Survey of Lightweight Aggregate Materials of Mississippi

GEOLOGY
William S. Parks

ECONOMICS
Clyde A. McLeod

TESTS
Allan G. Wehr

BULLETIN 103

MISSISSIPPI GEOLOGICAL, ECONOMIC AND
TOPOGRAPHICAL SURVEY
FREDERIC F. MELLEN
Director and State Geologist

This Bulletin is the result of cooperative work between the Mississippi Geological, Economic & Topographical Survey and the

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RESEARCH COMMISSION
ROBERT FULTON DYE
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JACKSON, MISSISSIPPI
1964

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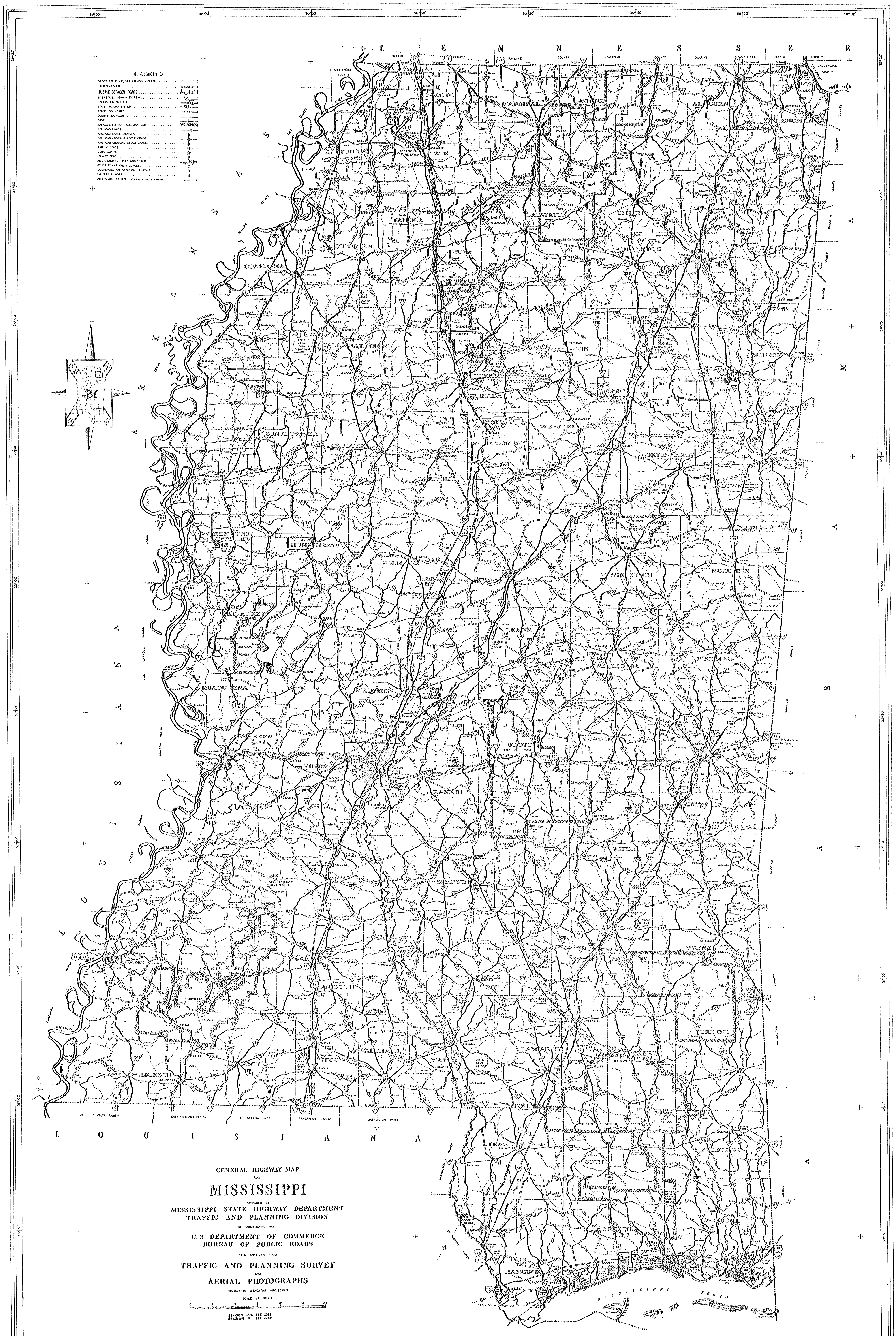
FREDRIC F. MELLEN, DIRECTOR

BULLETIN 103
PLATE 1



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STATE OF MISSISSIPPI

Hon. Paul B. Johnson .... Governor

MISSISSIPPI GEOLOGICAL, ECONOMIC AND TOPOGRAPHICAL SURVEY BOARD

STAFF

LETTER OF TRANSMITTAL

Jackson, Mississippi

June 30, 1964

Mr. Henry N. Toler, Chairman,
and Members of the Board,
Mississippi Geological, Economic & Topographical Survey

Mr. Harvey Lee Morrison, Vice Chairman
and Members of the Commission,
Mississippi Industrial & Technological Research Commission

Gentlemen:

It is our pleasure to hand you the manuscript entitled "Survey of Lightweight Aggregate Materials of Mississippi." This has been approved for publication as Bulletin 103 of the Geological Survey.

This report is the result of a cooperative study between our two agencies as approved by the Boards. It has been executed under the joint administrative supervision of the directors of these agencies and has, in fact, been a combined team effort of the two staffs.

This report is in three parts. The first deals with the geology of the raw materials and the method by which the selection of the materials was determined. The second part is concerned with the economics of the lightweight aggregate industry. The third part summarizes the testing of the materials. Together, the three parts give an objective picture of the raw materials, the quality of their aggregates, and the prospects for additional use of expanded clay aggregates in Mississippi.

In addition to the continuous efforts of our staffs, the Research Commission contracted with the Department of Metallurgical and Ceramic Engineering at Mississippi State University for making tests on the raw materials and for preparing the report on "Tests." The Mississippi State Chemical Laboratory through the cooperation of State Chemist M. P. Etheredge made eighteen detailed chemical analyses of clay samples, without charge to the project. The remaining six clays were analyzed by a commercial laboratory. The value of these data are lasting and continuing, far beyond their immediate application in evaluating the bloated characteristics of the expanded clay samples. They give accurate chemical compositions of thick deposits of clays of carefully determined stratigraphic and geographic positions within the State. These are data which can be utilized in the decades and centuries to come in the comparative study of our resources and in the development of additional capacity for old products, and in the discovery and development of new ones.

As a final phase in the testing, steel drums of 16 samples were shipped to the U. S. Bureau of Mines Norris Metallurgy Research Laboratory at Norris, Tennessee for firing in a rotary test kiln and additional tests on the aggregates. Arrangements for this work were negotiated by Mr. Robert S. Sanford, Director, U. S. B. M. Area IV with Mr. Frank Lamb, Research Director, U. S. Bureau of Mines, as Mississippi and Tennessee are in different Areas. These services were rendered to the State of Mississippi without charge and we wish to add a special note of appreciation here to the Bureau for this cooperation and for the prompt, efficient, and courteous services rendered by M. V. Denny, Physical Research Scientist, and Norman A. Pace, Project Coordinator.

It is usual that a project report such as this is followed by a long period of waiting—for the data to be circulated, read, assimilated, and then to be utilized through the construction of a new industrial plant. We are optimistic that the data presented in the pages that follow will lead to the establishment of new aggregate capacity in Mississippi in the very near future. This optimism is based upon the following facts:

1. Steady inquiry from within the construction industry for information on the bloatable clays or other lightweight aggregate materials in Mississippi.

2. The statistical growth of the lightweight aggregate industry as pointed out in the section on "Economics," brought about by (a) the improvement of the products, (b) the development of new uses of the products, and (c) the enlarging market caused by the population growth.

3. The favorable results of this study in respect to: (a) wide distribution of clays suitable for lightweight aggregate, (b) great thicknesses of the deposits, (c) favorable transportation, fuel and labor supply, and (d) a variation in quality of aggregates which can be made, thereby giving a degree of selectivity to the producer.

From our library research of the past seven months, during which hundreds of reports have been studied, we are convinced that no State has surveyed its lightweight aggregate resources and produced a more comprehensive report than ours. This, we are sure, is our final and strongest reason for believing that new lightweight aggregate capacity will be developed within the State in the very near future. **Without qualified research, publication of new data, and distribution of effective reports we cannot stand high in the competitive market for new industry.** This "Survey of Lightweight Aggregate Materials of Mississippi" meets that standard. The 3-pronged spear of research-publication-distribution should prove to be the most effective weapon of the "Third Plateau."*

Finally, the co-directors wish to express their appreciations to each member of the two Boards for the patience, understanding and confidence that has been manifest throughout the study. The Members of

*The new "Commerce" portion of Governor Johnson's AIC (Agriculture, Industry, and Commerce) program.

the Survey Board are elsewhere listed, but we make special acknowledgment of the Members of the Research Commission which organization, created in 1960, will be succeeded on July 1, 1964 by the Mississippi Research and Development Center; these are:

The Mississippi Industrial and Technological
Research Commission

Dr. Ben F. Hilbun, Sr., Chairman (Nov. 14, 1890-Dec.13, 1963)
Mr. H. L. Morrison, Vice Chairman
Dr. A. V. Beacham
Mr. M. M. Crisler
Dr. W. C. Flewellen, Jr.
Dr. C. R. Sayre
Mr. Boswell Stevens
Dr. A. E. Wood

The co-directors humbly and sincerely trust that this report comes up to the expectations of your Boards, of the Mississippi Administration, of the Public and of Industry. Work on this project, now concluded, has been a welcome challenge to us.

As is inevitable, the studies made during this investigation did not come up with all the answers. Parallel and divergent lines of investigation have suggested themselves and can be pursued in the future if needed. An example is further experimentation with the blending of clays to develop satisfactory bloating in non-bloating clays with minimal addition of other materials.

Many individuals over the State assisted our field party, newspapers gave publicity to the work, and people in industry gave information and advice as the work developed. To these fine citizens of Mississippi we are grateful.

Respectfully submitted,

Robert F. Dye, Ph.D.,
Director
Mississippi Industrial and Technological Research Commission

Frederic F. Mellen, M.S.
Director & State Geologist
Mississippi Geological, Economic and Topographical Survey

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GEOLOGY

WILLIAM S. PARKS

ABSTRACT

Heretofore there has been no State-wide survey of materials in Mississippi suitable for making lightweight aggregates. A review of previously published ceramic tests shows that samples of clay from many of the geologic units bloated when fired to temperatures within the range of lightweight aggregate materials.

The materials sampled during the present study were selected on the basis of previous testing and of various economic considerations. They are from the Ripley, Porters Creek, Zilpha, Yazoo, Bucatunna, Hattiesburg, Pascagoula and Graham Ferry formations and from the Loess and Alluvium. A total of 24 composite samples, chiefly clays, were taken by coring.

At present the Miss-Lite Division of Jackson Ready-Mix Concrete is the only producer of lightweight aggregate in Mississippi. The plant is located at Cynthia, Hinds County, near Jackson. The aggregate is made by expanding Yazoo clay in a rotary kiln.

INTRODUCTION

This report is a reconnaissance investigation of certain materials in Mississippi that may have possibilities for use, among other things, in the manufacture of expanded lightweight concrete aggregate. A lightweight concrete aggregate as defined by Wilson[1] is "... any inert material which, when bound together by cement, forms concrete of unit weight significantly less than of concrete incorporating conventional aggregate. The unit weight of lightweight structural concrete is 90 to 110 lb./cu. ft., and of conventional structural concrete, 140 to 150 lb./cu. ft."

Lightweight aggregate materials may be classed in three general groups, according to their sources: (1) naturally occurring—pumice, volcanic cinders, breccia, scoria, tuff and diatomite; (2) by-product—air-cooled slag, cinders and coke breeze; and (3) manufactured or specially processed—expanded clay, shale or slate, expanded slag, exfoliated vermiculite and perlite. In Mississippi there are no naturally-occurring lightweight aggregate materials of significance nor by-product materials in any quantity. Of the manufactured or specially processed aggregates, the only native materials available for processing are clays and shales. Clays, which vary widely in mineralogical and chemical composition and in purity, are abundant in the State.

However, not all clays meet the requirements for lightweight aggregate raw materials.

There are two principal commercial processes by which a clay or shale is made into lightweight aggregate—by rotary kiln and by sintering. In the rotary kiln method the clay or shale must bloat without the addition of a bloating agent; in the sintering method a bloating agent is added in the process. The present study is primarily concerned with those materials that require no addition of a bloating agent and, therefore, are especially suited to the rotary kiln method. In the rotary kiln process, a clay or shale is heated rapidly to incipient fusion and then cooled rapidly. In order that a lightweight aggregate be produced the material must bloat at nearly the same temperature as fusion begins. The generally accepted maximum temperature for commercial production of expanded lightweight aggregate is 2400°F. However, most commercial materials bloat between 2000 and 2200°F.

Published information available on the various aspects of expanded lightweight aggregates is abundant. Articles dealing with the industry, commercial practices in the manufacture, lightweight aggregate materials, experimental work and testing procedures, the theories of bloating, properties of lightweight aggregate concrete, etc., are published in many trade and professional journals and in the reports of various Federal and State agencies. A bibliography selected from those articles and reports that were found to be most informative is given in the section entitled "Selected Bibliography of Lightweight Aggregate Materials."

PREVIOUS INVESTIGATIONS

Heretofore there has been no State-wide survey of materials suitable for use in making lightweight aggregates. However, during the routine testing conducted in conjunction with the preparation of several of the Mississippi Geological Survey's county reports, it was recognized that certain materials, when fired, have properties which indicate that they have possibilities as lightweight aggregate materials.

The first study of lightweight aggregate materials in Mississippi was conducted as a part of the regular survey of Tippah

County and was published in 1940 in Bulletin 42, "Tippah County Mineral Resources." This preliminary investigation showed that the Porters Creek clay, when fired and crushed, makes a unique lightweight aggregate. As a continuation of this work, Bulletin 61, "Light-weight Aggregate," was prepared and published in 1945. This report gives the results of further testing of the Porters Creek clay as a fired lightweight aggregate and a discussion of its application in insulating concrete, concrete block, mortar, and plaster. Bulletin 61 also includes a parallel study of the Basic City claystone as a lightweight insulating aggregate. It was determined that the lightweight quality of both the Porters Creek clay and the Basic City claystone is attributed to their porous structure which is not appreciably affected by drying and burning. That is, their loss of water on drying and burning is not accompanied by a corresponding volume shrinkage. Samples from only two areas were tested—the Porters Creek clay from a locality in Tippah County and the Basic City claystone from a locality in Lafayette County.

The publication of Bulletins 42 and 61 resulted in private interests making their own investigations of the lightweight aggregate possibilities of the Porters Creek clay in Tippah County. From these studies it was concluded that this aggregate is not desirable for use in concrete products because of its absorptiveness and its salmon color. However, these properties that condemned it for use in concrete make it desirable as a fired granular aggregate to be used as an industrial absorbent. Since the publication of Bulletins 42 and 61, Howell-Southern Products, Inc. and Wyandotte Chemical Corporation have established plants in Tippah County producing this product. It should be emphasized, however, that **this lightweight clay aggregate is not an expanded or bloated lightweight clay aggregate—the object of the present testing program.**

More important to the present investigation is the fact that previous testing shows that certain clays have a tendency to bloat or expand when fired to temperatures in the range of expanded lightweight aggregate. This was first recognized during the testing of the Porters Creek and Ackerman clays from Winston County in conjunction with the preparation of Bulletin 38, "Winston County Mineral Resources," published in 1939. Bulletin 38 includes a discussion of the possibilities of these clays as lightweight aggregate materials and of the scope of the lightweight aggregate industry.

Generally, previous testing is inadequate and inconclusive, but it does provide important data as to the bloatable materials in the State. For example, the results of testing the Yazoo clay that were published in Bulletin 39, "Yazoo County Mineral Resources," and in Bulletin 49, "Scott County," provided basic information that led directly to an investigation of the Yazoo clay as a lightweight aggregate material and the establishment of the Jackson Ready-Mix Concrete plant at Cynthia, Hinds County. Because of the importance of previous tests in determining materials to be sampled, they are summarized in the section entitled "Summary of Previous Ceramic Tests."

SUMMARY OF PREVIOUS CERAMIC TESTS

A review of previously published ceramic tests included in the Survey's county reports provides some information as to the bloatable materials in the State. Eighteen of these reports contain original ceramic testing data. In order that these data may be more readily available for further study of lightweight aggregate materials, they are summarized in Table 1.

In compiling the Table, the geological classification of materials by previous authors was followed when practical, but it was necessary to re-classify some. Colluvium, highly weathered bedrock, and materials of doubtful classification are included under Miscellaneous and Unclassified.

TABLE 1

SUMMARY OF PREVIOUS TESTING SHOWING BLOATING MATERIALS

Geologic unit	County	No. of samples tested	No. of bloating samples	Bloating samples	Bloating temperature °F	Chemical analysis available	Reference to bloating samples (M.G.S. Bull. and Page Nos.)
Tuscaloosa	Itawamba	24	1	R52(1)	2,003	yes	64, 134,137,138.
	Monroe	35	5	P39(2)	2,282	no	57, 197.
				P42(1)	2,345	yes	57, 183,186.
				P50(OC1)	2,345	no	57, 186.
				P50(2)	2,345	yes	57, 183,186.
				P71(2)	2,003	no	57, 189,191,193.
Eutaw	Monroe	1	1	P55(1)	2,003	no	57, 191,193.
Selma	Monroe	12	0	------	-----	---	--------
	Clay	2	1	M35(3)	2,174	yes	53, 73,74,75,76.
Ripley	Union	9	0	------	-----	---	--------
	Pontotoc	4	1	N178(2)	2,057	no	54, 126,127
Porters Creek	Tippah	13	2	A171(C5)	2,057	no	42, 186.
				A263(C2)	2,282	no	42, 182.
	Union	6	0	------	-----	---	--------
	Pontotoc	32	10	N24(2-3)	1,976	no	54, 125.
				N70(2-3)	1,976	no	54, 125.
				N82(7)	2,390	yes	54, 93,94.
				N210(3)	2,174	no	54, 94.
				N212(1-2)	2,030	no	54, 125.
				N216(6)	2,237	no	54, 94.

				N216(7)	2,030	no	54, 125.
				N233(2-6)	2,075	no	54, 125.
				N243(4)	2,129	no	54, 94.
	Clay	15	2	M55(3)	2,129	yes	53, 75,76.
				M332(5)	2,030	no	53, 77.
	Winston	2	1	53AP1	2,057	yes	38, 140,144.
	Lauderdale	2	2	B50P1	2,030	no	41, 179.
				B50SP1	2,030	no	41, 179.
Naheola	Lauderdale	9	2	B71P2	2,174	no	41, 184.
				B87P1	2,174	no	41, 184.
Betheden	Tippah	89	0	-----	-----	---	--------
	Benton	32	0	-----	-----	---	--------
	Union	16	0	-----	-----	---	--------
	Pontotoc	21	1	N199(1)	2,534	yes	54, 96,97.
	Winston	11	0	-----	-----	---	--------
Fearn Springs	Tippah	6	0	-----	-----	---	--------
	Benton	25	4	A66(3.8-12.2')	2,282	no	42, 139.
				D39(7.1-21.2')	2,534	no	45, 115.
				D43(C1)	2,534	no	45, 115.
				D260(3.1-27.0')	2,534	no	45, 116.
	Union	3	0	-----	-----	---	--------
	Pontotoc	12	1	N192(1)	2,174	no	54, 94.
	Winston	14	0	-----	-----	---	--------
	Lauderdale	34	11	B1AP7	2,390	no	41, 206.
				B1AP8	2,300	no	41, 206.
				B1AP9	2,534	no	41, 206.
				B2P1	2,390	no	41, 206.
				B14P1	2,237	no	41, 206.
				B48P1	2,534	no	41, 208.
				B77P2	2,174	no	41, 209.
				B77P3	2,129	no	41, 209.
				B78P2	2,534	no	41, 210.
				B80P1	2,534	no	41, 210.
				B83P1	2,237	no	41, 210.

Ackerman	Tippah	16	0	-----	-----	---	--------
	Pontotoc	3	1	N288(3)	2,534	yes	54, 97.
	Choctaw	28	15	K1(3)	2,057	no	52, 144.
				K4(1)	2,345	yes	52, 125,127.
				K4(2)	2,057	no	52, 144.
				K7(3)	2,057	no	52, 144.
				K11(2)	2,057	yes	52, 143,144.
				K11(3)	2,057	no	52, 144.
				K16(3)	2,345	no	52, 136.
				K18(1)	2,345	yes	52, 135,136.
				K18(2)	2,057	no	52, 144.
				K63(1)	2,210	yes	52, 125,127.
				K63(2)	2,093	no	52, 144.
				K63(3)	2,093	no	52, 144.
				K64(1)	2,057	yes	52, 143,145.
				K74(2)	2,003	no	52, 145.
				K75(1)	2,345	yes	52, 125,128.
	Winston	9	5	18P2	2,093	yes	38, 140,144.
				20P1	2,156	yes	38, 140,144.
				20P2	2,057	yes	38, 140,144.
				20P3	2,093	yes	38, 140,144.
				57P1	2,210	yes	38, 140,144.
	Lauderdale	11	4	B63P1	2,300	no	41, 218.
				B85P1	2,534	no	41, 218.
				B86P1	2,174	no	41, 218.
				B86P2	2,300	no	41, 219.
"Holly Springs"	Montgomery	27	8	L85(4-5-6)	2,030	no	51, 101.
				L180(14-15-16)	2,300	yes	51, 84,85.
				L185(10)	2,237	yes	51, 93,94.
				L186(5)	2,300	yes	51, 84,86.
				L191(5-6)	2,300	no	51, 95.
				L193(2-3-4)	2,300	no	51, 86.
				L193(5)	2,300	no	51, 95.
				L235(2)	2,300	no	51, 95.

	Choctaw	27	11	K13(2)	2,057	no	52, 144.
				K26(1)	2,057	yes	52, 143,144.
				K34(1-2)	2,345	no	52, 127.
				K40(1)	2,057	no	52, 144.
				K71(1)	2,345	no	52, 127.
				K80(1)	2,210	no	52, 138.
				K87(1)	2,057	no	52, 145.
				K101(1)	2,345	yes	52, 126,128.
				K101(2-3)	2,345	no	52, 139.
				K112(2)	2,093	no	52, 145.
				K121(1)	2,345	yes	52, 126,129.
	Lauderdale	17	10	B93P1	2,030	no	41, 230.
				B93P2	2,030	no	41, 230.
				B98P2	2,030	no	41, 230.
				B109P1	2,534	no	41, 230.
				B110P1	2,129	no	41, 230.
				B121P1	2,534	no	41, 231.
				B250P1	2,210	no	41, 231.
				B260P1	2,210	no	41, 231.
				B262P2	2,129	no	41, 231.
				B263P2	2,210	no	41, 231.
Hatchetigbee	Attala	4	4	AE-1(12-33)	2,381	no	99, 100.
				AE-2(12-32)	2,185	no	99, 102.
				AE-5(4-10)	2,381	no	99, 112.
				AE-5(18-38)	2,381	no	99, 114.
	Winston	1	1	173P1	2,570	yes	38, 155.
Tallahatta	Montgomery	7	0	-----	-----	---	--------
	Choctaw	2	1	K36(1)	2,345	no	52, 137.
	Lauderdale	1	0	-----	-----	---	--------
Zilpha	Tallahatchie	76	2	H100(7-12)	2,534	no	50, 132.
				H115(1-3)	2,534	no	50, 136.
	Montgomery	8	0	-----	-----	---	--------
	Carroll	3	2	L22(3)	2,300	no	51, 90.
				L25(3)	2,300	yes	51, 89,90.

	Attala	2	2	AE-3(6-28')	2,200	yes	99, 104,105.
				AE-6(13-22')	2,381(2,200)	no	99, 116.
Kosciusko	Attala	3	1	AE-7(5-9;13-23')	2,381	no	99, 121.
Wautubbee (Lisbon)	Scott	4	1	J106(4)	2,129	no	49, 120.
Cockfield (Yegua)	Scott	5	1	J100P3	2,282	no	49, 115.
	Yazoo	2	0	-----	-----	---	--------
Yazoo	Scott	11	1	J85(2)	2,003	no	49, 120.
	Yazoo	53	20	C2(C1)	2,300	no	39, 82.
				C2(C3)	2,129	no	39, 82.
				C2(C5)	1,922	no	39, 82.
				C2(C8)	1,922	no	39, 82.
				C3(C1)	2,129	no	39, 83.
				C3(C2)	2,174	no	39, 83.
				C3(C5)	2,129	no	39, 83.
				C3(C8)	2,129	no	39, 83.
				C3(C9)	2,129	no	39, 83.
				C3(C10)	2,129	no	39, 83.
				C4(C1)	1,922	no	39, 84.
				C4(C2)	1,922	no	39, 84.
				C4(C3)	1,922	no	39, 84.
				C4(C9)	1,922	no	39, 84.
				C5(C2)	1,922	no	39, 85.
				C5(C3)	1,922	no	39, 85.
				C5(C6)	2,174	no	39, 85.
				C13(C1)	2,129	no	39, 87.
				C13 (C2)	2,129	no	39, 87.
				C13(C4)	2,174	no	39, 87.
Forest Hill	Scott	6	0	-----	-----	---	--------
Glendon (bentonite)	Yazoo	3	0	-----	-----	---	--------

Byram (Bucatunna)	Warren	2	2	E1(3.2-36.5')	2,093	yes	43, 92,93.
				E21P1(14.7-23.0')	2,003	yes	43, 92,93.
Hattiesburg	Forrest	39	13	F1(1.0-40.5')	2,390	no	44, 72.
				F3(7.5-63.0')	2,390	no	44, 72.
				F14AP1(4.8-44.8')	2,390	yes	44, 71,72.
				F47(11.1-45.1')	2,390	no	44, 72.
				F121AP1(10.4-30.1')	2,300	no	44, 64.
				F162(0.9-43.7')	2,300	no	44, 65.
				F164P2(37.5-53.0')	2,300	no	44, 65.
				F165(10.1-49.2')	2,390	no	44, 74.
				F167P1(0.2-63.9')	2,534	no	44, 80.
				F169(0.7-31.5')	2,300	yes	44, 63,65.
				F170(0.9-44.7')	2,390	no	44, 74.
				F171P1(0.8-49.5')	2,300	no	44, 65.
				F181P1(1.8-42.5')	2,390	yes	44, 71,75.
Pascagoula	Forrest	4	0	-----	-----	---	--------
	Adams	45	8	G16(1)	2,534	no	47, 149.
				G33(1)	2,534	no	47, 150.
				G35(1)	2,345	yes	47, 148,151.
				G39(1)	2,534	no	47, 151.
				G41(1)	2,534	no	47, 151.
				G42(1)	2,534	yes	47, 148,151.
				G90(1)	2,534	no	47, 155.
				G91(3)	2,534	no	47, 155.
Citronelle	Scott	10	0	-----	-----	---	--------
	Forrest	1	0	-----	-----	---	--------
	Adams	3	1	G114(1)	2,534	no	47, 157.
Loess	Yazoo	37	1	C24(C2)	2,300	no	39, 115.
	Warren	2	0	-----	-----	---	--------
	Adams	1	0	-----	-----	---	--------

Terrace	Itawamba	1	0	-----	-----	---	--------
	Clay	2	0	-----	-----	---	--------
	Scott	1	0	-----	-----	---	--------
	Forrest	4	0	-----	-----	---	--------
Alluvium	Union	8	0	-----	-----	---	--------
	Clay	1	0	-----	-----	---	--------
	Scott	1	0	-----	-----	---	--------
	Yazoo	10	9	C6(C1)	1,922		39, 119,120.
				C6(C2)	2,300	C6(C1,C2,C3)	39, 119,120.
				C6(C3)	2,300		39, 119,120.
				C7(C1)	1,922	no	39, 120.
				C7(C2)	2,075	no	39, 120.
				C7(C3)	2,075	no	39, 120.
				C40(C1)	1,922	no	39, 121.
				C40(C2)	1,922	no	39, 121.
				C43(C2)	2,300	no	39, 121.
	Warren	1	1	E52P1(7.8-23.2')	2,003	yes	43, 92,93.
	Forrest	1	0	-----	-----	---	--------
Miscellaneous & Unclassified	Prentiss	2	0	-----	-----	---	--------
	Tippah	3	2	A171(c4)	2,156	no	42, 177.
				A171(4.2-34.0')	2,282	no	42, 177.
	Benton	4	0	-----	-----	---	--------
	Union	5	0	-----	-----	---	--------
	Forrest	2	0	-----	-----	---	--------

Specific references to the actual testing data for the bloating samples are included in the Table as Bulletin and page numbers. The available chemical analyses of the samples that bloated below 2400°F, the maximum temperature for commercial production of expanded lightweight aggregates, are given in the section entitled "Chemical Analyses As Related to Bloating."

Of 947 samples fired through a range of temperatures, 172 or about 18 percent bloated, but only 148 or about 16 percent bloated in the range of lightweight aggregate materials (below 2400°F). All tests were made by slow firing under oxidizing kiln conditions.

Mississippi Geological Survey Bulletins containing original ceramic testing data are as follows:

38. Winston County Mineral Resources: Geology by F. F. Mellen and Tests by T. E. McCutcheon, 169 pp., 1939.
39. Yazoo County Mineral Resources: Geology by F. F. Mellen and Tests by T. E. McCutcheon, 132 pp., 1940.
41. Lauderdale County Mineral Resources: Geology by V. M. Foster and Tests by T. E. McCutcheon, 246 pp., 1940.
42. Tippah County Mineral Resources: Geology by L. C. Conant and Tests by T. E. McCutcheon, 228 pp., 1941.
43. Warren County Mineral Resources: Geology by F. F. Mellen; Tests—Clays by T. E. McCutcheon; Tests—Marls and Limestone by M. R. Livingston, 140 pp., 1941.
44. Forrest County Mineral Resources: Geology by V. M. Foster and Tests by T. E. McCutcheon, 87 pp., 1941.
45. Union County Mineral Resources: Geology by L. C. Conant and Tests by T. E. McCutcheon, 158 pp., 1942.
47. Adams County Mineral Resources: Geology by F. E. Vestal and Tests by T. E. McCutcheon, 200 pp., 1942.
49. Scott County: Geology by H. R. Berquist; Tests by T. E. McCutcheon; Fossils by H. R. Bergquist, 136 and 146 pp., 1942.
50. Tallahatchie County Mineral Resources: Geology by R. R. Priddy and Tests by T. E. McCutcheon, 157 pp., 1942.
51. Montgomery County Mineral Resources: Geology by R. R. Priddy and Tests by T. E. McCutcheon, 116 pp., 1943.
52. Choctaw County Mineral Resources: Geology by F. E. Vestal and Tests by T. E. McCutcheon, 156 pp., 1943.
53. Clay County: Geology by H. R. Bergquist; Tests by T. E. McCutcheon; Fossils by V. H. Kline, 91 and 99 pp., 1943.

54. Pontotoc County Mineral Resources: Geology by R. R. Priddy and Tests by T. E. McCutcheon, 139 pp., 1943.

57. Monroe County Mineral Resources: Geology by F. E. Vestal and Tests by T. E. McCutcheon, 217 pp., 1943.

64. Itawamba County Mineral Resources: Geology by F. E. Vestal and Tests by H. J. Knollman, 151 pp., 1947.

87. Prentiss County Geology: W. S. Parks. Groundwater Resources: B. E. Ellison and E. H. Boswell, 110 and 44 pp., 1960.

99. Attala County Mineral Resources: Surface Geology by W. S. Parks, Ceramic Tests by T. E. McCutcheon, Subsurface Geology by W. H. Moore, and Water Resources by B. E. Wasson, 192 pp., 1963.

SAMPLING CONSIDERATIONS

For the purpose of establishing general sampling areas, several geographic regions of probable best market potential were outlined on the basis of population centers and of the locations of existing lightweight aggregate plants. The four general areas selected are (1) the coastal region, (2) the "Delta", (3) the northeast Mississippi region, and (4) the Jackson area. The Jackson area is not considered of immediate importance because there is a lightweight aggregate plant in that vicinity.

For most of the probable market regions previously published ceramic tests were found either to be lacking or to show more or less negative results. Therefore, the selection of some materials for testing was made solely on the basis of geographic location. However, in order to have good representation of possible lightweight aggregate materials, other samplings were made in areas outlying the probable market regions. The general locations of the core holes drilled for sampling are shown in Figure 1. Some bloatable materials of previous testing were eliminated from the present program because it was thought that the samples represented only small local deposits or that the possibility of finding large deposits of acceptable material is unlikely.

Important factors determining the actual sampling sites are (1) apparent or actual thickness and/or extensiveness of the deposit, (2) nearness to rail transportation, (3) proximity of a natural gas supply, (4) topography, and (5) overburden. A summary of the more pertinent data concerning the various sampling localities is given in Table 2.

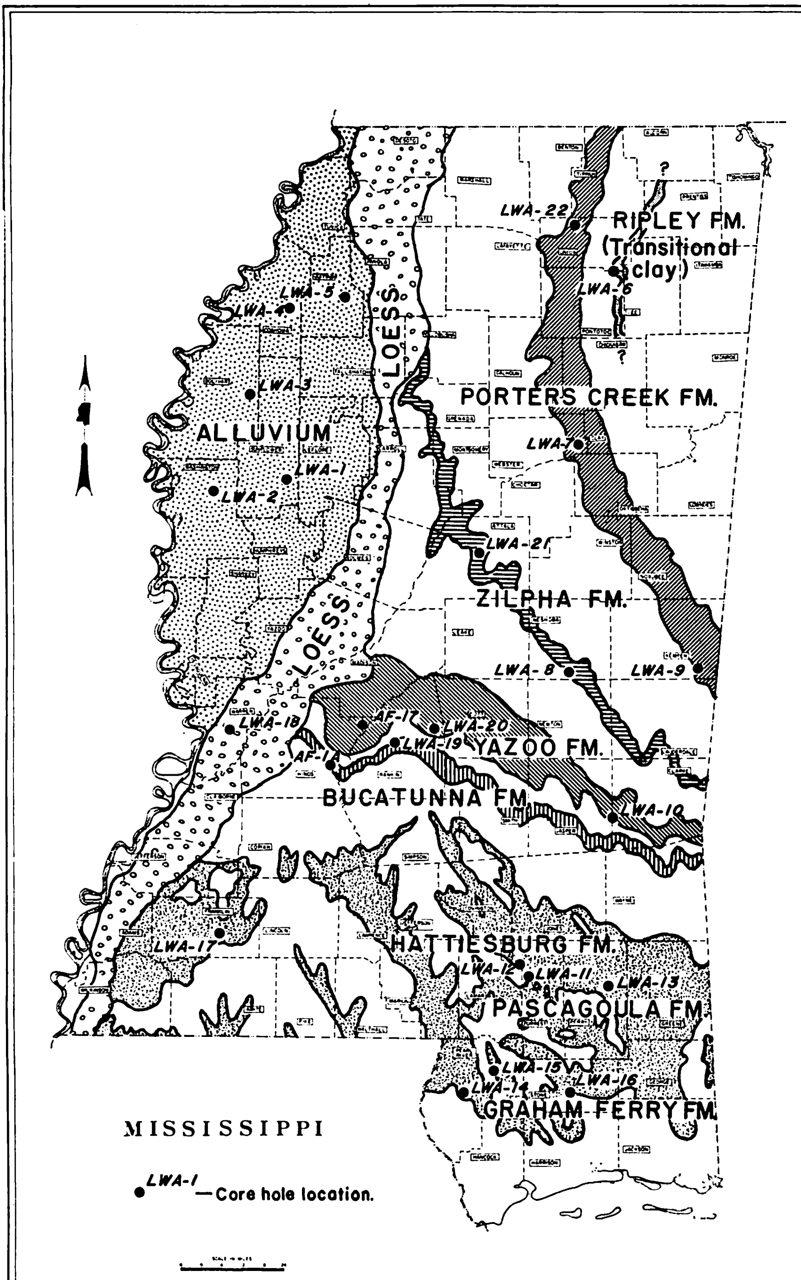

Figure 1.—Map showing distribution of units sampled and locations of core holes.

TABLE 2

SAMPLING LOCALITIES DATA

Core Hole No.	County	Nearest town or community	Distance from town (air miles)	Nearest* Railroad	Distance from R.R. (air miles)	Nearest** Gas Line	Distance from G.L. (air miles)	Geologic unit sampled
LWA-1	Sunflower	Moorhead	1/2	C.&G.	0	M.V.G.	1	Alluvium
LWA-2	Washington	Leland	1-1/2	I.C.	0	T.G.	1	Alluvium
LWA-3	Bolivar	Cleveland	2	I.C.	3/4	A.-L.P.L.	1/2	Alluvium
LWA-4	Coahoma	Clarksdale	2	I.C.	1/4	Texas G.T.	1	Alluvium
LWA-5	Quitman	Marks	1/2	I.C.	3/4	A.-L.P.L.	1-1/2	Alluvium
LWA-6	Union	Sherman	1/2	S.L.&S.F.	1	C.G.T.	10-1/4	Ripley
LWA-7	Webster	Maben	3	C.&G.	1-1/4	T.E.T.	3	Porters Creek
LWA-8	Neshoba	Union	1	G.M.&O.	1/2	U.G.P.L.	3/4	Zilpha
LWA-9	Kemper	Enondale	1	G.M.&O.	1	Tenn. G.T.	10	Porters Creek
LWA-10	Clarke	Vossburg	2	N.O.&N.E.	1/2	U.G.P.L.	1	Yazoo
LWA-11	Forrest	Hattiesburg	1/4	N.O.&N.E.	1/4	U.G.P.L.	5	Hattiesburg
LWA-12	Lamar	Hattiesburg	1/4	M.C.	0	U.G.P.L.	2	Hattiesburg
LWA-13	Perry	Beaumont	1/2	B.&H.S.	1/2	U.G.P.L.	8	Hattiesburg

LWA-14	Pearl River	Millard	1-1/4	N.O.&N.E.	0	U.G.P.L.	9	Graham Ferry
LWA-15	Pearl River	Poplarville	1	N.O.&N.E.	1-1/2	U.G.P.L.	1-1/2	Pascagoula
LWA-16	Stone	Perry	1/2	I.C.	1/2	U.G.P.L.	9	Graham Ferry
LWA-17	Franklin	Bude	1-1/4	M.C.	1-1/2	T.E.T.	2-1/4	Pascagoula
LWA-18	Warren	Bovina	1/2	I.C.	1/2	U.G.P.L.	4-1/2	Loess
LWA-19	Rankin	Brandon	1/4	I.C.	1/4	U.G.P.L.	1/2	Bucatunna
LWA-20	Rankin	Pelahatchie	1-3/4	I.C.	1/4	U.G.P.L.	0	Yazoo
LWA-21	Attala	Kosciusko	1-1/2	I.C.	2	S.N.G.	2	Zilpha
LWA-22	Union	Myrtle	1-1/2	SL.&S.F.	1-1/4	C.N.A.	3/4	Porters Creek
AF-1A	Hinds	Byram	1/4	I.C. (G.M. &O.)	3/4	U.G.P.L.	1	Bucatunna
AF-17	Hinds	Jackson	0	G.M.&O.	1/4	M.V.G.	0	Yazoo

*Railroads: C.&G.—Columbus and Greenville Railway Company; I.C.—Illinois Central Railroad Company; S.L. & S.F.—St. Louis and San Francisco Railroad Company; G.M.&O.—Gulf, Mobile and Ohio Railroad Company; N.O.&N.E.—New Orleans and Northeastern Railroad Company; M.C.—Mississippi Central Railroad Company; B.&H.S.—Bonhomie and Hattiesburg Southern Railroad Company.

**Gas Lines: M.V.G.—Mississippi Valley Gas Company; T.G.—Truckline Gas Company; A.-L.P.L.—American-Louisiana Pipeline Company; Texas G.T.—Texas Gas Transmission Company; C.G.T.—Columbia Gas Transmission Company; T.E.T.—Texas Eastern Transmission Corporation; U.G.P.L.—United Gas Pipeline Company; Tenn.G.T.—Tennessee Gas Transmission Company; S.N.G.—Southern Natural Gas Company; C.N.A.—City of New Albany.

NOTE: The railroads and gas pipelines shown are the nearest, but there are others nearby at a few localities. Distances indicated are approximate to 1/4 mile; zero indicates less than 1/4 mile.

METHOD OF FIELD INVESTIGATION

The field work for the present report consisted chiefly of reconnaissance trips in predetermined areas in order to select localities at which to drill core holes for the sampling of materials. The samples were taken as a continuous core with the Survey's Failing "750" truck-mounted drilling rig using core barrels of a plunger-extruding type (Figure 2). The core barrels used are 2 feet in length and of two diameter sizes, 6 inch and 3.5 inch. The diameter size selected for coring depended largely on the thickness of the material to be sampled.

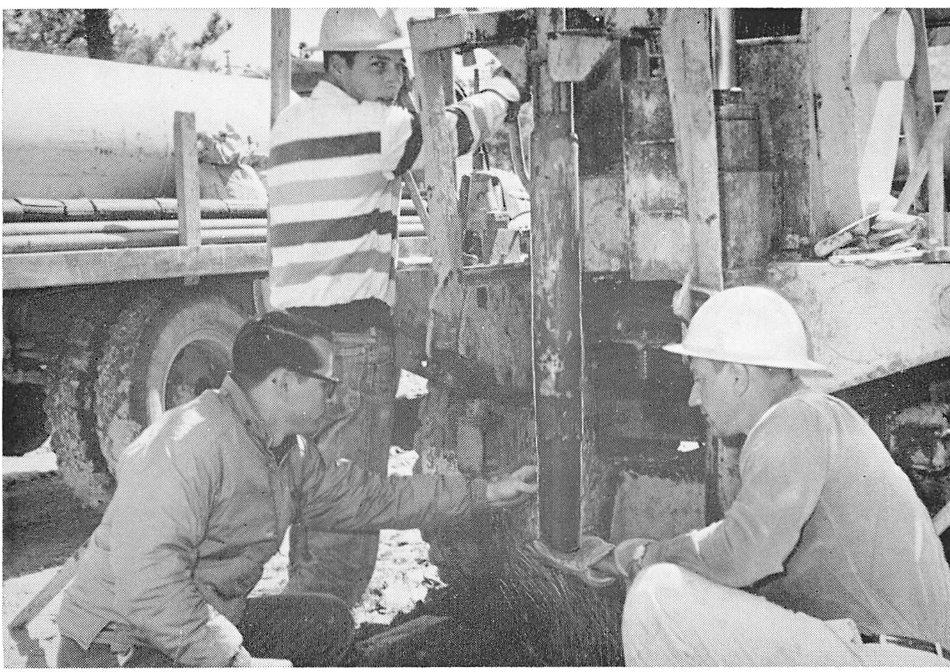

Figure 2.—Sampling of clay with the Survey's drilling rig using plunger-extruding core barrel. Note core lying on drill pipe on water truck. Photo by C. H. McMillan. March 5, 1964.

For each core hole small reference samples were taken to represent the lithologic changes encountered. A descriptive log was made in the field and later refined by the examination of the reference samples under the microscope. A small composite sample (12 to 15 pounds) of the interval selected to be tested was shaved from the cores and sacked, and the remaining bulk of this material was placed in a 55-gallon drum for storage.

GEOLOGY AND CHARACTER OF MATERIALS SAMPLED

Materials were sampled from 10 of the geologic units that comprise the surface rocks of the State. They are from the

SYSTEM	SERIES	GROUP	FORMATION
QUATERNARY	Pleistocene & Recent		Alluvium
			Coastal deposits
			Terrace deposits
			Loess
TERTIARY	Plio-cene		Citronelle
			Graham Ferry
	Miocene	Grand Gulf	Pascagoula
			Hattiesburg
			Catahoula
	Oligocene	Vicksburg	Bucatunna
			Byram
			Glendon
			Marianna—Mint Springs
	Eocene	Jackson	Forest Hill—Red Bluff
			Yazoo
			Moodys Branch
		Claiborne	Cockfield
			Wautubbee or Cook Mountain
			Kosciusko or Sparta
			Zilpha
			Winona
			Tallahatta
		Wilcox	Meridian
			Hatchetigbee
			Tuscahoma or "Holly Springs"
			Nanafalia or Ackerman
			Fearn Springs
	Paleocene	Midway	Betheden
			Naheola
			Porters Creek
			Clayton
UPPER CRETACEOUS	Gulfian	Selma	Prairie Bluff—Owl Creek
			Ripley
			Demopolis
			Coffee
			Mooreville
			Eutaw
		Tusca-loosa	McShan
			Gordo

Figure 3.—Generalized column of Post-Paleozoic surface formations of Mississippi.

Ripley, Porters Creek, Zilpha, Yazoo, Bucatunna, Hattiesburg, Pascagoula and Graham Ferry formations and from the Loess and the Alluvium.

The distribution of these units in the geologic column is given in Figure 3, and their general outcrop areas are shown in

Figure 1. Each unit is discussed as to general distribution, lithology, thickness and sampling, and some of the more important references that give local details are mentioned. The Hattiesburg, Pascagoula and Graham Ferry formations are grouped because not much detailed information has been published concerning their distribution and character and because of the similarity of the materials sampled. For specific data regarding lithologies and the locations of the core holes, the section entitled "Test Hole Records" should be consulted.

RIPLEY TRANSITIONAL CLAY

The transitional clay at the base of the Ripley formation crops out in a narrow, irregular belt across several counties in northeastern Mississippi. The unit has been mapped and described by Conant[2,3] in Tippah and Union Counties, by Parks[4]

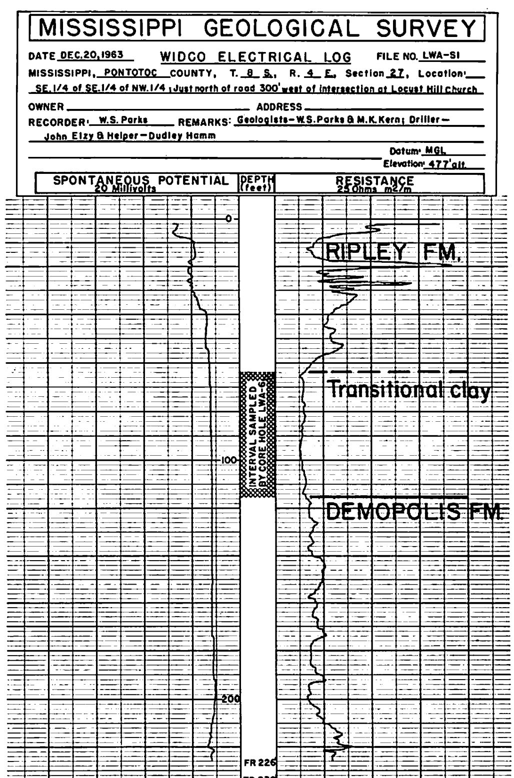

Figure 4.—Electrical log of Drill Hole LWA-S1 showing Ripley transitional clay.

in Prentiss County, and by Priddy[5] in Pontotoc County. The topography developed on the clay is a series of low rounded hills between the lower lying Black Prairie belt on the east and the higher relief Pontotoc Ridge on the west.

The clay is gray to dark-gray, calcareous, sandy in part, micaceous and fossiliferous to very fossiliferous. Where weathered, it is olive-gray to brown-gray. The unit is 40-50 feet thick.

The transitional clay was sampled near Sherman in Union County (Core Hole LWA-6). Composite sample LWA-6 (2-52′) was taken for testing. Drill Hole LWA-S1 was drilled to determine the stratigraphic and spatial position, the thickness, and the apparent uniformity of the clay (Figure 4).

PORTERS CREEK CLAY

The Porters Creek formation crops out in a broad, arcuate belt across northeastern and eastern Mississippi. It is present at the surface in parts of Tippah, Benton, Union, Lafayette, Pontotoc, Calhoun, Chickasaw, Webster, Clay, Choctaw, Oktibbeha, Winston, Noxubee, Kemper and Lauderdale Counties. The Porters Creek has been mapped and described by Bergquist[6] in Clay County, by Conant[7,8] in Tippah and Union Counties, by Hughes[9] in Kemper County, by Mellen [10] in Winston County, by Parks[11] in Calhoun County, by Priddy[12] in Pontotoc County, and by Vestal[13,14] in Webster and Choctaw Counties. The topography developed on the Porters Creek forms the Flatwoods which is characterized by gently rolling hills and flat lands.

In Lauderdale and Kemper Counties the Porters Creek formation is separated from the overlying Naheola formation by the Matthews Landing marl. To the north along strike this marker bed loses its identity and the recognition of the Porters Creek and the Naheola is made only on the basis of gross lithology and stratigraphic position. In the areas where the Matthews Landing marl is absent, some workers have used a tri-part division of the Porters Creek clay—a basal phase, a middle more typical phase, and an upper laminated phase. It has been suggested repeatedly that the upper laminated phase is the equivalent of the Naheola formation, and a few workers have mapped it as such. For simplicity the Porters Creek formation as used herein includes the upper laminated phase, but only the more typical Porters Creek clay was sampled. The Porters Creek formation is 200 to 250 feet thick in Tippah County thickening to the south along strike to as much as 450 to 500 feet in Kemper County.

The typical Porters Creek is a dark-gray to black, tough, pyritiferous, montmorillonitic clay. Most parts are relatively silt- and sand-free, but some parts are moderately silty and contain small amounts of fine-grained sand. Locally the clay contains discontinuous thin layers of concretionary siderite. The clay appears massive, but close inspection may reveal faint lamination, especially in the siltier portions. On weathering it is altered to a gray to brown-gray blocky clay that forms a gray sticky soil. On the outcrop, the clay commonly exhibits jointing and has a conchoidal fracture.

The Porters Creek was sampled near Myrtle in Union County (Core Hole LWA-22), near Maben in Webster County (Core Hole LWA-7), and near Enondale in Kemper County (Core Hole LWA-9). Composite samples LWA-7 (6-34′), LWA-9 (7-52′), and LWA-22 (2-32′) were taken for testing.

ZILPHA CLAY

The Zilpha formation crops out in a narrow, irregular belt across eastern, north-central and a part of northern Mississippi. The formation is present at the surface in parts of Clarke, Lauderdale, Newton, Neshoba, Leake, Attala, Carroll, Montgomery, Grenada, Tallahatchie, Yalobusha and Panola Counties. The Zilpha has been studied regionally by Thomas[15], and it has been mapped and described by Foster[16] in Lauderdale County (included in the Winona member of the Lisbon formation), by Parks[17] in Attala County, by Priddy[18,19] in Montgomery and Tallahatchie County, by Turner[20] in Yalobusha County, and by Vestal[21,22] in Carroll and Panola Counties. Where the thicker sections are present, the clays form a topographic flat or bench in the North Central Hills topography.

In Attala County the Zilpha formation has been subdivided into (1) a basal Zama member, consisting of clay, glauconite, silt, and concretionary siderite; (2) a middle clay member, consisting of relatively sand-and silt-free, blocky clay; and (3) an upper clay shale and silt member, consisting of carbonaceous clay shale and silt. Southeast of Attala County along its outcrop belt, the Zilpha consists of marine and marginal marine clays, clay shale and silt, having locally developed pockets and lenses of glauconite and discontinuous thin layers of concretionary siderite. Northwest of Attala County, the formation appears to give way gradually to non-marine sediments, and north of Grenada County the entire unit may be represented by non-marine clay, clay shale, silt and sand. Only the marine (or marginal marine) clays were sampled.

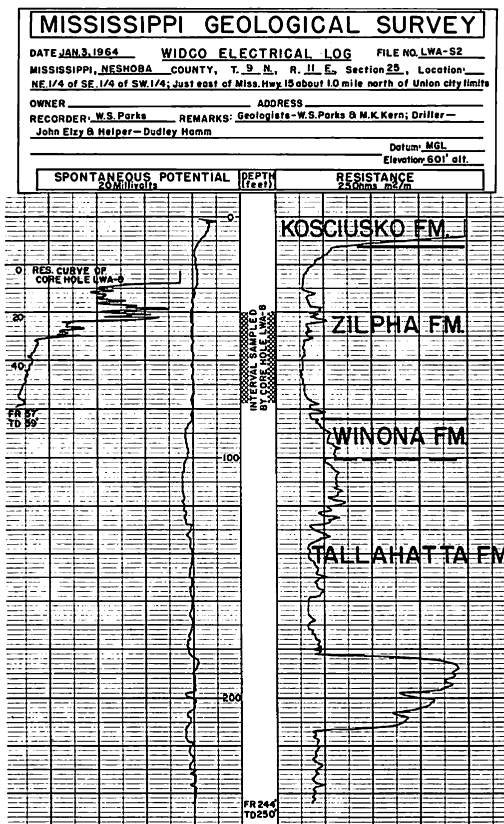

Figure 5.—Electrical log of Drill Hole LWA-S2 showing Zilpha clay.

The Zilpha formation varies considerably in thickness over short distances along its outcrop belt. The formation is thin or absent at a few places in Clarke and Lauderdale Counties, averaging about 15 feet. It becomes thicker to the northwest, averaging about 25 feet and reaching as much as 60 feet, but is absent at a few localities in Leake County. In Attala County the Zilpha has been measured to be as much as 105 feet thick.

The typical marine (or marginal marine) Zilpha clay is dark-gray to black, pyritiferous and montmorillonitic. Some parts are relatively sand- and silt-free, but others contain laminae and thin interbeds of silt. On weathering it alters to a chocolate-brown to brown-gray, blocky clay.

The Zilpha was sampled near Union in Neshoba County (Core Hole LWA-8) and near Kosciusko in Attala County (Core Hole LWA-21). Composite samples LWA-8 (18-55′) and LWA-21 (12-52′) were taken for testing. Drill Hole LWA-S2 was drilled to determine the stratigraphic and spatial position, thickness and apparent uniformity of the clay in the Union area (Figure 5).

YAZOO CLAY

The Yazoo formation crops out in a broad belt across the central part of the State. It is present at the surface in parts of Wayne, Clarke, Jasper, Smith, Newton, Scott, Rankin, Hinds, Madison, Yazoo and Warren Counties. The Yazoo has been mapped and described by Bergquist[23] in Scott County, by DeVries[24] in Jasper County, by Mellen[25] in Yazoo County, and by Priddy[26] in Madison County. The surface developed on the formation forms the Jackson Prairie belt which is characterized by a low rolling to flat topography.

In the Wayne, Clarke and Jasper Counties area the formation can be subdivided into four members, from the base upward —(1) the North Twistwood Creek clay, (2) the Cocoa sand (absent or poorly developed in Jasper County), (3) the Pachuta marl, and (4) the Shubuta clay. To the west-northwest along strike there are facies changes and no satisfactory subdivision of the formation is recognized. The Yazoo formation is about 125 feet thick in Clarke and Wayne Counties thickening to the west-northwest to over 400 feet in Hinds County.

The typical Yazoo clay is blue-green to dark blue-gray, calcareous, fossiliferous to very fossiliferous, massive and montmorillonitic. Where weathered it is a gray-green to yellow-buff, blocky clay which commonly contains scattered selenite crystals.

The Yazoo was sampled near Vossburg in Clarke County

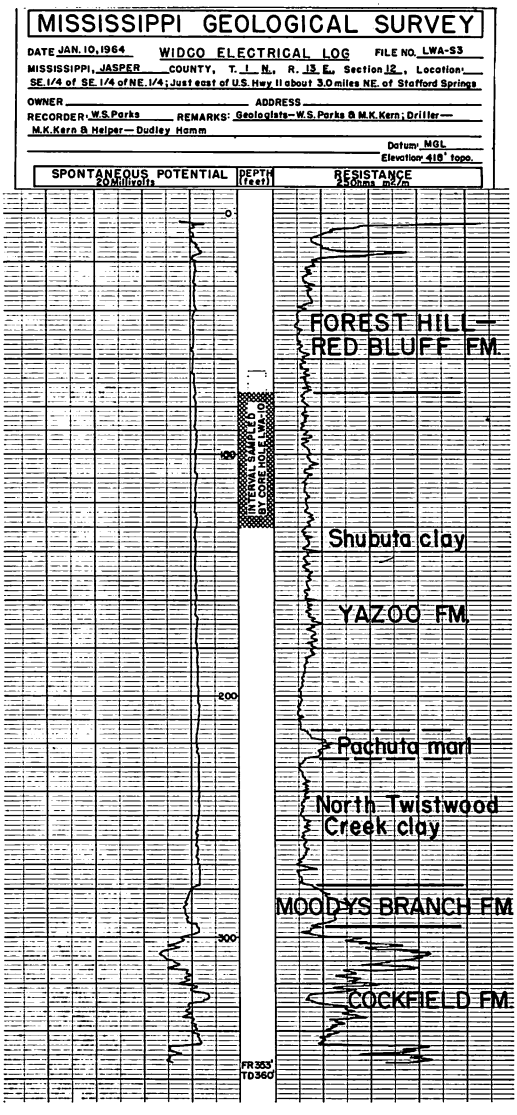

Figure 6.—Electrical log of Drill Hole LWA-S3 showing Yazoo clay.

(Core Hole LWA-10), near Pelahatchie in Rankin County (Core Hole LWA-20), and at Jackson in Hinds County (Core Hole AF-17). Composite samples LWA-10 (12-62′), LWA-20 (20-62′) and AF-17 (10-44′) were taken for testing. Drill Hole LWA-S3 was drilled to determine the stratigraphic position and the thickness of the clay in the Vossburg area (Figure 6).

BUCATUNNA CLAY

The Bucatunna formation crops out in a narrow, irregular belt northwesterly across the central part of the State. It is present at the surface in parts of Wayne, Clarke, Jasper, Smith, Rankin, Hinds, and Warren Counties. The formation has been

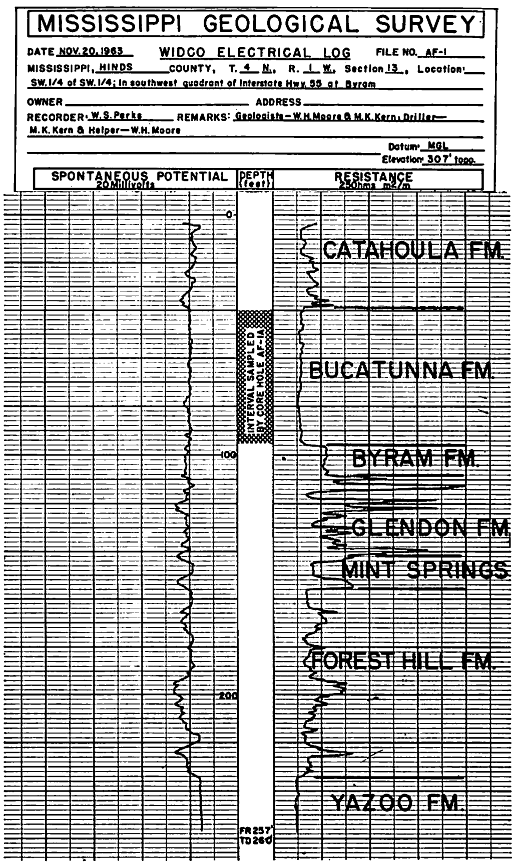

Figure 7.—Electrical log of Drill Hole AF-1 showing Bucatunna clay.

described by DeVries[27] in Jasper County and Mellen [28] in Warren County (as Byram clay).

The formation consists of fossiliferous calcareous clay, dark carbonaceous clay, interlaminated sand, silt and clay, and laminated clayey sand. At some places it contains thin beds or streaks of bentonite, and at other places it contains thin beds and streaks of marl. In the western part of its outcrop belt, the formation is predominantly clay containing thin silt interbeds and a few thin lignite seams; in the eastern part, the facies becomes very sandy at places. The thickness of the Bucatunna formation varies from place to place. The unit is as much as 60 to 70 feet thick, but it may be absent locally.

The typical Bucatunna clay is dark-gray to black, carbonaceous, pyritiferous, and variably silty and sandy. On weathering it alters to a chocolate-brown to brown-gray, blocky clay.

The Bucatunna clay was sampled near Brandon in Rankin County (Core Hole LWA-19) and near Byram in Hinds County (Core Hole AF-1A) (Figure 7). Composite samples LWA-19 (20-39′) and AF-1A (40-95′) were taken for testing.

HATTIESBURG, PASCAGOULA AND GRAHAM FERRY CLAYS

In south Mississippi, sediments of Miocene, Pliocene and Pleistocene age are subdivided into several units which include, from oldest to youngest, the Catahoula, Hattiesburg, Pascagoula, Graham Ferry and Citronelle formations. The Citronelle formation, which consists chiefly of sand and gravel, overlaps the older formations and conceals them except where it has been removed by extensive erosion.

Not much specific information has been published as to the distribution and character of the south Mississippi formations. The Catahoula, Hattiesburg, Pascagoula, and Citronelle (?) formations have been mapped and described by Foster[29] in Forrest County; and the Hattiesburg, Pascagoula, and Citronelle formations have been described by Vestal[30] in Adams County. Some information as to local details is given in reports on the geology and ground-water resources of the coastal area by Brown et al.,[31] of the Camp Shelby area by Brown,[32] and of Camp Van Dorn by Brown and Guyton.[33]

Clays of the Hattiesburg, Pascagoula, and Graham Ferry formations were sampled. They are light green-gray, gray-green,

TABLE 3

CORE HOLES IN SOUTH MISSISSIPPI MATERIALS

Core Hole No.	General Location	Formation	Materials Encountered	Total Depth (feet)	Depth Sampled (feet)	Remarks
LWA-11	Near Hattiesburg in Forrest County	Hattiesburg	Clay, silt & sand	36.0	12-32	T.D. in clay
LWA-12	Near Hattiesburg in Lamar County	Hattiesburg	Clay	51.0	4.5-51	T.D. in clay
LWA-13	Near Beaumont in Perry County	Hattiesburg	Chiefly clay; some sand	24.0	0-18	T.D. in sand
LWA-14	Near Millard in Pearl River County	Graham Ferry	Clay	36.5	4-33.5	T.D. in clay
LWA-15	Near Poplarville in Pearl River County	Pascagoula	Chiefly clay; some sand & silt	22.0	4.5-18	T.D. in sandy clay
LWA-16	Near McHenry in Stone County	Graham Ferry	Chiefly clay; some sand	24.0	1-12	T.D. in sand
LWA-17	Near Bude in Franklin County	Pascagoula	Chiefly clay; some sand & silt	47.0	9-41	T.D. in sand

olive-gray or gray and are variably silty and sandy. Some of the clays contain scattered calcium carbonate nodules, and some contain a small amount of carbonaceous material. All of the clays sampled were slightly weathered. A few of the core holes penetrated dark colored clays (blue-green and dark-gray) below the water table. The clays commonly have thin interbeds of sand and silt. They are present in lenticular bodies, but based on the outcrops studied, large deposits of clay appear to be developed locally. Drill hole records show that some clay bodies are as much as a few hundred feet thick.

Core Holes LWA-11, LWA-12, LWA-13, LWA-14, LWA-15, LWA-16 and LWA-17 were cored to sample south Mississippi clays. Data concerning these core holes are summarized in Table 3. Composite samples LWA-11 (12-32′), LWA-12 (4.5-51′), LWA-13 (0-18′), LWA-14 (4-33.5′), LWA-15 (4.5-18′), LWA-16 (1-12′) and LWA-17 (9-41′) were taken for testing.

LOESS SILT

Loess is present in many counties in the western half of the State. It is most prominently developed along the high Loess Hills or "Bluff Hills" which border the Mississippi Alluvial Plain or "Delta" from the Tennessee line south to Vicksburg and the Mississippi River bottom from Vicksburg south to the Louisiana line. Loess is typically represented in parts of DeSoto, Tate, Panola, Yalobusha, Tallahatchie, Grenada, Carroll, Holmes, Yazoo, Madison, Warren, Hinds, Claiborne, Jefferson, Adams and Wilkinson Counties. The Loess has been mapped and described by Mellen[34,35] in Yazoo and Warren Counties, by Priddy[36,37] in Tallahatchie and Madison Counties, by Turner[38] in Yalobusha County, and by Vestal[39,40,41] in Panola, Carroll, and Adams Counties.

The Loess is a light yellow-brown to gray-brown, slightly calcareous silt. Throughout its outcrop and thickness, the Loess varies only slightly in consistency. At many localities, land snails are scattered throughout, and it locally contains the bones of Pleistocene mammals. At places ground-water leaching and re-deposition has concentrated calcium carbonate in the form of caliche-like concretions. The Loess is thickest in the Loess Hills area and thins to the east. It is present only as a thin veneer at its easternmost extent. In the area of maximum development, the Loess varies from 25 to 75 feet or more in thickness.

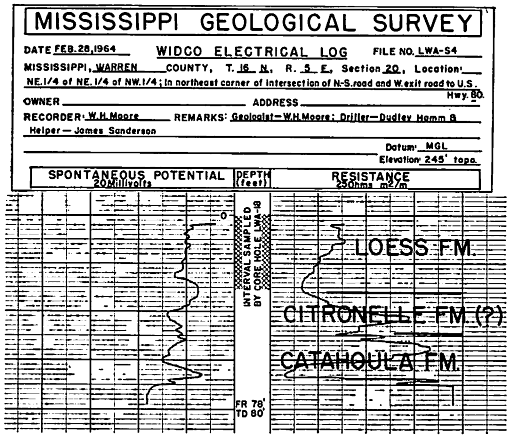

Figure 8.—Electrical log of Drill Hole LWA-S4 showing Loess silt.

The Loess was sampled near Bovina in Warren County (Core Hole LWA-18). Composite sample LWA-18 (3-30′) was taken for testing. Drill Hole LWA-S4 was drilled to determine the stratigraphic position and the thickness of the Loess in the Bovina area (Figure 8).

ALLUVIAL CLAYS

Although alluvium of variable composition exists beneath the flood plans of most of the larger streams that drain the State, the alluvial materials investigated are restricted to those of the Mississippi Alluvial Plain which in Mississippi is known as the "Delta." These materials were selected because of the great extensiveness of the alluvium in this area, and therefore, the possibility of finding large deposits of clay.

The "Delta" is a roughly oval area comprising all or parts of 19 counties in northwestern Mississippi, extending from Memphis, Tennessee, to Vicksburg. The area is about 200 miles long and 65 miles wide at its widest part. It is bounded on the west by the Mississippi River and on the east by the Loess Hills or "Bluff Hills."

The alluvial deposits consist of a more or less heterogeneous body of river-laid sand, gravel, silt and clay. Records of drill holes show that the lower part of the alluvium consists chiefly of sand and gravel, and the upper part consists chiefly of silt and clay. The thickness of the alluvium is from a few feet to

TABLE 4

CORE HOLES IN ALLUVIUM

Core Hole No.	General Location	Soil Type at Surface	Materials Encountered	Total Depth (feet)	Depth Sampled (feet)	Remarks
LWA-1	Near Moorhead in Sunflower County	Alligator clay (level phase)	Clay	22.0	1-22	T.D. in clay
LWA-2	Near Leland in Washington County	Sharkey clay (nearly level phase)	Chiefly clay; some silt & sand	14.0	1-12	T.D. in sand
LWA-3	Near Cleveland in Bolivar County	Sharkey clay (nearly level phase)	Chiefly clay; some silt	12.0	1-11	T.D. in sand
LWA-4	Near Clarksdale in Coahoma County	Alligator clay (nearly level phase)	Chiefly clay; some sand	12.0	1-8	T.D. in sand
LWA-5	Near Marks in Quitman County	Alligator silty clay (nearly level phase)	Chiefly clay; some sand	22.0	0-19	T.D. in sand

as much as 225 feet. In general the thicker alluvium extends parallel to the Loess Hills, and the thinner alluvium is found along the Mississippi River in Washington and Bolivar Counties.

The alluvial materials of particular interest to the present study are the very plastic, tenaceous clays commonly referred to as "gumbo" or "buckshot." These clays are extensively developed at places in the backswamps or slack-water flats where they have been deposited in shallow ponded areas during periods of overbank flow.

Soil surveys provide an excellent tool in prospecting for clay in the "Delta" area. Soils commonly developed on the slack-water flats clays are the Alligator, Sharkey, Dowling and Tunica. During the present investigation, the following Soil Surveys prepared by the U. S. Department of Agriculture, Soil Conservation Service were used:

Bolivar County, Miss.—Series 1951, No. 5, Issued Dec., 1958;
Coahoma County, Miss.—Series 1950, No. 6, Issued Dec., 1959;
Quitman County, Miss.—Series 1947, No. 9, Issued Dec., 1958;
Sunflower County, Miss.—Series 1952, No. 5, Issued Feb., 1959;
Washington County, Miss.—Series 1958, No. 3, Issued May, 1961.

Core Holes LWA-1, LWA-2, LWA-3, LWA-4, and LWA-5 were cored to sample alluvial materials. Data concerning these holes are summarized in Table 4. Composite samples LWA-1 (1-22′), LWA-2 (1-12′), LWA-3 (1-11′), LWA-4 (1-8′) and LWA-5 (0-19′) were taken for testing.

OTHER POSSIBLE MATERIALS

There are other materials in Mississippi that may be suitable for making expanded lightweight aggregates, but for various reasons they were not sampled. The more important of these materials are briefly described. Some data concerning the testing of a few are given in the section entitled "Summary of Previous Ceramic Tests."

Paleozoic shales. Mississippian (Chester) shales are at the surface in the southern half of Tishomingo County along Pennywinkle, Cripple Deer, Bear, and Mackeys Creeks. Because of their low resistance to weathering, outcrops are few. Isolated exposures indicate that some shale intervals are as much as 25 to 75 feet or more in thickness. No testing has been conducted.

McShan and Eutaw clays. The McShan and Eutaw formations crop out in a north-south belt through parts of Lowndes, Monroe, Itawamba, Prentiss, and Tishomingo Counties. Even though these formations consist largely of sand and thin interbeds and laminae of clay and clay shale, they contain some thicker clay beds locally. Not much is known as to the extent and uniformity of these thicker clays. Some of the bloating clays of previous testing that are included in the Tuscaloosa are probably from the McShan formation, and the only sample of Eutaw clay tested bloated in the range of lightweight aggregate materials. Tests made by the U. S. Bureau of Mines on samples of clay from a lense in the Eutaw sand on the James A. West property, east of Fulton, Itawamba County, showed that this clay has possibilities as lightweight aggregate materials.*

Mooreville clay. In Lee County southeast and east of Tupelo where the Mooreville formation merges with the Coffee formation, the Mooreville consists of clayey sandy chalk and sandy calcareous clay. It is reported that there are areas where large quantities of the clay could be strip mined. The Mooreville clay is similar to the transitional clay of the Ripley formation. No testing has been conducted.

Wilcox clays. Sediments of the Wilcox group that make up the Fearn Springs, Ackerman, "Holly Springs," and Hatchetigbee formations crop out in a belt through parts of Clarke, Lauderdale, Newton, Kemper, Neshoba, Noxubee, Winston, Attala, Choctaw, Oktibbeha, Montgomery, Webster, Grenada, Calhoun, Yalobusha, Lafayette, Pontotoc, Union, Marshall, Benton and Tippah Counties. In general the Wilcox formations are heterogeneous bodies that consist chiefly of sand, silt, clay and lignite. Some formations are composed largely of sand, and others contain more silt, clay and lignite. Individual beds are lenticular, and they are complexly interlensed and intertongued. The clays vary widely in mineralogical and chemical composition and in purity. Records of previous testing show that many samples bloated in the range of lightweight aggregate materials.

Wautubbee clay. The Wautubbee formation crops out in a southeast-northwest belt through parts of Clarke, Jasper, New-

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*Information provided by Mr. Berlen C. Moneymaker, Chief Geologist, Tennessee Valley Authority, Knoxville, Tennessee.

ton, Scott, Leake, Madison, Attala, Holmes and Carroll Counties. In the southeastern part of its outcrop belt, the formation can be subdivided into, from the base upward, (1) the Archusa marl member, (2) the Potterchitto member, and (3) the Gordon Creek shale member. The Gordon Creek shale member, 15 to 25 feet thick, is predominantly a carbonaceous clay or clay shale similar to the Zilpha clay. North of central Newton County, there are facies changes and the members are not easily recognized, but clay shales remain typical of the upper part of the formation. In Holmes and Carroll Counties, the larger part of the formation consists of carbonaceous clays and clay shales—the Shipps Creek shale member. The Wautubbee formation reaches its maximum development in Holmes and Carroll Counties and is as much as 200 feet thick. Previous testing shows that of four samples tested from Scott County one bloated in the range of lightweight aggregate materials.

Forest Hill-Red Bluff clays. The Forest Hill-Red Bluff formation crops out in an east-southeast to west-northwest belt through Wayne, Clarke, Jasper, Smith, Rankin, Hinds, Madison, Warren and Yazoo Counties. In the western part of the outcrop belt, the Forest Hill formation consists chiefly of fine-grained sand, silt, clay and lignite. Towards the east-southeast, there are facies changes; and in western Japser County, the Forest Hill begins to give way to the Red Bluff formation which consists predominantly of clay. The Red Bluff formation at its maximum development in Jasper County is 120 feet thick. No testing has been conducted.

CHEMICAL ANALYSES AS RELATED TO BLOATING

The chemical analyses of the 24 composite samples taken for testing during this study are given in Table 6. Also, the chemical analyses of 34 samples of previous testing that bloated below 2400°F, the maximum temperature for commercial production of lightweight aggregates, are given in Table 5.

For many years the phenomenon of the bloating of clays and shales has been of interest to the ceramic industry. Many theories have been advanced as to why some materials will bloat and others will not. It generally has been agreed that there are two basic conditions that must be fulfilled before bloating can take place. First, a high temperature glassy phase must be produced

TABLE 5

CHEMICAL ANALYSES OF SAMPLES OF PREVIOUS TESTING
THAT BLOATED BELOW 2400°F*
(in percent)

Sample No.	Geologic Unit	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	SO_3	TiO_2	MnO_2	Misc.	Ign.	Total
R52(1)	Tuscaloosa	70.88	13.81	5.35	-	0.22	-	-	-	0.80	-	2.44	7.50	101.00
P42(1)	Tuscaloosa	68.28	19.44	3.01	0.73	Trace	0.63		-	1.31	0.07	-	6.55	100.02
P50(2)	Tuscaloosa	65.95	22.96	2.00	0.50	Nil	0.86		-	0.72	Nil	-	6.83	99.82
M35(3)	Selma	53.71	11.67	3.55	0.81	14.90	0.43		-	0.71	Nil	-	13.97	99.75
N82(7)	Porters Creek	68.36	15.98	7.49	1.27	0.25	0.26		-	0.98	0.11	-	5.52	100.22
M55(3)	Porters Creek	67.39	16.60	5.84	0.87	1.97	0.53		-	0.81	Nil	-	6.01	100.02
53AP1	Porters Creek	61.87	21.12	6.07	0.94	1.42	0.93	0.24	0.55	1.05	-	-	7.07	101.26
K4	Ackerman	65.88	19.06	2.97	0.66	0.55	0.35		0.91	1.09	Nil	-	7.96	99.43
K11(2)	Ackerman	67.00	17.24	4.87	0.78	1.91	0.31		-	0.75	0.18	-	6.55	99.59
K18(1)	Ackerman	67.08	17.92	6.38	0.86	0.22	0.20		-	0.77	0.11	-	5.52	99.06
K63(1)	Ackerman	67.61	16.78	5.42	1.10	0.81	0.26		-	0.69	Trace	-	6.12	98.79
K64(1)	Ackerman	63.38	19.97	5.04	1.07	0.88	0.66		1.34	0.63	0.25	-	6.04	99.26
K75(1)	Ackerman	56.00	27.01	2.53	1.14	0.78	0.44		-	1.22	Nil	-	10.57	99.69
18P2	Ackerman	57.20	19.76	6.11	0.83	0.83	0.65	0.12	2.02	0.99	-	-	11.72	100.23

20P1	Ackerman	58.29	19.98	5.10	1.55	1.04	1.13	0.21	1.94	1.10	-	-	10.22	100.56
20P2	Ackerman	56.00	21.05	5.01	0.23	1.09	1.30	0.10	2.26	0.99	-	-	13.16	101.19
20P3	Ackerman	60.54	19.62	4.60	0.93	1.55	1.72	1.38	0.11	1.20	-	-	7.85	99.50
57P1	Ackerman	63.45	19.14	3.01	1.56	1.12	0.04	0.04	0.78	1.05	-	-	9.88	100.07
L180(14-15-16)	"Holly Springs"	64.29	20.54	3.27	0.37	Trace	0.13		1.20	1.11	Nil	-	7.79	98.70
L185(10)	"Holly Springs"	66.91	17.65	5.33	0.62	0.57	0.42		1.03	0.74	Nil	-	5.59	98.86
L186(5)	"Holly Springs"	63.55	18.70	2.53	0.76	0.45	0.40		-	0.77	Nil	-	12.72	99.88
K26(1)	"Holly Springs"	65.46	18.99	4.36	1.09	0.73	0.40		0.28	0.81	Nil	-	7.32	99.44
K101(1)	"Holly Springs"	69.31	19.04	2.17	1.23	Nil	0.20		-	0.98	Nil	-	6.24	99.17
K121(1)	"Holly Springs"	67.36	21.10	2.60	0.32	Nil	0.33		-	1.25	Nil	-	7.04	100.00
L25(3)	Zilpha	68.92	16.43	3.53	1.32	1.08	0.82		-	1.20	Nil	-	6.38	99.68
AE-3(6-28')	Zilpha	65.01	19.07	2.57	2.07	1.25	0.35	0.50	-	1.08	-	-	7.38	99.28
E1(3.2-36.5')	Byram	78.23	11.22	1.98	0.46	1.39	0.90	0.90	1.36	0.94	-	-	3.86	101.24
E21P1(14.7-23.0')	Byram	51.00	23.13	4.44	1.77	5.65	1.32	0.87	1.30	1.27	-	-	9.61	100.36
F14AP1(4.8-44.8')	Hattiesburg	74.44	17.97	0.96	0.09	1.23	0.83	0.22	-	0.47	-	-	3.91	100.12
F169(0.7-31.5')	Hattiesburg	72.65	14.92	2.84	Trace	1.15	0.49	0.20	-	0.92	0.21	-	7.04	100.42
F181(1.8-42.5')	Hattiesburg	74.48	16.99	1.40	0.02	1.11	0.75	0.35	-	0.56	-	-	3.98	99.64
G35(1)	Pascagoula	69.97	15.39	4.22	0.76	1.29	0.20		-	0.78	Trace	-	6.86	99.47
C6(C1,C2,C3)	Alluvium	73.01	14.73	3.60	Trace	3.14	0.09	0.04	0.23	-	-	-	3.65	98.49
E52P1(7.8-23.2')	Alluvium	60.30	24.74	1.85	1.04	0.78	1.57	0.99	0.01	0.88	-	-	7.66	99.82

*Analyses were taken from many M.G.S. Bulletins; see Table 1 for reference.

TABLE 6

CHEMICAL ANALYSES OF MATERIALS SAMPLED*
(in percent)

Sample No.	Geologic Unit	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	SO_3	P_2O_5	Cl	Other Non-vol. Solids	Ign.	Total
LWA-6(2-52')	Ripley (Trans. clay)	44.50	14.20	4.62	1.06	11.54	0.32	1.78	-	-	-	3.05	18.93	100.00
LWA-7(6-34')	Porters Creek	61.10	14.63	6.93	1.62	0.71	0.67	2.39	-	-	-	1.51	10.44	100.00
LWA-9(7-52')	Porters Creek	61.23	15.26	6.25	0.78	0.53	0.61	2.00	-	-	-	3.36	9.98	100.00
LWA-22(2-32')	Porters Creek	62.74	18.44	7.74	2.32	1.10	0.24	1.65	0.11	0.12	Nil	-	5.82	100.00
LWA-8(18-55')	Zilpha	61.52	13.72	5.20	1.03	0.99	0.61	1.83	-	-	-	2.53	12.57	100.00
LWA-21(12-52')	Zilpha	64.95	16.95	5.48	1.71	1.57	0.41	1.38	0.43	0.07	Nil	-	6.85	99.80
AF-17(10-44')	Yazoo	34.19	15.03	4.84	1.94	21.33	0.87	0.89	0.29	0.14	Nil	-	20.84	100.36
LWA-10(12-62')	Yazoo	36.20	14.18	4.14	0.58	16.19	0.19	1.02	-	-	-	3.84	23.66	100.00
LWA-20(22-62')	Yazoo	41.29	17.79	5.24	1.93	14.92	0.82	1.06	0.08	0.17	Nil	-	15.87	99.17
AF-1A(40-95')	Bucatunna	59.80	18.77	5.68	1.58	0.99	0.58	1.37	-	-	-	0.80	16.23	105.80
LWA-19(20-39')	Bucatunna	61.35	17.23	7.20	1.91	1.67	0.80	0.43	1.65	0.08	Nil	-	8.52	100.84
LWA-11(12-32')	Hattiesburg	72.38	11.75	4.04	0.63	0.34	0.74	1.54	-	-	-	0.80	8.86	101.08
LWA-12(4-51')	Hattiesburg	70.83	11.66	4.04	0.96	0.84	0.63	1.54	-	-	-	0.80	10.80	102.10
LWA-13(0-18')	Hattiesburg	70.39	13.56	3.94	0.73	0.15	0.31	1.20	-	-	-	0.95	8.99	100.22
LWA-15(4.5-18')	Pascagoula	68.12	13.52	5.97	0.90	0.39	0.75	2.10	-	-	-	0.80	10.51	103.06
LWA-17(9-41')	Pascagoula	67.12	12.88	4.52	0.93	1.47	0.39	1.28	-	-	-	0.90	12.66	102.15
LWA-14(4-33.5')	Graham Ferry	70.32	13.60	4.33	0.80	0.39	0.47	1.40	-	-	-	0.80	9.20	101.31
LWA-16(1-12')	Graham Ferry	62.50	17.77	4.71	0.80	0.32	0.41	1.57	-	-	-	0.80	12.93	101.81
LWA-18(3-30')	Loess	63.44	9.53	3.12	4.57	6.52	1.38	1.47	0.05	0.14	Nil	-	9.52	99.74
LWA-1(1-22')	Alluvium	60.65	15.52	4.81	1.16	1.12	0.92	2.11	-	-	-	3.53	10.18	100.00
LWA-2(1-12')	Alluvium	67.39	13.23	5.20	0.98	0.98	0.97	2.17	-	-	-	1.21	7.87	100.00
LWA-3(1-11')	Alluvium	60.23	14.81	4.43	1.74	1.74	0.92	2.42	-	-	-	2.58	11.13	100.00
LWA-4(1-8')	Alluvium	59.11	16.55	4.91	1.96	1.25	0.75	2.52	-	-	-	2.00	10.95	100.00
LWA-5(0-19')	Alluvium	68.00	13.15	3.27	0.70	1.12	1.06	2.07	-	-	-	2.89	7.74	100.00

*Analyses LWA-1(1-22') consecutively by number through LWA-17(9-41') and AF-1A(40-95') are by Mississippi State Chemical Laboratory, State College, Mississippi; analyses LWA-18(3'30') consecutively through LWA-22(2-32') and AF-17 are by Shilstone Testing Laboratory, New Orleans, Louisiana.

having a viscosity high enough so that gases being formed will be trapped. Second, a gas or gases must be liberated by the dissociation of some of the constituents at the temperature at which a glassy phase has formed. There is some disagreement among workers as to what constituents release the gases and as to what gases actually cause bloating. The compounds are most generally thought to be any one or a combination of carbonates, organic material, sulphates, sulfides, hydrous minerals, and ferric oxide. The gases produced are water vapor (H_2O), carbon dioxide (CO_2), hydrogen sulfide (H_2S), and sulfur oxides (SO_2,SO_3).

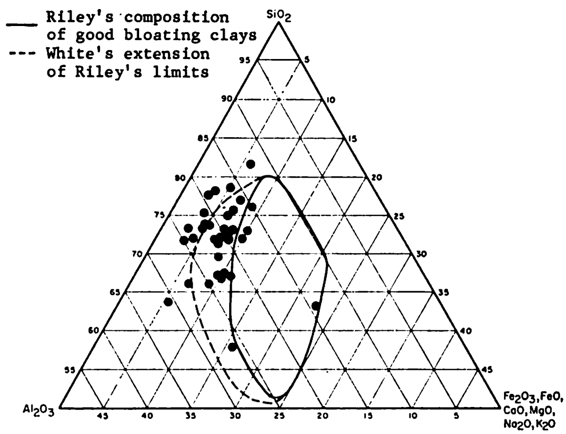

Figure 9.—Riley's diagram showing chemical analyses of 34 samples of previous testing that bloated below 2400°F.

Riley[42] showed a correlation between the chemical composition of materials and their bloating properties. He was able to define roughly an area of chemical composition on a triaxial diagram within which bloating clays are to be found. Riley's composition diagram (Figure 9) has silica (SiO_2), alumina (Al_2O_3), and total fluxing constituents (CaO, MgO, FeO, Fe_2O_3, Na_2O, K_2O) as the corners. In order to plot an analysis, the minor constituents and volatile materials are excluded, and the analysis is recalculated to 100 percent. Riley's region of bloating is the approximate limit of chemical composition for the formation of a melt of proper viscosity to trap the gases. The presence of a gas-forming constituent is not taken into consideration; therefore, because an analysis falls within the limits of composition bloating is not necessarily insured. In a later study, White[43] extended Riley's region of bloating on the basis of additional test data (Figure 9).

Riley's composition diagram was used during the present study as a basis of comparison of the chemical compositions of materials to their bloating properties. Figure 9 shows the chemical analyses of 34 samples of previous testing that bloated below 2400°F plotted on Riley's diagram. Several of the analyses fall within Riley's limits of composition, many fall within White's extension, and many fall outside these limits in the area of low total fluxing constituents. This would seem to indicate that many Mississippi clays require less fluxing agents in order to bloat than is indicated by Riley's and White's limits of composition. However, little information is available on the actual condition of the bloated materials of previous testing, and it is probable that some samples bloated poorly.

Figures 10, 11, 12 and 13 show the chemical analyses of the 24 samples of the present study plotted on Riley's diagram, and the results of the preliminary firing tests are summarized below. Other important test data such as the actual bloating temperatures, results of rotary-kiln firings, etc. are included in the part of this report dealing with the testing of materials. The preliminary firing results provided by Dr. Allan G. Wehr, Department of Metallurgical and Ceramic Engineering, Mississippi State University, are as follows:

BLOATERS*	NON-BLOATERS*
LWA-1 (1-22′)—Alluvium	**LWA-6 (2-52′)—Ripley (Transitional clay)
LWA-2 (1-12′)—Alluvium	***LWA-10 (12-62′)—Yazoo
LWA-3 (1-11′)—Alluvium	LWA-11 (12-32′)—Hattiesburg
LWA-4 (1-8′)—Alluvium	LWA-12 (4-51′)—Hattiesburg
LWA-5 (0-19′)—Alluvium	LWA-13 (0-18′)—Hattiesburg
LWA-7 (6-34′)—Porters Creek	**LWA-14 (4-33.5′)—Graham Ferry
LWA-8 (18-55′)—Zilpha	**LWA-15 (4.5-18′)—Pascagoula
LWA-9 (7-52′)—Porters Creek	LWA-16 (1-12′)—Graham Ferry
LWA-19 (20-39′)—Bucatunna	LWA-17 (9-41′)—Pascagoula
LWA-21 (12-52′)—Zilpha	LWA-18 (3-30′)—Loess
LWA-22 (2-32′)—Porters Creek	**LWA-20 (22-62′)—Yazoo
AF-1A (40-95′)—Bucatunna	**AF-17 (10-44′)—Yazoo

*Results based on firings to temperatures below 2400°F.

**These samples may have undergone slight bloating, but bloating occurred very near the melting temperature.

***Sample melted and showed no evidence of bloating.

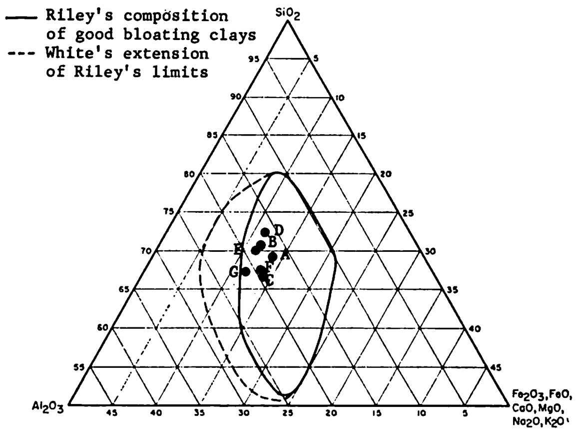

Figure 10.—Riley's diagram showing chemical analyses of Porters Creek clay [A=LWA-7 (6-34'); B=LWA-9 (7-52'); C=LWA-22 (2-32')], Zilpha clay [D=LWA-8 (18-55'); E=LWA-21 (12-52')] and Bucatunna clay [F=LWA-19 (20-39'); G=AF-1A (40-95')].

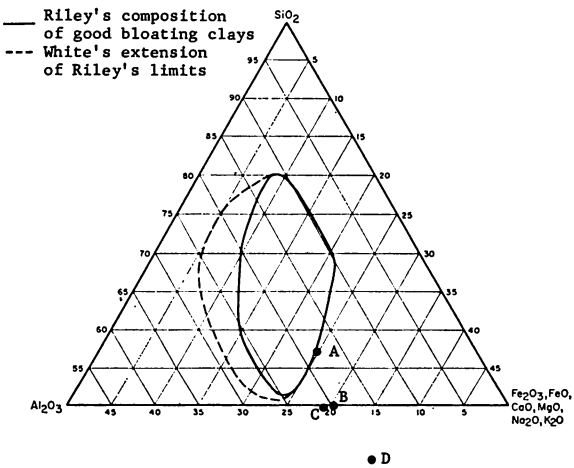

Figure 11.—Riley's diagram showing chemical analyses of Ripley transitional clay [A=LWA-6 (2-52')] and Yazoo clay [B=LWA-10 (12-62'); C=LWA-20 (22-62'); D=AF-17 (10-44')].

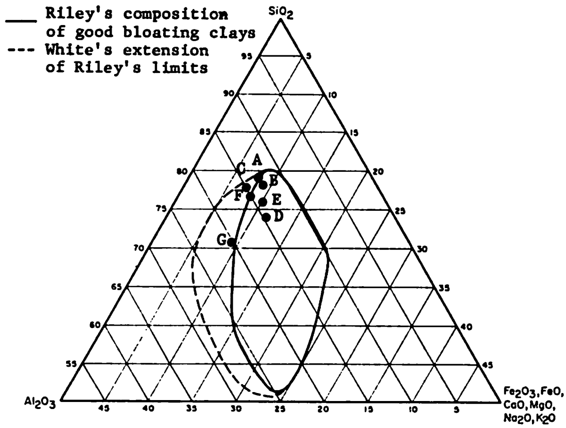

Figure 12.—Riley's diagram showing chemical analyses of Hattiesburg clay [A=LWA-11 (12-32'); B=LWA-12 (4-51'); C=LWA-13 (0-18')], Pascagoula clay [D=LWA-15 (4.5-18'); E=LWA-17 (9-41')] and Graham Ferry clay [F=LWA-14 (4-33.5'); G=LWA-16 (1-12')].

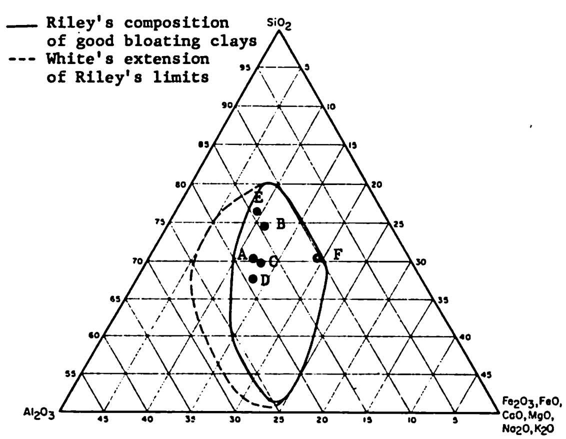

Figure 13.—Riley's diagram showing chemical analyses of alluvial clay [A=LWA-1 (1-22'); B=LWA-2 (1-12'); C=LWA-3 (1-11'); D=LWA-4 (1-8'); E=LWA-5 (0-19')] and Loess silt [F=LWA-18 (3-33')].

By comparing the test results with the analyses plotted on Riley's diagram as shown in Figures 10, 11, 12 and 13, certain relationships are apparent. The samples of Porters Creek, Zilpha, and Bucatunna clays and of Alluvium are excellent bloaters, and all fall well within Riley's region of bloating (Figures 10 and 13). The sample of Ripley transitional clay barely falls within Riley's region of bloating, and the samples of Yazoo clay were so high in fluxes that they did not even fall within the composition diagram (Figure 11). These materials showed little evidence of bloating before they melted. They are characteristically high in calcium carbonate which acted as the fluxing agent causing them to melt. The samples of Hattiesburg, Pascagoula and Graham Ferry clays were non-bloaters (two bloated slightly before melting) even though several fall within Riley's region of bloating and the rest fall within White's extension (Figure 12). These materials must lack the necessary gas-forming constituents. The sample of Loess silt, a non-bloater, is low in alumina and barely falls within Riley's region of bloating (Figure 13).

In summary, the present study shows that of the samples tested the best bloaters fall within Riley's limits of chemical composition of bloatable materials, but not all of the samples within these limits bloated. Therefore, the chemical composition of a material is a useful index in preliminary examinations in which materials unsuitable for use in the manufacture of expanded lightweight aggregate may be eliminated. The actual suitability of a material for expanded lightweight aggregate must be determined by firing tests.

LIGHTWEIGHT AGGREGATE INDUSTRY

At present the Miss-Lite Division of Jackson Ready-Mix Concrete is the only producer of lightweight aggregate in Mississippi. The plant is located at Cynthia, Hinds County (NW.¼, Sec. 36, T.7 N., R.1 W.), on the Yazoo and Mississippi Valley Branch of the Illinois Central Railroad at a distance of about nine air miles northwest of downtown Jackson (Figure 14). The plant site and mine are situated on a 666-acre tract of land owned by the company. Natural gas is supplied for the kiln by a line of the Mississippi Valley Gas Company extending from the City

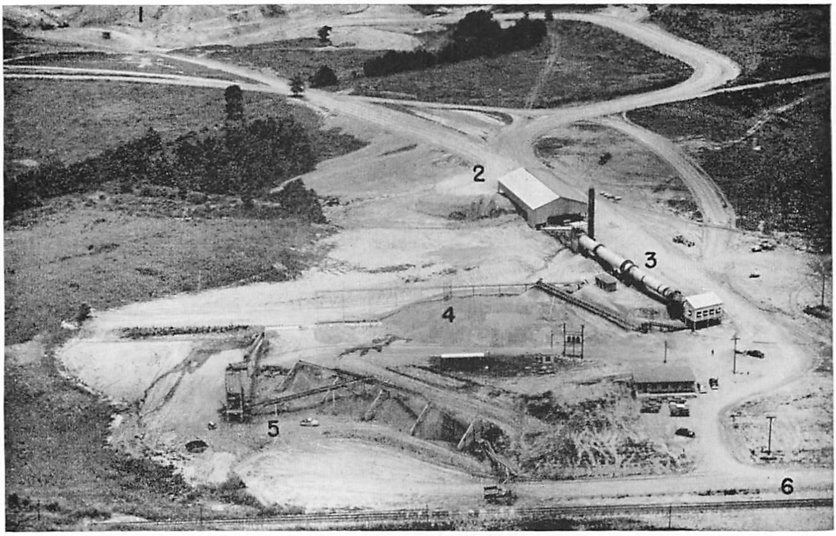

Figure 14.—"Miss-Lite" aggregate plant of Jackson Ready-Mix Concrete at Cynthia, Hinds County: (1) pits opened in the Yazoo clay, (2) clay dry shed, (3) rotary kiln, (4) cinder storage area, (5) grinding, screening and storage of graded aggregates, and (6) rail or truck shipping facilities. (M.G.S. Bull. 86, Fig. 24).—Frank Noone photo, July 2, 1958.

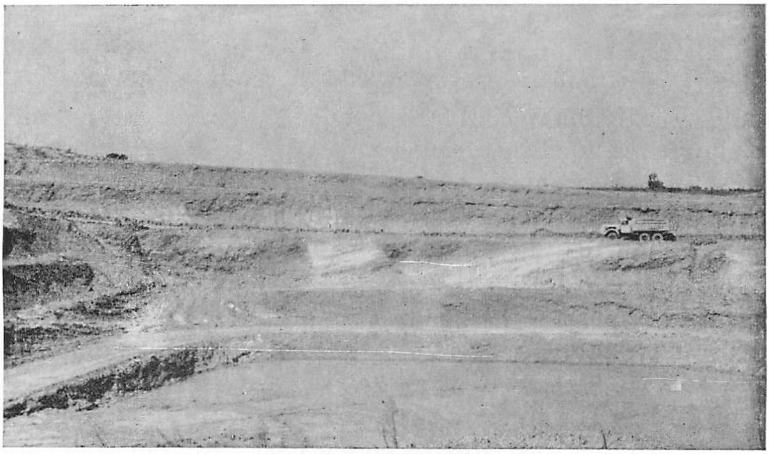

Figure 15.—Open-cut pit of Jackson Ready-Mix Concrete at Cynthia, Hinds County (SE.¼, SW.¼, Sec. 25 and NE.¼, NW.¼, Sec. 36, T.7 N., R.1 W.). The mine is over 60 feet deep and has several tiered benches from which the clay is worked. (M.G.S. Bull. 88, Fig. 9). September 4, 1959.

of Jackson. The mine is an open-cut pit over 60 feet deep that has several tiered benches from which the clay is worked (Figure 15).

The raw material is the clay of the Yazoo formation, which crops out extensively in the area and has a maximum thickness of about 400 feet. Both the weathered (oxidized) and the unweathered (unoxidized) clay is utilized in a blending process. A typical section of the mine area follows:

Section of the pit at the Jackson Ready-Mix, Miss-Lite Division's strip mine (SE.¼, SW.¼, Sec. 25, and NE.¼, NW.¼, Sec. 36, T.7 N., R.1 W.)—Hinds County:

	Feet	Feet
"Brown loam"		8.0
3. Silt, tan to light-brown, clayey; contains scattered caliche nodules and iron oxide "buckshot"	8.0	
	Feet	Feet
Yazoo formation		62.0
2. Clay, olive-gray to yellow-buff, slightly to moderately silty, calcareous, jointed, fossiliferous in part; contains scattered clusters and joint fillings of selenite, scattered caliche nodules, common limonite, and a thin bed of bentonite that exhibits slumping by its disarrangement	22.0	
1. Clay, green-gray to dark blue-gray, slightly to moderately silty, calcareous, tough, massively bedded, jointed, fossiliferous; contains some very fossiliferous and calcareous lenses and scattered pyrite nodules. (Fossil remains of the whale **Basilosaurus cetoides** have been found during excavation)	40.0	
Total section		70.0

In the operation, the raw clay is stripped with a dragline and loaded into trucks to be moved a short distance to the dry shed at one end of the kiln. From the dry shed the clay is moved with a front-end loader to the blender. From the blender the clay is carried by a conveyer to the rotary kiln, which is 12 feet in diameter and 200 feet in length. In the kiln the clay reaches a temperature of 2200°F under reducing atmospheric conditions. In the firing process the clay is calcined and bloated to form a cinder. As the cinder leaves the kiln it is picked up by a conveyor and carried to the cinder pile. From the cinder pile the material is carried by conveyer to a hammer mill where it is crushed. From the hammer mill the aggregate is carried to a series of screens where it is sized and dumped into finished bins. Stock sizes are three-quarters to three-eighths inch, three-eighths to three-sixteenths inch, and three-sixteenths inch to dust. The aggregate is moved from the finished bins, blended when gradations other than stock sizes are required, and loaded into rail cars or trucks for delivery.

Production began at the plant in 1958. In 1959 it was reported that production was 300 tons of graded aggregate daily. The product, which is classed as a graded expanded clay aggregate, is used chiefly by the producers of concrete block throughout the State. The aggregate also has a variety of other uses. It is used in road and street construction as a double bituminous surfacing aggregate and in hot and cold asphaltic plant mixes. It has application in refractory or insulative concrete, and as an athletic track aggregate, tennis court base and surface material, and built-up roofing aggregate.

TEST HOLE RECORDS

A total of 22 core holes (Core Holes LWA-1 through LWA-22), having an aggregate depth of 803.5 feet, were drilled to sample materials for testing. For each core hole, small reference samples were taken to represent the lithologic changes, and Core Holes LWA-8, LWA-9 and LWA-21 were logged with the Survey's Widco electrical logger. Also, samples from two core holes (Core Holes AF-1A and AF-17), which were drilled in conjunction with the Survey's study of the geology and mineral resources of Hinds County, were included for testing.

Four drill holes (Drill Holes LWA-S1 through LWA-S4) having an aggregate depth of 920 feet, were drilled to determine the stratigraphic and spatial position, the thicknesses and the apparent uniformity of certain materials. The drill holes were sampled at 5-foot or 10-foot intervals and logged with the electrical logger.

The descriptive logs of the core holes are given herein in order to provide specific information as to the lithologies of the materials tested. Samples and the electrical logs of the core holes and the drill holes are available for further study at the Mississippi Geological Survey Sample Library, 2525 North West Street, Jackson, Mississippi.

Core Hole LWA-1

Location: Between the Columbus and Greenville Railroad track and a parallel east-west road at farm road crossing (SW.1/4, SE.1/4, SE.1/4, Sec. 3, T.18 N., R.3 W.), about 0.8 mile east of the intersection of this east-west road and State Highway 3 at Moorhead—Sunflower County.

Elevation: 112 feet (topographic map) Date: December 16, 1963

Thickness (feet)	Depth (feet)	Description of strata
1.0	1.0	Soil—brown-black, silty clay.
		Alluvium
8.0	9.0	Clay, tan to light brown-gray mottled, slightly silty, plastic; has some iron oxide staining; contains a small amount of carbonaceous material and gypsum.
3.0	12.0	Clay, light brown-gray to gray mottled, very silty; has some iron oxide staining; contains a small amount of carbonaceous material and gypsum.
6.5	18.5	Clay, light brown-gray to gray mottled, plastic; has iron oxide staining; contains a small amount of carbonaceous material including some plant remains and scattered small calcareous nodules.
3.5	22.0	Clay, gray to blue-gray, plastic; has streaks and splotches of iron oxide staining; contains small scattered calcareous nodules.

Composite sample taken from 1.0 to 22.0 feet.

Core Hole LWA-2

Location: In field near fence gap approximately 65 feet northwest of the center line of U. S. Highway 61 (NE.1/4, NW.1/4, NE.1/4, Sec.12, T.18 N., R.7 W.), about 2.8 miles northeast of the junction of U. S. Highways 61 and 82 at Leland—Washington County.

Elevation: 118 feet (topographic map) Date: December 17, 1963

Thickness (feet)	Depth (feet)	Description of strata
1.0	1.0	Soil—brown-black, silty clay.
		Alluvium
7.0	8.0	Clay, light-brown to gray-brown mottled, slightly silty and sandy, plastic; has streaks and splotches of iron oxide stain; contains scattered small brown-black "buckshot" pellets.
3.0	11.0	Clay, light brown-gray to gray, silty, slightly sandy; has many thin streaks of iron oxide stain; contains more brown-black "buckshot" pellets than unit above, some of which are up to one-quarter inch in diameter.
1.0	12.0	Silt, light-brown to gray mottled, clayey, slightly sandy; has iron oxide staining; contains scattered small brown-black "buckshot" pellets and some limonite.
2.0	14.0	Sand, light-brown to gray-brown mottled, clayey, fine-grained; has iron oxide staining.

Composite sample taken from 1.0 to 12.0 feet; cored two holes.

Core Hole LWA-3

Location: In edge of field near farm access road approximately 50 feet west of the center line of U. S. Highway 61 (NE.1/4, NW.1/4, SE.1/4, Sec.4, T.22 N., R.5 W.), about 2.4 miles north of the intersection of U. S. Highway 61 and State Highway 8 at Cleveland—Bolivar County.

Elevation: 141 feet (topographic map) Date: December 17, 1963

Thickness (feet)	Depth (feet)	Description of strata
1.0	1.0	Soil—light-brown, silty, sandy clay.
		Alluvium
3.0	4.0	Clay, light brown-gray to gray mottled, plastic; has some iron oxide staining; contains scattered small brown-black "buckshot" pellets up to one-eighth inch in diameter and a small amount of carbonaceous material
7.0	11.0	Clay, gray, slightly slity, plastic; has some splotches and streaks of iron oxide stain; contains scattered small brown-black "buckshot" pellets and some scattered calcareous nodules
1.0	12.0	Silt, gray-brown, clayey, slightly sandy; has streaks and splotches of iron oxide stain.

Composite sample taken from 1.0 to 11.0 feet; cored two holes.

Core Hole LWA-4

Location: In U. S. Highway 49 right-of-way approximately 20 feet northeast of the center line of Highway (NE.1/4, SE.1/4, SW.1/4, Sec.31, T.27 N., R.3 W.), about 2.4 miles southeast of the intersection of U. S. Highways 49 and 61 at Clarksdale—Coahoma County.

Elevation: 162 feet (topographic map) Date: December 18, 1963

Thickness (feet)	Depth (feet)	Description of strata
1.0	1.0	Soil—Dark-gray, sandy clay.
		Alluvium
2.0	3.0	Clay, gray-brown mottled, plastic; has some streaks and splotches of iron oxide stain; contains a small amount of carbonaceous material
5.0	8.0	Clay, gray, plastic; has streaks and splotches of iron oxide stain; contains a small amount of carbonaceous material and some scattered calcareous nodules
4.0	12.0	Sand, gray-brown mottled, very fine-grained, silty; stained in part with iron oxide.

Composite sample taken from 1.0 to 8.0 feet; cored three holes.

Core Hole LWA-5

Location: On house site approximately 300 feet southeast of the center line of State Highway 6 and 25 feet north of the center of road east (SE.1/4, SW.1/4, SW.1/4, Sec.25, T.28 N., R.1 W.), about 1.0 mile east and north of the intersection of State Highways 6 and 3—Quitman County.

Elevation: 159 feet (topographic map) Date: December 18, 1963

Thickness (feet)	Depth (feet)	Description of strata
		Alluvium
5.0	5.0	Clay, brown-gray mottled, plastic; has some streaks and splotches of iron oxide stain; contains a small amount of carbonaceous material

3.0	8.0	Clay, brown-gray, plastic; has some streaks and splotches of iron oxide stain; contains scattered calcareous nodules
2.0	10.0	Sand, gray-tan mottled, very fine-grained, silty, clayey; has streaks and splotches of iron oxide stain
3.0	13.0	Clay, gray, plastic, moderately silty, slightly sandy; has streaks and splotches of iron oxide stain; contains some small brown-black "buckshot" pellets and scattered calcareous nodules
2.0	15.0	Clay, blue-gray mottled, plastic; has some splotches of iron oxide stain; contains some scattered calcareous nodules
4.0	19.0	Clay, blue, plastic; has some splotches of iron oxide stain; contains a few scattered calcareous nodules
3.0	22.0	Sand, blue-gray, fine-grained, silty, clayey.

Composite sample taken from 0.0 to 19.0 feet.

Core Hole LWA-6

Location: In pasture east of fence gap approximately 50 feet north of the center of county-line road (SE.1/4, SW.1/4, SE.1/4, Sec.22, T.8 S., R.4 E.), about 1.4 miles west of U. S. Highway 78 at Sherman—Union County

Elevation: 418 feet (topographic map) Date: December 27, 1963

Thickness (feet)	Depth (feet)	Description of strata
2.0	2.0	Soil—tan to buff, sandy clay.
		Ripley formation (Transitional clay)
10.0	12.0	Clay, gray-brown to buff mottled, slightly sandy, micaceous, calcareous, fossiliferous to very fossiliferous; stained with iron oxide along joints and fractures; contains streaks of red-brown very micaceous sand from 1 to 3 inches thick
8.0	20.0	Clay, gray-brown to gray mottled, slightly sandy, micaceous, calcareous, fossiliferous; stained with iron oxide along joints and fractures
5.0	25.0	Clay, gray, slightly sandy, micaceous, calcareous, shaley; stained with iron oxide along joints and fractures
27.0	52.0	Clay, dark-gray, slightly sandy, micaceous, calcareous, fossiliferous; becomes very calcareous at 47 feet—may be top of the Demopolis.

Composite sample taken from 2.0 to 52.0 feet.

Core Hole LWA-7

Location: In State Highway 50 right-of-way approximately 25 feet north of the center line of Highway (NW.1/4, SW.1/4, Sec.15, T.20 N., R.12 E.), about 2.0 miles east of the junction of State Highways 50 and 15—Webster County.

Elevation: 343 feet (altimeter) Date: December 28, 1963

Thickness (feet)	Depth (feet)	Description of strata
		Porters Creek formation
6.0	6.0	Clay, tan to gray mottled, moderately silty; has splotches and streaks of iron oxide stain
14.0	20.0	Clay, tan to gray to dark-gray mottled, plastic; has some iron stain along joints and fractures
14.0	34.0	Clay, dark-gray, blocky; has a small amount of iron oxide stain along joints and fractures.

Composite sample taken from 6.0 to 34.0 feet.

Core Hole LWA-8

Location: In State Highway 15 right-of-way approximately 35 feet east of center line of Highway (NE.1/4, NE.1/4, SW.1/4, Sec.25, T.9 N., R.11 E.), about 1.2 miles north of Union City limits—Neshoba County.

Elevation: 592 feet (altimeter) Date: January 4, 1964

Thickness (feet)	Depth (feet)	Description of strata
		Zilpha formation
6.0	6.0	Sand, yellow-tan to orange-red, fine-grained, clayey, sparingly glauconitic; stained in part with iron oxide
3.0	9.0	Clay, tan to purple-brown mottled, plastic; stained in part with iron oxide
3.0	12.0	Clay, purple-brown, slity, plastic; stained in part with iron oxide
1.0	13.0	Silt, purple-brown, clayey, slightly sandy, glauconitic; has some iron oxide staining
0.5	13.5	Silt, gray to dark green-gray, glauconitic to very glauconitic; contains laminae of dark-gray clay
4.5	18.0	Silt, gray, glauconitic to very glauconitic; contains interbeds and laminae of dark-gray clay
10.0	28.0	Clay, dark-grey, moderately silty; contains thin interbeds and laminae of silt and scattered small pyrite nodules
27.0	55.0	Clay, dark-gray, sparingly glauconitic, slightly to moderately silty; contains some laminae of silt and scattered small pyrite nodules; lower foot is glauconitic
4.0	59.0	Clay, dark green-gray, very glauconitic, fossiliferous; upper 6 inches sideritic.

Composite sample taken from 18.0 to 55.0 feet.

Core Hole LWA-9

Location: Near edge of woods approximately 35 feet south of the center of east-west road (center SW.1/4, Sec.8, T.9 N., R.18 E.), about 0.9 mile west of the Gulf, Mobile and Ohio Railroad at Enondale—Kemper County.

Elevation: 311 feet (altimeter) Date: January 8, 1964

Thickness (feet)	Depth (feet)	Description of strata
5.0	5.0	Soil—red-brown, silty, sandy clay.
		Porters Creek formation (Matthews Landing member)
2.0	7.0	Limonite (weathered marl), dark red-brown to yellow, sandy, clayey, glauconitic, concretionary; grades into clay below.
		Porters Creek formation
12.6	19.6	Clay, tan-gray to dark-gray mottled; stained with iron oxide along joints and fractures
0.1	19.7	Limonite, dark red-brown to yellow, clayey
5.3	25.0	Clay, dark-gray to black; stained with iron oxide along joints and fractures; contains scattered small clusters of selenite
5.0	30.0	Clay, dark green-gray to green-black, slightly to moderately silty; contains scattered small pyrite nodules and some laminae of light-gray finely micaceous silt
9.5	39.5	Clay, dark-gray to black; contains some laminae of light-gray, finely micaceous silt
12.5	52.0	Clay, dark-gray to black, slightly to moderately silty; contains some scattered small pyrite nodules and laminae of light-gray, finely micaceous silt.

Composite sample taken from 7.0 to 52.0 feet.

Core Hole LWA-10

Location: In U. S. Highway 11 right-of-way approximately 35 feet east of center line of Highway (NW.1/4, NW.1/4, Sec.7, T.1 N., R.14 E.), about 3.35 miles northeast of Stafford Springs Lodge—Clarke County.

Elevation: 359 feet (topographic map) Date: January 15, 1964

Thickness (feet)	Depth (feet)	Description of strata
1.0	1.0	Soil—dark-gray to black, sandy, clay loam.
		Red Bluff formation
4.5	5.5	Clay, red-brown, sandy, plastic.
		Yazoo formation (Shubuta member)
26.0	31.5	Clay, buff to yellow-tan, slightly silty in part, plastic, fossiliferous, calcareous; has some splotches and streaks of iron oxide stain; contains scattered clusters and a few thin layers of selenite and scattered small pyrite nodules
30.5	62.0	Clay, blue-green to green-gray, slightly silty in part, fossiliferous, calcareous; contains scattered clusters of selenite and small pyrite nodules.

Composite sample taken from 12.0 to 62.0 feet.

Core Hole LWA-11

Location: In U. S. Highway 11 right-of-way approximately 40 feet west of center line of Highway (SE.1/4, SW.1/4, Sec.20, T.4 N., R.13 W.), about 0.25 mile south of the New Orleans and Northeastern Railroad over-pass—Forrest County.

Elevation: 216 feet (topographic map) Date: January 17, 1964

Thickness (feet)	Depth (feet)	Description of strata
1.0	1.0	Soil—dark-gray to black, silty, sandy, clay loam.
		Hattiesburg formation
5.5	6.5	Sand, varicolored (gray, buff, yellow and red mottled), fine-grained, silty; has splotches and streaks of iron oxide stain
5.5	12.0	Silty clay and silt interlayered, varicolored (light-gray, buff, yellow, red and dark-gray mottled); has splotches and streaks of iron oxide stain; contains a few thin layers of light-gray to buff, moderately hard claystone
20.0	32.0	Clay, light-gray to gray, mottled yellow, buff, tan and red in part, slightly silty to very silty; stained with iron oxide in part
3.0	35.0	Silt, light-gray --
1.0	36.0	Clay, gray to tan mottled, silty.

Composite sample taken from 12.0 to 32.0 feet; cored two holes.

Core Hole LWA-12

Location: In U. S. Highway 59 right-of-way between 4th Avenue and the Mississippi Central Railroad track approximately 80 feet north of the center of 4th Avenue (NE.1/4, SE.1/4, Sec.1, T.4 N., R.14 W.), about 1.2 miles west-northwest of U. S. Highway 49—Lamar County.

Elevation: 223 feet (topographic map) Date: January 18, 1964

Thickness (feet)	Depth (feet)	Description of strata
4.5	4.5	Road fill—clay, sand and gravel mixed.
		Hattiesburg formation
25.5	30.0	Clay, varicolored (light green-gray, gray, buff, dark-gray mottled), slightly to very silty, plastic to semi-plastic; has splotches and streaks of iron oxide stain; contains a few thin streaks of carbonaceous material and some calcareous nodules

5.0	35.0	Clay, light chocolate-brown to gray-green mottled, slightly silty, plastic
16.0	51.0	Clay, light green-gray to gray, silty to very silty; stained in small part with iron oxide.

Composite sample taken from 4.5 to 51.0 feet.

Core Hole LWA-13

Location: At top of hill on northeast side of a segment of old State Highway 24 (NE.1/4, NE.1/4, NW.1/4, Sec.36, T.3 N., R.10 W.), about 2.2 miles northwest of the junction of State Highways 24 and 15 at Beaumont—Perry County.

Elevation: 151 feet (topographic map) Date: January 19, 1964

Thickness (feet)	Depth (feet)	Description of strata
		Hattiesburg formation
1.0	1.0	Clay, red-brown, slightly silty
3.0	4.0	Clay, light-gray mottled red, slightly silty
6.0	10.0	Clay, light-gray to light-brown mottled, slightly silty; has splotches and streaks of iron oxide stain
8.0	18.0	Clay, light-gray, silty
3.0	21.0	Clay, light-gray, very silty; has some splotches and streaks of iron oxide stain; contains some thin streaks of carbonaceous material
3.0	24.0	Sand, light-gray, very fine-grained, silty; stained in small part with iron oxide.

Composite sample taken from 0.0 to 18.0 feet; cored two holes.

Core Hole LWA-14

Location: On the southeast side of the Pearl River Clay Company pit approximately 170 feet north of the plant and 130 feet west of the center line of U. S. Highway 11 (SW.1/4, SW.1/4, SE.1/4, Sec.9, T.4 S., R.16 W.), about 1.1 miles southwest of Millard—Pearl River County.

Elevation: 182 feet (topographic map) Date: January 21, 1964

Thickness (feet)	Depth (feet)	Description of strata
		Graham Ferry formation
4.0	4.0	Clay, gray mottled tan to red-brown, silty to very silty, slightly sandy; has splotches and streaks of iron oxide stain
15.5	19.5	Clay, gray mottled red, slightly silty to silty; has some splotches and streaks of iron oxide stain
0.5	20.0	Clay, tan, slightly silty, bentonitic (?); has some splotches of iron oxide stain
13.5	33.5	Clay, olive-gray to yellow-tan mottled, slightly to very silty; has some splotches of iron oxide stain
3.0	36.5	Clay, green-gray to blue-green, moderately silty, moderately hard, bentonitic (?).

Composite sample taken from 4.0 to 33.5 feet.

Core Hole LWA-15

Location: In State Highway 26 right-of-way approximately 60 feet south of the center line of Highway (SW.1/4, NW.1/4, Sec.28, T.2 S., R.15 W.), about 1.2 miles east of the junction of State Highways 26 and 53 at Poplarville —Pearl River County.

Elevation: 264 feet (topographic map) Date: January 22, 1964

Thickness (feet)	Depth (feet)	Description of strata
		Pascagoula formation
4.5	4.5	Clay, light-gray mottled red to orange-red, silty
3.5	8.0	Clay, light green-gray mottled tan to red-brown in part, slightly to moderately silty; has some splotches and streaks of iron oxide stain
1.5	9.5	Silt, light green-gray mottled tan, very clayey
8.5	18.0	Clay, light green-gray mottled tan to light-brown in part, slightly to moderately silty
2.0	20.0	Sand, light green-gray, very fine-grained, clayey
2.0	22.0	Clay, light green-gray, very silty; becomes sandy in lower parts.

Composite sample taken from 4.5 to 18.0 feet; cored two holes.

Core Hole LWA-16

Location: In U. S. Highway 49 right-of-way approximately 60 feet east of the center line of the east lane of Highway (Center SW.1/4, Sec.6, T.4 S, R.11 W.), about 1.0 mile north of the intersection of the road west to McHenry —Stone County.

Elevation: 231 feet (altimeter) Date: January 23, 1964

Thickness (feet)	Depth (feet)	Description of strata
		Graham Ferry formation
1.0	1.0	Clay, light-gray mottled red, silty, very sandy, plastic
1.5	2.5	Clay, light-gray mottled red and tan, silty, plastic
8.0	10.5	Clay, light gray-green mottled tan, slightly to moderately silty
1.5	12.0	Clay, tan-gray to dark-gray, slightly silty, carbonaceous, plastic
12.0	24.0	Sand, light gray-green, fine-grained, silty, clayey; contains some carbonaceous material disseminated.

Composite sample taken from 1.0 to 12.0 feet; cored two holes.

Core Hole LWA-17

Location: Near top of hill approximately 120 feet south of east-west road and 15 feet south of a segment of the old road (Center N.1/2, SW.1/4, SW.1/4, Sec.32, T.6 N., R.4 E.), about 1.4 mile east of State Highway 98—Franklin County.

Elevation: 310 feet (altimeter) Date: January 27, 1964

Thickness (feet)	Depth (feet)	Description of strata
		Citronelle formation
8.5	8.5	Sand, red-brown, fine- to coarse-grained, silty; contains scattered gravel
0.5	9.0	Sand, light-gray to tan mottled, medium- to coarse-grained, clayey; contains scattered gravel.
		Pascagoula formation

4.5	13.5	Clay, light gray-green, slightly silty
0.5	14.0	Silt, light-gray, clayey
6.0	20.0	Clay, light gray-green, slightly silty; contains specks of light-gray silt
2.0	22.0	Clay, light gray-green mottled red-brown, slightly silty; has splotches and streaks of iron oxide stain
2.5	24.5	Clay, red-brown mottled light gray-green, slightly silty
10.5	35.0	Clay, light gray-green mottled gray-brown, slightly silty
0.5	35.5	Sand, light-gray, very fine-grained, clayey
5.0	40.5	Clay, light gray-green mottled red-brown, slightly silty; has splotches and streaks of iron oxide stain
0.5	41.0	Clay, light gray-green, slightly sandy; contains some carbonaceous material.
6.0	47.0	Sand, light gray-green, fine-grained, clayey; contains some carbonaceous material.

Composite sample taken from 9.0 to 41.0 feet.

Core Hole LWA-18

Location: In northwest corner of intersection of north-south road and west exit to U. S. Highway 80 approximately 250 feet north of the center line of Highway (NE.1/4, NE.1/4, NW.1/4, Sec.20, T.16 N., R.5 E.), at Bovina—Warren County.

Elevation: 245 feet (topographic map) Date: February 28, 1964

Thickness (feet)	Depth (feet)	Description of strata
3.0	3.0	Soil—tan, silt loam
		Loess formation
25.0	28.0	Silt, light-brown to tan, slightly calcareous, sparingly fossiliferous
2.0	30.0	Silt, yellow-brown to tan, slightly sandy.
		Citronelle formation
1.0	31.0	Sand, red-brown to orange-red, fine-grained, silty, clayey.

Composite sample taken from 3.0 to 30.0 feet; cored two holes.

Core Hole LWA-19

Location: In power line right-of-way approximately 15 feet east of the center of northeast trending road from Brandon (Center NW.1/4, SE.1/4, Sec.10, T.5 N., R.3 E.), about 1.5 miles northeast of U. S. Highway 80 at Brandon—Rankin County.

Elevation: 475 feet (topographic map) Date: March 2, 1964

Thickness (feet)	Depth (feet)	Description of strata
		Citronelle formation (?)
10.0	10.0	Sand, buff mottled red, fine- to coarse-grained, silty, clayey; stained in part with iron oxide.
		Catahoula formation
8.0	18.0	Clay, gray mottled maroon; contains sandy streaks and limonite inclusions
2.5	20.5	Sand, buff to orange red, fine- to medium-grained.
		Bucatunna formation
12.5	33.0	Clay, brown-gray to chocolate, plastic; contains some silt laminae and scattered clusters of selenite; has coatings of iron oxide along laminae and joints
6.0	39.0	Clay, dark-gray, slightly silty; contains scattered clusters of selenite and a few small pyrite nodules.
3.0	42.0	Marl, gray-green, sandy, fossiliferous

Composite sample taken from 20.0 to 39.0 feet.

Core Hole LWA-20

Location: In pasture approximately 50 feet southwest of a segment of old U. S. Highway 80 and 0.5 mile northeast of U. S. Highway 80 (Center SW.1/4, SE.1/4, Sec.26, T.6 N., R.5 E.), about 1.7 air miles northeast of Pelahatchie —Rankin County.

Elevation: 444 feet (topographic map) Date: March 4, 1964

Thickness (feet)	Depth (feet)	Description of strata
		Terrace deposit
12.0	12.0	Silt, light-gray to tan, slightly sandy, clayey
10.0	22.0	Sand, red-brown to orange-red, medium- to coarse grained; contains some streaks of light-gray mottled pink clay; stained with iron oxide.
		Yazoo formation
40.0	62.0	Clay, green-gray to gray-green, slightly silty in part, calcareous, fossiliferous.

Composite sample taken from 22.0 to 62.0 feet.

Core Hole LWA-21

Location: In State Highway 43 right-of-way approximately 30 feet east of center line of Highway (NE.1/4, NE.1/4, Sec.9, T.14 N., R.7 E.), about 1.9 miles north of State Highway 12 at Kosciusko—Attala County.

Elevation: 487 feet (altimeter) Date: March 5, 1964

Thickness (feet)	Depth (feet)	Description of strata
		Colluvium
10.0	10.0	Silt, varicolored (buff, tan and yellow), clayey, sandy.
		Zilpha formation
2.0	12.0	Silt, light-gray mottled red; contains laminae of gray clay; has splotches and streaks of iron oxide stain
11.0	23.0	Clay, varicolored (chocolate, gray and dark-gray mottled, slightly to moderately silty; contains scattered clusters of selenite; stained with iron oxide along joints and fractures
16.0	39.0	Clay, dark-gray to black, slightly to moderately silty
1.5	40.5	Clay, dark green-gray to green-black, silty, very glauconitic
10.5	51.0	Clay, dark-gray to black, slightly silty; contains thin layers and laminae of silt and very glauconitic clay
1.0	52.0	Clay, dark green-gray, silty, very glauconitic
3.0	55.0	Clayey silt or silty clay and glauconite; contains thin layers of siderite up to 2 inches thick.

Composite sample taken from 12.0 to 52.0 feet.

Core Hole LWA-22

Location: Approximately 20 feet north of the center of east-west road at junction of road south (SW.1/4, SW.1/4, NW.1/4, Sec.15, T.6 S., R.2 E.), about 1.4 miles east of Myrtle—Union County.

Elevation: 445 feet (topographic map) Date: March 17, 1964

Thickness (feet)	Depth (feet)	Description of strata
2.0	2.0	Soil—brown, plastic clay.
		Porters Creek formation
30.0	32.0	Clay, brown-gray to dark-gray mottled, slightly micaceous in part, conchoidal fracture; stained with iron oxide along joints and fractures.

Composite sample taken from 2.0 to 32.0 feet.

Core Hole AF-1A

Location: In the southwest quadrant of the Interstate Highway 55 interchange (SW.1/4, SW.1/4, Sec.13, T.4 N., R.1 W.), at Byram—Hinds County.

Elevation: 307 feet Date: November 20, 1963

Thickness (feet)	Depth (feet)	Description of strata
		Catahoula formation
16.0	16.0	Drilled interval, no record kept.
4.0	20.0	Cored interval, recovered 3.5 feet: clay, brown to gray, hard, silty in part; stained with iron oxide along joints and fractures
10.0	30.0	Cored interval, recovered 3.5 feet: clay, gray to purple, hard, silty in part; contains disseminated sand grains and some yellow clay; stained in part with iron oxide
10.0	40.0	Cored interval, recovered 4.0 feet: 2 feet—sandstone, fine-grained, silty, clayey, glauconitic; contains some clay laminae 2 feet—clay, dark-gray; contains small particles of carbonaceous material disseminated throughout and some thin silt laminae.
		Bucatunna formation
		(Cored interval, complete recovery from 40.0 to 96.0 feet)
12.0	52.0	Clay, gray, very finely micaceous; contains thin laminae of fine- to very fine-grained, glauconitic sand
38.0	90.0	Clay, dark-gray, very finely micaceous; contains thin laminae of silt
5.0	95.0	Clay, dark-gray, very finely micaceous, sparingly fossiliferous; contains thin laminae of silt
1.0	96.0	Clay, dark-gray, very finely micaceous, sandy, silty, fossiliferous.
		Byram formation
		(Cored interval, complete recovery from 96.0 to 107.0 feet)
11.0	107.0	Marl, green, clayey, very glauconitic, very fossiliferous; contains only minor amounts of sand becoming slightly more sandy in lower part.

Composite sample taken from 40.0 to 95.0 feet; descriptive log by W. H. Moore.

Core Hole AF-17

Location: Approximately 800 feet from west line and 750 feet from north line of Section 36, T.6 N., R.1 E., about 400 feet south of gulch exposing Yazoo clay, Moodys Branch marl and Cockfield lignitic silty clay at Riverside Park in Jackson—Hinds County.

Elevation: 340 feet (topographic map) Date: March 7, 1964

Thickness (feet)	Depth (feet)	Description of strata
6.0	6.0	Soil and tan to brown silt ("brown loam").
		Terrace deposit
3.0	9.0	Sand, yellow mottled red, fine- to medium-grained with some coarse grains; stained with iron oxide.
		Yazoo formation
1.0	10.0	Clay, light-gray to yellow mottled; stained with iron oxide; has brown to black streaks of manganiferous material
3.5	13.5	Clay, as above, less iron oxide staining and more manganiferous staining

5.0	18.5	Clay, tan to pale green, calcareous, gypsiferous, very fossiliferous; contains foraminifera and some macrofossils
2.5	21.0	Clay, tan mottled blue-gray, calcareous, fossiliferous
13.0	34.0	Clay, blue-gray to gray-green, calcareous, very fossiliferous
4.5	38.5	Clay, blue-gray, very calcareous, very fossiliferous; contains some pyrite
2.5	41.0	Clay, light gray-green, very calcareous, very fossiliferous, glauconitic
3.0	44.0	Clay, as above, with some sand grains.
		Moodys Branch formation
4.0	48.0	Sand, green, fine-grained, very fossiliferous, very glauconitic, clayey, very calcareous
10.0	58.0	Sand, green, fine-grained, very fossiliferous, very glauconitic, calcareous.
		Cockfield formation
6.0	64.0	Clay, gray, slightly carbonaceous; contains streaks and borings filled with green, fine-grained, glauconitic, fossiliferous sand
5.0	69.0	Sand, gray, very fine-grained, silty, micaceous, carbonaceous; contains rare grains of glauconite (?).

Composite sample taken from 10.0 to 44.0 feet; descriptive log by W. H. Moore.

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ECONOMICS

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ABSTRACT

Mississippi, along with the rest of the Nation, is experiencing a growing use of lightweight aggregates produced from clays, shales, and slates. These aggregates are most extensively utilized in concrete block or other masonry units and in structural concrete where reduced dead loads are very attractive to the architect and builder. Wider acceptance of this material will come as experience is gained in its use.

Lightweight aggregates must compete with conventional aggregates used in construction and have the best opportunity to penetrate the market in areas where a deficiency in the supply of well-graded sand and gravel or crushed rock exists. Even though a manufactured product of higher value than conventional aggregates, lightweight aggregates are characterized by a high bulk weight relative to value, and for this reason cannot be economically transported long distances. A manufacturing plant would need to be located within 100 miles of the majority of its sales outlets.

Based on information gained from interviews, mail questionnaires and study of published data, it is estimated that the current annual consumption of expanded clay lightweight aggregates in Mississippi is 239,000 cubic yards. Based on the national market outlook, consumption of this material should double by 1970.

INTRODUCTION

The purpose of this paper is to explore the economic potential for development of clay deposits in Mississippi which can be processed into satisfactory lightweight aggregate materials. It is part of an over-all project including efforts by the Mississippi Geological Survey, the Materials Research Center at Mississippi State University, the Mississippi Industrial and Technological Research Commission, the Mississippi State Chemical Laboratory and the U. S. Bureau of Mines. Involved in this project were geologic reconnaissance for clay deposits likely to contain bloatable material, taking of representative samples, and testing to determine characteristics, as well as making a market appraisal.

Even though the term "lightweight aggregate" has come into frequent use only in very recent years, builders in the days of the Roman Empire made concrete with materials having properties of present-day lightweight aggregates. In those days large

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pieces of naturally occurring pumice were used in walls or domes of their buildings where a weight reduction was needed. After the Romans not much is known about the use of lightweight materials until the early nineteenth century when the Germans started using slag as a concrete aggregate. This idea spread to the United States about 1890 and was followed by the rather wide use of cinders from coal-burning furnaces in concrete blocks, known to many as "cinder blocks."

Important advances in lightweight aggregate production started in 1917 when a ceramic engineer named Stephen Hayde found that certain clays and shales would expand and bloat when heated intensively in a rotary kiln. This discovery brought lightweight aggregate from the "by-product" category into a position where it could stand on its own as a "manufactured" product. Hayde received a patent on his discovery and, consequently, all plants built across the country in the next several years after 1918 licensed his patent and produced an aggregate marketed under the trade name, "Haydite." Since the expiration of this patent many more plants have been constructed over the country using the basic idea but with other descriptive trade names such as "Gravelite," "Lite-Rock," "Materialite," and those which show a state origin as "Miss-Lite," "Galite" and "Kenlite."

THE PRODUCT AND ITS USES

Lightweight aggregate is first and foremost a construction material. Any other uses are incidental and would be inconsequential in a comparison of tonnages used to that used in construction. It is utilized in almost all instances as a substitute for normal weight aggregates (sand, gravel, or crushed rock) being mixed with cement, or asphalt, or as a fill material when reduction of weight is a primary consideration. The three main applications are in insulating concrete, masonry units, and structural concrete. Although expanded clay aggregate which can be produced from Mississippi deposits does have insulative value, the minerals ordinarily used in insulating concretes and for fireproofing mixes are expanded vermiculite and perlite neither of which is found in the state. In comparison to expanded clays and shales these materials are super-lightweight aggregates but do not develop the strength necessary in mixes for masonry and structural purposes. This report, therefore, deals only with the masonry and structural applications of lightweight aggregates.

The American Society for Testing and Materials has tentative specifications[1] which it has issued for lightweight aggregates to be used in concrete masonry units and in structural concrete. The items covered in these specifications include grading requirements, unit weights, deleterious substances, and concrete making properties. Using the ASTM grading requirements to separate the various size designations the maximum dry loose weight that the ASTM specifications allow for a material to be classified as a lightweight aggregate are:

Size Designation	DRY LOOSE WEIGHT Max., Lb. per Cubic Foot
Fine aggregate	70
Coarse aggregate	55
Combined fine and coarse aggregate	65

In concrete making properties these specifications set compressive strengths which must be developed with the aggregates while keeping the unit weight of the concrete below the maximums shown below:

Average 28 Day Compressive Strength Min., psi	Average Unit Weight Max., Lb. Per Cubic Foot
4000	115
3000	110
2000	105

Other considerations are important in selecting an aggregate but when it is realized that structural concrete made with conventional aggregate ranges in weight from 140 to 150 lbs. per cu. ft. compared to those unit weights specified above, the main attraction is obvious. In massive concrete pours such as a highway bridge deck or a building floor slab system, the economies that can be achieved because of the substantial reduction in dead loads are extremely attractive to designers. Concrete blocks made with a lightweight aggregate also have this weight advantage and weigh 25 to 28 pounds in contrast to approximately 40 to 44 pounds when conventional aggregate is used. These lighter blocks not only offer the same dead load reduction when used in a building but may offer lower labor expenses. It stands to reason that the average worker laying blocks would handle more 25 pound units in a day than 40 pound units. Too, higher wages are paid to workers laying conventional blocks than to men handling lightweight units in some labor markets.

The growing use of concrete block has been mainly responsible for increasing lightweight aggregate consumption in this country. **Pit and Quarry** in its annual survey of the industry estimates that in 1963 slightly over 68 percent of all lightweight aggregate production was sold to producers of concrete masonry units. National block production more than doubled in the eight year span, 1947 to 1955, increasing from one billion units to slightly more than two billion.[2] The growth rate has slowed down since those post-war construction boom years but **Concrete Products** estimates that 1964 will bring an all-time production record of 2.6 billion 8-inch concrete blocks or their equivalent. With continued improvement in the quality of concrete blocks as to shrinkage characteristics, absorption, and paintability as well as the creation of many new designs with high decorative appeal, this use should continue to offer an excellent market for lightweight aggregates.

The second most important outlet for this material, structural concrete, is consuming a higher percentage of the industry's production each year. The same **Pit and Quarry** survey for 1963 mentioned above indicated that 24 percent was sold for this purpose. The structural concrete utilization of lightweight aggregates has seen a number of problems, as is the case with almost any new product, because of improper handling and use. Mistakes were made when engineers and construction men did not make changes in concrete mix design because of water absorption characteristics of individual lightweight aggregates and their differences in this respect from conventional materials.

A good educational program in the proper handling of lightweight aggregates and design of concrete mixes is being conducted and is having the desired effect. Much is being written each year on the subject in the technical literature and trade periodicals, and individual producers are furnishing excellent engineering advice in the use of their products. In addition "the various trade institutes or associations formed by the industry in the past few years to improve manufacturing methods and techniques and to determine and evaluate the physical properties of, and uses for, their respective products is further proof of the growth of the lightweight aggregate industry."[3]

Much work has been done in Mississippi to develop information on available lightweight aggregates as to their use in structural concrete and numerous other outlets. In early 1964 a significant research project directed by the Engineering and Industrial Experiment Station at Mississippi State University under sponsorship of the State Highway Department and U. S. Bureau of Public Roads was completed. This study had as its primary objective the development of design and economic criteria for the utilization of lightweight concrete in prestressed concrete bridge girders. Lightweight concrete has played an important role in the construction of many buildings both local to Mississippi and of national prominence. Locally, the Coliseum at the State Fairgrounds and the Veterans Administration Hospital, both at Jackson are examples of its use. Nationally, Chicago's Marina City Twin Towers are striking examples in that they establish a new record height of 588 feet for structures formed of reinforced-concrete. With modern tilt-up construction methods using precast building sections and with new creative designs in prestressed reinforced concrete, the outlook for lightweight aggregate in structural concrete is bright indeed.

The remaining lightweight aggregate production in 1963, less than 8 percent, was marketed for all other purposes, most prominent of which is the use as an aggregate in asphalt pavements. The material has good skid resistance and can be useful in paving intersections.

A characteristic of this aggregate resulting from the expansion process is that there are void spaces within individual particles which may cause the particles to take up some of the asphalt cementing medium through absorption. If absorption of asphalt can be maintained at a reasonably low level, this use could show a strong growth tendency and tremendous volumes could be consumed. Some states have seen acceptance of this aggregate for asphalt paving. At this time the Mississippi Highway Department allows its use as an alternate seal material and has several test sections of roadway where it has been used in the surface coat under observation.

Space does not permit mentioning all the various uses to which lightweight aggregates have been put. A few uses of interest, however, are as loose fill insulation, roofing granules or chips, a carrying vehicle for a number of chemical weed killers, and for horticultural purposes. Many new uses will no doubt be found for this material in the future as active sales promotion efforts are made.

COMPETITIVE MATERIALS

The conventional aggregates used in construction—sand, gravel and crushed rock—are of course the main materials with which lightweight aggregates must compete on the market. Mississippi has good supplies of sand and gravel. Reported production of these materials for 1963 totals 7,100,000 short tons.[4] While this figure is substantial, it amounts to an approximate production rate of 3.2 tons per capita while Louisiana's rate is 3.5, Arkansas' is 6.0 and the national average is just less than 4.0 tons per person. This would seem to indicate that there is not an over-supply of conventional aggregate in Mississippi. In addition, sand and gravel is a commodity of high place value having high transportation costs relative to its value; and even though production sources are well distributed over the state, there are a number of counties which have a deficiency.

Crushed rock produced in Mississippi for construction purposes is of no real significance. There are sources in neighboring states which do market rock in Mississippi for highway construction and for other jobs where larger aggregate than available locally is required for massive concrete of high strength. Generally this is not considered a competitive field for lightweight aggregates.

Within the lightweight aggregate classification itself there are two important competitive materials to an expanded clay aggregate. These are expanded slag available as a by-product from steel and phosphate plants in Alabama and an aggregate made from crushed oyster shells dredged along the Alabama, Mississippi, and Louisiana Gulf Coast.

The availability of expanded slag is dependent on the rate of steel production which has been relatively stable in recent years as U. S. producers had difficulty in meeting foreign competition which had more modern plants and equipment. Locally, much will depend on modernization plans in the steel industry in the Birmingham, Alabama area and the percentage of the available slag which will be processed into expanded slag. This latter decision will no doubt hinge on the prospective concrete block market as 98 percent of the expanded slag production goes into the manufacture of block. No attempt will be made to compare the relative merits of expanded clay aggregate to expanded slag but it is significant that there is an average reduction of ten percent in the unit weight of a clay aggregate concrete when compared to slag aggregate concrete.

Oyster shell aggregate has been used widely by block makers near the Gulf Coast because of its relative inexpensiveness and lower transportation costs. In addition, the producers of this material have done an excellent sales and distribution job with their product.

GEOGRAPHIC CONSIDERATIONS

In the early discussions concerning the planning of this project the participants recognized that expanded clay lightweight aggregate, even though a processed product of more worth than sand and gravel, was still one having high bulk weight relative to its value. Because of this, the need of locating the plant as close as possible to the best markets for its product was considered extremely important in order to keep down transportation expense. The conclusion was borne out in discussions with several lightweight aggregate plant operators. A response common to several of these men when asked the extent of their marketing area was that they reached out to a point half way to their nearest competition, not as a result of any gentlemen's agreement, but solely because of the importance of the transportation factor. Two of the operators were specific enough to say that if a sufficient percentage of a plant's output could not be marketed within an area having a radius less than 75 to 100 miles to reach a break-even point in its business, then an aggregate plant in that location would be a risky investment.

With these facts in mind the state was considered as four separate but slightly overlapping areas for appraising lightweight aggregate marketing potential. In this appraisal population concentrations of people in urban areas are considered of primary

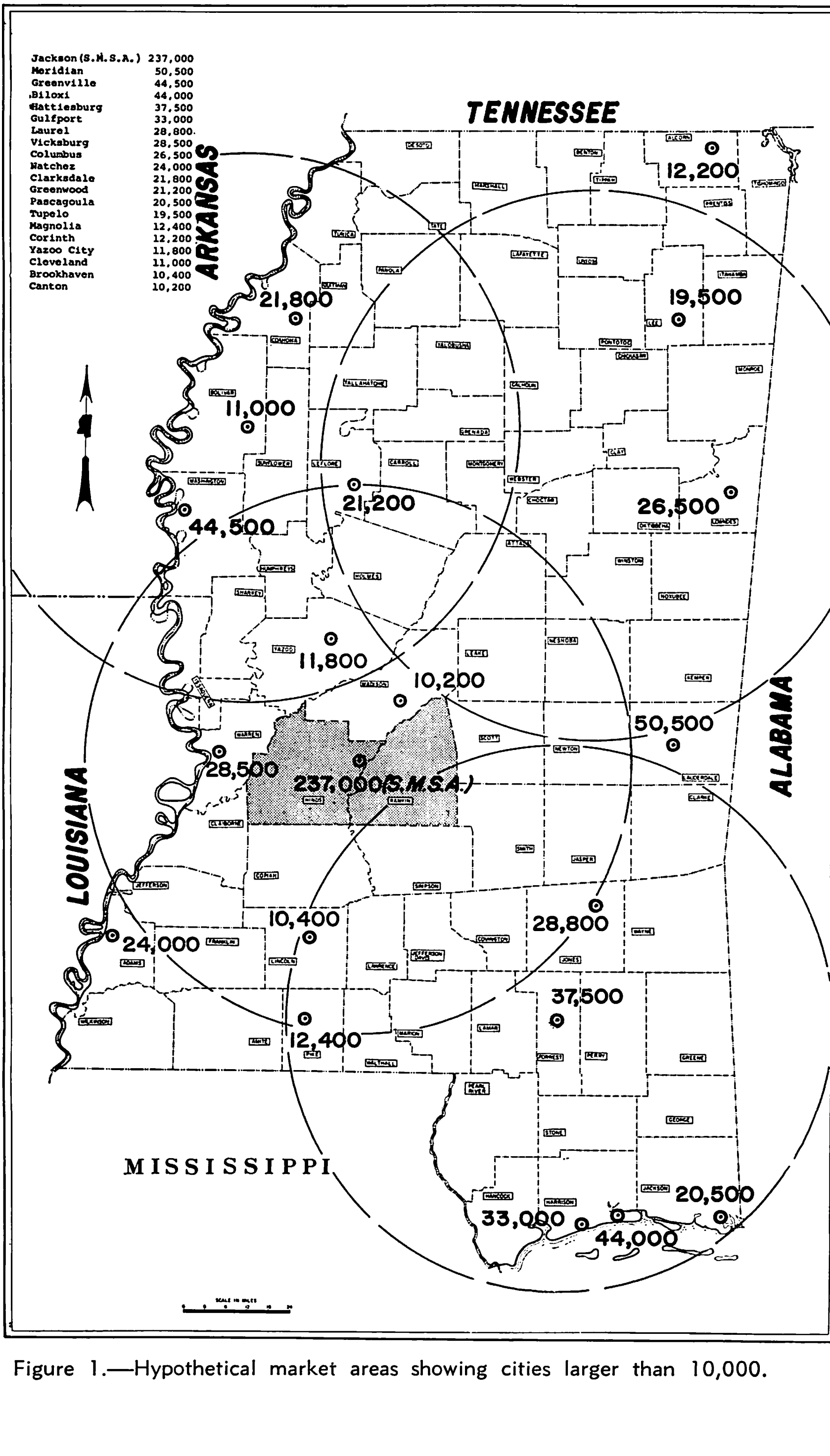

Figure 1.—Hypothetical market areas showing cities larger than 10,000.

importance as nothing is more basic to the creation of a demand for construction materials. The designation with their approximate centers are as follows:

Central	Jackson
Southeast	Hattiesburg
Northwest	Cleveland
Northeast	Maben-Mathiston

The circular areas as shown in Figure 1 are drawn with a radius of 75 miles and show without name all centers of population above 10,000 according to the Rand-McNally Atlas estimates for January 1, 1964. For readers not familiar with Mississippi and unable to identify the cities by their county location a list with population is shown on Figure 1.

Looking briefly at the areas one can visualize some of the factors which would affect the marketing opportunities for a lightweight aggregate processor located at some point within them. No attempt is made to define a market area for the location of each sample of material yielding a satisfactory aggregate (see the previous section of this report on tests). Instead, it is suggested that a reader considering the potential of a particular plant location far away from the center of one of the circular areas in Figure 1 mentally construct a service area diagram for that location. He can then weigh the effect of population concentrations, transportation, and other factors mentioned for the general areas.

The Central Area with the Jackson Standard Metropolitan Statistical Area population of 237,000 at its center is of course the prime market area. The number of people in the five Central Area cities, Figure 1, totals almost 298,000. The attractiveness of this area comes quickly into view when the service radius is lengthened to 100 miles which takes in eight of the thirteen cities in the state larger than 20,000. Rail lines and highways fan out in all directions from the center of this area allowing for efficient transportation of this material. This can be seen clearly from Plate 1 on the inside cover of this publication. The only production of lightweight aggregate in the State, at this time, is by Jackson Ready-Mix Concrete at its plant just outside of Jackson. This plant has seen increasing sales each year of its lightweight aggregate, Miss-Lite, as it served this prime market area, and as a result of its educational program along with sales engineering efforts which are bringing wider acceptance of the material.

The Southeast Area has a population of 166,000 included in six cities with the excellent advantage of including the Gulf Coast where construction activity is particularly vigorous. Here large numbers of houses are being started, but, more important to lightweight aggregate consumption, multi-unit apartments are being built as land values quickly rise. The impact of NASA's Saturn Assembly Plant at Michoud, Louisiana and Test Facility in Hancock County, Mississippi will be felt on the Gulf Coast for several years to come. The Southeast Area enlarged to a service area with a 100 mile radius becomes more attractive since it not only takes in Meridian but reaches the metropolitan area of Mobile, population 396,500, which has no clay lightweight aggregate production. Inasmuch as Mobile is a source of crushed oyster shell aggregate there is little doubt that a quality expanded clay aggregate could penetrate this market.

In the Northwest Area, shown in Figure 1, which includes that part of the state known to Mississippians as the Delta, the total population of the five cities shown is approximately 110,000. The economy of this area has a strong agricultural base but in the last decade has seen a marked increase in manufacturing employment with a resulting growth in city populations. Then too, this area's location adjacent to Arkansas and Tennessee should be given consideration. A plant established near the center of this area would have Pine Bluff, Arkansas and Memphis, Tennessee within 100 miles and the Little Rock-North Little Rock market just beyond that distance. The lack of railroad crossings over the Mississippi River might present some problems as to transportation of the commodity into Arkansas by that means, but truck transportation could be considered. No such problem would exist in serving Memphis because rail and highway routes are quite adequate and barge transportation is also available if volumes to be moved are great enough to justify.

Two plants already established approximately on the 100 mile limit of the Northwest Area are the Arkansas Lightweight Aggregate Corporation at England, about halfway between Little Rock and Pine Bluff, and the John A. Denie's Sons Co.

plant in the northeast suburbs of Memphis. No marketing is done in North Mississippi by the Arkansas producer but the Memphis company is a well established company with a varied line of building construction materials, and it sells to several concrete block plants in the area.

The Northeast Area, as shown in Figure 1 with its center in the vicinity of Maben and Mathiston, has a number of smaller cities with good growth potential but at the present has only three cities above the 10,000 population mark with a total of slightly over 67,000 people in them. Of course increasing this area to one having a radius of 100 miles would take in several more cities, the most populous of which would be Meridian. Any location in the area closer to Memphis than Maben would also bring that large market into an economical service range. A plant located in this area would have to reckon with competing expanded slag aggregate which would be available from the vicinity of Birmingham and Wilson Dam, Alabama.

Previously mentioned in this section on geographic considerations has been the necessity of adequate rail transportation for movement of the finished product to markets near the limits of its service range. This point was kept in mind as the Geological Survey team selected locations for drilling holes to obtain material for testing. Very important, too, in selecting a plant location is the proximity of the clay deposit to be exploited to the processing facility. Obviously, the profit margin in this type process could disappear very rapidly if the raw material had to be transported any appreciable distance.

Large quantities of natural gas would be used in any expanded clay aggregate plant whether a rotary kiln or a sintering process were used. Mississippi is extremely fortunate in having both natural gas production and many natural gas transmission lines crossing the State resulting in reasonable industrial gas rates. Location of a plant where the length of a service line can be kept to a minimum would be another consideration. Plate 2 on the inside back cover is the most recent map available giving location of pipe line facilities and company ownership.

CONSUMPTION ESTIMATES

Much has been stated previously about the growing use of lightweight aggregates as a construction material. As a verifica-

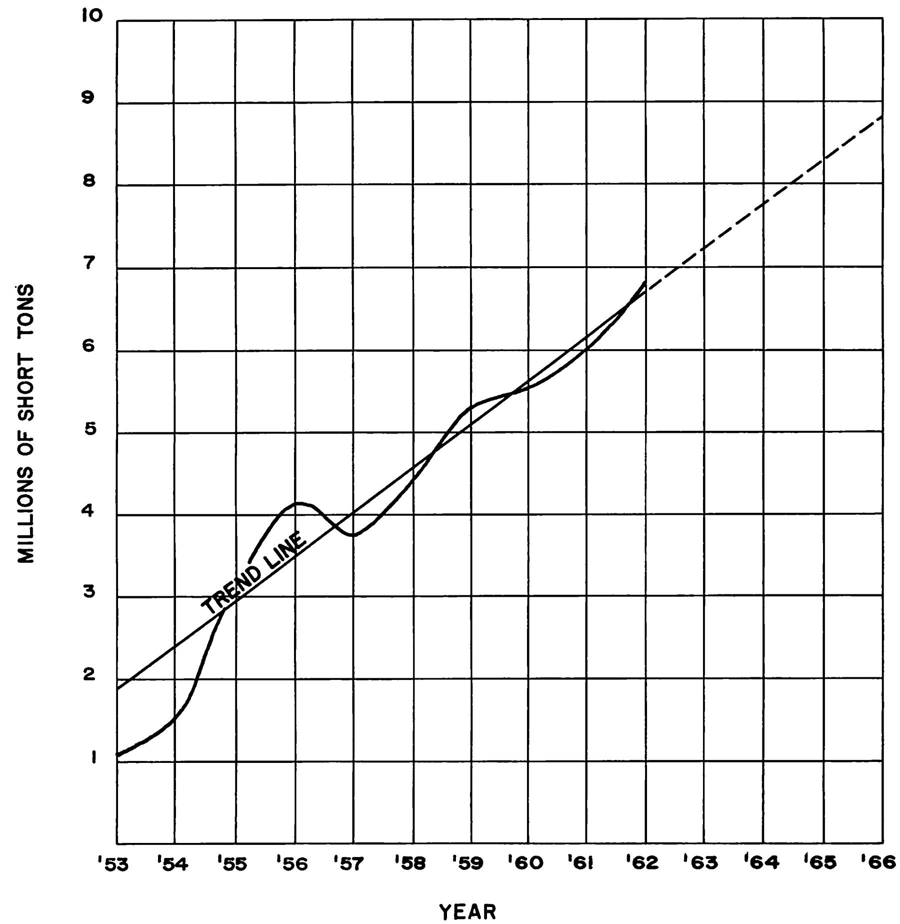

Figure 2.—National consumption of clays, shales, and slates for lightweight aggregate production.

tion of this the consumption of raw materials for these processed lightweight aggregates in the United States is shown for the decade ending in 1962—the last year for which published records are available—in Figure 2. A closer check reveals that the Bureau of Mines reported consumption in 1962, 6,679,912 short tons, was more than five times the 1953 consumption of 1,166,553 short tons. Projection of the growth trend line shown in Figure 2 indicates that consumption should reach almost nine million tons by 1966. Market research people in the construction materials industry anticipate a growth reaching 13 to 15 million tons of clays, shales, and slate going into lightweight aggregate production by 1970. This will be caused by the continued movement of people to the cities and wider acceptance by architects of lightweight concrete as result of the research work now being conducted.

Narrowing the view from the whole nation to the deep southern states, we see that the number of production facilities for structural lightweight aggregates is small compared to the more populous areas of the country. According to the latest available map of plant locations[5] their distribution is as shown below:

State	Number of Plants	Location
Mississippi	1	Near Jackson
Louisiana	1	Near Baton Rouge
Arkansas	2	Ft. Smith; Near Little Rock
Tennessee	3	Memphis; Near Knoxville (2)
Alabama	0	Has only slag and shell
Georgia	1	Near Atlanta
Florida	1	Near Jacksonville

It is noteworthy that with only one exception each plant is near a city having a population of at least 150,000. The exception is the plant at Ft. Smith, Arkansas, a city of 66,000 people. Proximity to large cities is becoming less important, however, because of the rapid growth of towns in the 20,000 to 100,000 population range. Resulting increased land values make multi-story building for apartments, offices, and public use economical. Architectural practices common in the major cities will gradually become the acceptable pattern in the smaller cities.

In order to get an idea of the use of lightweight aggregates in Mississippi many interviews were held with architects, engineers, construction people over the State, Highway Department personnel, and representatives of trade associations connected with the industry. In addition mail questionnaires, Appendix, were used to canvass the major concrete block makers in the State in order to determine current total production and type aggregates being used. Information was made available to us by 12 of the 21 producers canvassed who are estimated to have 60 percent of the block capacity of the state. Using this representative sample it is estimated that the current production of blocks is now about 17 million per year. This figure, verified by individuals within the industry, shows a reasonable growth for the period of 1958-1963 over the 13 million units reported in Mississippi for 1958[6]. According to the questionnaire response, less than ten percent of the State's block production contains sand or small gravel as an aggregate, 28 percent are made with either slag or oyster shell, and 62.4 percent use an expanded clay aggregate. The latter percentage indicates that currently in Mississippi approximately 10,600,000 blocks are made with a clay lightweight aggregate. Based on this quantity of blocks, and assuming an average of 65 blocks per cubic yard of aggregate, the volume of this material going into blocks is estimated to be 163,000 cubic yards.

No satisfactory sources of information were found which would allow an accurate determination of the volume of expanded clay aggregate used in structural concrete. However, there is no reason to believe that the pattern of utilization in the State of Mississippi is much different from the national pattern previously mentioned. Factoring up the estimated volume of materials used in blocks to total for all uses, the quantities, by use, are estimated as shown below:

Use	National Average For This Use (percent)	Estimated Quantities Mississippi (cubic yards)
Block and Other Masonry Units	68	163,000
Structural Concrete	24	57,000
Other, Including Paving	8	19,000
Total—All Uses	100	239,000

As a check on the estimate for quantity in the use category—Other, including Paving—information was secured from the Mississippi State Highway Department as to its current annual use of lightweight aggregate. This is reported as 15,000 cubic yards of which more than 99 percent went into asphalt paving. Deducting this amount from the total shown in the particular use category would leave 4,000 cubic yards, probably used for city paving jobs and in other miscellaneous ways.

A number of factors must be considered in any use projections for lightweight aggregate in Mississippi. Its use is tied to the level of construction activity which is of course subject to wide economic fluctuations. Building construction in Mississippi is definitely on an upward trend, more so than in some surrounding states, as can be seen in the comparison of total contract awards in Figure 3, the source for which is "Dodge Construction Statistics."

Scaling national market projections down to Mississippi proportions, the consumption of lightweight aggregates in the state should reach 500,000 cubic yards by 1970. This estimate is in line with the national market outlook which is that the 1970 production rate will almost double the present. This figure could prove to be low if aggregates now being tested and new aggregates which may become available prove to be worthy of wider acceptance for asphalt paving. Quantities going into that use could conceivably become greater than in blocks or in structural concrete, making a great change in the total demand.

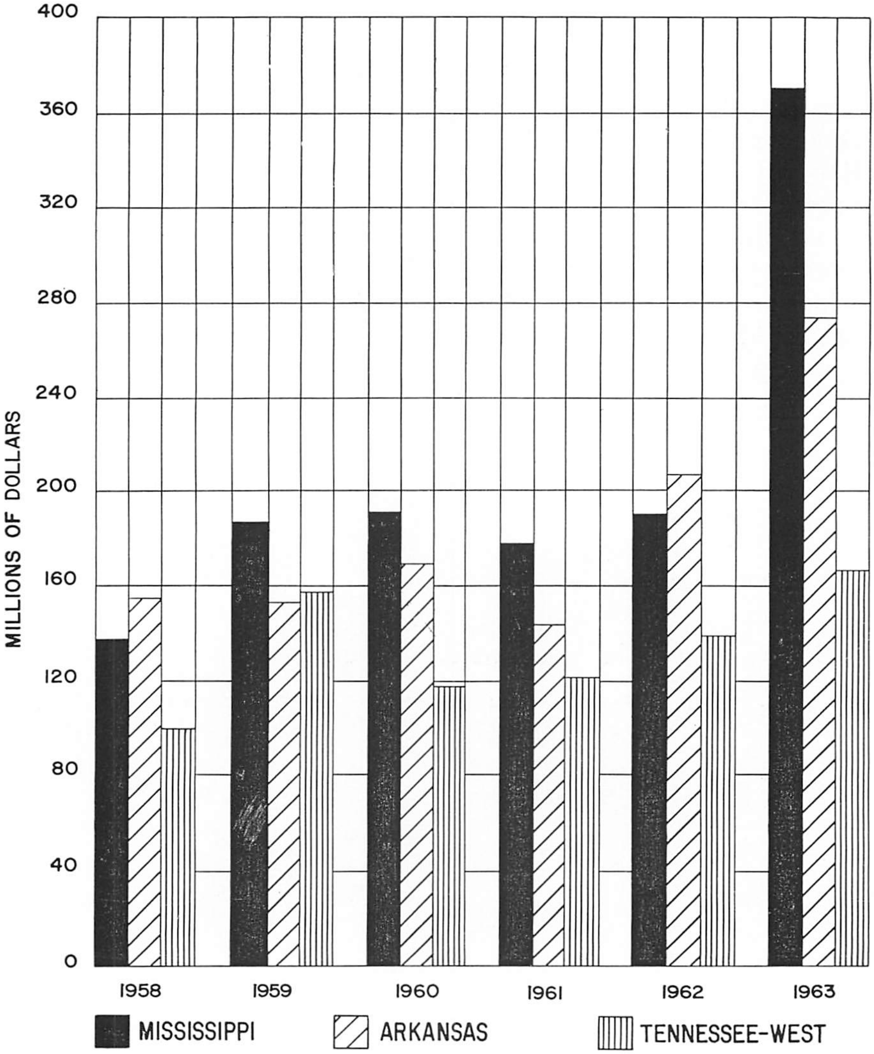

Figure 3.—Total residential and non-residential building construction contracts awarded.

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APPENDIX

Mississippi Industrial and Technological Research Commission

POST OFFICE DRAWER 2470 / JACKSON, MISSISSIPPI 39205 / TELEPHONE 355-1516 / AREA CODE 601

April 21, 1964

Mr. John Doe, Manager
ABC Block Company
P. O. Box 1111
Ocean Park, Mississippi

Dear Mr. Doe:

We are endeavoring to learn the volume of concrete block production in the state. Would you assist us by answering the short questionnaire below?

A stamped, addressed envelope is enclosed for your reply. Thank you for your cooperation.

Sincerely,

Clyde A. McLeod
Staff Engineer

CAMc:dm
Encl

- -

1. What was your production, in terms of 8" x 8" x 16" equivalents, of concrete blocks during 1963 or your latest fiscal year?

    ______________________________equivalents.

2. In what percentage of your concrete block production were the following aggregates used?

sand or gravel	________%
expanded slag	________%
expanded clay or shale aggregate	________%
shell	________%
other (____________)	________%
TOTAL	100 %

3. Has your annual production of concrete blocks increased or decreased since 1961?

increased	________% annually
decreased	________% annually

4. Do you expect to use more cubic yards of lightweight aggregate material (such as expanded clay) during 1964 than you used in 1963?__________
How much?____________________

TESTS

ALLAN G. WEHR*

ABSTRACT

In order to learn further information than permitted through chemical analysis as to the potential for lightweight aggregate production of the clay samples secured by the Mississippi Geological Survey, evaluative tests were performed. Twelve of the twenty-four clays tested in electric furnaces at the Materials Research Center, Mississippi State University showed favorable tendencies to bloat. These twelve along with four others of doubtful potential were tested by the Bureau of Mines at Norris, Tennessee in a small gas-fired rotary kiln under conditions more closely simulating actual production conditions than the electric furnace.

The aggregates produced in the rotary kiln were evaluated for concrete making properties, soundness or resistance to weathering, and abrasion resistance. Test results indicated that several of the deposits sampled contained materials with good potential for processing into lightweight aggregate.

INTRODUCTION

Preliminary bloating tests were performed on the twenty-four clays by the staff of the Materials Research Center at Mississippi State University. The results of these tests were used to determine which of the clays had sufficient promise to warrant further evaluation. Samples of the promising clays were then shipped to the U. S. Bureau of Mines Laboratory in Norris, Tennessee for testing in a rotary kiln. The staff at the Norris Laboratory used some of the aggregate produced in their rotary kiln tests to prepare concrete block specimens for compression testing. The remainder of the aggregate was sent to the Materials Research Center at Mississippi State University for soundness and abrasion tests.

LABORATORY TESTS

SAMPLE PREPARATION

Six hundred grams of each clay was dried in air, and then crushed and ground until it could pass through a 20 mesh screen. The sized clay was formed into a plastic mass by mixing with

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water, and the amount of water used and the working properties of the mass were noted. Twenty-seven briquets were prepared from each clay, and all of the briquets were dried at 230°F for 24 hours.

FIRING TESTS

Six of the briquets were marked for shrinkage and then placed in the kiln for the slow fire test. The temperature of the kiln was raised 400°F per hour for three hours, and then the heating rate was sharply increased and samples were removed from the furnace at 1800°F, 2000°F, 2100°F, 2200°F, 2300°F and 2400°F, or until the samples melted. After firing, the physical properties of the briquets were determined including the percent shrinkage, the apparent specific gravity and the percent absorption.

The other twenty-one briquets were used in the quick fire tests. A sample was placed in a preheated kiln (1800°F) and removed after a period of 15 minutes. The kiln temperature was raised in 100°F steps and subsequent samples were processed in the same manner until either 2400°F was reached or the sample melted. Additional samples were fired using 5 and 10 minute retention times. After firing, the density and the absorption properties of the aggregate were determined. This data, given in tables, can be used to plot graphs which are helpful in establishing the temperature and retention time for rotary kiln tests.

CLAY LWA-1

CLAY LWA-1 Bloated over a wide range of firing temperatures. The extent of bloating was limited, reaching a maximum after being fired for five minutes at 2200°F. The clay bloated only a small amount when it was slow-fired and it melted at 2300°F. It was observed that the samples tended to disintegrate before the bloating range was reached.

SLOW-FIRING TESTS

TEMPERATURE (°F)	COLOR	SHRINKAGE (PER CENT)	APPARENT SP. GR. (GMS/CC)	ABSORPTION (PER CENT)
1800	Orange	3.44	2.21	14.7
2000	Red	6.55	2.32	8.0
2100	Red-Brown	Bloated	1.69	8.51
2200	Brown	Bloated	1.34	7.35
2300	Melted	Melted	Melted	Melted
2400	Melted	Melted	Melted	Melted

FAST-FIRING TESTS

RETENTION TIME	5 MINUTES		10 MINUTES		15 MINUTES	
TEMPERATURE (°F)	DENSITY (LB/FT^3)	ABSORPTION (PER CENT)	DENSITY (LB/FT^3)	ABSORPTION (PER CENT)	DENSITY (LB/FT^3)	ABSORPTION (PER CENT)
1800	105.2	-	106.0	21.5	100.0	17.7
1900	95.0	22.3	99.4	24.2	90.5	14.5
2000	97.0	19.5	77.6	23.3	51.2	26.0
2100	63.6	23.4	57.2	18.8	60.2	16.6
2200	32.6	28.1	54.8	63.3	54.7	4.2
2300	43.8	26.0	46.8	26.2	Melted	Melted
2400	Melted	Melted	Melted	Melted	Melted	Melted

Table 1.—Observations and results, preliminary bloating tests.

CLAY LWA-2

Clay LWA-2 bloated extensively over a wide range of firing temperatures. The maximum bloating was obtained by firing for five minutes at 2200°F. Visual examination noted that the sample had very small uniform pores, and large pores were only seen in the samples fired at the higher temperatures. The slow-fired specimens showed very little evidence of bloating and melting was observed at 2300°F. The fired aggregate was noted to be very strong and it was very hard to crush.

SLOW-FIRING TESTS

TEMPERATURE (°F)	COLOR	SHRINKAGE (PER CENT)	APPARENT SP. GR. (GMS/CC)	ABSORPTION (PER CENT)
1800	Orange	0.49	2.26	19.5
2000	Orange-Red	3.53	2.33	10.0
2100	Red-Brown	6.37	2.21	1.79
2200	Red-Brown	5.00	1.87	6.5
2300	Melted	Melted	Melted	Melted
2400	Melted	Melted	Melted	Melted

FAST-FIRING TESTS

RETENTION TIME	5 MINUTES		10 MINUTES		15 MINUTES	
TEMPERATURE (°F)	DENSITY (LB/FT^3)	ABSORPTION (PER CENT)	DENSITY (LB/FT^3)	ABSORPTION (PER CENT)	DENSITY (LB/FT^3)	ABSORPTION (PER CENT)
1800	107.5	22.0	48.8	18.0	53.7	20.0
1900	77.5	16.9	47.5	23.8	43.8	25.0
2000	63.5	22.8	32.9	50.0	38.5	20.4
2100	32.0	28.2	28.2	36.0	50.0	21.4
2200	27.9	34.0	-	-	60.5	27.4
2300	31.6	32.2	33.1	24.0	Melted	Melted
2400	Melted	Melted	Melted	Melted	Melted	Melted

Table 1, continued.—Observations and results, preliminary bloating tests.

CLAY LWA-3

Clay LWA-3 Bloated extensively over a moderate range of firing temperatures. The samples tended to crack and break up before the bloating temperature was reached. The slow-fired samples expanded at a low firing temperature (2000°F) and also melted at a low temperature (2200°F). Samples fast-fired above 2000°F were extremely glassy and were very brittle.

SLOW-FIRING TESTS

TEMPERATURE (°F)	COLOR	SHRINKAGE (PER CENT)	APPARENT SP. GR. (GMS/CC)	ABSORPTION (PER CENT)
1800	Orange	5.32	2.19	10.1
2000	Red-Brown	Bloated	1.10	7.5
2100	Red-Brown	Bloated	1.07	7.36
2200	Melted	Melted	0.81	19.9
2300	Melted	Melted	Melted	Melted
2400	Melted	Melted	Melted	Melted

FAST-FIRING TESTS

RETENTION TIME	5 MINUTES		10 MINUTES		15 MINUTES	
TEMPERATURE (°F)	DENSITY (LB/FT³)	ABSORPTION (PER CENT)	DENSITY (LB/FT³)	ABSORPTION (PER CENT)	DENSITY (LB/FT³)	ABSORPTION (PER CENT)
1800	84.2	18.7	86.3	18.6	88.3	16.1
1900	88.8	22.6	84.6	20.4	87.1	22.6
2000	47.1	27.0	46.5	20.2	58.5	18.8
2100	36.2	42.4	38.4	28.2	38.2	21.2
2200	-	-	24.0	43.0	21.2	12.8
2300	34.2	49.0	Melted	Melted	Melted	Melted
2400	Melted	Melted	Melted	Melted	Melted	Melted

Table 1, continued.—Observations and results, preliminary bloating tests.

CLAY LWA-4

Clay LWA-4 only bloated a small amount and exhibited melting at a low temperature. The samples fast-fired at low temperatures were extremely strong. The slow-fired specimens started bloating at 2000°F and were also extremely strong. The fast and slow-fired specimens melted at 2200°F

SLOW-FIRING TESTS

TEMPERATURE (°F)	COLOR	SHRINKAGE (PER CENT)	APPARENT SP. GR. (GMS/CC)	ABSORPTION (PER CENT)
1800	Orange	4.60	2.10	7.65
2000	Red-Brown	Bloated	1.80	5.7
2100	Red-Brown	Bloated	1.11	9.37
2200	Melted	Melted	Melted	Melted
2300	Melted	Melted	Melted	Melted
2400	Melted	Melted	Melted	Melted

FAST-FIRING TESTS

RETENTION TIME	5 MINUTES		10 MINUTES		15 MINUTES	
TEMPERATURE (°F)	DENSITY (LB/FT³)	ABSORPTION (PER CENT)	DENSITY (LB/FT³)	ABSORPTION (PER CENT)	DENSITY (LB/FT³)	ABSORPTION (PER CENT)
1800	55.5	23.6	46.5	21.2	39.4	23.4
1900	43.3	22.2	57.6	24.6	44.6	22.2
2000	38.6	29.0	58.5	16.9	38.2	29.2
2100	38.9	27.8	29.2	28.0	42.4	22.2
2200	Melted	Melted	Melted	Melted	Melted	Melted
2300	Melted	Melted	Melted	Melted	Melted	Melted
2400	Melted	Melted	Melted	Melted	Melted	Melted

Table 1, continued.—Observations and results, preliminary bloating tests.

CLAY LWA-5

Clay LWA-5 bloated extensively over a wide range of firing temperatures. The samples fired at temperatures below 2100°F were very strong and had only small uniform pores. Samples fired at 2100°F and above were overbloated, had large pores and were extremely brittle. The slow-fired specimens showed a small amount of bloating and even samples fired at 2400°F didn't melt.

SLOW-FIRING TESTS

TEMPERATURE (°F)	COLOR	SHRINKAGE (PER CENT)	APPARENT SP. GR. (GMS/CC)	ABSORPTION (PER CENT)
1800	Orange	1.72	2.25	11.0
2000	Dark Orange	1.62	2.22	8.05
2100	Red Brown	1.64	2.06	3.2
2200	Brown	1.31	1.55	5.37
2300	Green Brown	Bloated	1.34	5.1
2400	Green Brown	Bloated	1.12	15.7

FAST-FIRING TESTS

RETENTION TIME	5 MINUTES		10 MINUTES		15 MINUTES	
TEMPERATURE (°F)	DENSITY (LB/FT^3)	ABSORPTION (PER CENT)	DENSITY (LB/FT^3)	ABSORPTION (PER CENT)	DENSITY (LB/FT^3)	ABSORPTION (PER CENT)
1800	96.4	10.1	90.5	10.1	91.1	9.45
1900	81.6	9.34	78.2	11.7	77.2	10.3
2000	49.1	16.1	34.2	19.9	55.1	16.6
2100	41.3	23.1	51.5	22.1	42.0	30.0
2200	48.25	23.9	38.5	9.6	33.4	11.0
2300	Melted	Melted	Melted	Melted	Melted	Melted
2400	Melted	Melted	Melted	Melted	Melted	Melted

Table 1, continued.—Observations and results, preliminary bloating tests.

CLAY LWA-7

Clay LWA-7 bloated extensively over an extremely long firing range. The samples bloated at 2000 and 2100°F exhibited excellent aggregate properties. Samples fired above 2100°F were overbloated and had very large pores. The slow-fired specimens started bloating at 2100°F and melted at 2400°F. The samples fired at 2200 and 2300°F exhibited bloating but were very dark brown in color. This clay appeared to be one of the best for the production of lightweight aggregate.

SLOW-FIRING TESTS

TEMPERATURE (°F)	COLOR	SHRINKAGE (PER CENT)	APPARENT SP. GR. (GMS/CC)	ABSORPTION (PER CENT)
1800	Orange	3.16	2.26	20.6
2000	Dark Orange	11.2	2.29	6.2
2100	Brown	7.87	2.20	9.1
2200	Brown	Bloated	0.72	34.6
2300	Brown	Bloated	- -	-
2400	Green Brown	Melted	Melted	Melted

FAST-FIRING TESTS

RETENTION TIME	5 MINUTES		10 MINUTES		15 MINUTES	
TEMPERATURE (°F)	DENSITY (LB/FT^3)	ABSORPTION (PER CENT)	DENSITY (LB/FT^3)	ABSORPTION (PER CENT)	DENSITY (LB/FT^3)	ABSORPTION (PER CENT)
1800	83.0	22.6	72.0	23.1	76.0	23.0
1900	70.0	21.6	52.8	30.2	55.8	25.6
2000	32.3	41.8	45.2	36.8	36.3	46.2
2100	20.8	83.8	25.4	42.3	19.5	41.8
2200	33.8	31.4	20.1	78.7	18.9	47.0
2300	41.4	43.0	Melted	Melted	Melted	Melted
2400	Melted	Melted	Melted	Melted	Melted	Melted

Table 1, continued.—Observations and results, preliminary bloating tests.

CLAY LWA-8

Clay LWA-8 bloated over a wide range of temperatures but the aggregate only had good properties over a very narrow range of temperatures. The aggregate fired at the high temperatures was very vitreous in appearance, had large pores, and was extremely brittle. The slow-fired specimens started bloating at 2100°F and the samples fired at 2300°F were over-bloated. The clay had a high melting point, as the sample fired at 2400°F didn't show any evidence of melting except that it was green-brown in color.

SLOW-FIRING TESTS

TEMPERATURE (°F)	COLOR	SHRINKAGE (PER CENT)	APPARENT SP. GR. (GMS/CC)	ABSORPTION (PER CENT)
1800	Orange	2.07	1.90	20.4
2000	Orange	3.10	2.24	17.6
2100	Brown	0.87	1.91	18.6
2200	Brown	Bloated	1.05	12.0
2300	Red-Brown	Bloated	0.84	19.5
2400	Green-Brown	Bloated	0.60	34.1

FAST-FIRING TESTS

RETENTION TIME	5 MINUTES		10 MINUTES		15 MINUTES	
TEMPERATURE (°F)	DENSITY (LB/FT³)	ABSORPTION (PER CENT)	DENSITY (LB/FT³)	ABSORPTION (PER CENT)	DENSITY (LB/FT³)	ABSORPTION (PER CENT)
1800	79.2	23.8	75.0	23.8	79.6	22.8
1900	78.1	27.0	46.9	33.2	48.5	30.4
2000	50.5	36.1	39.6	47.0	43.8	37.8
2100	41.3	49.2	28.8	62.0	27.1	80.5
2200	33.8	59.6	23.2	91.8	-	-
2300	30.7	84.0	18.3	68.1	Melted	Melted
2400	Melted	Melted	Melted	Melted	Melted	Melted

Table 1, continued.—Observations and results, preliminary bloating tests.

CLAY LWA-9

The firing of clay LWA-9 samples over a wide range of temperatures resulted in an excellent lightweight aggregate. This aggregate was the best obtained in the tests run at Mississippi State University. The fast-fired specimens started bloating at 1900°F and were well bloated at 2000°F. Slow-fired specimens started bloating extensively at 2100°F and the specimens started melting at 2300°F.

SLOW-FIRING TESTS

TEMPERATURE (°F)	COLOR	SHRINKAGE (PER CENT)	APPARENT SP. GR. (GMS/CC)	ABSORPTION (PER CENT)
1800	Orange	1.59	2.19	22.6
2000	Light Brown	8.30	2.30	7.1
2100	Brown	Bloated	1.56	4.95
2200	Brown	Bloated	0.54	22.2
2300	Melted	Melted	Melted	Melted
2400	Melted	Melted	Melted	Melted

FAST-FIRING TESTS

RETENTION TIME	5 MINUTES		10 MINUTES		15 MINUTES	
TEMPERATURE (°F)	DENSITY (LB/FT³)	ABSORPTION (PER CENT)	DENSITY (LB/FT³)	ABSORPTION (PER CENT)	DENSITY (LB/FT³)	ABSORPTION (PER CENT)
1800	93.5	25.3	90.9	21.4	90.1	20.4
1900	81.6	19.0	73.6	18.3	77.1	19.8
2000	38.2	38.1	37.2	36.4	51.7	44.0
2100	42.0	38.0	40.5	56.3	44.7	32.7
2200	39.3	43.2	26.1	47.7	Melted	Melted
2300	32.4	81.8	Melted	Melted	Melted	Melted
2400	Melted	Melted	Melted	Melted	Melted	Melted

Table 1, continued.—Observations and results, preliminary bloating tests.

CLAY LWA-19

Clay LWA-19 bloated extensively over a narrow range of temperatures. The fast-firing of clay samples at 2000°F and 2100°F resulted in an excellent aggregate. Clay samples fast-fired at 2200°F were overbloated and the clay samples melted when fired at 2300°F. The slow-fired specimens started bloating at 2100°F and melted at 2300°F.

SLOW-FIRING TESTS

TEMPERATURE (°F)	COLOR	SHRINKAGE (PER CENT)	APPARENT SP. GR. (GMS/CC)	ABSORPTION (PER CENT)
1800	Red-Tan	1.20	2.12	16.3
2000	Tan	4.93	2.22	21.6
2100	Brown	2.88	2.04	12.7
2200	Gray-Green	Bloated	1.14	18.7
2300	Melted	Melted	Melted	Melted
2400	Melted	Melted	Melted	Melted

FAST-FIRING TESTS

RETENTION TIME	5 MINUTES		10 MINUTES		15 MINUTES	
TEMPERATURE (°F)	DENSITY (LB/FT^3)	ABSORPTION (PER CENT)	DENSITY (LB/FT^3)	ABSORPTION (PER CENT)	DENSITY (LB/FT^3)	ABSORPTION (PER CENT)
1800	117.5	21.8	128.5	24.9	128.5	24.8
1900	120.0	23.4	125.0	25.5	124.9	24.75
2000	106.3	22.7	71.6	19.4	77.0	22.2
2100	63.6	20.0	64.4	17.3	58.9	18.75
2200	31.3	40.5	34.2	35.6	34.2	44.2
2300	Melted	Melted	Melted	Melted	Melted	Melted
2400	Melted	Melted	Melted	Melted	Melted	Melted

Table 1, continued.—Observations and results, preliminary bloating tests.

CLAY LWA-21

Clay LWA-21 bloated extensively over a wide range of temperatures. The aggregate produced by fast-firing the clay samples at 2000 and 2100°F was extremely strong. Firing at 2200°F produced aggregate that was overbloated, had large pores and was very brittle. The slow-fired specimens started bloating at 2200°F and melted at 2400°F.

SLOW-FIRING TESTS

TEMPERATURE (°F)	COLOR	SHRINKAGE (PER CENT)	APPARENT SP. GR. (GMS/CC)	ABSORPTION (PER CENT)
1800	Tan	1.87	2.18	21.6
2000	Tan	1.89	2.20	22.0
2100	Dark Tan	7.20	2.25	14.2
2200	Brown	Bloated	1.78	10.2
2300	Gray-Green	Bloated	0.93	25.2
2400	Melted	Melted	Melted	Melted

FAST-FIRING TESTS

RETENTION TIME	5 MINUTES		10 MINUTES		15 MINUTES	
TEMPERATURE (°F)	DENSITY (LB/FT^3)	ABSORPTION (PER CENT)	DENSITY (LB/FT^3)	ABSORPTION (PER CENT)	DENSITY (LB/FT^3)	ABSORPTION (PER CENT)
1800	99.0	30.8	114	28.0	113	28.0
1900	99.5	25.9	121	24.6	99.3	23.0
2000	70.5	15.5	65.6	15.5	71.0	32.0
2100	55.4	18.9	49.0	27.4	57.2	10.0
2200	31.2	30.8	25.1	46.7	26.8	20.4
2300	21.4	17.8	Melted	Melted	Melted	Melted
2400	Melted	Melted	Melted	Melted	Melted	Melted

Table 1, continued.—Observations and results, preliminary bloating tests.

CLAY LWA-22

Clay LWA-22 exhibited a moderate amount of bloating when fired over a narrow range of temperatures. It is interesting to note that the fast-fired specimens melted at 2200°F, while the specimens slow-fired at 2400°F still retained their shape. Visual examination of the bloated samples noted that while part of a sample bloated or even melted, the other part was unaffected by the high temperature.

SLOW-FIRING TESTS

TEMPERATURE (°F)	COLOR	SHRINKAGE (PER CENT)	APPARENT SP. GR. (GMS/CC)	ABSORPTION (PER CENT)
1800	Orange	2.36	2.42	13.3
2000	Orange-Brown	7.35	2.41	12.0
2100	Brown	10.60	2.33	5.8
2200	Brown	5.31	1.84	3.15
2300	Brown	Bloated	1.43	3.24
2400	Brown	Bloated	1.25	5.25

FAST-FIRING TESTS

RETENTION TIME	5 MINUTES		10 MINUTES		15 MINUTES	
TEMPERATURE (°F)	DENSITY (LB/FT³)	ABSORPTION (PER CENT)	DENSITY (LB/FT³)	ABSORPTION (PER CENT)	DENSITY (LB/FT³)	ABSORPTION (PER CENT)
1800	129.0	24.5	129.0	21.0	129.0	19.8
1900	119.3	14.0	122.4	18.7	122.0	18.25
2000	107.7	14.7	107.1	-	106.0	17.4
2100	111.5	16.65	64.5	129.0	57.4	20.0
2200	Melted	Melted	Melted	Melted	Melted	Melted
2300	Melted	Melted	Melted	Melted	Melted	Melted
2400	Melted	Melted	Melted	Melted	Melted	Melted

Table 1, continued.—Observations and results, preliminary bloating tests.

CLAY AF-1A

Clay AF-1 bloated extensively over a wide firing range. The resulting aggregate is strong and has an excellent bleb structure. Clays fired at 2200°F appear to be overbloated as they are greenish brown, vitreous, have large pores and are extremely brittle. This clay appears to be an excellent potential raw material for the production of lightweight aggregate.

SLOW-FIRING TESTS

TEMPERATURE (°F)	COLOR	SHRINKAGE (PER CENT)	APPARENT SP. GR. (GMS/CC)	ABSORPTION (PER CENT)
1800	Light Tan	4.13	2.18	14.4
2000	Brown	5.37	2.12	9.7
2100	Brown	Bloated	2.82	15.3
2200	Melted	Melted	Melted	Melted
2300	Melted	Melted	Melted	Melted
2400	Melted	Melted	Melted	Melted

FAST-FIRING TESTS

RETENTION TIME	5 MINUTES		10 MINUTES		15 MINUTES	
TEMPERATURE (°F)	DENSITY (LB/FT³)	ABSORPTION (PER CENT)	DENSITY (LB/FT³)	ABSORPTION (PER CENT)	DENSITY (LB/FT³)	ABSORPTION (PER CENT)
1800	79.0	25.6	79.9	25.5	79.8	23.6
1900	67.1	32.6	55.4	31.0	53.8	29.2
2000	44.5	40.4	48.5	36.5	36.9	52.6
2100	28.0	62.8	21.2	113.0	24.7	55.0
2200	27.1	64.0	14.3	87.0	Melted	Melted
2300	Melted	Melted	Melted	Melted	Melted	Melted
2400	Melted	Melted	Melted	Melted	Melted	Melted

Table 1, concluded.—Observations and results, preliminary bloating tests.

CLAY LWA-6

Clay LWA-6 did not bloat at any temperature. All of the fast and slow-fired specimens were a light orange in color except those that melted. The slow-fired specimens started to melt at 2100°F. Several large particles (+ 3/8 mesh) were fired for 15 minutes at 2000, 2100, 2200, and 2300°F. The sample fired at 2100°F was melted and exhibited a small amount of bloating.

CLAY LWA-10

Clay LWA-10 did not bloat except for a small amount of bloating right at the melting point. The clay fired to a light buff color up to the melting point. Several large particles were fired at the various temperatures and no evidence of bloating was observed.

CLAY LWA-11

Clay LWA-11 did not bloat. The fast and slow-fired specimens began melting at 2300°F. Several of the samples exhibited scumming. No bloating was observed when several large particles were fired at the various firing temperatures.

CLAY LWA-12

Clay LWA-12 did not bloat. The results were about the same as that for Clay LWA-11. There was a small amount of white scum present on some of the samples.

CLAY LWA-13

Clay LWA-13 did not bloat. The clay appears to have a high melting point as samples slow-fired at 2400°F did not completely melt. Specimens fired above 2100°F were extremely dark brown in color.

CLAY LWA-14

Clay LWA-14 did not bloat except right at the melting point. Samples fired as low as 2100°F appeared to be partially vitrified. Samples fired at 2100°F and above had a very dark brown color. The results of firing large particles of the clay at various temperatures showed that the clay bloated a small amount just below the melting point.

CLAY LWA-15

Clay LWA-15 did not bloat except right at the melting point. The samples fired above 1900°F were dark brown in color. The firing of large clay particles resulted in a little bloating at the melting point.

CLAY LWA-16

Clay LWA-16 did not bloat except right at the melting point. The samples fired above 1900°F were dark brown in color. The firing of large clay particles resulted in a little bloating at the melting point.

CLAY LWA-17

Clay LWA-17 bloated over a very short range of temperatures just below the melting point. Samples fired at 2300°F and 2400°F for five minutes appear to be bloated. Samples fired at 2400°F for ten minutes appear to be melted. This clay has a high melting point and appears to be a possible raw material for lightweight aggregate, but the rotary kiln operator may have trouble with the short firing range and the vitreous appearance of the bloated specimens suggest that the particles may tend to stick together in a rotary kiln.

CLAY LWA-18

Clay LWA-18 did not bloat. The clay melts at a very low temperature (2100°F) and develops quite a large amount of scum during firing.

CLAY LWA-20

Clay LWA-20 did not bloat except right at the melting point. The clay samples fired to a light color, melted at 2100°F, and developed a large amount of scum during firing. No evidence of bloating was observed when large particles of the clay were fired at the various temperatures.

CLAY AF-17

Clay AF-17 did not bloat. It fires to a light color, melts at a low temperature and tends to scum.

BLENDED LWA-10 AND LWA-12

Preliminary tests made on clay LWA-10 showed that it will not bloat over a wide range of temperatures, but there was some evidence that the clay may bloat over a very short range of temperatures just below its melting point. This could easily be missed in the preliminary tests, because the clays were fired at temperatures that were 100°F apart.

Clay LWA-10 was mixed with another non-bloating clay, LWA-12, in an attempt to cause bloating by either (1) obtaining a mixture with a chemical composition more suitable for good bloating, or (2) the addition of clay LWA-12 would cause the melting of clay LWA-10 to be delayed, resulting in a widening of the clays' bloating range. The experiment results showed that a mixture containing 50% clay LWA-10 and 50% clay LWA-12 bloated over a range of temperatures from 2100 to 2300°F. For example, a sample fired at 2200°F for 10 minutes had a density of 31.5 pounds per cubic foot and an absorption of 22.6%.

ROTARY KILN TESTS

TEST PROCEDURE

Approximately fifty pounds of each clay were air dried, then crushed in a jaw crusher set at one inch, and finally ground in rolls set at three-fourths of an inch. The crushing characteristics and a screen analysis of each raw material is recorded in Table 2. The material larger than one-fourth of an inch was used as the rotary kiln charge.

The rotary kiln was fired to the temperature indicated by the preliminary tests which will give a product weighing between 40 and 60 pounds per cubic foot. During the test, the kiln wall and particle temperatures were measured with an optical pyrometer, and the weight of the aggregate was checked periodically. Because there is often a variation between the laboratory and the rotary kiln results, some of the raw material was passed through the kiln as a preliminary test sample. During this test run a number of temperature adjustments were made until the aggregate reached the desired weight. With the kiln at the corrected temperature, additional raw material was started through the kiln and the temperature was gradually raised until sticking occurred. The temperature was then lowered until the aggregate just began to expand. Temperature readings at these points represent the minimum and maximum processing temperatures for the raw material being tested. After processing, the material was examined, tested, and screened.

Sender's Number		LMA-1			LMA-2			LMA-3			LMA-4	
Norris Lab. Number		1614-A			1614-B			1614-C			1614-D	
Crushing Characteristics		Good			Good			Good			Good	
Particle type & shape												
Angular - A Rounded - R		A			A			A			A	
Elongated - E Platey - P												
Thickness - Nonuniform NU		NU			NU			NU			NU	
Uniform U												
Uniformity Weathered W												
Unweathered UW		UW			UW			UW			UW	
Screen Analysis of Raw Material												
+1 + 3/4		10.5			13.5			3.1			0.6	
-3/4 + 1/2		21.5			15.0			15.6			16.5	
-1/2 + 3/8		16.2			11.3			16.6			21.2	
-3/8 + 1/4		26.4			16.4			32.5			29.1	
-1/4 + 1/8		25.4			43.8			31.8			32.6	
Size Used in Rotary Kiln												
-3/4 + 1/2		33.5			35.2			24.1			24.7	
-1/2 + 3/8		25.2			26.3			25.7			31.6	
-3/8 + 1/4		41.2			38.5			50.2			43.7	
Kiln Wall & Particle Temp °F	K.W.	Part.		K.W.	Part.		K.W.	Part.		K.W.	Part.	
Minimum	1940	1990		1940	1990		1965	2015		1910	1960	
Optimum	1940	2020		1940	2010		1965	2040		1925	2040	
Maximum	1990	2070		1970	2050		2000	2080		1950	2030	
Retention Time (Min.)		15			15			15			15	
Weight unfired Lb/Ft^3		76.3			74.1			73.2			73.0	
Weight fired Lb/Ft3		40.1			50.7			40.8			35.9	
Processing characteristics		Good			Good			Good			Good	
Material flow		U			U			U			U	
Point of material release		10:00			10:00			9:00			10:00	
Particle Shape												
Angular - A Rounded - R		AR			AR			AR			AR	
Elongated - E Platey - P												
Pore Structure												
Coarse, medium, fine		CMF			CMF			M.F.			M.F.	
Expansion		Good			Good			Good			Good	
Uniformity of firing		U			U			U			U	
Color		Brown			Brown			Brown			Brown	
Sizes	Asg.	Lb/Ft^3	% Abs.	Asg.	Lb/Ft^3	% Abs.	Asg.	Lb/Ft^3	% Abs.	Asg.	Lb/Ft^3	% Abs.
-3/4 + 1/2	1.12	69.8	11.8	1.15	71.6	7.0	1.03	64.2	7.7	0.74	46.1	7.6
-1/2 + 1/4	1.16	72.2	10.6	1.13	70.4	6.8	1.12	69.8	7.9	0.92	57.3	6.8
-1/4 + 8	1.72	107.0	14.6	1.63	101.5	7.7	1.15	71.6	7.2	1.11	69.2	8.5
Screen Analysis of Fired Material												
+3/8		26.9			23.8			23.7			49.6	
-3/8 + 1/4		52.8			52.9			48.1			38.4	
-1/4 - 8		14.5			15.4			21.9			10.4	
-8		5.8			7.9			6.3			1.7	
Bags Cement 5/Yd. - Autoclave Cure												
Bulk Sp.Gr.		1.75			2.42			1.82			1.74	
Lb/Ft^3		81			80			79			81	
Compression (PSI)		4365			3463			4268			3520	
% Abs.		5.61			2.96			4.36			3.90	
Bags Cement 7/Yd - Autoclave Cure												
Bulk Sp.Gr.		2.07			2.15			1.99			1.77	
Lb/Ft^3		82			81			81			82	
Compression (PSI)		5813			4203			3772			4585	
% Abs.		4.53			3.98			3.58			4.70	
Bags Cement 5/Yd - 28-Day Cure												
Bulk Sp.Gr.		1.81			1.97			1.76			1.57	
Lb/Ft^3		81			78			82			82	
Compression (PSI)		3252			2634			3049			3431	
% Abs.		5.64			4.48			4.74			4.98	
Bags Cement 7/Yd 28-Day Cure												
Bulk Sp.Gr.		1.99			1.98			1.70			1.63	
Lb/Ft^3		81			80			83			80	
Compression (PSI)		5016			4000			3276			4130	
% Abs.		5.95			5.35			4.98			5.51	

Table 2.—Observations and results, rotary kiln tests and concrete-making properties.

Sender's Number		LWA-5			LWA-6			LWA-7			LWA-8	
Norris Lab. Number		1614E			1614F			1614G			1614H	
Crushing Characteristics		Good			Good			Good			Good	
Particle type & shape												
Angular - A Rounded - R		A			A			A			A	
Elongated - E Platey - PNU												
Thickness - Nonuniform NU		NU			NU			NU			NU	
Uniform U												
Uniformity Weathered W												
Unweathered UW		UW			UW			UW			UW	
Screen Analysis of Raw Material												
-1 + 3/4		7.5			11.0			14.3			9.5	
-3/4 + 1/2		21.3			18.0			19.5			15.8	
-1/2 + 3/8		15.6			14.2			16.6			12.7	
-3/8 + 1/4		31.7			26.2			26.8			25.8	
-1/4 + 1/8		23.9			30.6			11.6			12.7	
-1/8								11.2			23.5	
Size Used in Rotary Kiln												
-3/4 + 1/2		31.0			30.8			30.5			29.3	
-1/2 + 3/8		22.8			24.3			26.0			23.3	
-3/8 + 1/4		46.2			44.9			41.9			47.4	
Kiln Wall & Particle Temp °F	K.W.	Part.		K.W.	Part.		K.W.	Part.		K.W.	Part.	
Minimum	1965	2015		1910	1960		1935	1985		1910	1960	
Optimum	1965	2000		1980	2020		1935	2030		1910	2100	
Maximum	1985	2065		1980	2060		1965	2045		2000	2080	
Retention time (Min.)		15			15			15			15	
Weight unfired Lb/Ft^3		72.7			69.0			59.3			69.2	
Weight fired Lb/Ft^3		49.8			35.2			37.5			38.8	
Processing characteristics		Good			Good			Good			Good	
Material flow		U			U			U			U	
Point of material release		10:00			10:00			10:00			10:00	
Particle shape												
Angular - A Rounded - R		AR			A			AR			AR	
Elongated - E Platey - P												
Pore Structure												
Coarse, medium, fine		M.F.			C.M.F.			M.F.			M.F.	
Expansion		Good			Good			Good			Good	
Uniformity of firing		U			U			U			U	
Color		Lt.Brow n			Grey			Brown			Lt. Brown	
Size	Asg.	Lb/Ft^3	% Abs.	Asg.	lb/Ft^3	% Abs.	Asg.	Lb/Ft^3	% Abs.	Asg.	Lb/Ft^3	% Abs.
-3/4 + 1/2	1.16	72.2	6.9	1.10	68.5	6.7	0.77	47.9	7.1	1.05	65.4	3.7
-1/2 + 1/4	1.14	71.0	8.3	1.13	70.4	7.9	1.02	63.5	8.4	0.95	59.2	3.6
-1/4 + 8	1.47	91.5	8.6	1.48	92.2	7.4	1.29	80.4	14.7	1.03	64.2	3.5
Screen Analysis of Fired Material												
+3/8		43.1			27.3			34.0			44.1	
-3/8 + 1/4		42.7			45.7			50.7			40.1	
-1/4 + 8		12.0			16.4			8.9			12.9	
-8		2.1			10.7			6.4			2.9	
Bags Cement 5/Yd - Autoclave Cure												
Bulk Sp.Gr.		1.92			2.38			1.85			1.71	
Lb/Ft^3		81			81			81			79	
Compression (PSI)		5366			3415			3187			3390	
% Abs.		6.05			3.44			4.15			3.50	
Bags Cement 7/Yd - Autoclave Cure												
Bulk Sp.Gr.		1.89			2.31			1.76			1.71	
Lb/Ft^3		82			82			80			80	
Compression (PSI)		5919			4195			3780			3552	
% Abs.		7.99			3.91			5.07			4.13	
Bags Cement 5/Yd - 28-day Cure												
Bulk Sp.Gr.		1.94			2.03			1.72			1.76	
Lb/Ft^3		78			81			79			82	
Compression (Psi)		4016			3098			2724			2602	
% Abs.		6.69			4.90			5.10			3.64	
Bags Cement 7/Yd 28-day Cure												
Bulk Sp.Gr.		1.96			2.09			1.74			1.73	
Lb/Ft^3		80			81			79			82	
Compression (PSI)		4366			4398			3309			3374	
% Abs.		7.17			5.03			5.35			4.25	

Table 2, continued.—Observations and results, rotary kiln tests and concrete-making properties.

Sender's Number		LWA-9			LWA-10			LWA-19			LWA-20	
Norris Laboratory Number		1614I			1614J			1614K			1614L	
Crushing Characteristics		Good			Good			Good			Good	
Particle type & Shape												
Angular - A Rounded - R		A			A			A			A	
Elongated - E Platey - P												
Thickness - Nonuniform - NU		NU			NU			NU			NU	
Uniform - U												
Uniformity Weathered - W												
Unweathered - UW		UW			UW			UW			UW	
Screen Analysis of Raw Material												
-1 + 3/4		.6			1.1			3.0			1.7	
-3/4 + 1/2		10.2			14.2			16.5			17.7	
-1/2 + 3/8		14.1			15.0			20.2			15.7	
-3/8 + 1/4		28.1			27.8			27.0			30.5	
-1/4 + 1/8		18.3			16.6			13.3			14.3	
-1/8		28.7			25.3			20.0			20.1	
Size Used in Rotary Kiln												
-3/4 + 1/2		19.5			24.8			26.0			27.7	
-1/2 + 3/8		26.8			26.2			31.6			24.5	
-3/8 + 1/4		53.6			49.0			42.4			47.8	
Kiln Wall & Particle Temp °F	K.W.	Part.		K.W.	Part.		K.W.	Part.		K.W.	Part.	
Minimum	1940	1990		1970	2020		1950	2000		1970	2020	
Optimum	1960	2035		2000	2050		1950	2030		1970	2015	
Maximum	1990	2070		2010	2090		1990	2070		2000	2080	
Retention time (Min.)		15			15			15			15	
Weight unfired Lb/Ft^3		68.4			70.3			70.6			67.9	
Weight fired Lb/Ft^3		46.3			34.8			45.0			34.4	
Processing characteristics		Fair			Fair			Fair			Fair	
Material flow		U			U			U			U	
Point of material release		11:00			10:00			10:00			10:00	
Particle Shape												
Angular - A Rounded - R		AR			AR			A			AR	
Elongated - E Platey - P								P				
Pore Structure												
Coarse, medium fine		MF			CM			F			CM	
Expansion		Good			Fair			Fair			Fair	
Uniformity of firing		U			NU			NU			NU	
Color		Lt. Brown			White-grey			Tan-grey			White-grey	
Sizes	Asg.	Lb/Ft^3	Abs.	Asg.	Lb/Ft^3	Abs.	Asg.	Lb/Ft^3	Abs.	Asg.	Lb/Ft^3	Abs.
-3/4 + 1/2	1.13	70.4	5.7	0.86	53.5	7.1	1.13	70.4	4.6	0	0	0
-1/2 + 1/4	1.12	69.8	5.6	0.85	52.9	8.6	1.31	81.6	5.8	1.07	66.7	5.2
-1/4 + 8	1.24	77.3	5.8	1.59	99.0	8.8	1.38	86.0	5.4	1.18	73.5	4.0
Screen Analysis of Fired Material												
+3/8		29.4			25.2			18.3			32.2	
-3/8 + 1/4		42.7			50.4			39.0			51.8	
-1/4 + 8		22.7			14.9			28.8			8.2	
-8		5.2			9.4			13.9			7.8	
Bags Cement 5/Yd - Autoclave Cure												
Bulk Sp.Gr.		1.96			2.17			1.99			2.34	
Lb/Ft^3		82			80			81			81	
Compression (psi)		5976			3593			4390			2813	
% Abs.		3.93			3.78			5.08			3.04	
Bags Cement 7/Yd - Autoclave Cure												
Bulk Sp.Gr.		1.98			2.08			2.03			2.22	
Lb/Ft^3		82			81			82			82	
Compression (psi)		6544			3984			4447			6138	
% Abs.		4.38			4.64			5.87			3.39	
Bags Cement 5/Yd - 28-Day Cure												
Bulk Sp.Gr.		1.77			1.87			2.10			1.31	
Lb/Ft^3		82			80			79			82	
Compression (psi)		5390			2902			2585			3219	
% Abs.		5.90			5.37			5.16			4.90	
Bags Cement 7/Yd - 28-Day Cure												
Bulk Sp.Gr.		1.78			1.94			1.94			1.38	
Lb/Ft^3		81			79			83			86	
Compression		4642			3236			4130			4447	
% Abs.		5.31			5.48			6.25			5.76	

Table 2, continued.—Observations and results, rotary kiln tests and concrete-making properties.

Sender's Number		LWA-21			AF-1A			AF-17			LWA-22	
Norris Laboratory Number		1614M			1614N			1614O			1614P	
Crushing Characteristics		Good			Good			Good			Good	
Particle type & Shape												
Angular - A Rounded - R		A			A			A			A	
Elongated - E Flatey - P												
Thickness Nonuniform - NU		NU			NU			NU			NU	
Uniform - U												
Uniformity Weathered - W												
Unweathered - UW		UW			UW			UW			UW	
Screen Analysis of Raw Material												
-1 + 3/4		.6			.6			3.1			4.5	
-3/4 + 1/2		12.5			11.5			20.4			19.4	
-1/2 + 3/8		17.1			17.4			18.0			14.4	
-3/8 + 1/4		26.9			33.3			24.6			21.8	
-1/4 + 1/8		14.7			17.2			12.2			15.0	
-1/8		28.2			20.0			21.7			24.9	
Size Used in Rotary Kiln												
-3/4 + 1/2		22.2			18.5			32.4			34.9	
-1/2 + 3/8		30.3			27.9			28.5			25.8	
-3/8 + 1/4		47.5			53.6			39.1			39.3	
Kiln Wall & Particle Temp °F	K.W.	Part.		K.W.	Part.		K.W.	Part.		K.W.	Part.	
Minimum	1940	1990		1900	1950		1920	1970		1940	1990	
Optimum	1940	2040		1950	2020		1960	2040		1950	1990	
Maximum	1970	2050		1960	2040		1960	2040		2010	2090	
Retention time (Min.)		15			15			15			15	
Weight unfired Lb/Ft^3		71.0			69.7			75.4			75.0	
Weight fired Lb/Ft^3		41.9			30.0			51.6			58.6	
Processing characteristics		Good			Good			Fair			Good	
Material flow		U			U			U			U	
Pointof material release		9:00			10:00			9:00			11:00	
Particle Shape												
Angular - A Rounded - R		A			A			A			A	
Elongated - E Platey - P												
Pore Structure												
Coarse, medium fine		F			F			CMF			F	
Expansion		Good			Good			Fair			Good	
Uniformity of firing		U			U			NU			U	
Color		Lt.Bro. - Dk.Bro			Lt.Brown			White-grey			Dk.Brown	
Sizes	Asg.	Lb/Ft^3	% Abs.	Asg.	Lb/Ft^3	% Abs.	Asg.	Lb/Ft^3	% Abs.	Asg.	Lb/Ft^3	% Abs.
-3/4 + 1/2	1.01	63.0	3.8	0.75	46.7	2.8	1.38	85.9	4.5	0.61	38.0	8.6
+1/2 + 3/8	1.13	70.0	4.3	0.84	52.3	3.0	1.53	95.3	5.5	0.76	47.3	9.4
-3/8 + 1/4	1.14	71.0	4.8	0.86	53.6	2.9	1.50	93.4	11.9	1.56	97.2	8.8
Screen Analysis of Fired Material												
-3/8		53.2			27.7			27.4			20.6	
-3/8 + 1/4		36.9			48.1			48.5			53.8	
-1/4 + 8		8.8			19.1			16.4			20.6	
-8		1.2			5.1			7.6			5.1	
Bags Cement 5/Yd - Autoclave Cure												
Bulk Sp.Gr.		2.19			2.13			2.46			2.14	
Lb/Ft^3		82			78			81			80	
Compression (psi)		4090			3659			5000			4968	
% Abs.		3.11			2.27			4.23			5.48	
Bags Cement 7/yd - Autoclave Cure												
Bulk Sp.Gr.		2.08			2.20			2.29			2.08	
Lb/Ft^3		80			77			81			81	
Compression (psi)		3610			4220			4846			5455	
% Abs.		3.81			2.30			5.03			6.76	
Bags Cement 5/yd - 28-Day Cure												
Bulk Sp.Gr.		1.80			1.09			2.15			2.06	
Lb/Ft^3		82			68			82			80	
Compression (psi)		3236			2300			3455			2984	
% Abs.		4.10			3.60			5.19			6.12	
Bags Cement 7/Yd - 28-Day Cure												
Bulk Sp.Gr.		1.78			1.11			2.14			2.04	
Lb/Ft^3		81			69			82			80	
Compression (psi)		3366			2854			5373			3870	
% Abs.		4.91			4.02			6.03			7.21	

Table 2, concluded.—Observations and results, rotary kiln tests and concrete-making properties.

TEST RESULTS

The results of the rotary kiln tests are listed in Table 2. Clays LWA-1, LWA-2, LWA-3, LWA-4, LWA-5, LWA-6, LWA-7, LWA-8, LWA-9, LWA-21, AF-1A, and LWA-22 exhibited good processing characteristics while the processing characteristics of the other clays were judged to be fair. It is interesting to note that clays LWA-6, LWA-10, LWA-20 and AF-17 originally exhibited unfavorable bloating characteristics when subjected to preliminary tests in a laboratory kiln.

The firing range (difference between maximum and minimum firing temperatures) for the clays varied from 50 degrees for clay LWA-5 to 120 degrees for clay LWA-8. The bulk density of the fired aggregate varied from 38.0 to 107.0 pounds per cubic foot and the absorption varied from 2.8 to 14.7 per cent.

EVALUATION OF ROTARY KILN PRODUCT

COMPRESSION TESTS OF CONCRETE SAMPLES CONTAINING AGGREGATE

TEST PROCEDURE

Concrete specimens were prepared which contained the aggregates produced by firing sufficient amounts of each of the 16 tested clays in the rotary kiln. The test specimens were prepared using equal volumes of fine and coarse aggregate, and sufficient cement to yield mixtures containing 5 bags of cement per cubic yard of concrete, and 7 bags of cement per cubic yard of concrete.

To insure uniform results, a definite mixing procedure was used in making the concrete. The batches were prepared in three stages: (1) coarse aggregate was mixed with enough water to wet the particle surface, (2) cement and fine aggregate were combined and mixed dry, (3) coarse and fine materials were mixed thoroughly and (4) additional water was added to obtain good workability. Normal water requirements for twelve 2-inch cubes varies between 200 and 350 cubic centimeters.

After mixing, the concrete was tamped into 2-inch cube molds, allowed to set for 2 hours, and then removed and stored overnight under wet paper towels. Curing was accomplished by two methods: (1) in a steam oven for 28 days and (2) in an autoclave for 6 hours at 140 p.s.i. steam pressure. At the end of the curing period, the cubes were soaked in water for 24 hours and the soaked and suspended weights were determined. The cubes were then dried for 8 hours at 140°F and 230°F and placed in a desiccator until cool. After cooling the cubes were weighed and measured, and the bulk density, per cent absorption and other properties were calculated.

Compression tests were made using a hydraulic testing machine. The cubes were capped with 1/2-inch insulation boards (top and bottom) and were placed in the testing macine. The load was applied at a constant rate (20 to 50 p.s.i per second) until failure occurred. The maximum load was recorded and the compression strength was calculated.

TEST RESULTS

The results of the compression tests are listed in Table 2. All of the samples exceeded the minimum compressive strength required for concrete containing lightweight aggregate as set forth by the standard ASTM specification C 330-60T. Concrete specimens containing aggregate produced from Clays LWA-1, LWA-5, LWA-9, LWA-20, AF-17, and LWA-22 exhibited unusually high strengths.

SOUNDNESS TESTS

TEST PROCEDURE

The resistance of the aggregates to disintegration by saturated solutions of magnesium sulfate was determined by means of the standard ASTM Soundness Test. Each aggregate sample was screened through a series of sieves and 100 grams of the following sizes were kept for the test:

Retained on Sieve	Passing Sieve
No. 50	No. 30
No. 30	No. 16
No. 16	No. 8
No. 8	No. 4
No. 4	3/8 in.

Each 100 gram sample was thoroughly washed and dried. The sample was then immersed in a saturated solution of magnesium sulfate for not less than 16 hours and not more than 18 hours.

The sample was maintained at a temperature of 21 degrees plus or minus 1°C during the immersion period.

After the immersion period, the aggregate sample was removed and thoroughly dried in an oven. After drying, the sample was cooled to room temperature and immersed again in the magnesium sulfate solution. The process was repeated until five cycles of immersion and drying were completed.

After the fifth cycle, each sample was thoroughly washed free of the magnesium sulfate and dried in an oven to a constant weight. The sample was then screened over the same sieve on which it was retained before the test. The amount passing through the sieve was expressed as a percentage of the total weight and was called the per cent loss.

TEST RESULTS

All of the aggregate samples exhibited excellent resistance to disintegration by the magnesium sulfate solutions. The results of the soundness tests are shown in Table 3.

The Mississippi State Highway Department's lightweight concrete specifications require that the percentage of loss should not exceed twelve per cent after five cycles of the soundness test. All of the aggregate samples tested in this study easily pass this requirement.

Aggregate	Retained on Sieve No.	Per Cent Loss (By Weight)
LWA-1	4	3.3
	8	5.6
	16	2.6
	30	2.5
	50	3.7
LWA-2	4	11.2
	8	6.1
	16	4.4
	30	5.8
	50	8.8
LWA-3	4	7.8
	8	3.3
	16	2.4
	30	3.1
	50	4.1
LWA-4	4	1.1
	8	1.4
	16	3.3
	30	3.6
	50	5.1
LWA-5	4	0.7
	8	8.9
	16	2.0
	30	6.6
	50	3.8
LWA-6	4	1.9
	8	1.9
	16	4.9
	30	3.3
	50	11.4
LWA-7	4	1.5
	8	6.4
	16	3.7
	30	5.3
	50	4.7

Table 3.—Results of soundness tests.

Aggregate	Retained on Sieve No.	Per Cent Loss (By Weight)
LWA-8	4	2.6
	8	3.9
	16	1.9
	30	2.4
	50	2.9
LWA-9	4	0.8
	8	2.3
	16	1.4
	30	2.6
	50	3.3
LWA-19	4	3.7
	8	6.3
	16	5.2
	30	1.5
	50	2.5
LWA-20	4	0.7
	8	0.5
	16	0.1
	30	0.7
	50	3.9
LWA-21	4	0.9
	8	3.2
	16	2.4
	30	3.0
	50	4.2
LWA-22	4	1.0
	8	5.2
	16	3.4
	30	4.5
	50	2.4
AF-1A	4	2.8
	8	2.4
	16	5.2
	30	2.2
	50	2.4

Table 3, concluded.—Results of soundness tests.

ABRASION TESTS

TEST PROCEDURE

The abrasion resistance of the lightweight aggregate was determined by means of the standard ASTM Los Angeles Abrasion Test. Each sample consisted of 2500 grams of aggregate that passed a 3/8 inch screen and was retained on a No. 3 screen, and 2500 grams of aggregate that passed a No. 3 screen and was retained on a No. 4 screen. The sample was placed in a cylindrical drum along with 8 steel balls which were approximately 1 7/8 inches in diameter. This drum had a rigid shelf mounted along one element of the interior surface of the cylinder, and the shelf projected radially 3 1/2 inches into the cylinder and was equal to it in length. After the sample was placed in the cylinder, a dust-tight cover was bolted over the only opening and the drum was rotated horizontally for 500 revolutions at a speed of 30 to 33 rpm.

At the completion of the test, the aggregate was discharged from the drum and a preliminary separation of the sample was made using a No. 10 sieve. The finer portion was then screened on a No. 12 sieve. The material coarser than the No. 12 sieve was washed, dried, and weighed. The difference between the original weight and the final weight of the test sample was expressed as a percentage of the original weight of the test sample and was reported as the percentage of wear.

TEST RESULTS

The results of the abrasion tests are shown in Table 4. Only nine aggregate samples were abrasion tested because of an insufficient quantity of the other seven aggregates for the abrasion test. Aggregate LWA-8 was the best of the samples, while Aggregate LWA-2 was the poorest. The Mississippi State Highway

Aggregate	Percentage of Wear
LWA-2	30.4
4	19.2
5	21.1
6	21.6
7	23.6
8	14.9
9	15.4
19	24.9
20	18.4

Table 4.—Results of abrasion tests.

Department's lightweight concrete specifications require that the percentage of wear should not exceed fifty per cent using a modified abrasion test where the volume of the charge is adjusted so that it will equal that for an aggregate having a bulk specific gravity of 2.65. All of the aggregates tested in this study have excellent abrasion resistance and thus can be used in the building of concrete bridges and structures, and should be investigated for use in bituminous paving.

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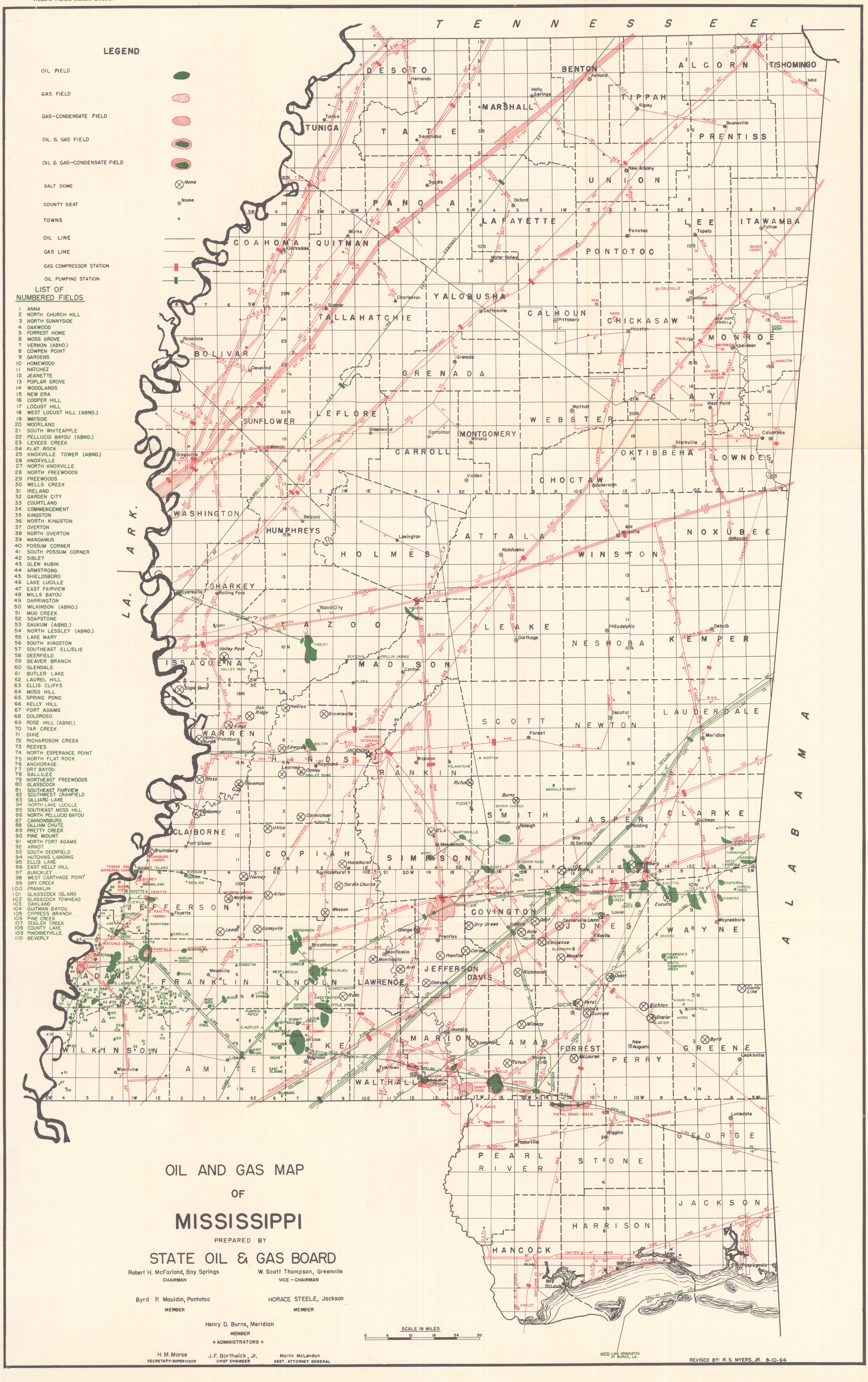
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GAS LINE
GAS COMPRESSOR STATION
OIL PUMPING STATION
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3 NORTH SUNNYSIDE
4 OAKWOOD
5 FORREST HOME
6 MOSS GROVE
7 VERNON (ABND.)
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101 GLASSCOCK ISLAND
102 GLASSCOCK TOWHEAD
103 OAKLAND
104 QUITMAN BAYOU
105 CYPRESS BRANCH
106 PINE CREEK
107 ZEIGLER CREEK
108 COUNTY LAKE
109 PINCKNEYVILLE
110 BEVERLY
TENNESSEE
ALABAMA
LA.
ARK.
OIL AND GAS MAP OF MISSISSIPPI
PREPARED BY
STATE OIL & GAS BOARD
Robert H. McFarland, Bay Springs
CHAIRMAN
W. Scott Thompson, Greenville
VICE-CHAIRMAN
Byrd P. Mauldin, Pontotoc
MEMBER
HORACE STEELE, Jackson
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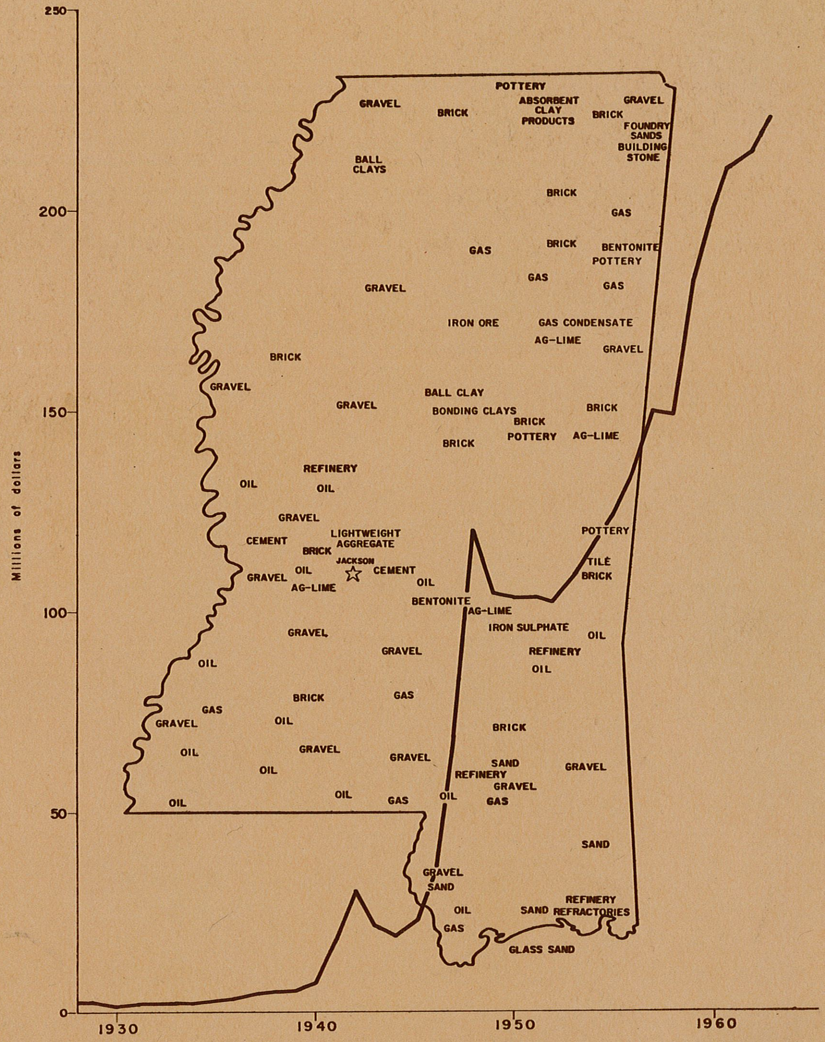
H. M. Morse
SECRETARY-SUPERVISOR
J. F. Borthwick, Jr.
CHIEF ENGINEER
Martin McLendon
ASST. ATTORNEY GENERAL
SCALE IN MILES
0 6 12 18 24 30
NOTE: LINE ORIGINATES AT BURAS, LA.
REVISED BY: R. S. MYERS, JR. 8-10-64



MISSISSIPPI'S MILLIONS IN MINERALS

Basic research into the economic geology of our State, largely by the Mississippi Geological Survey, has been a key factor in the phenominal growth of our extensive and diverse mineral resources—for further information write:

MISSISSIPPI GEOLOGICAL ECONOMIC AND TOPOGRAPHICAL SURVEY
POST OFFICE BOX 4915
JACKSON 6, MISSISSIPPI