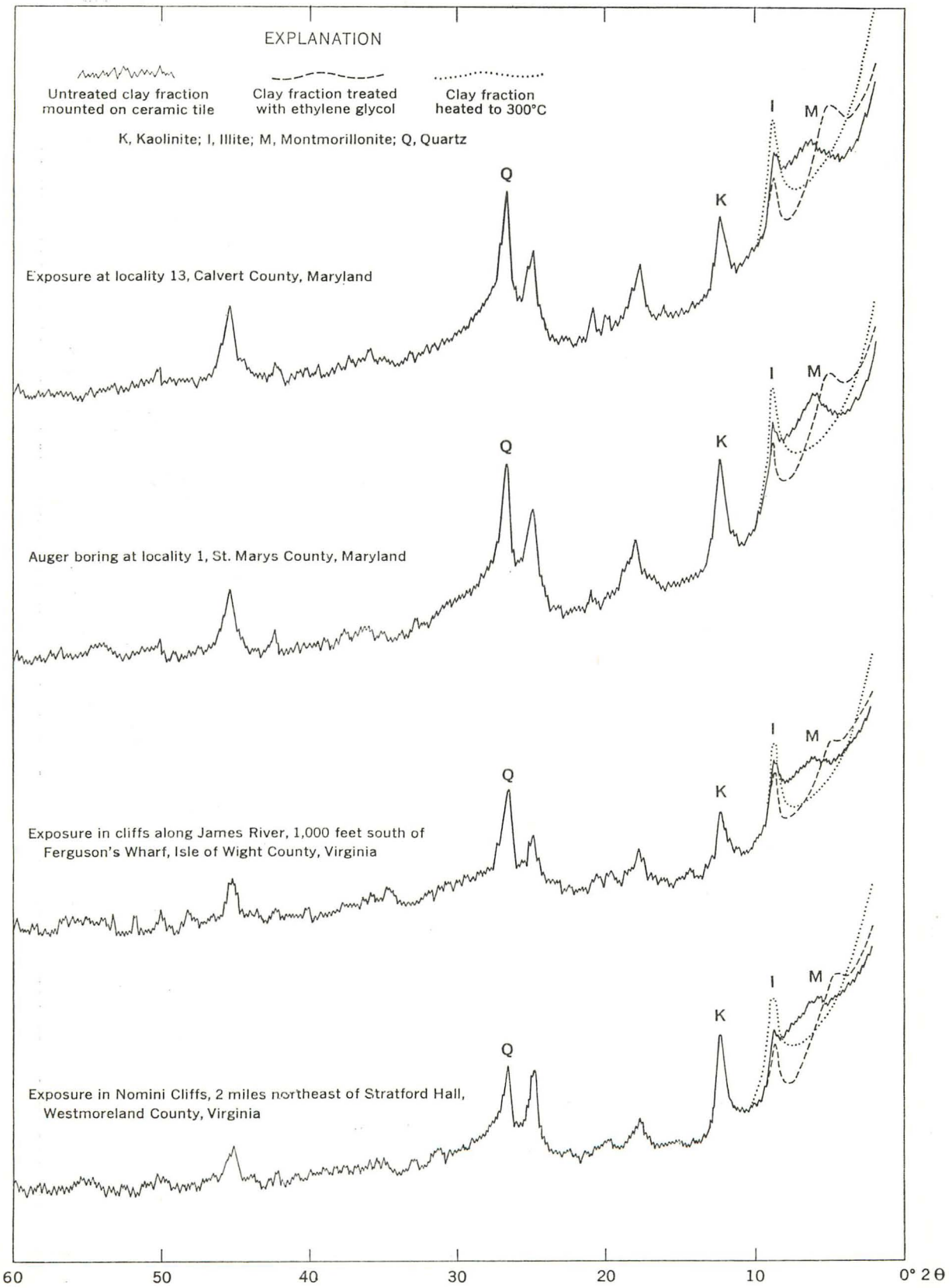


Figure 3—X-ray diffraction traces (CuKα radiation) of clay fractions of clay samples representing materials in St. Marys Formation (Miocene) of southern Maryland and eastern Virginia.

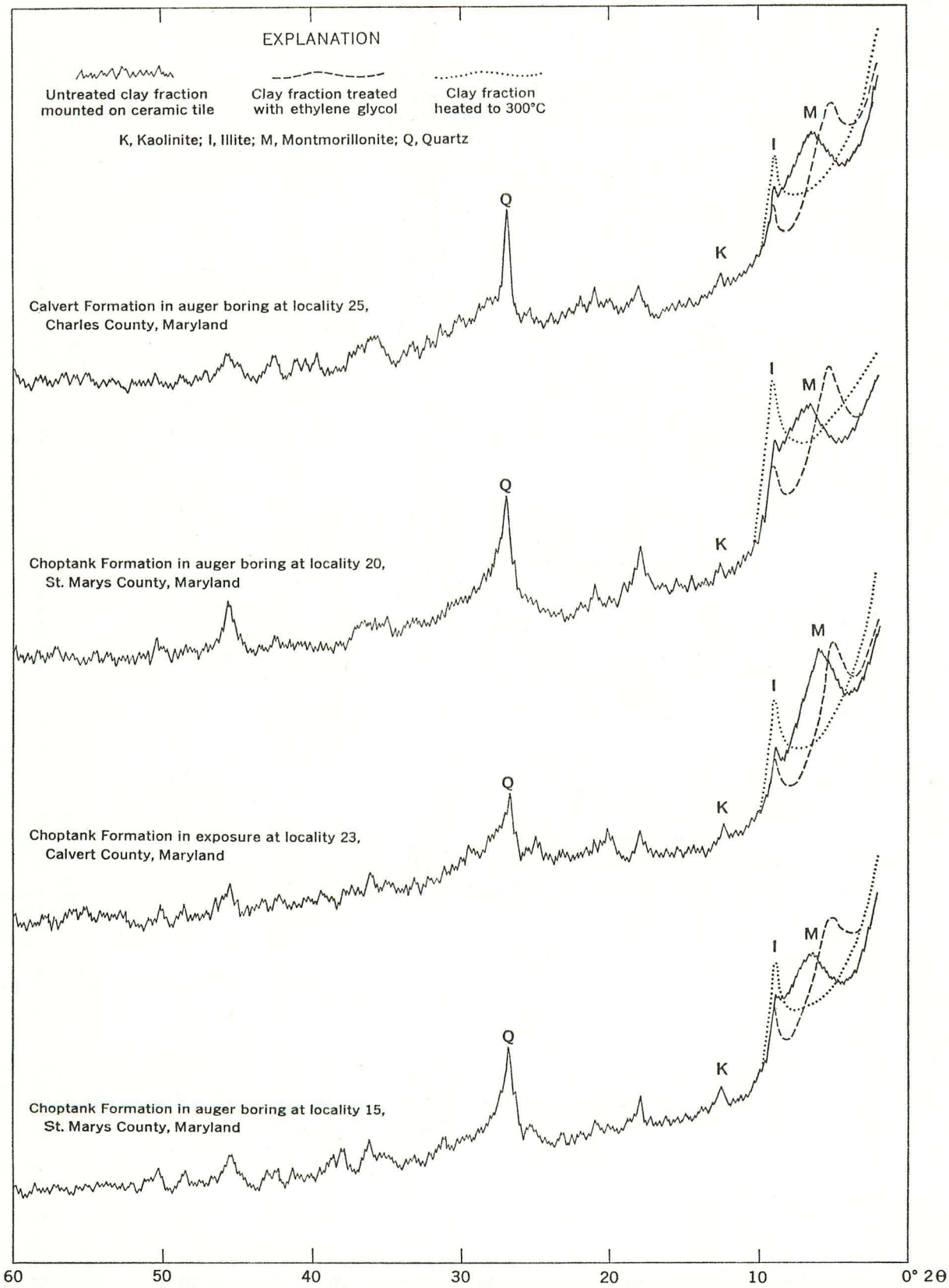


Figure 4—X-ray diffraction traces (CuKα radiation) of clay fractions of samples representing materials in Calvert and Choptank Formations (Miocene) of southern Maryland.

Table 2. Results of slow-fire muffle-kiln tests of four sampled materials listed in tables 3, 4, and 5.

Location and material sampled		Experimental data								
		Before firing			After heating to indicated temperatures					
Locality No.	USBM Lab. No.	Water added for plasticization (percent)	Plasticity	Drying shrinkage (percent)	Temperature (°F.)	Color	Hardness	Shrinkage (percent)	H_2O absorption (percent)	Specific gravity (approximate)
9	1020–K	40	G	7.5	1800	Orange red	Fairly hard	10.5	19.1	2.68
					2000	Dark red	Very hard	13.5	8.6	2.55
					2100	Reddish brown	Fairly hard	11.0	11.2	2.08
					2200	Brown	.....	Exp.[1]	.....	1.46
					2300	.....	.....	Mlt.[2]	.....	.....
13	1277–B	36	g	8.0	1800	Light red	Soft, crumbly	10.0	21.1	2.64
					2000	Medium red	Very hard	13.5	31.1	2.64
					2100	Brownish red	Steel hard	15.0	8.1	2.40
					2200	Medium brown	Steel hard	Exp.	.....	2.19
					2300	Dark brown	Steel hard	Exp.	.....	.....
					2400	.....	.....	Mlt.	.....	.....
16	1277–A	33	g	7.5	1800	Light red	Fairly hard	6.5	21.3	2.65
					2000	Medium red	Very hard	12.0	12.4	2.64
					2100	Dark rich brown	Steel hard	14.0	6.9	2.54
					2200	Dark brown	.....	Exp.	7.3	2.34
					2300	Brown, nearly black	.....	Exp.	.....	.....
21	1277–C	41	F*	6.0	1800	Light red	Soft, crumbly	6.0	31.0	2.64
					2000	Light red	Soft, crumbly	7.5	28.0	2.64
					2100	Dark brown	Soft, crumbly	11.0	24.8	2.60
					2200	Brown, nearly black	Fairly hard	11.5	18.6	2.41
					2300	Dark grayish brown	Steel hard	Exp.	20.2	2.04
					2400	Nearly black	Steel hard	Exp.	.....	1.96

*Slightly fatty and gritty
[1]Expanded
[2]Melted
g good
G very good

Table 3. Geographic and geologic data pertaining to samples from St. Marys County

Localities (Fig. 1)				Materials						
				Exposed or logged						Sampled
No.	State grid coordinates N	State grid coordinates E	Local details	Stratigraphic unit symbol**	Downward sequence	Lithology*	Thickness Ft.	Thickness In.		USBM Lab. No.
1	119	973	Near west side of Highway Md. 5; about 200 yards southwest of its junction with Villa Road. Approximately 50 feet above sea level on gently sloping hillside facing northeastward; near south side of small area mapped by Shattuck (1903) as St. Marys Formation. Power-auger boring.		1	Sand, moderate yellowish brown (10YR4/4)	19	.....		.....
				QTu	2	Sand, ferruginous	1	.....		.....
				.....	.....	..... UNCONFORMITY (?)				
					3	Clay, silty, olive gray (5Y3/1)	20	.....		1028-G
					4	Sand	10	.....		.....
					5	Silt, clayey, weak olive (5Y3/2)	5	.....		1028-F
				Tcs	6	Sand, clayey, weak olive (5Y3/2)	25	.....		1028-H
					7	Clay, silty, olive gray (5Y3/1)	20	.....		.....
4	132	939	700 feet west of Valley Lee;	.....	1	Soil cover	.....			.....
			150 feet north of Highway Md. 250; small exposure at base of steep, southeastward-facing slope northwest of Herring Creek.		2	Clay, silty, olive-gray (5Y3/1)	3	.....		1039-A
				Tcs	3	Covered				
5	141	968	0.7 mile east of Park Hall; about 200 feet south of macadam road, on east side of unimproved road; level ground about 105 feet above sea level. Power-auger boring.		1	Silt, clayey, strong yellowish brown (10YR5/8)	4	.....		.....
					2	Sand, silty, clayey, moderate yellowish brown (10YR5/6)	6	.....		.....
				QTu	3	Sand, clayey, moderate yellowish brown (10YR5/4)	2	.....		.....
					4	Sand, moderate yellowish brown (10YR5/6)	8	.....		.....
					5	Sand, moderate yellowish brown (10YR5/6)	25	.....		.....
				.....	.....	..... UNCONFORMITY (?)				
					6	Clay, silty, dusky olive (5Y2/2)	22	.....		1028-J
					7	Sand, silty, clayey, olive gray (5Y3/1)	18	.....		1028-K
				Tcs	8	Sand, silty clayey, olive black (5Y2/1)	15	.....		.....
					9	Covered.				
8	165	945	500 yards north of Ebenezer Church; east side of Chancellors Run Road, just north of small stream crossing; about 95 feet above sea level. Power-auger boring.	.....	1	Soil cover	2	.....		.....
					2	Sand and gravel, moderate olive (2.2Y4/4)	6	.....		.....
				QTu	3	Sand, strong yellowish brown (10YR5/8)	22	.....		.....
				.....	.....	..... UNCONFORMITY (?)				
					4	Sand, silty, clayey, olive gray (5Y3/1)	12	.....		1028-A
				Tcs	5	Sand, silty, clayey, olive gray (5Y3/1)	23	.....		.....
					6	Sand, silty, clayey, olive gray (5Y3/1)	15	.....		.....
					7	Sand, silty, clayey, dusky olive (5Y2/2)	10	.....		.....
9	166	908	1,500 yards southeast of Leonardtown; St. Marys Formation exposed on grass-covered hillside on southwest side of Highway Md. 5; 0.2 mile NW of junction of Highway 471 (St. Andrews Road) which leads to plant of Southern Concrete Co., and Leonardtown Sand and Gravel Co. 0.3 mile northwest of bridge across Glebe Run; about 40 feet above sea level.	.....	1	Soil cover	.....			.....
					2	Clay, silty, olive gray (5Y3/1)	.....	6		1020-K
				Tcs	3	Clay, silty, light olive brown (2.5)	5	.....		.....
				.....	.....	.....				
					4	Covered	.....			.....
12	179	930	2 miles southeast of Hollywood; 1 mile southeast of St. John School; northeast side of Highway Md. 235; level ground; about 110 feet above sea level. Power-auger boring.		1	Sand, gravelly, moderate yellowish brown (10YR4/4)	7	.....		.....
					2	Sand, moderate yellowish brown (10YR5/4)	6	.....		.....
				QTu	3	Sand, light olive brown (2.5Y5/4)	22	.....		.....
					4	Sand, light olive brown (2.5Y5/6)	20	.....		.....
				.....	.....	..... UNCONFORMITY (?)				
					5	Clay, silty, olive gray (5Y3/1)	20	.....		1028-D
				Tcs	6	Clay, silty, olive gray (5Y3/1)	20	.....		.....
					7	Sand, clayey, weak olive (5Y3/2)	5	.....		.....

*Color notations are those of the Munsell system: hue (e.g., 5Y) is followed by value/chroma (e.g., 5/6).
**Symbols are same as in Figure 1.

Table 4. Geographic and geologic data pertaining to samples from Calvert County

Localities (Fig. 1)				Materials					
				Exposed or logged					Sampled
No.	State grid coordinates N	State grid coordinates E	Local details	Stratigraphic unit symbol**	Downward sequence	Lithology*	Thickness Ft.	Thickness In.	USBM Lab. No.
13	184	970	Exposure in high cliff along Chesapeake Bay shore 1½ miles northeast of Drum Point lighthouse; 300 yards northeast of mouth of Fresh Creek.	QTu	1	Sand, in part clayey and silty, and conglomerate; most beds rusty brown	20+		
						UNCONFORMITY (?)			
				Tcs	2	Clay, very sandy, gray	12		
					3	Coquina, rusty with small *Turritellas* and other Molluscs	2		
					4	Clay, silty, a few small *Turritellas*	4		
					5	Coquina, containing abundant small *Turritellas*		6	
					6	Clay, silty, weak olive (5Y3/2)	17		1025-B; 1277-B
					7	Covered (below tide level)			
14	188	973	Exposure in high cliff along Chesapeake Bay shore 1 mile southwest of Little Cove Point; about 300 yards southwest of Calam's Run.	QTu	1	Sand, in part clayey and silty, and conglomerate, most beds rusty brown	40+		
						UNCONFORMITY (?)			
				Tcs	2	Clay, silty, containing a few fossils	8		
					3	Coquina, containing small *Turritellas* and other molluscs in rusty clay matrix	4		
					4	Clay, silty, containing a few *Turritellas*	4		
					5	Coquina, containing small *Turritellas* in rusty clay matrix		6	
					6	Clay, silty, weak olive (5Y3/2)	15		1025-A
					7	Covered by beach sand			
16	195	975	Exposure in high cliff along Chesapeake Bay shore, 1.35 miles south of Cove Point lighthouse; 350 yards south of mouth of Purgatory Creek.	QTu	1	Loam, sand and gravel, yellowish brown	60		
					2	Gravel, fine-grained, indurated rusty brown	2		
						UNCONFORMITY (?)			
				Tcs	3	Clay, silty, olive gray (5Y3/1)	22		958-A; 1277-A
					4	Coquina, containing mostly *Turritellas*		6	
					5	Clay, silty	8		
					6	Clay, silty containing layers of calcareous fossils	17		
					7	Covered by beach sand			
18	211	968	Exposure in high cliff along Chesapeake Bay shore. 2.5 miles northwest of Cove Point lighthouse; about 500 yards southeast of Point of Rocks.	QTu	1	Gravel, sand and clay; rusty brown	25+		
						UNCONFORMITY (?)			
				Tcs	2	Clay, silty, olive gray (5Y3/1)	12		1059-D
					3	Sand, clayey, rusty	4		
				Tcc	4	Marl, calcareous; abundant molluscan shells	15		
					5	Covered by beach sand			
19	213	966	Exposure in high cliff along Chesapeake Bay shore. 3 miles northwest of Cove Point lighthouse; 500 yards northwest of Point of Rocks.	QTu	1	Conglomerate, sand and clay, rusty brown	70+		
						UNCONFORMITY (?)	20		1059-B
				Tcs	2	Clay, sandy, silty, olive-gray	4		
					3	Sand, clayey, rusty			
				Tcc	4	Marl, calcareous; abundant molluscan shells	24		
					5	Covered by beach sand			
21	221	958	Exposure in high cliff along Chesapeake Bay shore. 1.85 miles southeast of Long Beach; 0.8 mile southeast of Flag Ponds fish-wharf.	QTu	1	Gravel, sand and loam; rusty	12+		
						UNCONFORMITY (?)			
				Tcs	2	Clay, silty, thin-bedded; many molluscan shells	14		
					3	Silt, clayey, weak olive (7.5Y4/2)	20		1059-C; 1277-C
				Tcc	4	Clay, sandy; abundant molluscan shells	23		
					5	Covered by beach sand			

*Color notations are those of the Munsell system: hue (e.g., 5Y) is followed by value/chroma (e.g., 5/6).
**Symbols are same as in Figure 1.

Table 5. Results of 15-minute muffle-kiln tests of sampled materials listed in tables 3 and 4.

Location		Sampled material	Experimental data																					Comments
			Before firing			After firing 15 minutes in muffle kiln at indicated temperatures																		
						1900°F			2000°			2100°			2200°			2300°					
County	Locality No.	USBM. Lab. No.	pH	Drying behavior	Crushing behavior	Expansion	Bulk density (lb/ft³)	Water absorption (percent)	Expansion	Bulk density (lb/ft³)	Water absorption (percent)	Expansion	Bulk density (lb/ft³)	Water absorption (percent)	Expansion	Bulk density (lb/ft³)	Water absorption (percent)	Expansion	Bulk density (lb/ft³)	Water absorption (percent)	Tentative evaluation		
St. Marys	1	1028-G		g	g	N	89.7	15.8	S	68.5	18.1	A	50.5	20.8	X†	28.7	32.4	X†	24.9	36.0	g		
		1028-F		g	g	N	105.3	13.0	A	62.3	18.1	A	53.0	16.0	X†	43.6	22.6	X†	48.6	17.0	E		
		1028-H		g	F	N	113.3	10.0	N	103.4	8.7	S	86.0	9.9	a	62.3	12.2	X†	54.8	12.2	F		
	4	1039-A		g	P				N	84.7	17.6	S	77.9	14.6	a	57.3	16.3	X	48.0	15.0	F		
	5	1028-J		F	g	N	82.2	15.3	N	76.6	13.4	A	55.4	15.9	X*	38.0	18.9	X	24.9	27.9	g	Product at 2100° strong; absorption low.	
		1028-K		F	g	N	95.9	14.2	N	85.4	13.4	a	64.8	15.7	X*	46.7	17.3	X†	39.9	17.2	g	Bloating range short; product at 2100° somewhat fragile.	
	8	1028-A		g	F	N	90.3	17.1	N	90.3	14.8	M	65.4	28.2	a	41.7	19.6	X†	26.8	35.4	g		
	9	1020-K		F	g	N	100.9	13.3	M	79.1	20.8	a	52.3	30.3	a	53.6	22.8	X	34.3	20.3	g	For further data see table 2.	
	12	1028-D		g	g				N	101.5	10.7	S	77.9	12.4	M	63.5	12.3	g*	45.5	12.8	F	Product at 2200° strong; absorption low.	
Calvert	13	1025-B		g	g	N	83.5	11.2	a	67.3	10.8	A	54.8	9.2	A	44.9	10.3	X	31.8	13.3	E		
		1277-B	5.5			N	85.4	13.9	M	72.3	12.9	E	49.2	12.8	X†						E	For further data see tables 2 and 6.	
	14	1025-A		g	g	N	88.5	10.8	M	77.9	9.2	A	48.6	8.2	A	47.3	10.6	X†	36.1	20.0	E		
	16	958-A		g	g	N	89.7	15.0	N	81.0	16.0	M	66.6	16.6	a	53.6	17.3	X†	33.0	24.9	E	For concrete evaluation test data see p. 14.	
		1277-A	3.5	g	g	N	90.3	13.8	M	81.6	13.9	E	44.9	20.4	X†						E	For further data see tables 2 and 6.	
		1059-D		g	g	N	92.8	22.0	N	89.1	22.5	N	87.2	22.6	S	72.3	16.0	S	62.3	9.8	U		
	19	1059-B		g	F	N	86.0	17.1	N	87.2	14.7	E	56.1	24.1	a	38.6	26.0	E†	33.6	27.6	g	Product at 2100° strong.	
	21	1059-C	3.5		E	N	96.6	13.7	N	84.7	16.8	E	59.8	20.4	E	38.0	33.5	X†	26.8	26.7	E	Expansion uniform; products at 2100° and 2200° strong; bloating range long.	
		1277-C	6.7	g	F	N	84.7	27.8	S	80.4	26.0	a	53.0	21.8	X*	55.4	35.0	X†	66.7		G	For further data see tables 2 and 6.	

Abbreviations and symbols

Expansion

N Negligible
S Slight
M Moderate
a Adequate
A Ample
X Excessive (overbloated)

Other

* Sticky to slaggy at temperature indicated

† Sticky to slaggy at temperature indicated; cooled product fragile

U Unsuitable
P Poor
F Fair
g Good
G Very good
E Excellent

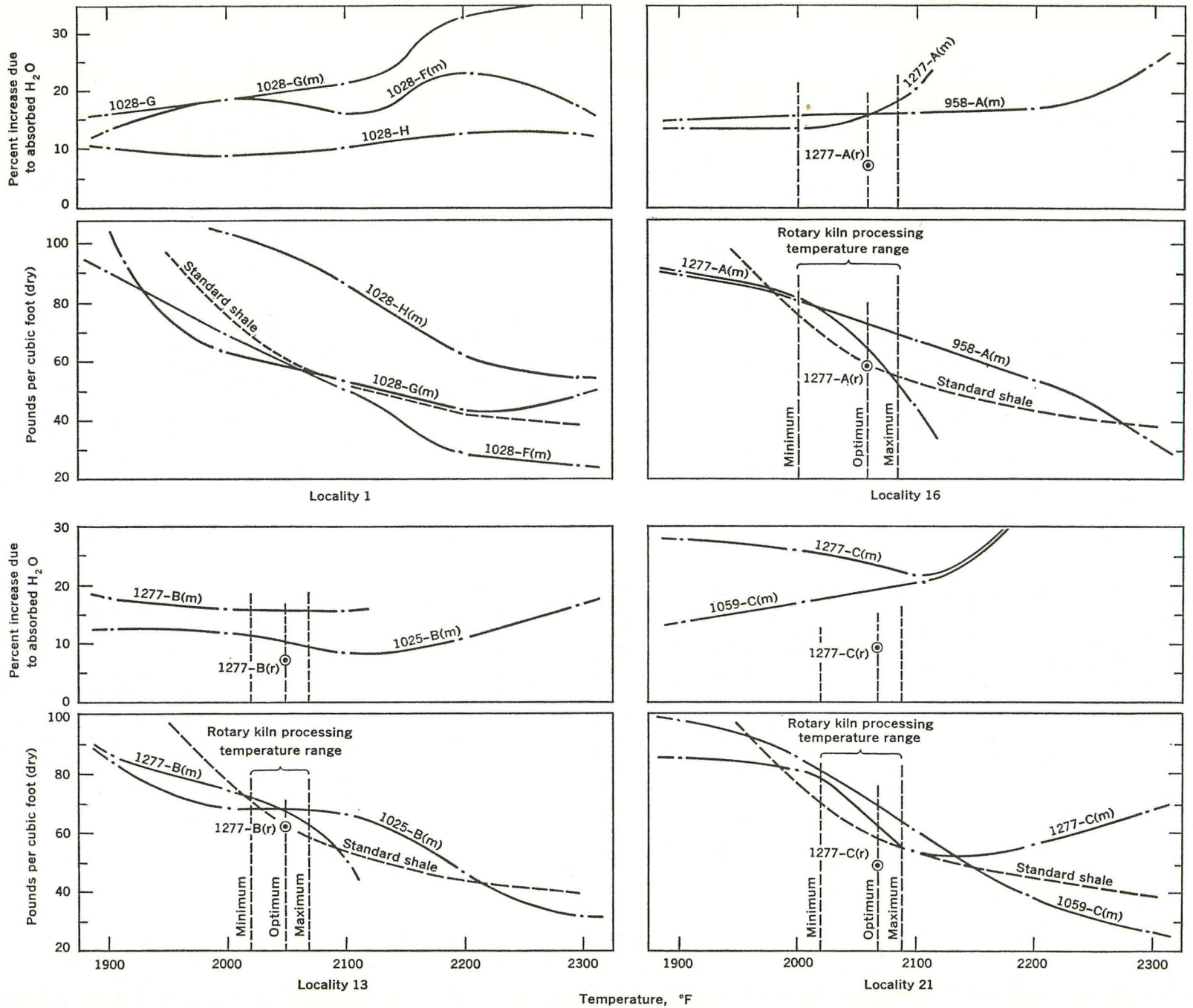


Figure 5—Diagrams showing bulk density and water-absorption capacity of products formed at temperatures between 1900° and 2300° F. in muffle-kiln (m) and rotary-kiln (r) tests of sampled materials (table 5) taken from St. Marys Formation (Miocene) at localities 1, 13, 16, and 21.

Some of the bloated products that formed in the muffle kiln at temperatures between 2000° and 2200° F. are comparable in lightness and low water-absorption capacity to many of the best commercial aggregates produced in the United States. Curves representing bulk density and water-absorption for several clay samples (m) from the St. Marys Formation are shown on figure 5; also shown, for comparison, are "standard shale" bulk density curves copied from diagrams by Hamlin and Templin (1962, p. 8, 9). Each of the curves shown represents a muffle-kiln firing test of a specimen weighing less than an ounce.

The bulk density, 86.3 pounds per cubic foot, of small concrete cubes prepared from bloated material that formed in one of two muffle-kiln firing tests of clay of the St. Marys Formation from locality 16 (table 4; U.S. Bur. Mines Lab. No. 958-A), is less than the bulk density of much concrete made from lightweight aggregates. The compression strength of the cubes, 3,500 pounds per square inch, surpasses the requirements of most specifications for lightweight concrete. Their 48-hour water-absorption capacity, 21.3 percent, is higher than that of most such concrete. This percentage, however, as indicated by data on another sample of clay from the same locality (tables 5 and 6; U.S. Bur. Mines Lab. No. 1277-A), would no doubt have been much lower, and hence much more favorable, if the aggregate from which the cubes were prepared had formed in a rotary kiln.

Rotary-kiln-test data

Large samples (U.S. Bur. Mines Lab. Nos. 1277-A, B, and C) of materials that bloated well in the preliminary muffle-kiln firing tests of smaller samples were subsequently obtained from three of the most accessible exposures (localities 16, 13, and 21 respectively) along the Chesapeake Bay shore in Calvert County. The results of rotary-kiln firing tests of these samples, using batches weighing many pounds for each test, are given in table 6 and figure 5. For use as lightweight aggregate, the quality of all three rotary-kiln-fired products is judged to be highly satisfactory; this is true especially of the bloated material prepared from Lab. No. 1277-B. The cellular structure of all three products is notably uniform as seen in cross section, and their water-absorption capacity, ranging from 7.2 to 9.4 percent of their weight, is much lower than that recorded in the preliminary muffle-kiln firing tests of the same three materials (fig. 5).

Procurement of comparably large samples at other localities was not feasible in the time and with the facilities at our disposal. In order to resample all the other bloatable materials reported in table 5, several relatively inaccessible exposures would have to be revisited, and sufficiently large samples of the promising materials logged in several boreholes could be obtained only by further drilling or by sinking shafts. The data given in the tables accordingly permit only a tentative evaluation of such materials, except those exposed at localities 13, 16, and 19. It is nevertheless the authors' opinion that most, if not all of the small samples that behaved well in the muffle-kiln-firing tests represent prospective deposits of good raw material for production of rotary-kiln-fired lightweight aggregate.

Plotted on the composition diagram (fig. 6) are percentages, calculated from chemical analyses

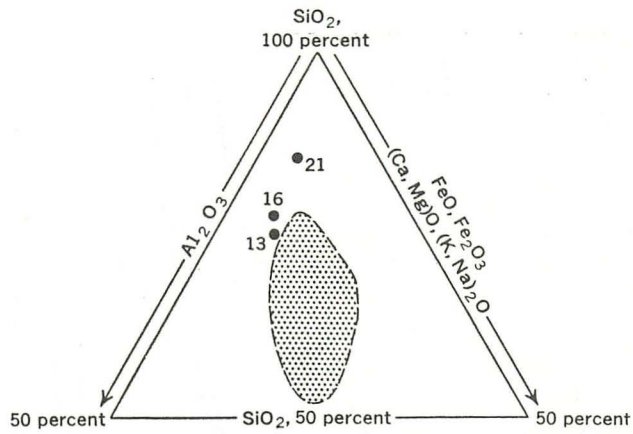


Figure 6—Composition diagram showing proportions of major oxides reported in chemical analyses (table 6) of three bloatable materials from Calvert County, Maryland. Shaded area embraces proportions of same oxides as plotted by Riley (1951, p. 123, fig. 1) for numerous bloatable materials.

(table 6), representing the relative proportions of silica, alumina, and fluxing agents in the three raw materials tested in the rotary kiln, all of which bloated satisfactorily. Also shown is the "area of bloating" defined by Riley (1951, p. 123, fig. 1) on the basis of numerous analyses of argillaceous materials, including bloaters and non-bloaters. The diagram reveals that the total percentage of fluxing constituents (FeO, Fe_2O_3, etc.) in all three Calvert County materials and the per-

Table 6. Physical properties, chemical analyses, and results of rotary-kiln firing tests of samples of clay from three localities in Calvert County (Preliminary firing test results and field data on samples from same localities are given in tables 2, 4, and 5. Analyses by personnel of Norris Metallurgy Research Laboratory.)

Localities	13	16	21
USBM Lab. Nos.	1277-B	1277-A	1277-C
Raw materials:			
Weight (lb/ft³)	70.0	70.0	68.2
Strength	Above average	Above average	Average
Crushing characteristics	Excellent	Good	Fair
Workability	Plastic, smooth	Plastic, smooth	Fairly plastic, smooth
H_2O needed for plasticity (percent)	36	33	41
Drying shrinkage (percent)	8.0	7.5	6.0
Drying defects	None	None	None
Screen analysis (sizes):			
-¾ ½	14.55	10.00	6.1
-½ ¼	48.00	38.00	40.2
-¼ 8M	12.50	14.50	14.3
-8M	25.00	37.30	39.4
TOTAL	100.05	100.00	100.0
Chemical analysis:			
SiO_2	65.77	69.51	76.38
Al_2O_3	15.70	14.66	9.09
Fe_2O_3	0.76	0.64	0.78
FeO	1.93	1.67	0.88
TiO_2	0.95	1.00	0.80
CaO	0.63	0.04	1.00
MgO	0.85	0.98	0.82
Na_2O	0.32	0.28	0.28
K_2O	2.04	2.00	1.40
P_2O_5	0.05	0.07	0.08
S*	(1.97)	(1.31)	(1.15)
SO_3	0.95	0.44	0.34
C*	(0.18)	(0.36)	(0.60)
CO_2*	(Trace)	(0.50)	(0.62)
H_2O loss:			
-140°C*	(2.79)	(2.37)	(2.87)
1100°C	8.94	7.72	6.43
S[1]	1.59	1.13	1.01
C[2]	.....	(0.22)	(0.43)
TOTAL	100.48	100.14	99.29
Fired products:			
Weight (lb/ft³, ASTM method)	50.0	53.0	50.0
Weight (lb/ft³)	61.7	59.2	63.0
Water absorption (percent)	7.2	7.3	9.4
Effect of quenching	Deleterious	Deleterious	Deleterious
Screening analysis, ⅜″ crush:			
½	4.6	3.0	1.3
-½ ⅜	29.3	23.3	21.3
-⅜ ¼	48.4	44.2	56.3
-¼ 8M	12.4	20.6	15.7
-8M 65M	3.5	6.7	3.2
-65 (Pressing	1.7	2.2	2.3
	99.9	100.0	100.1
Kiln temperatures (°F)			
Maximum	2070	2085	2090
Minimum	2020	2000	2020
Optimum	2050	2060	2070

*Not in total
[1]S not soluble
[2]C not CO_2

centage of alumina in the bloater from locality 21 are lower than in any of the bloaters studied by Riley. The percentages of silica in all his materials, nonbloaters as well as bloaters, are shown on his diagram as lower than the percentage reported in table 6 for the material from locality 21.

Prospective open-pit mining sites

As the surface of much of southern Maryland is somewhat hilly, prospective sites for open-pit mining excavations are more numerous here than in areas of less relief, such as the counties of Maryland east of Chesapeake Bay, which are more typical of the Atlantic Coastal Plain. Many such sites in parts of Calvert and St. Marys Counties that are underlain by the St. Marys Formation seem to deserve consideration as potential sources of raw material for lightweight aggregate production. The clay that is of interest in this connection is more than 20 feet thick in all the source localities of samples that bloated satisfactorily when tested, but, as shown in tables 3 and 4, its thickness and that of its overburden vary from place to place. As shown in tables 5 and 6, its capacity for expansion is also notably variable.

In some localities, particularly along the Chesapeake Bay shore in Calvert County, the lowermost expandable material that crops out is partly submerged at high tide, whereas the highest such material found in the boreholes at localities 8 and 12, in St. Marys County, is approximately 65 feet above sea level. Expandable clay probably occurs at still higher elevations in and adjacent to some of the benchlands that occupy considerable parts of both counties and that locally stand more than 160 feet above sea level. A thick bed of expandable clay, resting on shell marl of the Choptank Formation, occurs in the lower part of the St. Marys Formation of localities 18, 19, and 21, and a clay that behaves in nearly identical fashion in quick-firing tests occurs in the basal strata of the St. Marys Formation as exposed in the Nomini Cliffs, along the south shore of the Potomac River 2 miles northeast of Stratford Hall, Westmoreland County, Virginia (Stephenson and MacNeil, 1954, p. 735). The southeastward dip of the stratum thus defined brings its base from about 25 feet above sea level at localities 21 and 19 to sea level between localities 18 and 16 and to more than 50 feet below sea level at locality 1 (fig. 1).

In most areas, the St. Marys Formation is thickly covered by younger sedimentary material,

largely gravel, sand, and silt. As represented on figure 1, such cover comprises deposits of Tertiary and Quaternary age capping extensive upland terraces, which are more or less centrally located within St. Marys and Calvert Counties, and deposits occupying lowlands bordering on Chesapeake Bay and the Potomac and Patuxent Rivers. In the lowlands of St. Marys County, the cover has been shown by Ferguson (1953, pl. 5) to be material of Pleistocene age that is largely below sea level. Obviously, no prospective sites for mining the expandable clay occur where the St. Marys Formation is so deeply buried. At many sites, however, the formation is well exposed, and at numerous others it is covered by overburden sufficiently light to make strip-mining possible. At locality 1 (fig. 1) for example, the expandable clay at the bottom of the borehole is obviously too deep to permit open-pit mining, but comparable material from the part of the hole above sea level is relatively accessible and could perhaps be mined at a profit.

The St. Marys Formation is unusually well exposed along the Chesapeake Bay shore between Drum Point and Scientists Cliffs. Elsewhere it is only slightly less accessible, as at numerous points along the marginal escarpments of alluvium-capped terraces. Within such upland areas, as indicated in the profiles (fig. 1) and as noted in the upper parts of the geologic sections (tables 3 and 4), the formation is covered by thick deposits of gravel and sand. For example, the section measured by boring with the auger at locality 5 (table 3) shows 45 feet of sand (QTu) resting unconformably on argillaceous bedrock of the St. Marys Formation. The overburden in the vicinity of this boring and at localities 8 and 12 is thus exceedingly thick. As illustrated in the profile along line A-A', however, the uppermost argillaceous material in the borehole at locality 1 is nearer the surface. Here and at numerous comparable sites in St. Marys and Calvert Counties, the St. Marys Formation could no doubt be uncovered at small cost by digging through a light cover of soil and hillside debris. Many such sites occur along the sloping sides of stream courses like those shown in cross section beween localities 1 and 8.

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[1]The name of this agency changed to Maryland Geological Survey in June 1964.