ENVIRONMENTAL PROBLEMS AND THE CONSTRUCTION AGGREGATE INDUSTRY

by

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Abstract

The theme of the 70's will be the environment. The construction aggregates industry, already in difficulty with local zoning control, will be further affected by the requirements of the "new thing". However, it may well be that proposed legislation could be the vehicle which not only satisfies the wants of the environmentalist but also recognizes the need for a viable construction aggregates industry.

At the beginning of each new decade, wise men attempt to forecast the highlights of the upcoming ten years. In the past, there has been a lack of consensus upon the part of this honored group. However, there seems to be a general agreement upon the part of the prognosticating community this year that the "Theme of the 70's" will be the environment.

The actions of the Federal government generally reflect the concerns of the public body. Seldom has our government realigned itself so dramatically as it has with respect to this particular appeal. The "white hats" in Washington today are those who champion this cause.

In the past two years the Federal government has entered the fields of water and air pollution. There is pending before the Congress at this time a "Surface Mining Reclamation Act". With the enactment of this legislation, the Federal government will be involved in the control of air, water and land -- and this is the environment.

The construction aggregate industry is involved in all three of these environmental areas. With respect to air and water pollution, however, the solutions are finite and, although burdensome, should not threaten our existence. In the area of land environmental problems, a totally different situation exists for the extraction process is in direct conflict with the basic precepts of the environmentalist. It is in this area that I wish to direct my remarks.

The management of American Aggregates Corporation has no quarrel with the basic objectives of the environmentalists. It is our belief that it is each man's duty to make this world a better place in which to live. For the past fifty years our company has been recognized as the leader in the sand and gravel industry on the reclamation of worked-out lands. I should add that our "Project Parklands", the name we use to describe our reclamation efforts, is not purely motivated by our desire to be good neighbors. For over this period of fifty years we have found out that the reclamation business can be a profitable business.

In most of the construction aggregate industries, this fact should be true. Due to the heavy nature of our product, it is essential that production facilities be located as close as possible to the consuming market. Transportation costs double the cost of our product to the user every twenty miles that the commodity must be hauled. Therefore, most producing plants are located within metropolitan areas.

Due to the rapid urbanization of our country which will be further accelerated by the current population explosion, there exists a ready market for the lands excavated and properly reclaimed by the construction aggregate industry.

Furthermore, lakeside residential lots command twice the selling price per acre as lots located elsewhere. We have a commercial development overlooking a large lake in North Columbus, Ohio, where an acre lot to accommodate the district office of a major oil company was sold for a price of $150,000. This payment represented twice the original cost of the total tract which encompassed 150 acres.

It would be foolhardy to think that every reclamation project will generate such rewards. But at some date in the future, all projects will have greater value than if our operations had not taken place. Furthermore, to be economic, reclamation must be done as an integral part of the excavation process. So when active operations have ceased, the land is completely rehabilitated.

One might think that with such a record our company would have no problems obtaining from zoning boards the right to excavate on gravel-bearing lands which we may purchase. This is not the case.

When the public hears the words "sand and gravel", it does not think of "Project Parklands". Instead, it thinks of all the abandoned pits which dot the countryside. Generally, we can convince the neighbors that when our operations are completed, their property values will be enhanced. But the word "when" suggests a time factor, and, as Shakespeare stated, "Aye there's the rub".

In order to generate low-cost material for the construction market, one important factor is sufficient life over which to amortize developmental and plant costs. At a minimum a ten-year life is necessary and a twenty-year life is preferable.

Those neighbors who recognize the future benefits to their own property are generally unwilling to wait the 10 to 20 years until such gains could be realized. So through the expedient of local politics, zoning boards are induced to refuse to grant the right to excavate construction materials.

The construction aggregate industry is seeking relief from the failure of local zoning to make available sources for present and future needs. However, I feel that before our industry deserves such relief, it must first take a long hard look at itself and see what it might do to become a little more compatible with this impatient world.

It is often said that "necessity is the mother of invention". How true this statement is - and sometimes, I feel - how unfortunate. Let me illustrate.

Our people initially felt that we had run into a stone wall when we first encountered the "time" argument. An analysis of the factual situation showed that historically operators in our industry have selected plant sites (hopefully removed from existing nearby homes) and then conducted the operations outbound from this site to the boundaries of the properties. There seemed to be no reason to consider any other mode of operation.

On the other hand, consider the situation enjoyed by the neighbors. Initially, the operations are distant and therefore seem to be relatively innocuous. However, every year the mining operations get closer and closer -- the neighbors become more and more unhappy as time passes. It isn't until the operator has reached the limits of the property, if he is that lucky, that he finally reclaims the area which enhances the value of the adjoining properties.

It should have been evident years ago that, considering the cost of working the whole property, the total cost of working the property was essentially the same whether the operator started at the plant and worked outbound or started at the perimeter and worked plantward.

Furthermore, I have already pointed out how valuable these lands become after reclamation. Through experience our company has learned that when working outbound we could not dispose of any reclaimed lands until the whole operation was completed. If we worked from the perimeter inward, we could release reclaimed lands as fast as we desired, thereby permitting our company to realize the potential value much sooner.

Psychologists tell us that the human body can stand intense pain as long as the individual knows that relief is not far away. On the other hand, that same body will tolerate a much lower level of pain if the individual feels that it is going to get worse. I feel that this description is analogous to the relative effects upon the neighbor of the inbound and outbound operating techniques.

As a result of our difficulties in obtaining neighborhood acceptance and thereby the right from a local zoning board to operate, we have changed out pit operating procedures in such a way that we complete operations along our boundaries first. Because we have made this change, we can realize the potential gains in reclaimed properties much sooner.

I am convinced that there are other changes in operating procedures which could make our industry more acceptable to the urban areas in which we must exist. Despite this fact, I am also convinced that, even if all such changes were made, the construction aggregate industry will not be afforded a fair hearing at the local zoning level.

It is almost axiomatic that <u>the only landowner who views a sand and gravel or stone operation in his neighborhood as a tolerable thing is the one who is selling or leasing his land for that purpose</u>.

It is our belief that, to assure an economical source of construction aggregate to any consuming market, the granting of the right to produce such materials and the regulation of operating techniques and reclamation procedures must be removed as far as possible from the "backyard philosophy" of local zoning. Preferably this power should be vested in the state.

I have been voicing this opinion for over ten years. During this period of time, I have had the opportunity to discuss my feelings with many planners. Their reaction to my story ten years ago was completely negative. However, a softening in the planners' attitude has occurred during this period of time which is occasioned by their inability to handle adequately the problem of surface mining.

The professional planner today recognizes the fact that it is an essential part of the planning process to provide for sources of construction aggregates in such a way that materials will be economically available to carry forward the balance of his plan. However, particularly where there is township zoning, the recommendations of the professional planner have been turned down at the board level.

There are some areas today where it is virtually impossible to obtain the right to excavate and process construction aggregates. Recently, in some of these areas, operators have appealed to the courts for relief. The only plea possible is that the zoning resolution, as it applies to their property and the needs of the area, is arbitrary and capricious. The court, recognizing that construction aggregate must be available from some point within the affected area, has ruled in several cases in favor of the operator.

An unusual situation then exists. Usually the only regulatory body which requires reclamation by construction aggregate producers is the zoning authority. The court is unable to say that only part of the zoning resolution is arbitrary and capricious and the part which enforces reclamation provisions still applies. So the land under question ends up with no regulation of any type. This is a situation which could lead to more public indignation toward our industry.

To combat this problem, some forward-thinking planners are actively promoting State Surface Mining Reclamation Laws. A group of construction aggregates producers, including our company, was recently invited to attend a meeting with a group representing the planners, conservationists and land developers. The purpose of the meeting was to convince the producers that they should be willing to go along with a State Reclamation Law. The arguments cited by the proponents of the bill included the description just reported and other devices used by unscrupulous operators to bypass the control of local zoning. Fortunately, at this meeting there was a willingness to reason together. It was finally agreed that the suggested approach was in effect just treating a symptom; the basic problem was the inability of the planner to carry out his duty of providing areas from which construction aggregates could be removed. As a result of these discussions, it was mutually agreed to move ahead in the development of a State Law which would include both reclamation and regulation of the construction aggregates industry.

What are the advantages of the suggested approach? Paramount to our industry must, of course, be the opportunity to have a fair hearing. But there are advantages to the public which are equally important. As I have already pointed out, a problem within our industry is to develop, disseminate and enforce operating techniques which will make our operations more acceptable within urban areas. To put upon the planning community the burden of solving this problem would be asking a profession with what I consider to be an almost impossible task to do the absolutely impossible.

An agency of the state could develop such expertise. Furthermore, an agency of the state would be sufficiently removed from the pressures of local politics to weigh objectively the economic advantages to the public at large when considering a request to extract natural resources.

There remains but one problem and that is to coordinate the state-controlled reclamation and regulation with the comprehensive plan of the local planner. I believe that there is no way to set aside all natural resources for future exploitation. So if we are to think in terms of where sufficient reserves should be set aside to satisfy the demands of even the next fifty years, not only do I not know how much to set aside but where to select the sites. A realistic approach is to define all areas where natural resources may occur and to designate these on a comprehensive map, thereby indicating to any developer that the state may at some date grant a temporary permit for the utilization of such resources.

The planner can then develop his plan on the basis of ultimate uses of the land, and the state can require the operator to reclaim his property in such a way that it conforms to that predetermined plan.

There is a need for action on this matter as quickly as possible.

A recent survey by the National Sand and Gravel Association of its member companies showed that their total zoned reserves, if consumed at current rates, would support 15 years of demand. In my opinion, a calculation of zoned reserve life for the entire industry would be fewer than 15 years.

Recent studies by various governmental agencies show that in the next 20 years demand for construction aggregates will double. If these demands are to be supplied with construction aggregates at costs reasonably comparable to those experienced in the past, some level of government must intervene in the public interest to assure that construction aggregate bearing lands can be utilized where needed.

This is my story. I feel that I have related a tale that not only vitally affects the construction aggregates industry but yourselves and your futures as well. I solicit your help in carrying the story of this dilemma to the public.

I have heard throughout my listening life the statement made that "things will change". Without a doubt over that period, things have changed, but I believe that we are on the threshold of the era of the fastest rate of change that has ever occurred. Gentlemen, each of us should be involving ourselves in these realignments so that the end result is a better society for all.

POTENTIAL USE OF OHIO LIMESTONES AND DOLOMITES FOR ARCHITECTURAL AGGREGATE

by

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Abstract

The expanding use of exposed-aggregate concrete in architectural surfaces has caused an increase in requests for suitable stone. A literature survey was initiated to determine the requirements for architectural aggregate. A set of 18 carbonate rock samples was collected from various quarries in Ohio, providing a wide geographic and stratigraphic coverage of the State. The samples were subjected to physical tests for absorption, soundness, and hardness, as were two silica samples collected for comparison. Good results were obtained in two cases, a Guelph Dolomite sample and a Niagaran sample (Huntington, restricted). Fair results were obtained in four other cases, two Cedarville Dolomite samples, a Columbus Formation sample, and a Niagaran sample.

INTRODUCTION

The use of exposed-aggregate surfaces has become quite common in architectural design. These surfaces create patterns different in appearance and texture by using a great variety of colors and physical shapes of aggregate. Such surfaces are both precast and cast in place, with the decorative aggregate either dispersed throughout the concrete or concentrated in a facing layer.

In recent years the Ohio Division of Geological Survey has received a number of requests for sources of aggregate having specific colors for use in exposed-aggregate concrete. Consequently, a study was undertaken to determine the suitability of various aggregates produced in Ohio for use in architectural concrete. The study consisted of two phases, a review of the physical requirements for architectural aggregate and the selection and physical testing of a set of carbonate and silicate rocks from the State.

PHYSICAL REQUIREMENTS

The literature review on architectural aggregate gave a large number of physical properties and specifications. Many of these were similar (hardness, toughness, and durability) or were vague ("meet the specifications for high quality portland cement concrete aggregate"). In general, the most important properties were found to be color, hardness, soundness and absorption, particle shape and size distribution, and impurities. General designations or measurements are adequate for color, size, and absorption, but the other properties, hardness, soundness, and impurities, require specific numerical limits.

Color

Color is usually the main specification for any particular application of architectural aggregate. The required color is determined by the architect or builder in accordance with the desired appearance of the finished surface. The color of the stone used should be uniform and relatively permanent.

Hardness

Hardness is a rather ambiguous term in the stone industry. It can refer to the stone's resistance to abrasion, to impact, to compression, or, in general, to any physical deformation. The methods of hardness evaluation most commonly used for concrete aggregate are the Los Angeles and Deval tests, which evaluate aggregate resistance to impact and abrasion.

While aggregate in a wall is not subject to much abrasion, the overall strength of the concrete should be equal to or greater than the strength of that used for roadmaking because of the difficulty and expense in repairing large structures. It is important, therefore, to ascertain that the aggregate is not so brittle or soft that it breaks up in handling and mixing to the point that the percentage of fines increases enough to reduce the overall strength of the concrete. A specification of 50 percent maximum loss by the Los Angeles test has been suggested for architectural aggregate. This study used a different test, designed by the American Society for Testing and Materials. This ASTM test differs from the Los Angeles and Deval tests in that it determines resistance to impact more than to abrasion. The specification of 20 percent maximum loss in this test is used here for architectural aggregate.

[1] *Ohio Geological Survey*

Soundness

Perhaps the most critical property of architectural aggregate is its soundness. This is an approximation of an aggregate's resistance to mechanical weathering and is evaluated by several different tests involving freezing and thawing or solution and crystallization of a salt. In addition to economic and structural considerations, the different weathering conditions to which the aggregate in standard concrete and in exposed-aggregate concrete are subjected necessitate different specifications. Aggregate in a highway is surrounded by concrete but the surface layer of aggregate in an architectural panel is exposed to the elements. Each particle in such panels may have as much as one-half of its surface area exposed and is thus subjected directly to both wet-dry and warm-cold cycling. Consequently, the soundness specifications for architectural aggregate should be higher than those for standard concrete aggregate.

Soundness can be evaluated in a number of ways: by repeated soaking in Na_2SO_4 or $MgSO_4$ solution and drying in air; by slow or rapid freezing and thawing in air, water, or brine; by observation of the weathering characteristics of natural and manmade outcrops; and by study of the past performance record of an aggregate. This study used limits of 5 percent loss in 5 cycles of Na_2SO_4 testing and 3 percent loss in 50 cycles of rapid freezing and thawing in water.

One of the factors influencing soundness is water absorption. It is rather difficult to assess the effects of absorption alone on the performance of an aggregate and no specific limits have been set for architectural aggregate. In general, the absorption should be low since high absorption promotes weathering and staining. Research in Great Britain has indicated that aggregate with greater than 1.5 percent absorption was generally less sound than aggregate with less than 1.5 percent absorption (Shergold, 1954). Other work (Lewis and others, 1953; Verbeck and Landgren, 1960; and Yedlosky and Dean, 1961) has shown that the size of the average pore space and the percentage of saturation have an influence as great as or greater than absorption on the soundness of aggregate. Rocks with submicroscopic or capillary pores would be more susceptible to weathering than rocks with higher total absorption but with coarser pores through which the water could migrate. Also, rocks that easily become completely saturated on exposure to the elements would tend to be less sound than those which become only 90 to 95 percent saturated or less.

Particle Shape and Size Distribution

The shape and size of the aggregate particles are, to a large degree, not as critical as some of the other properties. The shape should be roughly equidimensional; an excess of thin or platy particles should be avoided. Each particle should be fairly rough and angular to promote adherence of the cement. Foremost consideration of size is the avoidance of an excess of dust and fine particles which lower the strength of the concrete. Usable sizes range from sand to cobble as well as flagstone but are usually restricted to one or two narrow ranges. If very coarse aggregate is used, sand-sized particles, of either an appropriately colored aggregate or normal quartz, should be included in the blend to assure adequate concrete strength.

Impurities

Finally, the aggregate should be free from any impurities that could damage either the appearance or the strength of the concrete. Shale, clay, pyrite, chert, gypsum, iron minerals, bituminous material, or any other reactive material present in amounts greater than 1 percent is considered excessive and disqualifies the aggregate.

PROCEDURE

Samples

Quarries were selected in 18 different counties in Ohio. Samples collected from these quarries were 18 carbonate rock samples ranging in age from Silurian to Pennsylvanian, a Mississippian age sandstone, and a Pennsylvanian age conglomerate.

Stockpiles were sampled at all selected quarries for gross samples ranging from 50 to 100 pounds, depending on maximum particle size. Where available, ASTM aggregate sizes #4 (¾ to 1½ inches) or #467 (³⁄₁₆ to 1½ inches) were sampled in order to obtain the maximum amount of the sizes (between ⅜ and 1½ inches) required for the projected tests with the minimum amount of laboratory crushing and waste.

Each gross sample was reduced by splitting to a laboratory sample of 18 to 26 pounds. Material greater than 1½ inches was removed, crushed to minus 1½ inches, and returned to the laboratory samples, which were then sieved on 1-, ¾-, ½-, and ⅜-inch sieves. Samples for the physical tests were prepared from the different size fractions of each laboratory sample.

Physical Tests

Hardness Test

To provide a measure of the handling hardness of the samples, ASTM D 1865-61T, "Hardness of Mineral Aggregate for Use on Built-Up Roofs," was modified as follows: the diameter of the test pipe was increased from 2 to 4 inches; the sample used was 500 grams of ½- to ¾-inch aggregate instead of 225 grams of ¼- to ⅜-inch aggregate; the test sieve used was a ¼-inch instead of a #6 sieve.

The apparatus consisted of a pipe, 4 feet long by 4 inches in diameter, mounted to permit 360-degree rotation about an axis perpendicular to the length. The ends of the pipe were covered by removable threaded caps. Each sample was placed in the pipe and rotated for 200 revolutions (400 half-turns). The pipe was stopped in a vertical position at each half-turn to allow the sample to drop cleanly to the other end of the pipe. At the end of the test the sample was sieved on ½- and ¼-inch sieves. Loss was determined by subtracting the amount retained above the ¼-inch sieve from the original weight.

Absorption Test

Absorption testing was performed according to ASTM C 127-59. The test samples, each consisting of approximately five kilograms, were washed, dried at 100° to 110°C, and weighed. Each sample was soaked in water for 24 hours, then dried on towels in such a manner that only the particle surfaces were dry and evaporation was held to a minimum. The saturated, surface-dry weights were obtained and then each sample was dried to constant weight and the absorption calculated from the saturated and second dry weights.

Na_2SO_4 Soundness Test

Soundness testing followed the procedures outlined in ASTM C88-61T. A saturated solution was prepared from sufficient anhydrous Na_2SO_4 to maintain an excess of crystals. This solution was kept at 20° to 22°C during testing. Each sample consisted of two size ranges of particles, where sufficient material was present in each size fraction. The coarse sample contained approximately 1,000 grams of 1- to 1½-inch aggregate and 500 grams of ¾- to 1-inch aggregate and the fine sample was composed of approximately 670 grams of ½- to ¾-inch aggregate and 300 grams of ⅜- to ½-inch aggregate. The samples were washed free of dust, dried, weighed, immersed in the solution for 16 to 18 hours, drained for 15 minutes, and oven dried at 100° to 110°C. The cycle of soaking, draining, and drying was performed five times for each sample. At the completion of the fifth cycle the samples were washed free of sulfate (determined by test with $BaCl_2$), dried, and sieved. The coarse sample was sieved on a ⅝-inch sieve and the fine on a 5/16-inch sieve. Loss was determined by subtracting the amount retained on the test sieve from the original sample weight.

Freeze-Thaw Soundness Test

The freeze-thaw procedure was devised by the writer and patterned after tests outlined by Cutcliffe and Dunn (1967) and Huang (1959). The samples were composed of approximately 1,000 grams of 1- to 1½-inch aggregate and 500 grams of ¾- to 1-inch aggregate in the coarse size and approximately 200 grams of ½- to ¾-inch aggregate and 100 grams of ⅜- to ½-inch aggregate in the fine size. The samples were washed free of dust, dried at 100° to 110°C, and weighed. They were then placed in copper pans, covered with approximately ⅛ inch of water, and placed in the freeze-thaw machine.

A Logan (or Utah) freeze-thaw machine was used for this test. It consisted of a chest-type insulated container with a horizontal freezer plate. The copper pans were placed on the freezer plate, separated from each other by electric strip heaters. A felt pad saturated with water was placed between the sample pans and the freezer plate for increased conductivity.

Both cycle control and temperature recording were automatic. The cycle controls were set for limits of 0° and 40°F and the temperature was recorded continually against time on a seven-day recording thermometer. A dummy sample of limestone aggregate contained separate thermocouples for cycle control and recording thermometer. Each set of samples was tested for 50 cycles. The cycles varied slightly from 4 to 4½ hours and temperature ranged from 1° to 4°F minimum and 42° to 44°F maximum. However, cycle time and temperature limits stayed fairly constant for each run and changed only when the machine was turned off and on.

At the end of 50 cycles the samples were dried at 100° to 110°C, sieved over the original base sieve (¾- or ⅜-inch), and weighed. The loss was determined by subtraction of the tested sieve weight from the original weight.

Munsell Color Determination

Color was determined by separating the five-kilogram absorption samples into distinct color groups and comparing these groups with the 1954 Munsell soil color charts.

RESULTS

Hardness

Only three samples exceeded the specification of the hardness test used. The Berea Sandstone (2041), which is very friable, had a substantial loss of 51.8 percent. The two Cedarville Dolomite samples (2028 and 2043B), with losses of 20.7 percent and 22.2 percent, could be considered marginal in hardness. All of the remaining samples were well below the suggested maximum 20 percent loss.

Absorption

Absorption results for the carbonate rock samples ranged from 0.5 to 3.0 percent. The quartz pebbles of the Sharon Conglomerate (2040) had the lowest absorption at 0.4 percent and the Berea Sandstone (2041) the highest at 5.9 percent. Of the 20 samples tested, 6 had absorption of less than 1.5 percent.

Na_2SO_4 Soundness

Ten samples failed the Na_2SO_4 soundness test but three of these could be considered marginal. Correlation of the soundness results with the absorption data is fair. Four of the samples with less than 1.5 percent absorption had acceptable soundness losses and the remaining two were marginal. Six of the samples with greater than 1.5 percent absorption passed, and eight failed, although one of those failing was marginal. However, of the six passing samples with greater than 1.5 percent absorption, five were dolomites exhibiting macroporosity: Cedarville Dolomite (2028 and 2043B), Guelph Dolomite (2032), and undifferentiated Niagaran dolomite (2034 and 2044). The remaining sample was a dolomite with normal intergranular porosity: Dundee Formation-Detroit River Group (2031). It appears that the average pore size in the coarsely crystalline dolomites was large enough that crystallization did not disrupt the stone as it did in rocks with normal porosity or microporosity.

Freeze-Thaw Soundness

Only four samples failed the freeze-thaw soundness test but one other, at 2.9 percent, was marginal. The same five samples either failed or were marginal in the Na_2SO_4 soundness test. All four samples that failed the freeze-thaw test had greater than 1.5 percent absorption but the Brassfield Formation (2042), with 2.9 percent loss, was well below 1.5 percent absorption. The five coarsely porous dolomites also passed the freeze-thaw test.

Munsell Color

Over one-half of the samples had colors that were considered acceptable or fair. The Guelph Dolomite sample (2032), one Cedarville Dolomite sample (2043B), and one undifferentiated Niagaran dolomite sample (2034) were white to very light gray with minimal iron staining or none at all. The other Cedarville Dolomite sample (2028) and the two Columbus Formation samples (2030A and 2035) were slightly grayer but still acceptable in color. The laboratory sample of the Brassfield Formation (2042) (handpicked to exclude upper Brassfield and bituminous staining) was white but the gross sample contained material with red and green colors due to quickly weathering iron oxides and clays as well as the bituminous staining.

CONCLUSIONS

The samples tested varied widely in their suitability for architectural aggregate. Sharon Conglomerate (2040) and Berea Sandstone (2041) were included in the project only for comparison. The Sharon pebbles, with a history of use for architectural aggregate, show good test results. The Berea, however, is totally unsuited for architectural aggregate although it has given very satisfactory use as dimension stone since the 1800's.

Two of the carbonates tested, Guelph Dolomite (2032) and one of the Niagaran samples (2034), had good test results as well as acceptable white to light-gray color. They should be good sources of architectural aggregate.

The Cedarville Dolomite, with marginal hardness, could well provide acceptable aggregate material if care is taken in handling or if the formation has a greater hardness in locations other than those sampled. The Columbus Formation has a light color that would be appropriate if it is found in an area where the rock is a little sounder. Likewise, the very white color characteristic of the lower part of the Brassfield Formation in the western portion of the State would be highly suitable if present in an area where the formation has greater soundness and is free of bituminous staining.

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APPENDIX

TABLE A.—*Sampling locations*

Sample designation[1]	Township	County	Ohio coordinate system location		
			x (ft)	y (ft)	zone
66-2027	Mifflin	Pike	1,779,000	399,000	south
12-2028	Springfield	Clark	1,612,000	701,000	south
21-2029	Scioto	Delaware	1,821,000	222,000	north
72-2030	York	Sandusky	1,903,000	588,000	north
87-2031	Milton	Wood	1,621,000	609,000	north
88-2032	Crawford	Wyandot	1,760,000	475,000	north
46-2033	Richland	Logan	1,655,000	296,000	north
54-2034	Jefferson	Mercer	1,401,000	324,000	north
25-2035	Franklin	Franklin	1,837,000	727,000	south
60-2036	Newton	Muskingum	2,102,000	668,000	south
79-2037	Dover	Tuscarawas	2,270,000	306,000	north
85-2038	Franklin	Wayne	2,158,000	369,000	north
50-2039	Poland	Mahoning	2,642,000	493,000	north
28-2040	Thompson	Geauga	2,398,000	736,000	north
47-2041	Amherst	Lorain	2,069,500	618,500	north
68-2042	Harrison	Preble	1,423,000	685,000	south
57-2043	Madison	Montgomery	1,496,000	642,700	south
14-2044	Richland	Clinton	1,658,000	539,000	south

[1]The first two digits of each sample designation are Ohio Division of Geological Survey file numbers and refer to the county where the sample was collected. The final four digits are the actual sample number and are used alone throughout the text and remainder of the appendix.

TABLE B.—*Summary of results*

Overall results	Sample number	Formation	Remarks
Good	2032	Guelph Dolomite	Good test results, good color
	2034	Undifferentiated Niagaran rocks	Good test results, good color
	2040	Sharon Conglomerate	Good test results, good color
Fair	2028	Cedarville Dolomite	Marginal hardness, good color, trace of iron staining
	2030A	Columbus Formation	Marginal Na_2SO_4, good color
	2043B	Cedarville Dolomite and Springfield Dolomite(?)	Marginal hardness, good color, trace of iron staining
	2044	Undifferentiated Niagaran rocks	Good test results, fair color
Poor	2027	Tymochtee Formation and Greenfield Dolomite	Good test results, poor color
	2029	Delaware Limestone	Marginal Na_2SO_4, poor color, trace of bituminous staining
	2030B	Columbus Formation and Detroit River Group	Failed Na_2SO_4; fair color
	2031	Dundee Formation and Detroit River Group	Good test results, fair color; pyrite
	2033	Tymochtee Formation	Failed Na_2SO_4; poor color; >1 percent bituminous staining
	2035	Columbus Formation	Failed Na_2SO_4; good color
	2036	Maxville Limestone	Failed Na_2SO_4 and freeze-thaw; fair color; minor shale
	2037	Vanport limestone	Failed Na_2SO_4 and freeze-thaw; poor color; iron staining; siliceous
	2038	Putnam Hill limestone	Good test results, poor color
	2039	Vanport limestone	Good test results, poor color
	2041	Berea Sandstone	Failed Na_2SO_4, freeze-thaw, and hardness; good color
	2042	Brassfield Formation	Marginal Na_2SO_4 and freeze-thaw; good color; iron and clay minerals; bituminous staining
	2043A	Laurel Dolomite, Euphemia Dolomite, and Springfield Dolomite	Failed Na_2SO_4 and freeze-thaw; fair color

TABLE C.—*Physical test results*

Sample number	Hardness loss (percent)	Absorption (percent)	Na_2SO_4 soundness loss (percent)	Freeze-thaw soundness loss (percent)	Predominant color
2027	10.3	1.3	3.0	0.4	gray to light gray
2028	20.7	2.6	1.7	1.6	light gray
2029	10.2	0.8	5.2	1.9	gray to light gray
2030A	13.5	2.3	5.2	1.0	light gray to white
2030B	13.0	3.0	6.6	0.9	light gray
2031	13.6	2.6	2.9	1.2	light gray to light brownish gray
2032	12.4	1.7	3.0	1.0	white to light gray
2033	11.0	1.7	8.8	2.3	light gray to dark gray
2034	12.6	2.2	2.7	0.8	white to light gray
2035	14.2	1.7	9.3	0.7	light gray to white
2036	10.8	1.6	7.4	5.6	light gray to gray
2037	13.2	1.5	10.6	10.2	gray to dark gray
2038	9.6	0.7	1.7	1.0	gray
2039	13.2	0.5	2.1	2.0	gray to dark gray
2040	14.4	0.4	3.4	2.7	milky white
2041	51.8	5.9	13.7	5.4	white
2042	14.7	0.8	5.6	2.9	white
2043A	14.9	1.5	12.4	6.4	light gray to gray
2043B	22.2	2.3	0.9	0.6	light gray to white
2044	15.4	2.1	3.0	1.1	light gray to gray

TRANSPORTATION ADVANTAGE — A UNIFYING FACTOR IN MINERAL AGGREGATE VALUATION

by

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Abstract

One of the more difficult and yet critical problems for producers of mineral aggregates is that of determining the dollar value of their mineral reserves. Valuations may differ by a factor of over one hundred depending on the perspective of the appraiser.

In spite of the formidable difficulties, it is necessary to make valuations for many purposes, such as eminent domain takings, mineral resource planning, and valuations by a company of its holdings. For a geologist who is exploring for mineral aggregate resources, such valuations are important and always implied in weighing one deposit against another. This paper reviews some methods in current use and suggests a new one: THE TRANSPORTATION ADVANTAGE METHOD.

The value of a mineral resource of low-intrinsic worth is most closely related to:

(1) *Engineering acceptability of the resource*
(2) *Size of reserves*
(3) *Time of mining and rate of mining*
(4) *Distance to the market*

The "distance-to-the-market criterion always is taken into account by a producer, and although it determines to a large extent the profitability of the venture, and thus the value of the mineral resource, it is rarely quantified in a meaningful way. A valuation formula adaptable to all valuation methods and including the transportation method is presented and explained.

INTRODUCTION

The Department of Highways is straightening a curve or building a branch of the interstate system of four lane highways. The Corps of Engineers is building a large multiple-use reservoir. A town board, feeling the population pressure, has rezoned certain areas from industrial to residential. Neapolitano Ready Mix Corporation has decided to purchase the adjoining 30 acres of land for a mineral reserve.

The scenario is set. The protagonists have been introduced, and the antagonist, though not necessarily the villain of the piece, is the person or corporate entity owning the land which the protagonists desire. The land has under it a deposit of usable, acceptable and increasingly scarce mineral aggregate. There you have the motive and the object of the struggle. How much is that mineral deposit worth? How can this worth be established so that it will be acceptable to both sides?

The problem is much more difficult than it appears. Estimates of the worth of an aggregate deposit, as seen in some recent court contests, can vary by a factor of over 100, depending on the point of view. There is no single unifying, acceptable method for arriving at the present worth of a low-value, transportation-sensitive aggregate deposit.

SIX HOWS

There are six basic questions that must be asked about a deposit in order to provide basic building blocks of valuation. They are:

(1) How good? ...the quality of the deposit

(2) How much? ...the size of the reserves, tons per acre

(3) How scarce? ...market demand, price of aggregate

(4) How soon? ...will it be mined, i.e., time of mining

(5) How fast? ...will it be mined, i.e., rate of mining

(6) How far? ...is it from the market-transportation cost

The questions will be discussed in turn.

How good? Most areas contain earth materials that may have some use under the right circumstances. However, the value of a commercial aggregate deposit lies in its quality, that is, in a practical sense, its ability to pass a battery of engineering tests to determine how well it may behave in concrete, bituminous mix, brick ovens, or any other specialized use. The quality of an aggregate affects its selling price, thus is a factor in valuation. However, for purposes of this paper the possible quality factor is not considered.

How much? How much aggregate a deposit contains is obviously important. Fortunately the size of the re-reserves is relatively simple to determine, and figures rarely differ by more than a factor or two although confusion may arise when operators consider the Mohorovicic discontinuity as the base level of their reserves. Standard reserve calculations must take into account areas of usable material, bounding berms, slopes of stability (in the case of sand and gravel), practical depth of mining or dredging, crushing loss, and gradation loss. Sand and gravel, perhaps more than stone, involve a number of special considerations which, in themselves, could form a basis of an extended discussion.

How scarce? Part of the value of an aggregate is dependent on supply and demand considerations. An undeveloped deposit out in the country and close to an established producer with large reserves has less value than an available deposit found a mile from the site of a proposed World's Fair or major interstate intersection. The abundance or scarcity of aggregate sources in a given area will determine to some extent the prevailing price of the aggregate, the prevailing royalty, and the prevailing profits of the operators.

How soon? How soon a deposit will be mined has a bearing on its present value. A dollar in hand now is worth \$10 in hand 20 years from now at a 12% interest rate. And conversely, \$10 in 20 years has a present worth of only \$1.00. Therefore, in valuing a deposit it is important to determine:

a. When the mining will begin.

b. How long it will take to mine out the deposit.

The latter, of course, will depend on the size of the deposit and on the speed of removal.

How fast? The present per ton value of the deposit is greater the faster the rate of mining. At a 12% discount rate, the value of stone or sand and gravel left in the ground decreases by half approximately every six years. In one sense, therefore, it is to the advantage of the operator to extract and sell the aggregate at an accelerated rate.

How far? Since aggregates are high bulk-low value commodities, their value is sensitive to transportation distances. The location of the deposit is of paramount importance in valuing its profitability and even viability in a given market. Since, through competition, the price of an aggregate at the market center is often fixed, the profit margin is severely affected by the haul distance. Thus, the transportation advantage of a deposit has to be figured into every valuation method.

Having answered these basic questions, let us attempt to assign some dollar values to the deposit. Three general methods will be discussed first and a fourth one will be proposed.

VALUATION METHODS

The three methods reviewed are:

(1) Comparable sales

(2) Discounted cash flow

(3) Royalty income

A fourth method that takes into account an often overlooked cost factor— the distance to market— is proposed and called the Transportation Advantage Method.

Comparable Sales. The comparable sales approach is the simplest to apply. Basically, the question is: For how much did a similar resource sell in the immediate past? The inherent trouble lies in defining "similar resource." Like finger prints, no two resources are exactly alike. They differ in all the six "Hows" previously outlined and, therefore, cannot be compared directly. In short, there is rarely such a thing as a "comparable sale."

Discounted Cash Flow. A standard appraisal method in valuing an income-producing property is to capitalize that income or cash flow over the expected life of the income [reviewed by Colby and Brooks, 1968]. Although the method is accepted in real estate and base metal mine evaluation, it has not found favor in courts when applied to an aggregate resource. Capitalization of income from aggregate production is considered too speculative.

The developed resource, i.e., an established producer with a functional plant and an established market, is readily valued by the capitalization of income method, since a record of several years' production costs and sales exists. However, an undeveloped resource is somewhat more difficult— a number of assumptions must be made. These are:

a. Cost of the plant (capital expenditure)

b. Size of the plant (capacity)

c. Size of reserves

d. Expected annual sales

The expected income from an undeveloped resource is understandably uncertain, depending on the assumptions made and on the validity of these assumptions in a given market area.

Once the most probable cash flow or income stream from a developed or an undeveloped resource is determined, the net income can be capitalized over the expected life of the deposit and plant at a chosen rate of interest. Twelve percent seems to be an acceptable discount rate for speculative ventures [Colby and Brooks, 1968].

Royalty Income. The royalty method of calculating the present value of mineral resources seems to find some favor in the courts. Generally, the prevailing royalty for an area is taken. However, the royalty must be viewed as a custom for an area and not necessarily a value which is relevant to the deposit to which it is being applied.

Comparable royalties in an area are hard to obtain; to use royalties from geographically widely scattered areas would be applying the economics and land values of those areas to the property in question. If royalty must be used, it should be a graduated percentage royalty, tied to size of reserves, distance to the market, and time and rate of mining.

Transportation Advantage. Perhaps the most important consideration, and one that affects all three of the foregoing methods, is the transportation advantage. Because of urbanization pressures, the distances to the market are increasing and the cost of moving the aggregate to the market is becoming the single major cost item at the point of consumption. Depending on the transportation method, the cost of getting a ton of material over a distance of one mile can be from 1 to 5 percent of the sale price. If a producer is forced to move away from his market area because of loss of reserves through condemnation or zoning, his profits may be reduced, or he may be forced out of business.

VALUATION FORMULA

Regardless of which method is used (except the comparable sales method), the present value of a mineral resource under question still has to be determined. The present value is the amount of money an investor is willing to pay for future income derived from the aggregate resource. Simplified even further, the present value is the worth of a thing now as compared to its worth at some later date.

The simplified valuation formula we suggest to calculate the present value is as follows:

$$V_p = (A - I) \; a_{\overline{n|}} + P$$

Where

V_p = Present value of the resource over the life of the resource

A = Expected net income from whatever method. Income tax may be subtracted for some purposes [Colby and Brooks, 1968]

I = Annual interest on capital invested

P = Value of plant, land, capital invested

$a_{\overline{n|}}$ = Inwood annuity coefficient or Hoskold sinking fund coefficient[1] at n years

The equation can be expanded readily to determine other values; for example, the present cost and future value of the land after rehabilitation. This is discussed in greater detail by Dunn, Hudec and Brown [1970].

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[1]*These coefficients are tabulated in Parks (1967) and the Inwood annuity coefficient, the present value of one paid over a number of years, is also available in any appraiser's handbook.*

Because we consider the transportation advantage method of resource valuation very important, we will enlarge upon some of the concepts and fortify them with a few examples.

Example I - Aligned Resources

Several possible resources may exist along a valley, along a major interstate route, or along a waterway, and can be considered to be aligned. The one closest to the market will have the greater advantage, all other conditions being equal. Assume that the producer at "A" is 20 miles closer to the market than the producer at "C." Assuming barging costs of $0.01 per-ton-mile (excluding loading and unloading costs), the producer at "A" has a 20¢ per ton advantage over the producer at "C."

Assuming that both producers mine at a rate of 200,000 tons a year, and both deposits have a 20-year life, the present value of the transportation advantage of producer at "A" over producer at "C" is:

$$V_p = (200{,}000 \times .20) \times 7.469 = \$298{,}760$$

This gives the present amount of greater value which deposit "A" enjoys over deposit "C" considered over a 20-year period.

Example II-Sharing of Central Market

A common situation is that of a central market area surrounded or semi-surrounded by competing producers. Figure 1 shows an idealized situation, with four producers equidistant from the market center. The consumption of stone in the market area is indicated by concentric slices. This simulates a situation where the consumption is greatest at the "core" and decreases toward the periphery of the market area, where the producers are located.

All conditions being equal, each of the producers has an equal share of the market, supplying it from comparable deposits. Assuming that the annual consumption of aggregate was spread evenly, the volume or tonnage of the material delivered by each producer might represent a pie-shaped slice, as illustrated in Figure 2.

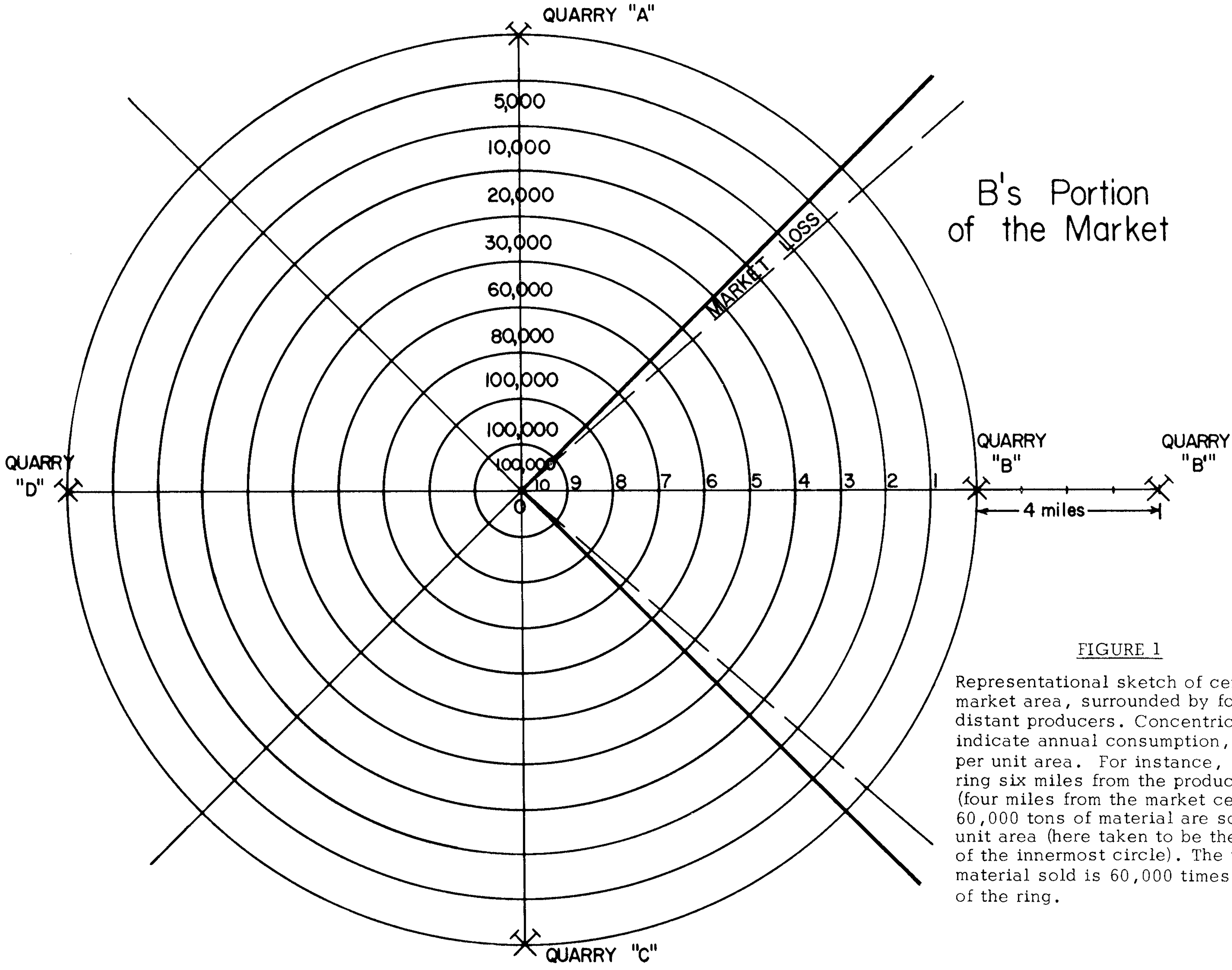

FIGURE 1

Representational sketch of central market area, surrounded by four equidistant producers. Concentric rings indicate annual consumption, in tons per unit area. For instance, in the ring six miles from the producers (four miles from the market center) 60,000 tons of material are sold per unit area (here taken to be the area of the innermost circle). The total material sold is 60,000 times the area of the ring.

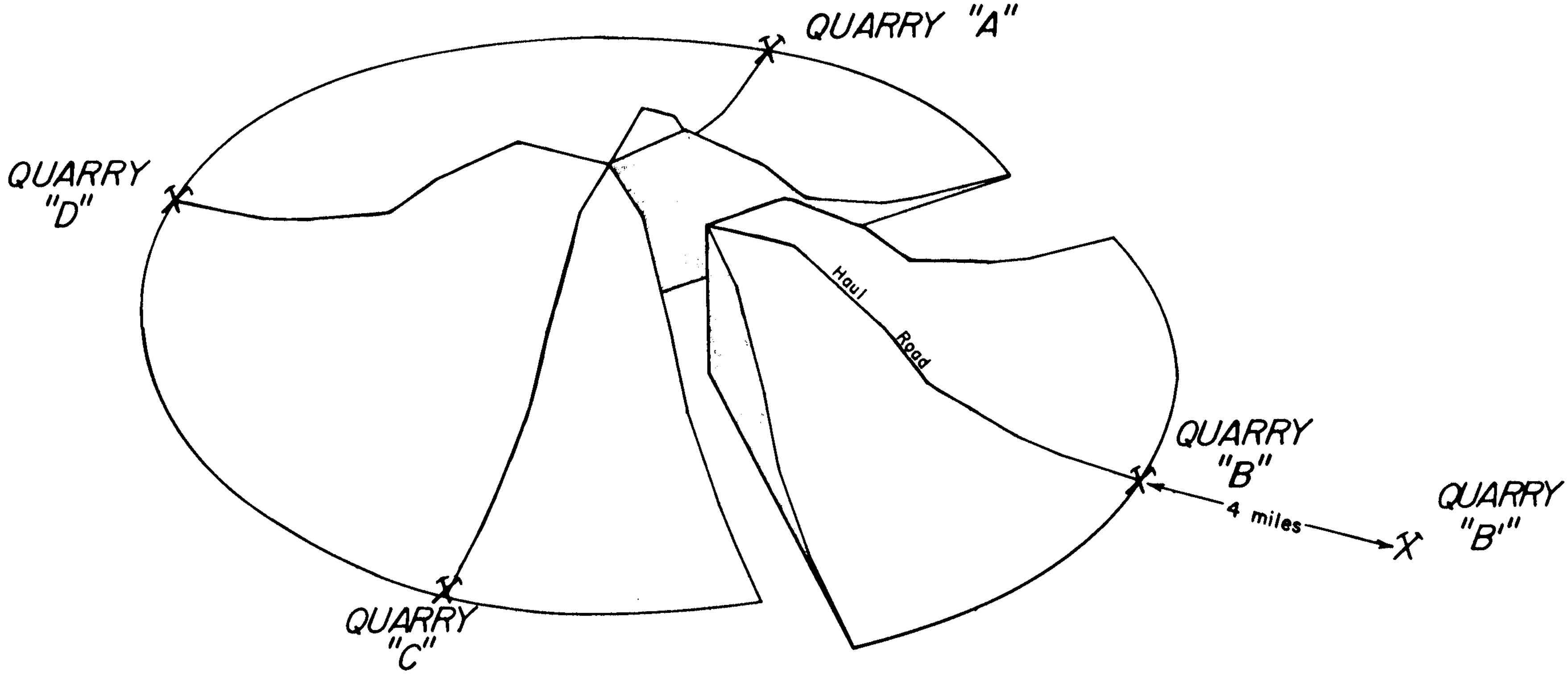

FIGURE 2

Three-dimensional representation of volume of material supplied by the producers, and assumed share of the market of producer at "B."

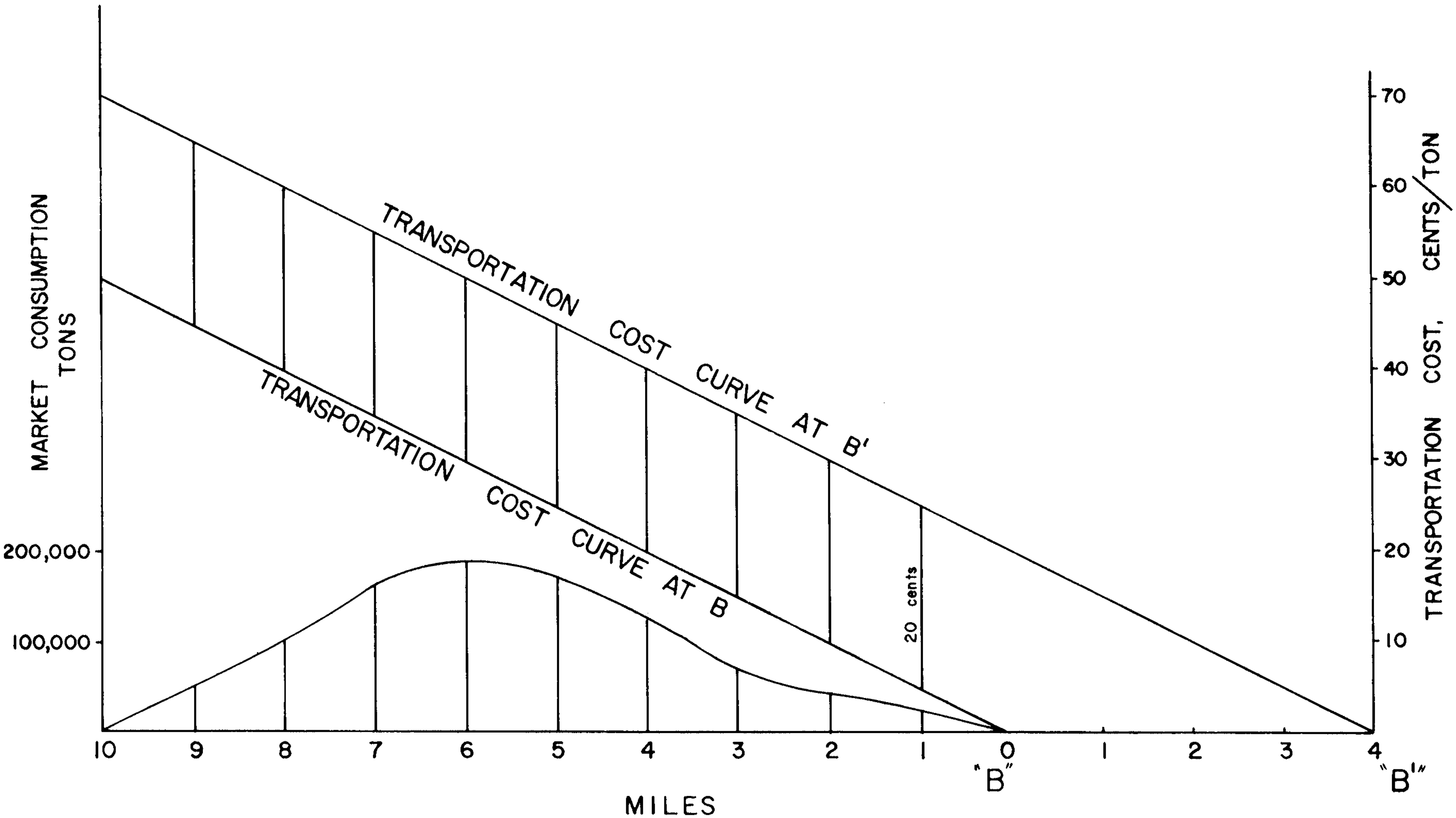

FIGURE 3

Two-dimensional translation of Figures 1 and 2: The lower curve illustrates the quantity of material sold. Although the market center enjoys highest quantity of material sold sold per unit area, the bulk of the material is sold some four miles from the market center.

The three-dimensional share can be translated into a two-dimensional graph representing the tonnage and distance from the market [Figure 3]. Although the greatest consumption density per unit area is in the core center, the weighted market center falls four miles outside the center of the core.

Let us consider what might happen if a producer at "B" is forced to move four miles further out from his present position to position "B'." The new deposit at "B'" is in all respects similar to the deposit just left. The producer, because of this move, will be affected in two ways:

(1) His transportation costs will increase if he is to retain all of his former markets.

(2) He may lose some of his markets, because he may become locally non-competitive [Figure 1]. The market lost is not figured in the following calculation.

As an example, assume:

"B" operator share of market- 915,000 tons/year (determined from Figure 3)

Value of transportation advantage lost- 20¢/ton

Total annual value of transportation advantage lost- 915,000 x .20 = $183,000

Present value of lost transportation advantage over life of property (20 years) 12% interest rate

$$V_p = 183{,}000 \times 7.469 = \$1{,}366{,}800$$

The foregoing example illustrates a rather simple possibility. In actuality, a weighted market center will have to be determined for each producer, and the haul distance to this calculated market center established, first from the original operation site, then from the new operation site. The difference will be the transportation advantage lost or gained by the move.

It should be stressed that the calculation of the transportation advantage, in detail, may be very complex.

CONCLUSION

An attempt has been made to review very quickly some common valuation methods and how and when they can be used to give a dollar value to an aggregate deposit. The transportation method, although often implied in valuation, was illustrated and shown to play an important role in determining the value of reserves lost or the value of deposits being considered for development.

The valuation of aggregate deposits need not be the rather haphazard, individualistic affair it seems to be at the moment, where too often random figures are claimed as true value of the deposit. By following a few simple, standard rules, and intelligently considering and applying the variables to each deposit, the disparity in claimed value can be brought down from an extreme of over 100 to 1 to a more realistic value based on the real market worth.

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EVALUATION OF THREE GRAVEL SAMPLING METHODS

by

T. A. Herbert and N. E. Wingard [1]

Abstract

Three sampling methods: auger boring, channeling, and grab sampling are compared on the basis of their ability to detect natural variations within a gravel deposit. Often, these methods have been used for sampling when too little information has been known about the bias imparted by subsurface conditions and sampling techniques. This has lead to serious errors in the evaluation of deposits.

Uncased auger boring is used extensively for soil sampling but usually for qualitative information only. Channeling is the accepted method of sampling, but it is usually limited to fresh excavations, and is generally a cumbersome technique. Grab sampling is another method sometimes used by geologists to sample both sedimentary formations and hard rock. However, grab sampling by sedimentation unit is not widely accepted in the gravel industry for commercial evaluations.

In the study, 32 uncased auger, 14 channel, and 128 grab samples from a small area in one gravel pit were examined on the basis of the size-frequency distributions for each sample so as to compare the three methods and assign confidence levels to each method. An analysis of variance statistical treatment of the median grain size and sorting coefficient data established that auger boring is sufficiently representative where sizes below one inch are considered, and where the lift recovery method is used. Grab samples provide a representative sample where bank exposures are available and all particle sizes are considered. Channel samples were found to be less reliable and subject to larger sample error due to inconsistent sample size than either auger boring or grab sampling.

INTRODUCTION

Purpose

This investigation examines the variables that affect a sample of unconsolidated sand and gravel obtained by uncased auger boring, channeling, and grab sampling. These three methods have been used in the past to evaluate gravel deposits but often the samples obtained were biased by unknown geological and mechanical factors. The specific problem is, therefore, to examine and compare the results from several different sampling methods so that the most representative sample can be obtained and degrees of confidence assigned to the other methods.

Reason for Study

The size distribution or grading and the total usable reserves within the boundary of a deposit are the two most important factors in evaluating a gravel deposit. Accurate reserves of a property can only be calculated after information about the natural variability among samples is determined. To do this, representative samples must be taken from the deposit, the samples analyzed by sieving, and the size distribution calculated. In order to be reasonably sure that a representative sample is being obtained, sampling along the face of a deposit should provide statistically significant differences between sample sites which, by visual observation, are known to be slightly different. Geological factors

[1] *Michigan Dept. State Highways*

such as changes in stratigraphy, grading, pellicular water, and position of ground water table are a few of the more obvious factors that could reasonably be expected to bias samples from the same deposit. An understanding of comparisons and relations between samples which do detect natural variations will allow more confidence to be placed upon each of these sampling methods and correspondingly a better estimate of the grading and total reserves will be made.

Cased test holes provide the necessary information for an evaluation but their use is often limited because of high cost. Vertical channeling of a pit face is the accepted method but several problems occur when sampling in this manner that may affect the final evaluation to some degree. For example, caving of bank material, and the inability to maintain a constant width and depth of channel, cause the size-frequency distributions of several adjacent channel samples to have a wide range in values. Sample bias introduced in the laboratory by splitting the large, cumbersome channel sample also reduces confidence in this method.

Grab samples taken from a vertical nested pattern provide more information about size-frequency distributions within a deposit than the other methods. Grab sampling, however, has been slow to gain acceptance in the sand and gravel industry because of adherance to ASTM procedures.

The factor thought to contribute most to bias when sampling with the uncased auger was selectively introduced by the drilling equipment or technique. It was thought that by studying one gravel pit with near uniform stratigraphy and by using a uniform drilling procedure, an evaluation of selectivity could be made.

PROCEDURE

Samples were obtained from a large gravel deposit which had essentially uniform stratigraphy and ground water conditions along the working face. Four auger bore samples were taken at each of eight sample sites adjacent to the working face. A standardized drilling technique was used for all test holes. Two channel samples were dug from the face opposite the four bore holes at seven of the eight bore hole sites. Grab samples from a nested grid sample pattern were taken in the same position as each of the channels. (Fig. 1)

The data from three hundred mechanical analyses were used to plot cumulative size-frequency distribution curves. Statistical moments determined from the graphical data were then used to determine the between-site variability and the reliability of the three sampling methods. The percentage of fine aggregate, or more specifically, the material passing the 3/8-inch sieve for each sample was used in an attempt to relate the stratigraphic variability indicated by the three sampling methods.

Support

This project was supported by the Michigan Department of State Highways, Testing and Research Division, as a supplementary phase of Research Project number 63 A-21, "Evaluation of Aggregate Sources of Glacial Origin."

Geology of the Deposit

The deposit is located on a well drained upper level terrace of the Kalamazoo River near Cooper, Michigan. The deposit used for the study is operated by the American Aggregates Corporation. Approximately eighty feet of vertical exposure is found along the 1/4 mile of pit face below the soil horizon which has been stripped off as overburden because of its high clay content. There are four strata exposed in the working area where the sample sites were located; they are, from top to bottom:

Bed 1 -- 4 to 6 feet of cobbles, pebbles, and sand, cross-bedded at the bottom, transitonal to Bed 2.

Bed 2 -- 10 to 16 feet of cross-bedded coarse sand, with a few pebbles and cobbles.

Bed 3 -- 4 to 6 feet of cross-bedded cobbles and pebbles, well sorted.

Bed 4 -- 40 to 60 feet of well sorted, medium to fine sand extending to bottom of pit (not included in samples). All textural terms are based on the Wentworth grade scale.

Channel Method

Channel samples were obtained at seven sites along the near vertical face at the deposit. Two channels were excavated at each sample site with a separation between them of from four feet to eight feet (Fig. 1). The ASTM method of bottom to top vertical channeling was used.

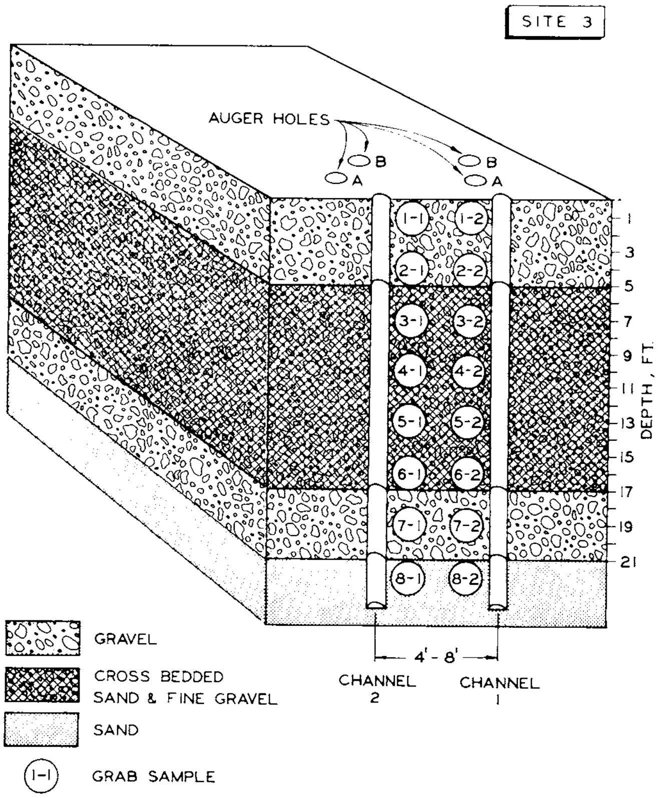

Figure 1. Sampling positions for each method.

Since stratigraphic variation was apparent over the short distance between the two channels at one site, the "sample" was considered to be the entire amount of material removed from one 8-inch by 4-inch by 21-feet excavation. However, the samples were analyzed on the basis of the individual bags, seven for each channel, and then combined arithmetically.

Grab Method

Krumbein and Graybill (1966) define a grab sample as a relatively small fixed volume of material. Grab samples are usually taken from a predetermined grid in either a regular or random pattern and may be either single or nested. The selection of the sampling plan is usually determined by the complexity of the deposit and the information desired.

Grab samples, in this study, were obtained from a regular, nested grid sampling plan. The sampling plan is illustrated in Figure 1. Two samples were taken at eight vertical positions at each of eight sample sites, a total of 128 individual samples were obtained from the eight sites.

The regular grid pattern was used so that the grab samples would be adjacent to the channels in order to compare grab and channel samples. The nested, two-sample design was used to check the small-scale variations between the two samples taken from the same vertical position. The position of the eight vertical samples was determined by the thickness of the sedimentation unit at the sample site.

Samples from each bed were obtained in a ratio in rough proportion to the thickness of each bed in feet. All samples were of approximately the same bulk weight (8 to 10 lbs).

Auger Method

Opposite each channel position two auger holes were bored and a portion of the material brought to the surface was taken as the sample. A total of 36 bore holes were drilled to a depth of 21 feet. Figure 1 illustrates the relation between auger holes and the grab samples and channels.

The auger boring equipment and operator were furnished by the Department of State Highways, Soils Division, District 7. The drilling rig, a Mobile Drill Model B-52 was mounted on a four-wheel drive truck. Standard 6-inch diameter construction augers which have an actual diameter of 5-1/2 inches, a pitch of 5 inches, and a length of 5 feet were used.

The slowest feed rate was used to minimize disruption of the material, when a depth of 21 feet was reached, the auger string was lifted slowly from the hole and the material adhering to the auger flutes was removed. A sample was split from this material and put into canvas sample bags. Because the sample was mixed to some degree by the augering action and no clear-cut sedimentation unit boundaries were observed, no attempt was made to separate the sedimentation units.

LABORATORY ANALYSIS

The laboratory phase of this project involved a total of 600 sieve analyses; 300 each of material larger and smaller than 3/8 inch diameter. The samples were brought in from the field and allowed to air dry for three weeks.

Analysis of the Channel and Auger Samples

Both the channel and auger samples were 300-400 lbs. in siz e. A composite sample this large cannot be sieved at one time. In order to avoid splitting the sample and introducing possible errors in the large size fraction (The ASTM Standard recommends 300 lbs. of sample for 3-inch diameter maximum size) each bag was sieved separately and the results combined arithmetically.

Each bag, representing three feet of vertical exposure, was first sieved through the 2-, 1/1/2-, 1-, 3/4-, 1/2-, and 3/8-inch screens. The material passing the 3/8-inch screen (the fine aggregate) was then split to from 400 to 800 grams (1 to 2 lbs.) for fine sieve analysis. The fine screens included the U. S. Standard Numbers 5, 10, 18, 35, 60, and 120 which correspond to -2, -1, 1, 2, and 3 units on the Phi Scale. This allowed the cumulative size-frequency distributions to be plotted on rectangular coordinate paper so that the statistical moments could than be taken from the frequency curves directly in phi unit. Phi units are defined as the negative logarithm to the base 2 of the sieve opening in millimeters.

Analysis of the Grab Samples

The grab samples ranged in weight from 3000-4000 grams (6 to 10 lbs). A slightly different mechanical analysis procedure was used due to the smaller sample size. The coarse fraction was separated by hand sieving through 10-inch diameter sleeves. Then the fine fraction was split to 400-800 grams (1 to 2 lbs) and sieved in the same nammer as the channel and auger samples.

STATISTICAL ANALYSIS

Mechanical analysis data provides quantitative i nformation about the size distributions or grading within a deposit. In order to proceed from raw data to refined data which could be used in statistical comparisons, weight percentages were calculated. The Michigan Department of State Highways Burroughs B5500 computer was used in all calculations except for the analysis of variance (AOV) routine which was run at Michigan State University.

In order to examine the selectivity factors of size and mechanical dislodgement in the auger boring method; the mechanical analysis data was treated by calculating weight percentages for the samples in the following five ways:

1. A complete distribution for the twelve sieve sizes from 2 inches to .0049 inches with the plus 3/8 inch and minus 3/8 inch percentages adjusted to plot on the same frequency curve.
2. A size-frequency distribution for the minus 3/8 inch sizes only to eliminate bias due to oversize material not included in the auger samples.
3. Complete adjusted distributions with 2 inch size deleted from calculation.
4. Complete adjusted distributions with 2 inch and 1-1/2 inch size deleted.
5. Complete adjusted distribution with 2 inch, 1-1/2, and 1 inch sizes deleted.

According to Krumbein and Pettijohn (1938) perhaps the most important statistical measure is that of central tendency. Measures of central tendency would include such diverse measures as the arithmetic mean size, median size, modal size, and the geometric mean size. The most readily available of these, at least from the cumulative frequency curves, is the median size. The median size is the Y intercept at the Q_2 or 50 percent level on a size-frequency distribution curve.

The sorting coefficient was used for the auger and channel samples where less data were available and it was felt that the addition of this data would provide more specific information about the shape of the frequency curves.

The sorting coefficient as defined by Trask (1932) is the square root of the quotient of Q_3 and Q_1 which represent the size values of the Y intercept at the 75 percent and 25 percent levels, respectively.

In order to determine which sampling method is most reliable in detecting the stratigraphic variation within the deposit, the sample data were analyzed using an analysis of variance (AOV) computer routine. The grab sample median grain size data of the minus 3/8 fraction for vertical positions at each site were fed into the computer to calculate the significance of: (1) repetition of sample, (2) vertical position, and (3) site. Both median grain size and sorting coefficient were used in the analysis of the channel and auger data.

AOV of Grab Sample Data

The median grab size data in Table 1 was tested in two different ways. First, the nested data was tested to check the repeatability of the sampling method. AOV of this data established that the method was providing a statistically similar set of values for each position in the grid. Second, the data was used to check the significance of sites in the horizontal direction. The AOV routine established that the data was statistically unique for each site. In other words, a measure of the natural between-site variability was being detected. Both site and position had significance at the 0.99 level (Table 2).

TABLE 1
MEDIAN GRAIN SIZE DATA FOR GRAB SAMPLES AT EACH SITE AND POSITION, MINUS 3/8-IN. FRACTION, EXPRESSED IN PHI UNITS

Position No.	Sample Site							
	11	10	8	7	6	5	3	2
1	-0.71 -0.87	-1.27 -1.08	-1.57 -1.43	-0.28 -0.40	-0.85 -1.04	-0.81 -0.69	-0.98 -0.94	-0.7 -1.0
2	0.08 0.34	-0.19 -0.38	0.42 0.38	-1.82 -1.77	-1.11 -1.40	-1.76 -1.77	0.76 0.53	0.00 0.18
3	-0.44 -0.32	-0.01 0.07	-1.63 -1.51	-0.14 -0.05	-0.58 -0.59	1.62 1.63	0.77 0.92	0.90 0.92
4	0.14 0.16	0.06 0.09	0.51 0.46	-0.13 -0.19	0.08 0.07	0.30 0.39	-0.03 0.03	0.82 0.66
5	0.23 0.21	0.84 0.90	-0.10 -0.32	-0.27 -0.57	-0.14 0.02	-0.72 -0.62	0.78 0.82	0.90 0.95
6	0.30 0.78	0.93 1.00	0.26 0.57	0.59 0.19	0.78 0.66	1.03 1.51	0.61 0.58	0.32 0.53
7	-0.83 -0.63	-1.32 -1.23	0.59 0.60	-1.14 -1.14	-0.33 -0.27	0.36 -0.20	-1.97 -1.99	-1.80 -1.88
8	-1.78 -1.90	-0.68 -0.76	-1.14 -0.96	-0.48 -0.21	0.60 0.74	1.87 1.83	-1.92 -1.94	-1.50 -1.60

TABLE 2
AOV RESULTS FOR THE GRAB SAMPLE MEDIAN GRAIN SIZE DATA, MINUS 3/8-IN. FRACTION

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio
Position	33.71503393	6	5.61917232	320.9[2]
Site	3.63913929	7	0.51987704	29.7[2]
Position x Site	45.32912321	42	1.07926484	61.6[2]
Repetition of Samples[1]	0.00965714	1	0.01751[3] (pooled, rows Repetition of Samples through Remaining Error)	
Position x Repetition[1]	0.08910536	6		
Site x Repetition[1]	0.13517143	7		
Position x Site x Repetition[1]	0.74696607	42		
Remaining Error	0.00000001	0		

(1) Effects pooled for error estimate
(2) Significant at 0.99 level
(3) Mean square error

AOV of Auger Sample Data

The analysis determined that there was no significant difference between the four auger holes within a site (Table 3). Neither the median size nor the sorting coefficient data showed significant differences between paired auger holes at any one site at the 0.95 level. The auger method, however, was effective in determining between site variability. Both the median grain size and sorting coefficient data indicated significant difference at the 0.99 level of confidence.

AOV of Channel Sample Data

The channel method proved less reliable in detecting between site variation than either auger boring or grab sampling. Neither the median grain size data nor the sorting coefficient data indicated a significant difference between sites at the 0.99 level. The difference between two channels at one site was not significant. The F ratio was tested at the 0.95 level for both the median grain size data and the sorting coefficient data. The sorting coefficient data provied significant at the 0.95 level but the median grain size values were not.

TABLE 3
AOV RESULTS FOR THE SORTING COEFFICIENTS AND MEDIAN GRAIN SIZE DATA FOR THE CHANNEL AND AUGER METHODS, MINUS 3/8-IN. FRACTION

		Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio
Median Grain Size	Auger Method	Hole	0.08623	3	0.02874	1.9314[1]
		Site	2.22480	7	0.31783	21.3595[2]
		Hole x Site	0.31253	21	0.01488	----
		TOTAL	2.62355	31		
	Channel Method	Channel	0.02161	1	0.02161	0.8511[1]
		Site	0.37337	6	0.06223	2.4510[1]
		Channel x Site	0.15234	6	0.02539	----
		TOTAL	0.54732	13		
Sorting Coefficient	Auger Method	Hole	0.05294	3	0.01765	1.6016[1]
		Site	1.25954	7	0.17993	16.3276[2]
		Hole x Site	0.23151	21	0.01102	----
		TOTAL	1.54399	31		
	Channel Method	Channel	0.01086	1	0.01086	0.3731[1]
		Site	0.90869	6	0.15145	5.2027[3]
		Channel x Site	0.17469	6	0.02911	----
		TOTAL	1.09424	13		

(1) Not significant at 0.95 level
(2) Significant at 0.99 level
(3) Significant at 0.95 level

Examination of the Factors Which Bias Auger Samples

In order to evaluate the auger boring method of sampling, the factors that contribute to bias must be examined. Two factors were thought to influence the sample: size selectivity due to the physical dimensions of the auger tool and sample loss due to mechanical vibrations during recovery of the sample.

In order to study the effects of size selectivity and sample loss the original weight percentages were recalculated deleting the larger sized material (2 inch and 1-1/2 inch) from the channel samples and the calculated composite grab samples. Vertical positions 7 and 8 (Fig. 1) which were used in the calculation of the composite grab sample were deleted and the weight percentages recalculated. Table 4 lists the comparisons between methods of sampling.

It was thought that if the average percentages for the recalculated channel and composite grab samples approached the values obtained for the auger samples, there would be an indication of the degree of bias imparted to the auger samples by the two factors of sample loss and size selectivity. The thirty-two auger holes had an average value of 88.5 percent fine aggregate (minus 3/8 inch) while the fourteen channel samples averaged 77.6 percent and the calculated composite of the grab samples averaged 80.6 percent. The minus 3/8 inch percentages were calculated from the cased test hole data supplied by the American Aggregates Corporation and were found to be 80.6 percent fine aggregate for five test holes located in the vicinity of the sample sites for this study.

The recalculated average values for the channel method with the 2 inch and the combined 2 inch and 1-1/2 inch sizes deleted increased to 82.7 percent and 84.0 percent, respectively (Table 4). The channel samples included the lower three to four feet of coarse gravel which was lost in part with auger boring. It is possible that a portion of the 1 inch size was also selectively "missed" by the auger tool so that the 84.0 percent value for 2 inch and 1-1/2 inch deleted would be increased even more, approaching the 88.5 percent value of the auger samples.

The calculated composite grab samples were also used to reconstruct and examine the selectivity of the auger method. The average composite grab sample fine aggregate percentage, was 80.6 percent, which is in agreement with the 77.6 percent value of the channel method and the 80.6 percent value of the cased test hole samples. Deletion of vertical positions 7 and 8 (Fig. 1) which were from the coarse aggregate horizon increased the percentage of fine aggregate to 83.1 percent. The additional deletion of the 2 inch size and 2 inch and 1-1/2 inch sizes combined produced values of 84.5 percent and 85.4 percent, respectively (Table 4).

The fine aggregate percentages for the channel and grab sample methods approach the auger value to within four percent which is still a significant value. The four percent difference possibility can be explained by the fact that the horizontal distance between the samples taken from the bank-face and the channels was only approximately eight feet apart at the edge of the pit, but due to the slope of the pit face, the bottom of the channel and the bottom of the auger holes were up to 20 feet apart. It was shown from the analysis of variance that sites were significantly different while the between sample differences at one site were insignificant. However, when considering the four percent difference in fine aggregate between the auger samples and the channel and composite grab samples, it must be noted that the separation between the auger holes and the channel was often as great as between sample sites. If there is a significant difference between sample sites 20 to 30 feet apart, it would be reasonable to assume that there might be significant difference between the auger and channel samples separated by 10 to 20 feet.

While the normal pit variation explains the differences to some degree there are no doubt additional variables which cannot be attributed to any one factor. The sample error among all the samples is dependent not only on the natural variation but also on the personal bias involved when sampling by either of the three methods.

CONCLUSIONS

Auger Method

Where visual inspection of a deposit is not possible, auger samples obtained using the six-inch diameter auger are shown to be sufficiently representative for commercial evaluation provided particle sizes smaller than one inch are considered. In order to be reasonably certain of the validity, however, an exposure such as a trench or pit should be dug so visual inspection of the subsurface conditions can be made. Once the subsurface conditions are known the uncased auger can be used to complete the reconaissance. Likewise where cased holes are used the uncased auger can be used to fill-in the sample spacing. Where visual inspection of a working cut is possible, auger boring provides a more representative sample for evaluating size variations than the channel method and one comparable to grab sampling.

TABLE 4
COMPARISONS BETWEEN THE THREE SAMPLING METHODS ON THE BASIS OF THE MINUS 3/8-IN. FRACTION, VALUES ARE PERCENT PASSING THE 3/8-IN. SIEVE

Sample Site	Position No. of Channels	Channel Samples	Channel Samples		Paired Auger Holes	Auger Test Holes	Position of Paired Grab Samples	Calculated Composite of Grab Samples	Calculated Composite of Grab Samples		
			2 inch Dia Deleted	1-1/2 and 2 inch Dia Deleted					7 & 8 Deleted	7 & 8 plus 2 inch Dia Deleted	7 & 8 plus 1-1/2 & 2 inch Dia Deleted
1	1	81.0	84.1	85.9	1	90.0	1	N. S.	N. S.	N. S.	N. S.
					2	89.7					
	2	81.0	86.4	88.1	1	89.6	2	N. S.	N. S.	N. S.	N. S.
					2	89.6					
2	1	83.8	89.6	90.4	1	87.6	1	86.3	86.5	87.8	88.4
					2	92.8					
	2	78.5	84.5	86.0	1	89.1	2	87.5	88.3	88.3	89.6
					2	86.5					
3	1	79.6	83.9	85.2	1	88.4	1	79.5	79.5	82.3	84.5
					2	92.9					
	2	76.1	83.4	84.0	1	89.9	2	81.2	83.0	83.7	85.1
					2	91.0					
5	1	74.2	80.3	81.5	1	87.6	1	83.2	87.4	87.4	87.8
					2	88.6					
	2	77.8	82.2	83.9	1	84.4	2	84.1	86.9	88.4	88.4
					2	91.4					
6	1	76.2	83.0	84.2	1	86.4	1	75.6	77.5	77.8	80.7
					2	87.7					
	2	81.9	85.5	86.4	1	85.4	2	79.3	80.3	81.5	82.6
					2	86.1					
7	1	74.7	80.6	81.5	1	N. S.	1	72.3	81.0	81.0	82.3
					2	N. S.					
	2	70.8	72.9	74.9	1	N. S.	2	74.5	81.0	81.9	81.9
					2	N. S.					
8	1	74.4	80.7	82.5	1	90.1	1	84.3	86.2	87.2	87.5
					2	89.5					
	2	77.0	81.0	82.3	1	89.8	2	84.3	87.3	88.2	88.2
					2	89.1					
10	1	N. S.	N. S.	N. S.	1	90.0	1	84.1	83.5	85.4	85.4
					2	88.8					
	2	N. S.	N. S.	N. S.	1	88.8	2	78.0	79.9	82.1	84.1
					2	83.2					
11	1	N. S.	N. S.	N. S.	1	87.3	1	78.3	80.9	84.2	85.4
					2	86.5					
	2	N. S.	N. S.	N. S.	1	85.4	2	76.8	80.5	84.5	84.5
					2	88.1					
Average Values		77.6	82.7	84.0		88.5		80.6	83.1	84.5	85.4

Near-surface ground water conditions, while not a factor in this study will limit the usefulness of the uncased auger. Saturated materials from below the water table may be dislodged more easily than less moist material from above the water table. Conversely, extremely dry conditions also may disrupt auger sampling. The best time of the year for auger boring is probably when pellicular water is at maximum. Auger sampling may become difficult when "tight" clay or large cobbles or boulders are encountered. At this time the skill of the rig operator becomes important.

Channel Method

The channel method remains a good technique for sampling bank exposures. However, the difficulties in excavating channels and in performing the laboratory analysis indicates that a nested grab sampling method could be used alternatively with both an increase in the information gained from the resulting samples and a reduction in the total time and energy expended.

Grab Method

The grab sample method is as reliable as the auger method in its ability to detect natural sedimentary variation within a deposit. The total amount of time involved in any evaluation is critical not only for the recipient of the study in terms of cost but also in terms of efficiency and validity of the method. The grab sample method provides a sample much smaller in size, eliminating extra handling while it provides more valuable information about the deposit with correspondingly reduced sample error.

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A STUDY OF THE SAND AND GRAVEL DEPOSITS OF THE MAUMEE RIVER ESTUARY, OHIO

by

Charles E. Herdendorf and Lawrence L. Braidech[1]

Abstract

A study of the sand and gravel resources of the lower Maumee River between Toledo and Perrysburg was initiated in 1964 by the Ohio Division of Geological Survey. Thirty test borings were made in river-bed sediments by the hydraulic jetting method and cores were taken with a hand-driven check-valve sampler. Samples were mechanically analyzed for grain size by hydrometer and sieve methods. Surface samples consisted of 21 percent silt and clay-sized particles, 54 percent sand, and 25 percent gravel. Subsurface samples from the northern portion of the study area and from areas nearest the banks contained more silty material than did samples from other areas. The best graded sand for concrete aggregate was found in the midstream deposits adjacent to Delaware and Clark Islands. The jetting method was found to be unsatisfactory for penetrating a compact gravel layer which underlies much of the river bed at depths of approximately 23-26 feet below water level. A recording water-level gage was operated for three months in 1965 at Rossford, near the center of the study area. Gage records indicated that the lower Maumee River is, in actuality, an estuary of Lake Erie, with its level being controlled by the lake. During the period of record the average level at Rossford was 0.52 foot above Low Water Datum for Lake Erie; the corresponding level from the U.S. Army Corps of Engineers gage at the Toledo harbor entrance was 0.51 foot, a difference of only 0.01 foot. During the period 1948-1969, an average of slightly less than 150,000 cubic yards of material per year was removed from the Maumee River estuary. Based upon this rate of removal, a 110-year reserve is available.

INTRODUCTION

In January 1967 the State of Ohio designated a portion of the lower Maumee River in Lucas and Wood Counties as an area available for commercial dredging of sand and gravel. The Maumee-Toledo Dredging Corridor, as it is called, is located between Toledo and Perrysburg, from about 6 to 13 miles upstream from Maumee Bay (fig. 1). The corridor is approximately 7.3 miles long, and has an average width of 1,100 feet and an area of 1.53 square miles (approximately 1,000 acres). A more detailed description of the corridor with reference to dredging restrictions can be found in the following section of this report.

Section 123.03 of the Ohio Revised Code declares: ". . . the waters of Lake Erie consisting of the territory within the boundaries of the state, extending from the southerly shore of Lake Erie to the international boundary line between the United States and Canada, together with the soil beneath and their contents, do now and have always, since the organization of the state of Ohio, belonged to the state as proprietor in trust for the people of the state, for the public uses to which it may be adapted, subject to the powers of the United States government, to the public rights of navigation, water commerce and fishery, and further subject to the property rights of littoral owners, including the right to made reasonable use of the waters in front of or flowing past their lands."

Geologic and hydrologic studies of the lower Maumee River have shown that this reach is, in actuality, an estuary of Lake Erie. Water levels in the estuary are controlled by Lake Erie as far south as the rapids at Perrysburg, where the true mouth of the Maumee River is located.

Section 1505.07 of the Ohio Revised Code states: ". . . the chief of the Division of Geological Survey with the approval of the director of Natural Resources, the Attorney General, and the Governor, may issue permits and make leases to parties making application, for permission to take and remove sand, gravel, stone, gas, oil, and other minerals or other substances from and under the bed of Lake Erie, either upon a royalty or rental basis, as he deems best for the state . . . . Such taking and removal shall be within certain fixed boundaries that do not conflict with the rights of littoral owners."

The objectives of this study were (1) to map the sand and gravel deposits of the lower Maumee River, (2) to estimate the quantity of commercial sand available, and (3) to ascertain the quality and potential uses of the sand and gravel lying within the Maumee-Toledo Dredging Corridor.

DESCRIPTION OF MAUMEE-TOLEDO DREDGING CORRIDOR

The Maumee-Toledo Dredging Corridor extends upstream from the centerline of the abandoned Fassett

[1] *Ohio Geological Survey*

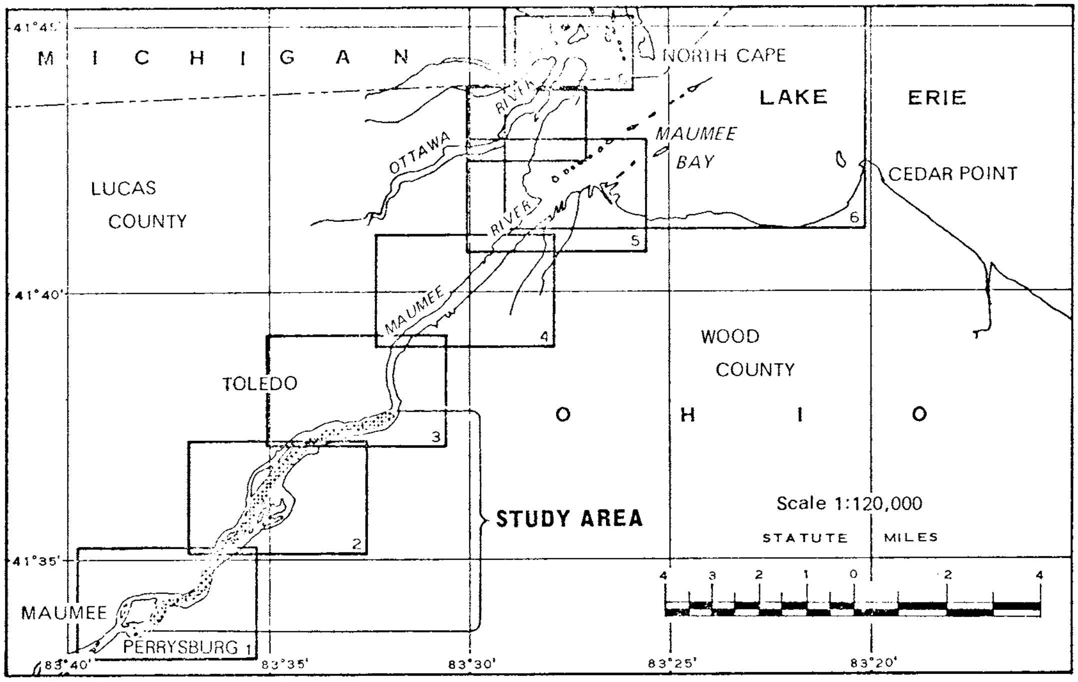

FIGURE 1.--Locality map of the Maumee-Toledo Dredging Corridor showing U.S. Lake Survey Navigation Chart 370 coverage of the area.

Street bridge (1,100 feet south of the Penn Central RR. bridge) to a line that is the projection (N. 30° W.) of Rte. 23 (Louisiana Avenue) in Perrysburg. The edges of the corridor are defined by lines 200 feet from the shore of the mainland or the islands (fig. 2). The passages between the mainland and the islands are excluded from the dredging corridor.

River crossings or manmade structures in the river will be given clearance as shown on navigation charts and as described below:

Commercial dredging activity is prohibited in the area bounded by the east edge of the turning basin and a direct northerly extension of this line approximately 500 feet east of the pipeline crossing and by a line 200 feet west of the Interstate 75 Highway bridge.

A 200-foot zone is reserved for the water pipeline crossing between Rossford and the end of Stebbins Avenue across Corbutt Island about 10,700 feet south and west of the Penn Central RR. bridge. The zone is marked by the wall on the east side of the Rossford Marina. The pipeline is located on the centerline of the restricted area.

An area 200 feet by 500 feet off the southern part of Clark Island is reserved by the City of Toledo. The corridor line in this area lies approximately 400 feet offshore (southeast) from Clark Island.

A zone 200 feet wide is reserved for the cable crossing approximately 15,700 feet south and west of the Penn Central RR. bridge and is located between the Eagle Point shore and Walbridge Park. The cable occupies the centerline of this prohibited zone.

The area in the vicinity of the water intake structure of the River Road filtration plant is restricted. It is about 20,500 feet south and west of the Penn Central RR. bridge. Commercial dredging is prohibited within 200 feet of the bridges of the Toledo Terminal RR. and the Ohio Turnpike.

METHODS OF INVESTIGATION

Field investigations were conducted in August and September 1964, May 1965, May and November 1967, April 1968, and September 1969.

The 1964 study included bottom profiling, sampling, and test boring. An 8,000-foot baseline was set up along the southeast shore, from Mid-States Terminal to the vicinity of Corbutt Island. From this baseline, perpendicular profile sections were run from shore to shore at intervals of 500 feet. The bottom depths were recorded with a Raytheon portable fathometer mounted in a small outboard motorboat. Horizontal control for the profile lines was obtained by stretching a tag line, marked every 10 feet, across the section being profiled. Vertical control was achieved by relating all depths to feet below Low Water Datum (568.6 feet above mean water level at Father Point, Quebec, International Great Lakes Datum, 1955). Water levels during the study period were obtained from a recording water-level gage located at the Toledo office of the U.S. Army, Corps of Engineers, in Bay View Park.

Bottom samples were taken at 500-foot intervals along each profile line. Samples were taken with a 100-cubic-inch capacity La Fond-Dietz type snapper sampler.

Three test borings (MR-1 through MR-3) were made during the 1964 study. Additional borings were subse-

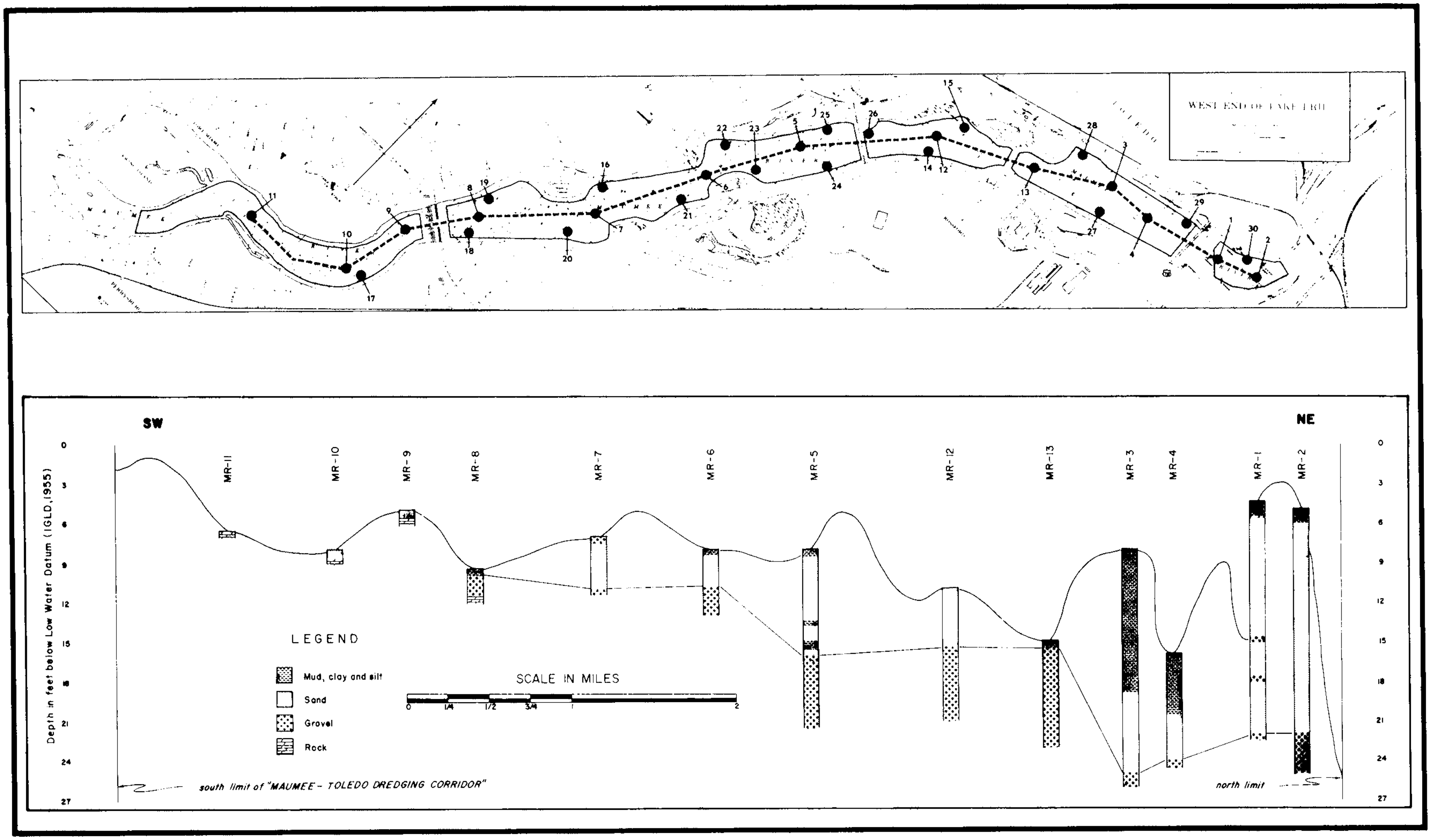

FIGURE 2.—Maumee-Toledo Dredging Corridor cross section and boring locations.

quently made in the study area, 2 in 1965 (MR-4 and MR-5) and 25 in 1967 (MR-6 through MR-30). The test borings were made by the hydraulic jetting method. This operation consists of jetting water under 40 pounds per square inch pressure through 2-inch, 1-inch, or ½-inch aluminum pipe. The 2-inch pipe generally penetrates unconsolidated silt, clay, sand, and fine gravel; but in many cases it meets refusal in compact clay, medium gravel, and glacial till. The 1-inch or ½-inch pipe is then used inside the larger pipe. The smaller diameter pipe can usually penetrate clay, till, and medium gravel but meets refusal in coarser material. Samples are taken with a hollow-tube check-valve sampler driven into the subsurface material by hand. Cores up to 3 feet in length are obtained by this procedure. Samples of the subsurface material are normally taken at 5-foot intervals. Wash samples, which often come to the surface between the 2-inch and smaller diameter pipe, and the resistance to penetration also give valuable information on the character of the material being penetrated.

In May 1965 a Stevens A-35 recording water-level gage was installed at the Rossford Municipal Dock in order (1) to correlate water levels in the study area with those recorded by the Corps of Engineers at the Harbor entrance and (2) to provide vertical control for bottom deposit investigations.

In April 1968 and September 1969 current velocities were measured in the river at three stations with a Hydro Products model 460/465 current meter. Measurements were taken at 5-foot depth intervals from surface to bottom to determine the sediment-carrying capacity of the river. The sand and gravel deposits on Ewing Island were also investigated in April 1968.

RESULTS OF INVESTIGATION

Bottom Samples and Borings

Samples were mechanically analyzed for grain size by the hydrometer method. Selected sand fractions from the hydrometer tests were retained and passed through a series of sieves. The sieve grouping used for the size analyses is that used by the Ohio Highway Testing Laboratory for construction aggregate analyses (fig. 3). A conversion table from sieve numbers to millimeters and phi units is given in figure 4. The results of the sieve analyses for all samples are given in terms of phi median (ϕm) and Trask sorting coefficient (So).

The Trask sorting coefficient (So) is a measure of the uniformity of particle sizes in a sediment sample. It is based on the statistical spread of the first and third quartiles on the percent passing curve (Krumbein and Pettijohn, 1938). These quartiles lie on each side of the median particle diameter (ϕm) or 50 percent passing and correspond to 25 and 75 percent passing. A sediment that is perfectly uniform in particle diameter has a sorting coefficient of 1.0. As this number increases the sediment is more poorly sorted. The following classification is useful in describing uniformity of diameters in the sand and gravel ranges:

Sorting coefficient	*Classification*
1.0-1.5	well sorted
1.5-2.5	medium sorted
>2.5	poorly sorted

Sieve Number	Size Grade	Phi Units	Total Percent Passing: Portland Cement	Mortar & Grout	Asphalt Concrete	Sand Cover
3/8"	Pebbles		100	–	100	100
		-3				
4	Pebbles		95-100	100	90-100	90-100
		-2				
8	Pebbles		70-95	95-100	65-100	65-100
		-1				
16	Coarse Sand		45-80	85-100	40-85	40-85
		0				
30	Coarse Sand		25-60	–	20-60	20-60
		1				
50	Medium Sand		10-30	–	7-40	7-40
		2				
100	Fine Sand		1-10	0-10	0-20	0-20
		3				
200	Fine Sand		0-4	0-4	0-10	0-10
		4				
	Silt					

FIGURE 3.—State of Ohio Department of Highways aggregate specifications ("Construction and Materials Specifications," 1969 edition).

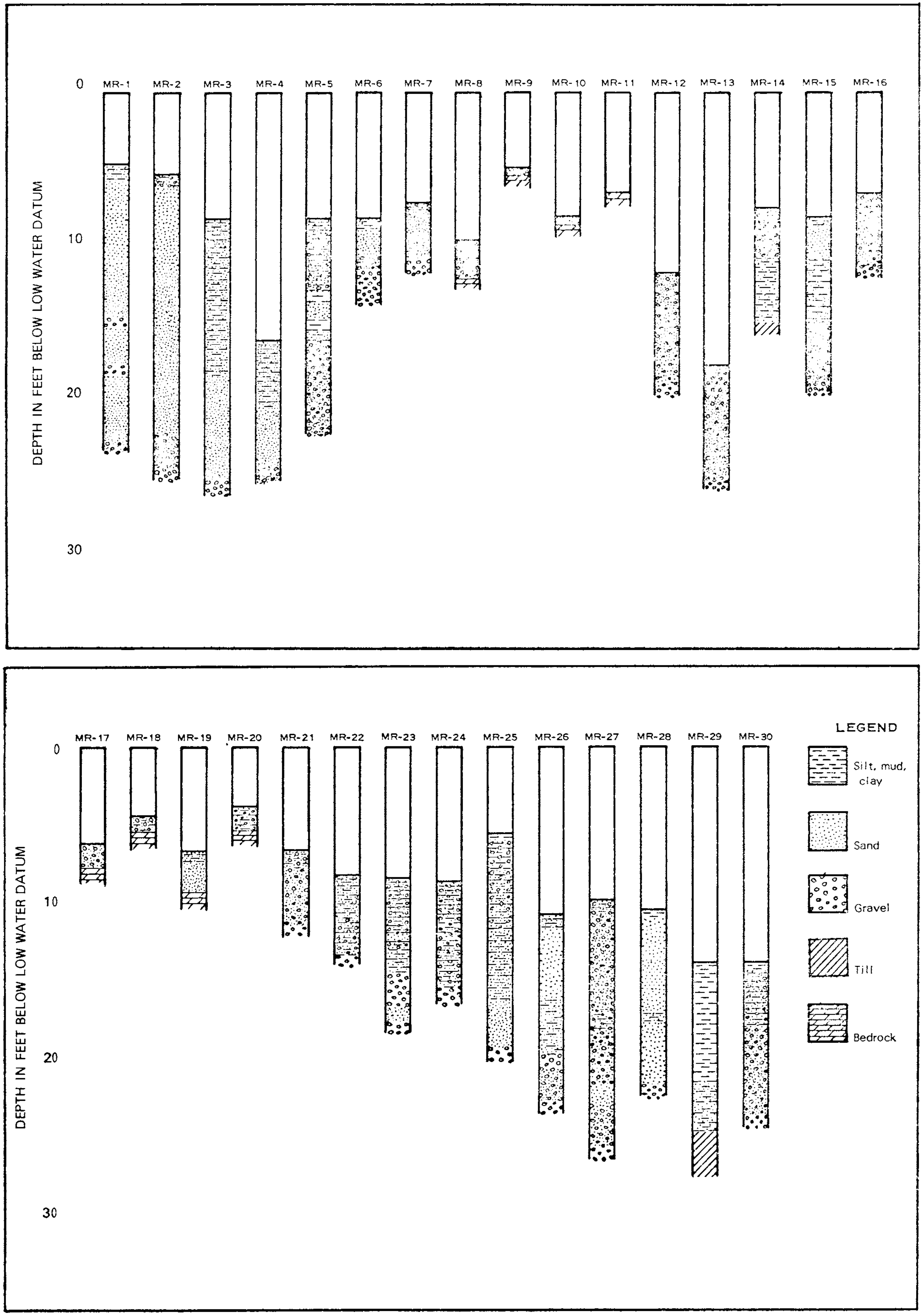

FIGURE 5.—Graphic logs of borings MR-1 through MR-30; depths below Low Water Datum of 568.6 feet above mean water level at Father Point, Quebec (IGLD, 1955).

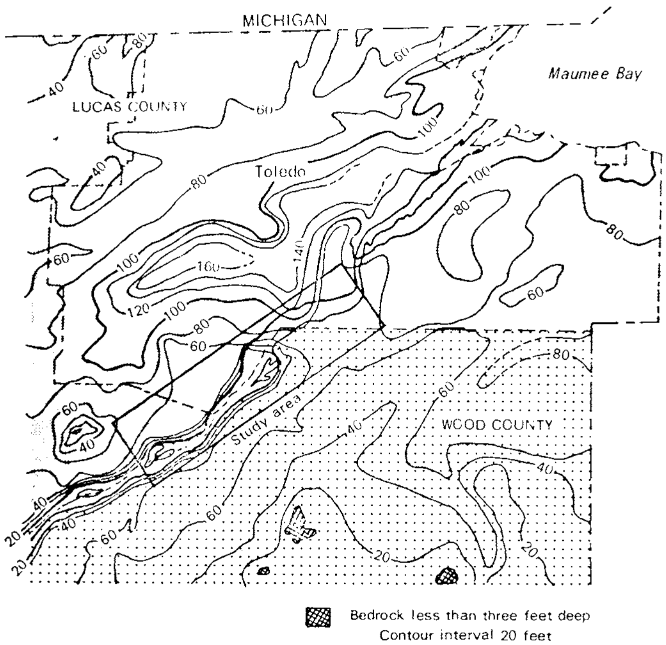

FIGURE 6.—Depth to bedrock in the vicinity of the Maumee-Toledo Dredging Corridor (modified from Forsyth, 1968).

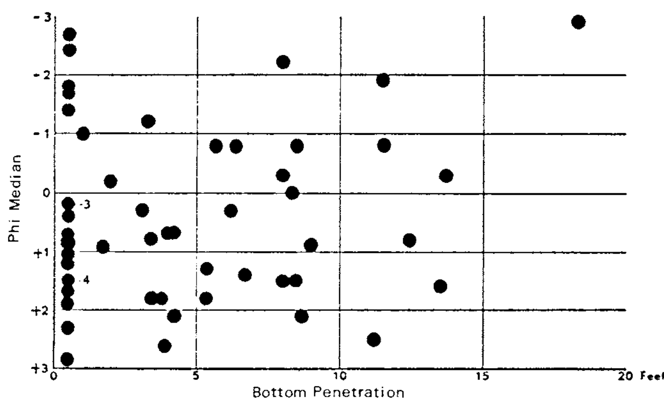

FIGURE 7.—Phi median versus bottom penetration.

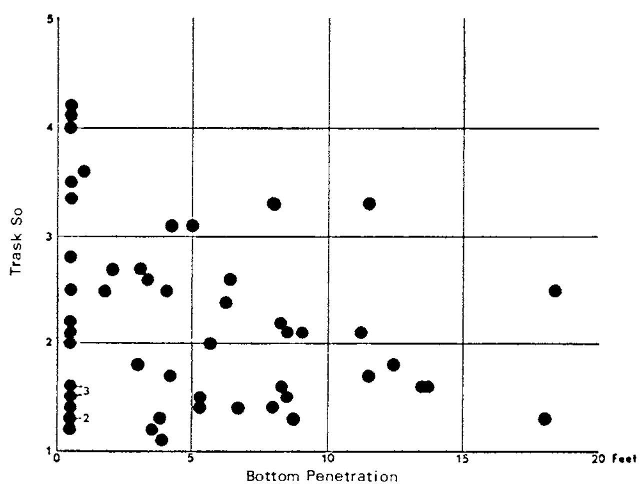

FIGURE 8.—Sorting versus bottom penetration.

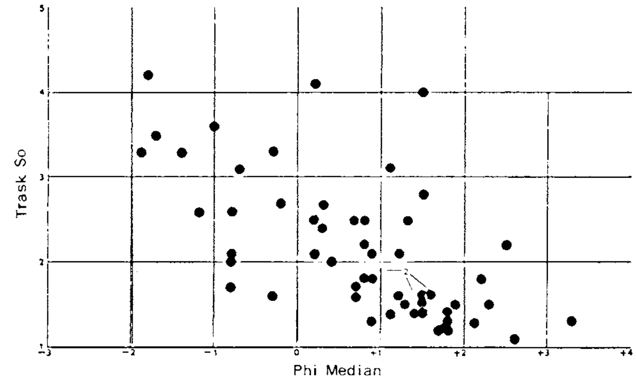

FIGURE 9.—Sorting versus phi median.

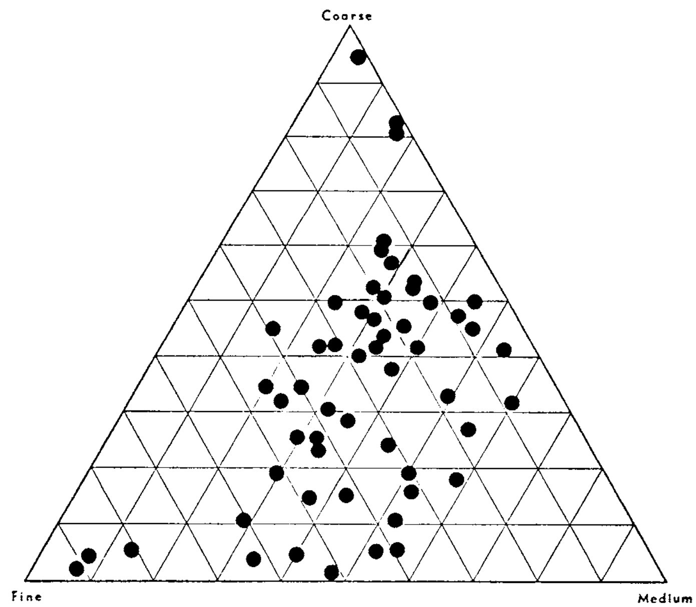

FIGURE 10.—Triangular diagram for sand samples.

(1) the composition of material forming the island, (2) the potential use of the mineral resources on the island, and (3) the geologic origin of the island. Samples of the island material were collected and analyzed optically for grain size and mineral composition.

The material forming the surface of the island was found to be river-deposited alluvium ranging in size from silt to large gravel. Large cobbles and boulders were found mixed with sand at the south (upstream) terminus of the island. The deposited sediment graded to finer sand and silt toward the north (downstream) end of the island.

The island appears to have been formed by the deposition of material carried by a rapidly moving stream as it flowed into the quiet water of the drowned river mouth. Evidence on the island, such as recently deposited coarse material, indicates that this process is continuing to build the island at the present time. Because the sand is mixed with abundant amounts of gravel and silt its extraction would demand an elaborate screening operation. The smaller downstream islands contain smaller amounts of coarse gravel and are considered better sources of commercial sand.

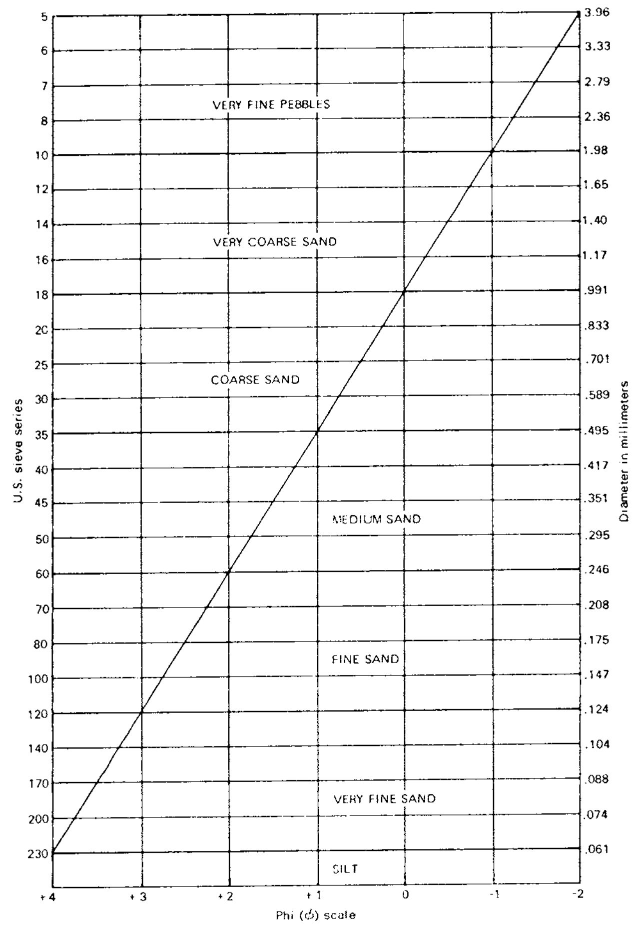

FIGURE 4.–Grain-size conversion table.

In general, Maumee River surface sand deposits are medium or well sorted.

Surface samples from the 30 test borings, which were taken at various times of the year throughout the study area, show the following grade distribution:

	Percent
Mud (silt and clay sizes)	21
Sand	54
Gravel	25

Generalized graphic logs of the 30 test borings are shown in figure 5. Detailed descriptions of test borings are given in table A of the Appendix. Eighty-two samples were retrieved from the test boring cores. Samples containing predominantly fine material were analyzed by the hydrometer method and the coarser samples were tested by sieving. The coarse samples were washed to remove any silt and clay and screened to remove gravel larger than ⅜ inch in diameter before sieving. The analyses results are given in tables A and B of the Appendix.

Data from test borings MR-1 through MR-13 have been used to construct a cross section of the dredging corridor (fig. 2). The cross section generally follows the centerline of the corridor. Figure 2 shows that commercially usable sand deposits extend from the north limit of the dredging area southwest to the vicinity of boring MR-7. Borings MR-8 through MR-10 indicate sand of good grade but of limited thickness. Bedrock was reached at shallow depths at the south end of the dredging corridor.

Test borings MR-14 through MR-30 were made near the shoreward limits of the dredging corridor. Generally the edge borings indicated considerably more silty material than did the central borings. However, in the vicinity of borings MR-25 through MR-28, edge sand deposits are of good quality.

The jetting method used for these borings is not satisfactory in gravel. Usable sand and gravel beds probably extend to depths greater than those reached during this study. Test data from the construction of the Interstate 75 bridge over the Maumee River indicate that sand and gravel deposits may extend as deep as 40 feet below water level. Forsyth (1968) plotted the depth to bedrock in the vicinity of the lower Maumee River (fig. 6). Her map shows bedrock ranging from about 10 feet below water level at the south limit of the dredging corridor to 115 feet near Walbridge Park to approximately 70 feet at the north limit.

Quality and Potential Uses

Sieve analyses of the test boring samples show that the surface deposits have a greater range of sizes than do the subsurface materials (fig. 7). This may be due to seasonal variations in the velocity and consequent carrying capacity of the stream, as well as to ice-rafting. The overall degree of sorting is poorest at the surface and increases with depth of penetration (fig. 8). This may also be accounted for by the annual variation of load-carrying capacity. A comparison of phi median versus sorting (fig. 9) indicates that the best sorting occurs in the medium sand range (ϕm +1 to +2) and the degree of sorting decreases with an increase in particle size. All samples shown in figure 9 which exhibit a degree of sorting (So) greater than 3 are samples from boring locations which are located nearest the outer boundaries of the dredging corridor. The median diameter of the test boring samples ranged from 0.1 mm to 7.4 mm and averaged 0.7 mm. Gravel layers were found at the bases of two-thirds of the test holes. Further analysis of the boring samples shows fairly even distribution for all grades of sand-sized particles (fig. 10). Most of the samples do not exceed 60 percent for any grade size and the medium sand size ranges mostly between 20 and 60 percent, a grade distribution highly desirable for pumping and sieving operations. Midriver borings (MR-5 and MR-12) adjacent to Delaware and Clark Islands yielded the best material for concrete sand. The best mortar and mason sand was found in samples (MR-1 and MR-2) from the north limit of the dredging corridor and north (MR-23) of Burns Island. Good mix and cover sand was found throughout the corridor.

Island Sand Deposits

Ewing Island, situated below the rapids of the Maumee River at Perrysburg, was investigated to determine

Maumee River Mouth

The geologic mouth of the Maumee River is located just above the Maumee-Perrysburg bridge. This is the place where the bed of the river rises above Low Water Datum for Lake Erie, i.e., where Low Water Datum intersects the shoreline on either side of the river. A line drawn between these points is the demarcation between the Maumee River and the estuary of Lake Erie.

The location of the mouth of the Maumee River in the vicinity of the Maumee-Perrysburg bridge is further supported by water levels recorded at the Rossford Marina, which is abreast of Corbutt Island. A comparison of water levels recorded at the Rossford gage and at the U.S. Army Corps of Engineers gage at the harbor entrance, for September 15, 1965, through November 8, 1965, indicates that the average water level in the dredging corridor is essentially the same as the average level of Lake Erie. During the period of record, the average hourly level at Rossford was 0.52 foot above Low Water Datum and the corresponding level at the harbor entrance was 0.51 foot, a difference of only 0.01 foot.

Crustal movements account for the fact that water at the level of Lake Erie extends so many miles inland. These movements have depressed the lower Maumee River valley to the point where Lake Erie has encroached on the valley, forming the drowned river mouth or estuary that exists today.

Moore (1948) studied crustal movements in the Great Lakes area. His measurements showed that the Toledo area was depressed at a rate of 0.72 foot per century for the period 1877 to 1944. Considering that Lake Erie has been at its present level for several thousands of years, significant drowning of the lower Maumee River valley is understandable.

Current Studies

In the spring of 1968, currents were measured midstream near the Interstate 75 bridge, near the Rossford Municipal Dock, and between Delaware and Grassy Islands. Current directions at each station were downstream and within the northeast quadrant. Velocities ranged from 0.72 foot per second to 0.17 foot per second. Surface velocities averaged 0.33 foot per second while bottom currents averaged 0.28 foot per second. These velocities are insufficient to erode sand but a velocity of only 0.23 foot per second is sufficient to transport particles as large as coarse-grained sand (Hjulström, 1939) once the particle is in motion.

Current measurements on September 4, 1969, at 1500 hours yielded quite different results. With wind velocities of 15 to 20 mph from NNE, the surface currents near the Rossford Municipal Dock were moving upstream (210°) at 0.51 foot per second. However, at depths greater than 5 feet the direction was nearly reversed (70°) and the flow was downstream at 0.17 foot per second. Records for this period show water level rising at a rate of 0.23 foot per hour in response to the wind. By 1600 hours the force of the wind-driven lake water was apparently strong enough to stop the downstream river flow and currents from top to bottom were moving upstream at an average velocity of 0.23 foot per second.

RESERVES

The Ohio Department of Natural Resources has kept records of sand and gravel removal from the Maumee River since 1948 (fig. 11).

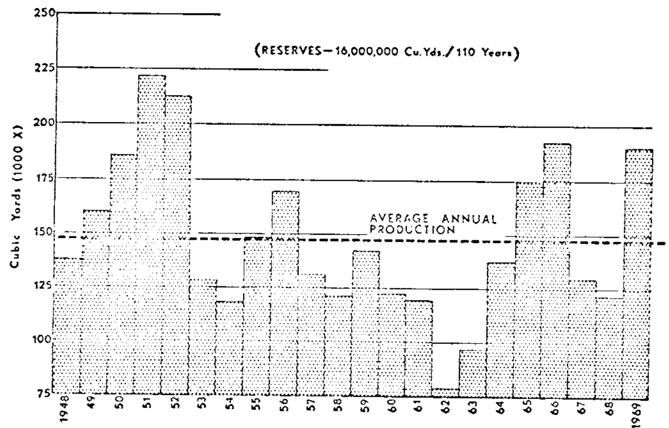

FIGURE 11.—Annual production of sand and gravel from the Maumee-Toledo Dredging Corridor, 1948-1969.

The average rate of sand removal is somewhat under 150,000 cubic yards per year. The average thickness of commercially usable sand throughout the dredging corridor, based on the 30 test borings, is approximately 10 feet. This yields a volume of about 16,000,000 cubic yards of sand: a 110-year reserve at the present rate of removal. Considering the likelihood of usable deposits below the limits of test borings, sand reserves could amount to two or three times this figure.

Investigations of Ewing Island and the bottom surface sediments indicate that the sand and gravel resources of the dredging corridor are being added to as a result of upstream erosion, but only slowly. The recently deposited material, particularly in the northern limits of the study area, is much finer than the subsurface deposits. Apparently higher stream velocities occurred in the Maumee River during a low water level stage in western Lake Erie about 12,000 years ago (Lewis and others, 1966, and Herdendorf, 1968) and resulted in the deposition of much of the coarser material found at depth within the dredging corridor.

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APPENDIX

TABLE A.—*Logs of Maumee River test borings*

Boring no. Water depth Date	Sample number	Particle size (percent) Gravel	Sand	Silt	Clay	Depth and *elevation* (ft)	Bottom penetration (ft)	Field description
MR-1 4.5 ft 8-25-64	MR-1-1	0.00	35.80	64.20	0.00	4.5 *564.1*	0.0-0.5	Sand, mixed with olive-gray mud, shells
	MR-1-2	0.00	89.20	10.80	0.00	7.5 *561.1*	3.0-3.4	Sand, medium- to coarse-grained
	MR-1-3	0.00	14.90	77.30	7.80	12.5 *556.1*	8.0-8.7	Sand, medium- to fine-grained
						14.5 *554.1*	10.0	No sample, appeared to be gravel layer with sand below
						17.5 *551.1*	13.0	No sample, appeared to be gravel layer with sand below
	MR-1-4	69.30	6.44	24.18	0.08	22.5 *546.1*	18.0-18.3	Sand, coarse-grained; with gravel
						23.0 *545.6*	18.5	No sample, refusal in compact sand and gravel layer
MR-2 5.0 ft 8-25-64	MR-2-1	16.08	65.52	18.40	0.00	5.0 *563.6*	0.0-0.5	Sand and gravel, medium- to fine-grained; mixed with brown mud, shell fragments, and wood detritus
	MR-2-2	1.15	77.95	20.90	0.00	8.0 *560.6*	3.0-3.8	Sand, medium- to fine-grained; with shell fragments
	MR-2-3	0.00	89.60	10.40	0.00	13.0 *555.6*	8.0-8.7	Sand, medium- to fine-grained, with shell fragments and wood detritus
	MR-2-4	1.95	85.65	12.40	0.00	18.0 *550.6*	13.0-13.5	Sand, fine- to coarse-grained; with shell fragments
						22.0 *546.6*	17.0	No sample, appeared to be compact gravel layer
	MR-2-5	20.35	75.65	4.00	0.00	23.0 *545.6*	18.0-18.4	Sand, coarse-grained; with pebbles and shell fragments
						25.0 *543.6*	20.0	No sample, refusal in compact gravel layer
MR-3 8.0 ft 8-25-64	MR-3-1	0.00	36.50	63.50	0.00	8.0 *560.6*	0.0-0.5	Mud, gray-brown, silty; with fine-grained sand
	MR-3-2					13.0 *555.6*	5.0-6.5	Mud, gray, laminated; with silt and fine-grained sand, shell fragments
	MR-3-3					18.0 *550.6*	10.0-10.5	Mud, gray-brown, silty
	MR-3-4					18.5 *550.1*	10.5-11.0	Sand, medium- to coarse-grained
	MR-3-5					23.0 *547.6*	15.0-15.4	Sand, medium- to coarse-grained; with clay material
						25.0 *543.6*	17.0	No sample, appeared to be gravel layer
						26.0 *542.6*	18.0	No sample, refusal in compact gravel layer
MR-4 16.0 ft 5-19-65	MR-4-1	0.00	51.90	46.70	1.40	16.0 *552.6*	0.0-0.5	Mud, dark-brown, silty, sandy
	MR-4-2					20.0 *548.6*	4.0-5.0	Mud, dark-brown, silty
						20.5 *548.1*	4.5	No sample, appeared to be sand layer
						24.0 *544.6*	8.0	No sample, appeared to be gravel layer
	MR-4-3					24.5 *544.1*	8.5-8.6	Sand, fine-grained; with pebbles, shell fragments, and wood detritus
						25.0 *543.6*	9.0	No sample, refusal in compact sand and gravel layer

Boring no. Water depth Date	Sample number	Particle size (percent)			Depth and *elevation* (ft)	Bottom penetration (ft)	Field description
		Gravel	Sand	Silt and clay			
MR-5 8.0 ft 5-19-65	MR-5-1	0.09	93.19	6.72	8.0 *560.6*	0.0-0.5	Sand, dark-brown, medium- to fine-grained, silty; with shells and wood detritus
	MR-5-2	7.40	87.12	5.48	13.0 *555.6*	5.0-5.3	Sand, coarse-grained; with pebbles and gray-brown silt
					13.5 *555.1*	5.5	No sample, appeared to be compact clay layer with sand below
					15.0 *553.6*	7.0	No sample, appeared to be compact clay layer with sand below
	MR-5-3	1.70	97.27	1.03	15.5 *553.1*	7.5-8.0	Sand, medium-grained, silty; with shells
	MR-5-4	41.35	58.49	0.16	16.0 *552.6*	8.0-8.5	Sand, medium- to coarse-grained; with pebbles
	MR-5-5	9.23	86.77	4.00	20.0 *548.6*	12.0-12.4	Sand, medium- to coarse-grained, silty; with pebbles
					20.5 *548.1*	12.5	No sample, appeared to be compact gravel layer
	MR-5-6	5.21	93.39	1.40	21.5 *547.1*	12.5-13.7	Sand, medium- to coarse-grained; with pebbles and shell fragments
					22.0 *546.6*	14.0	No sample, refusal in compact gravel layer
MR-6 8.0 ft 5-3-67	MR-6-1	2.11	96.61	1.28	8.0 *560.6*	0.0-0.5	Sand, medium- to fine-grained, silty; shells
	MR-6-2	50.29	49.12	0.58	10.5 *558.1*	2.5-3.3	Sand, medium- to coarse-grained; with gravel and snail shells
					11.5 *557.1*	3.5-5.5	No sample, appeared to be gravel layer
					13.5 *555.1*	5.5	No sample, refusal in compact gravel layer
MR-7 7.0 ft 5-3-67	MR-7-1	57.08	42.01	0.91	7.0 *561.6*	0.0-0.5	Sand, poorly sorted; gravel up to 0.2 ft in diameter
	MR-7-2	1.82	93.93	4.25	10.5 *558.1*	3.5-4.2	Sand, medium- to fine-grained; shell fragments
					11.5 *557.1*	4.5	No sample, refusal in compact gravel layer
MR-8 9.5 ft 5-3-67	MR-8-1	15.49	83.32	1.19	9.5 *559.1*	0.0-0.5	Sand and gravel, thin layer of brown sand and gravel over dark-gray mud mixed with sand and gravel
	MR-8-2	39.16	60.14	0.70	10.0 *558.6*	0.5-2.0	Sand, medium- to coarse-grained; with gravel
					12.0 *556.6*	2.5	No sample, refusal at bedrock
MR-9 5.0 ft 5-3-67	MR-9-1	4.63	94.99	0.38	5.0 *563.6*	0.0-0.5	Sand, medium-grained, clean; pebbles
					5.5 *563.1*	0.5	No sample, refusal at bedrock
MR-10 8.0 ft 5-3-67	MR-10-1	2.40	96.96	0.64	8.0 *560.6*	0.0-0.5	Sand, medium- to coarse-grained; with a few pebbles
					8.5 *560.1*	0.5	No sample, refusal at bedrock
MR-11 6.5 ft 5-3-67					6.5 *562.1*	0.0	No sample, bedrock at bottom surface
MR-12 11.7 ft 5-3-67	MR-12-1	5.33	94.17	0.50	11.7 *556.9*	0.0-0.5	Sand, medium- to coarse-grained; pebbles, shells
					12.3 *556.3*	0.5-4.5	No sample, appeared to be compact sand and gravel layer
	MR-12-2	42.86	56.27	0.87	16.2 *552.4*	4.5-5.0	Sand, medium- to coarse-grained; with pebbles and shells
	MR-12-3	72.20	25.62	2.18	18.7 *549.9*	7.0-8.0	Sand and gravel; coarse-grained sand and pebbles
					19.7 *548.9*	8.0	No sample, refusal in compact gravel layer

TABLE A.—*Logs of Maumee River test borings*—Continued

Boring no. Water depth Date	Sample number	Particle size (percent)			Depth and *elevation* (ft)	Bottom penetration (ft)	Field description
		Gravel	Sand	Silt and clay			
MR-13 17.7 ft 5-3-67	MR-13-1	78.55	21.08	0.37	17.7 *550.9*	0.0-0.5	Mud, gray-brown; mixed with sand, pebbles, and plant detritus
	MR-13-2	23.66	75.36	0.98	18.7 *549.9*	1.0-1.7	Sand, medium- to fine-grained; pebbles
	MR-13-3	45.62	54.06	0.32	23.7 *544.9*	6.0-6.4	Sand, medium- to coarse-grained; with pebbles and shells
					25.7 *542.9*	8.0	No sample, refusal in compact gravel layer
MR-14 7.6 ft 11-14-67	MR-14-1	30.19	62.59	7.22	7.6 *561.0*	0.0-0.5	Sand, medium-grained; mixed with silt and gravel
					10.5 *558.1*	2.9	No sample, appears to be clay
	MR-14-2	3.39	28.63	67.98	12.0 *556.6*	4.4-5.7	Clay, medium-gray, smooth, sandy
	MR-14-3		2.08	97.92	15.0 *553.6*	7.4-7.7	Glacial till, very hard compact yellow-brown till clay
					15.6 *553.0*	8.0	No sample, refusal in hard till clay
MR-15 8.1 ft 11-15-67	MR-15-1	3.30	89.41	7.29	8.1 *560.5*	0.0-0.5	Sand, medium- to fine-grained; silty at surface
	MR-15-2	0.37	44.35	55.28	10.6 *558.0*	2.5-3.6	Clay, smooth, soft, sandy
	MR-15-3	0.41	37.78	61.81	11.7 *556.9*	3.6-3.8	Sand, silty; with shell fragments
					14.7 *553.9*	6.5	No sample, appeared to be a gravel layer
	MR-15-4	44.66	48.08	7.26	15.6 *553.0*	7.5-8.0	Sand and gravel, with shell fragments
					18.6 *550.0*	10.5	No sample, hard layer, appeared to be sand and gravel
					19.4 *549.2*	11.3	No sample, refusal in compact gravel layer
MR-16 6.4 ft 11-15-67	MR-16-1	28.09	67.09	4.82	6.4 *562.2*	0.0-0.5	Sand, medium- to coarse-grained; with gravel
					11.5 *557.1*	5.1	No sample, appeared to be coarse sand and gravel
					11.9 *556.7*	5.5	No sample, refusal in compact gravel layer
MR-17 6.1 ft 11-15-67	MR-17-1	44.52	54.41	1.07	6.1 *562.5*	0.0-0.5	Sand, brown; with pebbles and cobbles
					7.6 *561.0*	1.5	No sample, refusal at bedrock
MR-18 4.3 ft 11-15-67	MR-18-1	63.10	25.12	11.78	4.3 *564.3*	0.0-0.5	Sand and gravel, mixed with mud
	MR-18-2	46.46	43.36	10.18	4.8 *563.8*	0.5-1.0	Sand, with silt and gravel
					5.3 *563.3*	1.0	No sample, refusal at bedrock
MR-19 6.6 ft 11-15-67	MR-19-1	17.78	80.85	1.37	6.6 *562.0*	0.0-0.5	Sand, medium- to coarse-grained; silty at surface
					9.4 *559.2*	2.8	No sample, refusal at bedrock
MR-20 3.7 ft 11-15-67	MR-20-1	92.10	7.13	0.77	3.7 *564.9*	0.0-0.5	Gravel, pea-sized pebbles with sand and silt
					5.2 *563.4*	1.5	No sample, refusal at bedrock
MR-21 6.5 ft 11-15-67	MR-21-1	62.62	32.30	5.08	6.5 *562.1*	0.0-0.5	Gravel, mixed with sand and mud
	MR-21-2	14.41	85.14	0.45	12.0 *556.6*	5.5-5.7	Sand and gravel, medium- to coarse-grained; with shell fragments
					12.2 *556.4*	5.7	No sample, refusal in compact gravel layer
MR-22 8.2 ft 11-15-67	MR-22-1	0.00	28.19	71.81	8.2 *560.4*	0.0-0.5	Mud and sand, gray-brown, smooth
	MR-22-2	37.43	58.78	3.79	11.0 *557.6*	2.8-5.3	Sand, coarse-grained; with gravel and silt
					14.0 *554.6*	5.8	No sample, refusal in compact gravel layer

TABLE A.—*Logs of Maumee River test borings*—Continued

Boring no. Water depth Date	Sample number	Particle size (percent)			Depth and *elevation* (ft)	Bottom penetration (ft)	Field description
		Gravel	Sand	Silt and clay			
MR-23 8.4 ft 11-16-67	MR-23-1	9.52	86.64	3.84	8.4 *560.2*	0.0-0.5	Sand and gravel, medium-grained; silty at surface
	MR-23-2	39.22	54.41	6.37	11.5 *557.1*	3.1-3.5	Silt, gray-brown; mixed with sand and gravel
	MR-23-3	0.52	92.46	7.02	11.9 *556.7*	3.5-3.9	Sand, yellow-brown, fine-grained
	MR-23-4	33.40	61.22	5.38	12.3 *556.3*	3.9-4.2	Sand, gray-brown, very fine-grained; mixed with silt and gravel
	MR-23-5	0.00	46.41	53.59	12.6 *556.0*	4.2-4.5	Clay, yellow-brown, compact, sandy
					14.5 *554.1*	6.1-8.3	No sample, appeared to be compact gravel layer
	MR-23-6	1.02	96.05	2.93	16.7 *551.9*	8.3-8.5	Sand, brown, medium- to coarse-grained
					17.5 *551.1*	9.1	No sample, appeared to be compact gravel layer
					18.5 *550.1*	10.1	No sample, refusal in compact gravel layer
MR-24 8.7 ft 11-16-67	MR-24-1	74.50	23.19	2.31	8.7 *559.9*	0.0-0.5	Sand and gravel; brown sand, cobbles; silty
	MR-24-2	37.11	58.72	4.17	11.5 *557.1*	2.8-3.1	Sand, with fine-grained gravel and compact clay
					15.5 *553.1*	6.8	No sample, appeared to be compact gravel layer
					16.5 *552.1*	7.8	No sample, refusal in compact gravel layer
MR-25 5.6 ft 11-16-67	MR-25-1	55.64	37.24	7.12	5.6 *563.0*	0.0-0.5	Sand and gravel, 0.2 ft of brown mud at surface over silty sand to cobbles
	MR-25-2	27.45	70.45	2.10	11.5 *557.1*	5.9-6.2	Sand and gravel, coarse-grained sand and fine-grained pebbles, with shells
	MR-25-3	0.54	36.47	62.99	11.8 *556.8*	6.2-6.7	Sand, fine-grained; with gray-brown clay
	MR-25-4	19.78	76.60	3.62	16.5 *552.1*	10.9-11.2	Sand, medium- to coarse-grained; with shells
					19.5 *549.1*	13.9	No sample, appeared to be compact gravel layer
					20.2 *548.4*	14.6	No sample, refusal in compact gravel layer
MR-26 10.8 ft 11-16-67	MR-26-1	9.21	86.66	4.13	10.8 *557.8*	0.0-0.5	Sand, medium-grained; silty at surface; shells
	MR-26-2	12.79	81.30	5.91	16.8 *551.8*	6.0-6.7	Sand, medium- to fine-grained, silty; clay at base
					19.7 *548.9*	8.9-9.9	No sample, appeared to be gravel layer
	MR-26-3	68.41	29.37	2.22	21.8 *546.8*	11.0-11.5	Sand, with abundant snail shells and pea-sized pebbles
					23.7 *544.9*	12.9	No sample, refusal in gravel layer
MR-27 9.9 ft 11-16-67	MR-27-1	81.50	11.45	7.05	9.9 *558.7*	0.0-0.5	Sand and gravel, silty; cobbles, shells
	MR-27-2	18.76	78.29	2.95	16.9 *551.7*	7.0-9.0	Sand, medium- to fine-grained; shells, pebbles; two thin (0.1 ft) clay layers
	MR-27-3		100.00		21.9 *546.7*	12.0-12.5	Sand, medium- to fine-grained; shell fragments
					23.7 *544.9*	13.8	No sample, appeared to be compact sand and gravel layer
					26.5 *542.1*	16.6	No sample, refusal in gravel layer
MR-28 10.5 ft 11-16-67	MR-28-1	0.72	85.36	13.92	10.5 *558.1*	0.0-0.5	Mud, gray-brown; mixed with fine-grained sand and plant detritus
	MR-28-2	3.88	93.01	3.11	16.8 *551.8*	6.3-8.3	Sand, medium-grained; shells; thin (0.2 ft) clay layer at 7.0 ft penetration
	MR-28-3	51.74	46.47	1.79	21.8 *546.8*	11.3-11.5	Sand, with pebbles and shells
					22.3 *546.8*	11.8	No sample, refusal in compact gravel layer

TABLE A.—*Logs of Maumee River test borings*—Continued

Boring no. Water depth Date	Sample number	Particle size (percent)			Depth and *elevation* (ft)	Bottom penetration (ft)	Field description
		Gravel	Sand	Silt and clay			
MR-29 13.8 ft 11-16-67	MR-29-1	0.00	7.77	92.23 (silt only)	13.8 *554.8*	0.0-0.5	Mud, gray-brown, sandy
	MR-29-2	0.66	9.73	89.61 (silt only)	16.8 *551.8*	3.0-4.5	Clay, gray-brown, smooth
	MR-29-3	7.10	34.16	58.74 (silt only)	21.8 *546.8*	8.0-8.3	Clay, medium-gray, compact; with fine-grained sand
					24.8 *543.8*	11.0	No sample, hard layer, appeared to be top of till
	MR-29-4	7.13	38.64	54.23 (silt only)	26.8 *541.8*	13.0-13.7	Glacial till, reddish-gray, compact, gritty; till clay
					27.8 *540.8*	14.0	No sample, refusal in hard till clay
MR-30 13.8 ft 11-16-67	MR-30-1		12.86	87.14	13.8 *554.8*	0.0-0.5	Mud, gray-brown, smooth, sandy
	MR-30-2	30.93	53.31	15.76	16.8 *551.8*	3.0-4.0	Sand and gravel, silty
	MR-30-3	33.04	65.30	1.66	21.8 *546.8*	8.0-8.3	Sand and gravel, medium-grained sand to fine-grained pebbles; shells
					24.3 *543.3*	10.5	No sample, refusal in compact gravel layer

TABLE B.—*Sieve analyses of Maumee River test boring samples*

Sample number	U.S. sieve series (percent passing)								ϕm	So	Water depth (ft)	Bottom penetration (ft)
	⅜ in	4	8	16	30	50	100	200				
MR-1-2	100.00	100.00	100.00	91.75	54.74	8.20	0.31	0.00	0.8	1.8	4.5	3.0-3.4
MR-1-4	100.00	34.35	8.68	1.68	0.68	0.42	0.20	0.08	-2.9	1.3	4.5	18.0-18.3
MR-2-1	100.00	91.05	84.61	73.66	50.57	24.14	17.98	2.94	0.8	2.2	5.0	0.0-0.5
MR-2-2	100.00	100.00	98.46	97.88	94.39	54.93	9.77	0.79	1.8	1.3	5.0	3.0-3.8
MR-2-3	100.00	100.00	100.00	99.94	98.17	62.91	14.68	1.19	2.1	1.3	5.0	8.0-8.7
MR-2-4	100.00	100.00	97.77	94.26	83.17	48.04	6.16	0.78	1.6	1.6	5.0	13.0-13.5
MR-2-5	100.00	90.37	85.18	75.73	63.31	36.41	3.49	0.39	1.3	2.5	5.0	18.0-18.4
MR-5-1	100.00	100.00	99.91	99.26	95.77	65.34	20.24	6.72	1.9	1.5	8.0	0.0-0.5
MR-5-2	100.00	97.25	92.60	87.36	79.37	33.83	9.41	5.48	1.3	1.5	8.0	5.0-5.3
MR-5-3	100.00	99.12	98.30	97.41	92.13	39.24	3.31	1.03	1.5	1.4	8.0	7.5-8.0
MR-5-4	100.00	81.58	59.83	35.39	10.58	0.94	0.22	0.16	-0.8	2.1	8.0	8.0-8.5
MR-5-5	100.00	98.91	90.77	79.27	52.39	18.22	7.39	4.00	0.8	1.8	8.0	12.0-12.4
MR-5-6	100.00	100.00	94.79	52.91	19.27	2.48	1.81	1.40	-0.3	1.6	8.0	13.5-13.7
MR-6-1	100.00	99.25	97.89	95.85	92.48	42.59	4.41	1.28	1.5	1.5	8.0	0.0-0.5
MR-6-2	100.00	75.44	75.44	36.64	21.57	8.68	2.82	0.62	-1.2	2.6	8.0	2.5-3.3
MR-7-1	100.00	66.02	46.57	34.47	20.48	7.46	2.00	0.99	-1.4	3.3	7.0	0.0-0.5
MR-7-2	100.00	100.00	98.18	84.40	50.37	21.67	11.60	4.25	0.7	1.7	7.0	3.5-4.2
MR-8-1	100.00	94.30	88.95	83.29	72.30	28.31	5.11	1.25	1.5	1.6	9.5	0.0-0.5
MR-8-2	100.00	82.10	66.60	53.51	36.37	6.63	1.82	0.77	-0.2	2.7	9.5	0.5-2.0
MR-9-1	100.00	98.43	95.81	87.27	56.85	5.63	1.04	0.38	0.9	1.3	5.0	0.0-0.5
MR-10-1	100.00	99.79	97.60	90.89	66.91	8.01	1.04	0.64	1.1	1.4	8.0	0.0-0.5

TABLE B.—*Sieve analyses of Maumee River test boring samples*—Continued

Sample number	U.S. sieve series (percent passing)								ϕm	So	Water depth (ft)	Bottom penetration (ft)
	⅜ in	4	8	16	30	50	100	200				
MR-12-1	100.00	98.66	94.67	82.50	47.85	7.23	0.82	0.50	0.7	1.6	11.7	0.0-0.5
MR-12-2	100.00	79.05	61.76	46.41	29.71	13.09	3.32	0.94	-0.7	3.1	11.7	4.5-5.0
MR-12-3	100.00	56.97	29.81	20.13	12.80	5.86	3.58	2.34	-2.2	--	11.7	7.0-8.0
MR-13-1	100.00	47.24	33.97	27.50	20.39	10.60	2.55	0.58	-2.7	--	17.7	0.0-0.5
MR-13-2	100.00	90.48	81.32	72.25	58.83	29.61	4.66	1.06	0.8	2.5	17.7	1.0-1.7
MR-13-3	100.00	74.67	57.41	44.80	32.47	10.16	1.25	0.34	-0.8	2.6	17.7	6.0-6.4
MR-14-1	100.00	91.65	73.95	57.00	38.02	9.93	1.79	0.20	0.2	2.5	7.6	0.0-0.5
MR-15-1	100.00	98.27	97.09	96.33	95.62	49.63	1.56	0.12	1.7	1.2	8.1	0.0-0.5
MR-15-4	100.00	73.45	61.18	49.28	33.71	14.04	3.45	0.49	-0.3	3.3	8.1	7.5-8.0
MR-16-1	100.00	92.46	76.12	61.21	36.18	11.41	2.86	0.41	0.2	2.1	6.4	0.0-0.5
MR-17-1	100.00	73.86	59.98	53.27	46.32	26.14	5.96	0.75	0.2	4.1	6.1	0.0-0.5
MR-18-1	100.00	60.50	45.22	37.06	30.43	18.95	7.50	1.51	-1.8	4.2	4.3	0.0-0.5
MR-18-2	100.00	75.41	58.06	42.32	30.39	17.09	4.96	0.62	-1.0	3.6	4.3	0.5-1.0
MR-19-1	100.00	94.47	87.79	80.97	65.08	17.16	3.04	0.89	1.2	1.6	6.6	0.0-0.5
MR-20-1	100.00	29.48	12.51	8.82	6.55	3.57	1.29	0.32	--	--	3.7	0.0-0.5
MR-21-1	100.00	64.17	53.55	50.38	47.80	32.94	6.69	1.21	0.4	2.0	6.5	0.0-0.5
MR-21-2	100.00	92.92	68.50	28.62	4.36	0.86	0.06	--	-0.8	2.0	6.5	5.5-5.7
MR-22-2	100.00	87.55	73.74	60.16	42.46	25.05	4.40	0.40	1.8	1.4	8.2	2.8-5.3
MR-23-1	100.00	95.11	90.77	88.80	85.97	74.17	31.52	2.22	2.3	1.5	8.4	0.0-0.5
MR-23-2	100.00	81.52	66.58	55.97	41.06	19.99	5.86	0.54	1.8	1.2	8.4	3.1-3.5
MR-23-3	100.00	100.00	99.55	98.96	97.48	91.08	21.52	2.09	2.6	1.1	8.4	3.5-3.9
MR-23-4	100.00	85.85	74.40	66.91	54.87	34.32	9.21	1.09	1.1	3.1	8.4	3.9-4.2
MR-23-6	100.00	100.00	99.64	95.59	75.62	33.08	7.13	0.63	1.5	1.5	8.4	8.3-8.5
MR-24-1	100.00	64.08	47.17	38.50	29.29	11.19	3.05	0.39	-1.7	3.5	8.7	0.0-0.5
MR-24-2	100.00	87.03	68.91	51.94	35.95	17.10	4.03	0.29	0.3	2.7	8.7	2.8-3.1
MR-25-1	100.00	86.20	69.03	56.70	47.67	26.94	4.70	2.27	1.5	4.0	5.6	0.0-0.5
MR-25-2	100.00	93.07	79.55	60.91	42.80	18.92	4.26	0.51	0.3	2.4	5.6	5.9-6.2
MR-25-4	100.00	92.64	83.79	76.75	68.12	44.24	9.02	1.23	2.5	2.2	5.6	10.9-11.2
MR-26-1	100.00	95.07	91.60	87.32	74.79	21.49	1.25	0.11	1.5	2.8	10.8	0.0-0.5
MR-26-2	100.00	94.40	91.00	88.24	80.63	33.51	3.40	0.43	1.4	1.4	10.8	6.0-6.7
MR-26-3	100.00	71.81	41.23	33.14	27.12	18.73	3.93	0.42	-1.9	3.3	10.8	11.0-11.5
MR-27-1	100.00	53.29	31.68	25.69	21.59	14.84	5.98	1.13	-2.4	0.0	9.9	0.0-0.5
MR-27-2	100.00	92.68	82.79	74.02	55.04	22.70	4.18	0.71	0.9	2.1	9.9	7.0-9.0
MR-28-1	100.00	100.00	99.59	98.80	96.70	89.51	76.97	18.15	3.3	1.3	10.5	0.0-0.5
MR-28-2	100.00	98.95	97.28	92.76	80.46	41.14	7.15	0.83	1.6	1.6	10.5	6.3-8.3
MR-28-3	100.00	79.34	58.91	45.63	31.94	11.32	2.35	0.34	-0.8	1.7	10.5	11.3-11.5
MR-30-2	100.00	86.31	76.02	66.58	50.75	13.54	3.43	0.56	0.7	2.5	13.8	3.0-4.0
MR-30-3	100.00	96.43	75.26	54.90	34.76	9.67	1.98	0.26	0.0	2.2	13.8	8.0-8.3

SLAG - MICHIGAN'S ALL-PURPOSE CONSTRUCTION AGGREGATE

by

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Abstract

Iron ores, fluxstones, and coke are heedfully combined into Detroit's steel making furnaces to form pig iron, steel, and slag. Detroit's slag, a nonmetallic material consisting mainly of silicates and alumosilicates of lime, was once discarded as a waste material, but since 1921, this slag has been processed economically by the Edward C. Levy Company of Detroit. New uses and continual growing markets for slag combined with the higher transportation costs for sand and gravel into the Detroit area have lead to one of Michigan's most important construction stone industries.

INTRODUCTION

Natural aggregates for use in the Detroit area, as well as other large cities in the United States, are no longer found in close proximity. As the population increases, the city and its suburbs continually stretch outward. As this occurs, new sites for aggregate supplies are located farther and farther from the central city area.

Truck transportation of natural aggregate to Detroit is not a physical problem because the highway system makes it quite efficient--the problem lies in the cost of transportation. One of the nearest sand and gravel producers is located approximately 25 miles from downtown Detroit. At current prices, a 6A gravel aggregate for use in concrete, costs approximately $2.00 per ton at the plant. The truck transportation charge for the 25 mile trip to Detroit would be at least $1.11 per ton, resulting in a total cost of $3.11 per ton. This is a conservative estimate since most of the sand and gravel operations nearest to Detroit would fall in the 40 to 50 mile range; hence, a transportation charge of as high as $2.56 per ton.

There is an aggregate that is available in large quantities within ten miles of downtown Detroit - slag. Once a waste byproduct of the iron and steel makers, slag is now processed and marketed successfully by the Edward C. Levy Co. A slag aggregate similar to natural 6A gravel costs $2.90 at the plant, but is transported to downtown Detroit at a cost of as little as 50¢ per ton. Since slag weighs only 1.1 tons per cubic yard as compared to gravel which weighs 1.5 tons per cubic yard, slag yields an additional 5 cubic yards per ton (Michigan Public Service Commission, Motor Freight Tariff Naming, Tariff No. 106A). These facts, along with many other outstanding properties, classify slag as one of Michigan's important construction aggregates.

TABLE 1
TON-MILE RATES (JAN. 1, 1970)
Michigan Public Service Commission

	Truckload minimum weight rates		
MILES	Column 1 (12,000 lbs.)	Column 2 (40,000 lbs.)	Column 3* (60,000 lbs.)
1- 5	$ .67	$ .61	$ .50
6-10	.89	.76	.65
11-15	1.11	.91	.80
16-20	1.33	1.07	.96
21-25	1.55	1.22	1.11
26-30	1.77	1.38	1.27
31-35	1.97	1.53	1.42
36-40	2.17	1.68	1.57
41-45	2.37	1.84	1.73
46-50	2.56	1.99	1.88
51-55	2.76	2.15	2.04

*These rates to apply only for the following named construction projects: HIGHWAY, AIRPORT, RAILROAD or BRIDGE.

GRAVEL	SLAG
20 T. yield 13 cu. yds.	20 T. yield 18 cu. yds.
$3.11/ton	$3.40/ton
21¢/cu. yd.	19¢/cu. yd.

HISTORY AND DEVELOPMENT

Over seventy years ago when slag was removed from the iron furnaces it had little intrinsic value and was termed a "waste product". Even though slag had been used as early as 1589 in making cast-slag cannon balls in Germany, there was no real compulsion to develop markets in the United States until 1916. Before 1916, railroad companies disposed of large quantities of slag for little or no cost to the steel industries. Since 1916, as a result of a ruling by the Interstate Commerce Commission, railroads have charged for disposing of slag, causing a boost in total cost to furnace operators. Consequently, steel companies used slag for their own plant construction purposes. This resulted in such a success that steel companies and independent firms under contract to the steel companies produced, processed, and marketed slag.

At Detroit, Michigan in 1920, Edward C. Levy was asked to haul slag by the Leeland Faulkner Foundry. Before this time the foundry had dumped their slag along the Detroit River as fill until no available frontage remained. In 1921, Mr. Levy began processing slag for use in aggregates and since then, as a result of new markets for slag, the Edward C. Levy Company now processes all slag from the Ford Motor Company Steel Division, Great Lakes Steel, and McClouth Steel.

At the present time, the wastage of slag has been greatly reduced. In 1968 approximately 70% of the blast furnace slag produced in the United States was used commercially; therefore, slag can no longer be classified or termed a "waste product".

BLAST FURNACE SLAG

Production

Blast furnace slag is a byproduct of ironmaking and is processed in Detroit from a total of nine blast furnaces: two at McClouth Steel Corp.; three at Ford Motor Company; and four at Great Lakes Steel Corporation.

Iron ore from Michigan and Minnesota, limestone from Michigan quarries, and coked coal from Kentucky and West Virginia are the raw materials used by Detroit's ironmakers. These ingredients are accurately weighed and mixed. The resulting mixture drops into a skip car and is hoisted to the top of the blast furnace. Here, the ingredients are dropped through a valve-like arrangement which allows very little gas to escape. The iron ore, coke, and limestone work their way down from the top, becoming hotter as they sink. In the top half of the furnace, gas from the coke reduces the iron ore. Midway, limestone begins to react with impurities in the ore and coke to form slag, which in turn absorbs ash from the coke. Some silica in the ore is reduced to silicon and dissolves in the iron, as does some carbon in the coke.

The molten slag which floats on the molten iron is tapped through a slag notch and flows along a slag runner into open air pits, or into large ladles.

Processing

Air-Cooled Slag

Air-cooled blast furnace slage as defined in A.S.T.M. C-125 is: "The material resulting from solidification of molten blast-furnace slag under atmospheric conditions. Subsequent cooling may be accelerated by application of water to the solidified surface."

The majority of slag from blast furnaces is of the air-cooled variety. The molten slag flows periodically from the furnace into an open-air pit until it is full. A typical pit at Great Lakes Steel Corporation is about 50 feet wide and about 150 to 200 feet long, confined by a wall 8-10 feet high at the furnace end and tapering to about 5 feet high at the open end. Each pit is divided into two compartments, separated by a thick wall of solidified slag. This enables the removal of cooled slag from one compartment while another is being filled. After the slag is partially solidified, it is cooled by a spray of water for about 8 to 10 hours. This causes the slag to crack in the different layers as water percolates downward, thus facilitating subsequent removal operations. Since there is an indefinite boundary between molten slag and iron in the blast furnace, certain amounts of iron find their way to the pits. When the slag is sufficiently cooled, it is removed by power shovels and transported to one of the processing plants where it is crushed and screened. While the slag is being crushed and screened, iron is magnetically separated to give a virtually iron-free slag product.

At the Ford Motor Company's blast furnace site, molten slag runs into cast-steel ladles of the side-dump type, mounted on railroad trucks. After being filled the slag is hauled to long, narrow excavated pits. Slag can be poured at one end of a pit while solidified slag is being excavated from the other end. The slag is then transported to a crushing and screening plant.

Expanded Slag

Expanded blast furnace slag as defined in A.S.T.M. C-125 is: "The lightweight cellular material obtained by controlled processing of molten blast-furnace slag with water, or with water and other agents such as steam or compressed air, or both." Of the several methods of expanding slag, water is used at the Ford Motor Company site. Ladles mounted on railroad trucks are filled with molten slag at the blast furnace and transported to a pit site equipped with an underground water system. Ladle-mounted rail trucks are positioned and molten slag is poured over an embankment alongside the track where horizontal, high-pressure jets of water are being sprayed. The water and molten slag meet in mid-air and the resulting expanded slag falls into the dry pit. The solidified expanded slag is then removed from the pit, crushed, and screened.

Granulated Slag

Granulated slag as defined by A.S.T.M. C-125 is: "The glassy, granular material formed when molten blast furnace slag is rapidly chilled, as by immersion in water." Granulated slag is also processed from Ford Motor Company's blast furnaces. The slag is transported in ladles, as mentioned above, to a water-filled pit. Ladles containing molten slag are transported in the same manner described with expanded slag. But in this case the molten slag is poured into a pit filled with water. The resulting noise could be compared to making "giant popcorn". The granulated slag is then dredged, and stockpiled, ready for use.

Characteristics & Properties

Physical Properties

Physical properties: texture, weight, structural properties, etc., vary with each of the three types of blast furnace slag processed. Since these properties relate directly to end-use recommendations, each type of slag will be discussed separately.

Air-cooled Slag

Most literature reports that crushed air-cooled slag is "roughly cubical" in shape, but this writer finds that "angular to sub-angular" would be a more accurate description. A characteristic rough texture is due to the vesicular pitted surface. This feature provides an excellent bond with portland cement and high-strength in bituminous mixtures.

The bulk specific gravity of the slag (including its interior cells or pores) on a dry basis ranges from 2.0 to 2.5. The bulk density or weight per cubic foot is the accepted method for determining the strength of a slag for a given use. An average weight of processed air-cooled slag as used in concrete is approximately 70-85 pounds per cubic foot. Although the specific gravity of slag varies with individual furnace operation and cooling, both are adequately controlled to eliminate excessive variation in weight per cubic foot. Unit weight of slag also varies with the size and grading of the slag, method of measuring, and bulk specific gravity.

Absorption of slag usually is determined by the Standard Method of Test for Specific Gravity and Absorption of Coarse Aggregate (A.S.T.M. C-127-42). Absorption ranges from 1% to 5%. Because all the water does not enter the pores but is held in the shallow pits on the surface, figures for testing are somewhat higher than are reported for natural aggregates.

Durability, the ability of a material to withstand the action of the natural elements, is tested by its resistance to corrosive liquids and accelerated soundness, abrasion, and attrition tests. Slag is highly resistant to natural weathering agents, will withstand an unusual number of cycles of the sodium sulfate soundness test (ASTM C88), and is almost unaffected by freezing and thawing or wetting and drying tests. Since slag aggregate is formed in the blast furnace at about 3000° F., high temperatures have very little effect. A slow, uniform expansion of 0.000006 per degree Fahrenheit, up to its melting point (2100° F to 2600° F) is also accepted as the coefficient of expansion for cement mortar and steel. Therefore, when slag is combined with those constituents to form reinforced concrete, a high degree of compatability exists.

Abrasion loss for slag, as tested in the Los Angeles Abrasion Machine, is generally higher than natural aggregates. This is a reasonable result since slag does have a rough vesicular texture. In spite of abrasion loss, a striking characteristic of slag is its toughness and resistance to polishing under traffic as is demanded for skid-resistant surfaces.

The possibility of inclusions consisting of deleterious materials is sometimes thought of as a negative aspect of slag, but one should face the facts. Since slag is formed in the blast-furnace at about 3000° F., all organic materials such as clay, loam, lignite, and coal are eliminated. The constituents or possible inclusions that would remain are metallic iron, small quantities of coke, and burned fluxing stone, all of which are occasionally carried out of the furnace with slag. The amount of coke that appears in processed slag is less than one percent by weight. Tests made showed "only negligible" differences in comprehensive or transverse strengths when comparing coke-free and coke-containing slag concrete. The Levy Company reports that their processed slag contains insignificant quantities of free iron due to removal during processing with magnetic equipment including magnets suspended from cranes, magnetic pendulums, and magnetic pulleys. Since iron is worth more as a salvage material, they remove all iron possible. Such residual-free iron may be considered deleterious because of possible oxidation; however, experience has shown that this iron presents no problem. Pieces of burned fluxing stone approaching a dead-burned magnesite could hydrate slowly when in concrete so as to disintegrate causing spalls or popouts. Fortunately, by spraying hot slag with water while in the cooling pit, such slow disintegrating fragments can be rendered harmless.

Expanded Slag

Crushed expanded slag is angular to subangular in shape. Because of the action of water during the expanding process, the vesicular structure is even more pronounced than with the air-cooled slag.

The bulk density of the slag, depending on gradation, ranges between 45 and 65 pounds per cubic foot (loose) and from 35 to 50 pounds per cubic foot for the coarse aggregate. This characteristic is important as a light-weight aggregate.

Values for thermal conductivity for expanded slag "K" (Btu/hr/ft^2/^{o}F/in) were determined at the Southern Research Institute in accordance with ASTM C-177. Results indicate that it has insulating qualities if used alone as well as an aggregate in concrete products.

Tests also show that expanded slag is nonstaining and readily meets the requirements of ASTM C-331, and Corps of Engineers Guide Specification for Military and Civil Works Construction - Masonry - CE 206.01.

THERMAL CONDUCTIVITY VALUES
OF EXPANDED SLAG*

Coarse Expanded Slag ½" to No. 4 Wt. 40 lbs./cu.ft.		Blended Expanded Slag ½" to dust Wt. 60 lbs./cu.ft.	
(1)	(2)	(1)	(2)
92.9	0.77=	103.3	1.16
100.9	0.78	112	1.25
120.4	0.96	121.4	1.32
		124	1.42

(1) = Mean Temperature ^{o}F
(2) = Thermal Conductivity -- Btu/hr/ft^2/^{o}F/in.

*Processed Blast Furnace Slag - The All-Purpose Construction Aggregate, S NSA 169-1

Granulated Slag

Granulated slag is a glassy, granular product. It has excellent hydraulic properties in that when compacted in the presence of moisture, it will set up similar to cement mortar. Its thermal insulation compares favorably with that of expanded slag.

Chemical Composition

Oxides of silica, alumna, lime, and magnesia constitute about 95% of blast furnace slag. Minor elements include sulfur, manganese, iron, and traces of other elements and compounds such as titanium, barium, boron, potassium, sodium, and chloride. Molten slag contains everything charged into the blast furnace except what goes into the pig iron or up the stack. The iron ore furnishes the silica, alumna, iron, and sulphur; coke also supplies silica, alumna, and sulphur, and flux stone supplies the lime and magnesia content.

Silica-alumna ratio in slag is approximately 3:1 by weight, and ratios of acids (S_1O_2 and Al_2O_3) and bases CaO and MgO) approximates 1:1. The terms "acid" and "base" refers to the arbitrary ratio of the basic oxides - CaO plus MgO to the acidic constituents SiO_2 and Al_2O_3. Hence, an "acid" slag does not contain free acids because silica and alumina are weak acid constituents and will form alkaline compounds. Lime and magnesia combine more readily with water than the acid constituents. Thus, blast-furnace slag is alkaline in its reaction with water making it hydrophobic, therefore, has a great affinity for bituminous material than for water.

Mineral Composition

Differences in the combination of raw materials for the blast furnace, variations in the temperature of fusion within the blast furnace, and the rate of cooling of slag from the liquid to the solid state are important factors responsible for crystallization of various mineral combinations.

When the rate of cooling is rapid as with granulated slag, there is not time for crystal formation to develop and the result is a glass Slow cooling, as in air-cooled slag, permits normal crystallization of various minerals beginning at a temperature of about 2,640^o F and ending when the slag solidifies. Rate of crystallization has been reported to "proceed rather slowly in slags high in silica and more rapidly and completely in those high in lime and magnesia". (Josephson, Silbert, Jr., and Runner, 1949). Crystal size varies from submicroscopic to ¼" long.

The following minerals in various combinations have been reported in blast furnace slags:

Melilite series: Ca_2 (MgFeAl) $(SiAl)_2O_7$
Akermanite - Ca_2 (MgFeAl) $(SiAl)_2O_7$
Gehlenite - $Ca_2Al_2SiO_7$
Pseudowollastonite - $CaO.SiO_2$
Calcium-Orthosilicate - Ca_2SiO_4
Periclase - MgO
Olivine - $(MgFe)_2$ SiO_4
Glass - variable
Anorthite - $CaA_2Si_2O_8$
Monticellite - $CaMgSiO_4$
Forsterite - Mg_2SiO_4
Pyroxene - XO (Si_2O_6)
Merwinite - Ca_3Mg $(SiO_4)_2$
Calcium Sulfide - CaS (Oldhamite)
Manganous Sulfide - MnS
Ferrous Sulfide - FeS

Orthosilicate slag is undesirable for commercial processing. It is developed in the alpha, beta, and gamma phases. The Alpha phase is stable above 2588° F; below this temperature it inverts to the Beta form. While inverting to the Gamma form at 1247° F volume increases about 10%. This creates a change in density causing it to crumble into a fine powder.

Orthosilicate slag usually forms when lime content is 10% higher than silica content. Therefore, the best way of preventing an orthosilicate slag is by the control of raw materials charged into the blast furnace. Another common deterrent of orthosilicate slag is increasing the magnesia content by the use of dolomite.

Uses

According to the "1968 Bureau of Mines Yearbook", 76% of the total blast-furnace slag produced in the United States in 1968 was screened air-cooled:

Screened	76%	21,757,000 T.	$39,034,000
Unscreened	6%	1,826,000 T.	1,493,000
Granulated	10%	2,944,000 T.	2,631,000
Expanded	8%	2,215,000 T.	6,251,000
Total		28,742,000 T.	$49,408,000

Air-Cooled Slag

Over 55% of all air-cooled slag produced in 1968 was used as aggregate in Portland Cement concrete construction (structures & highways). The comprehensive and flexural strength compare favorably with natural aggregate. Changes in cement characteristics, amount of cement, and water-cement ratio used produce variations in strength. The National Slag Association reports that: "...under normal conditions, 28-day strength with slag aggregate of 4000-6000 psi in compression and 600-700 psi in flexure, are readily obtained with a cement factor of 5-7 sacks per cu. yd. Slag concrete weighs about ten pounds per cubic yard less than concrete made of natural materials (except some special light-weight aggregates such as sintered clay). Due to the rough vesicular texture of this slag, bonding with the mortar is excellent. In addition, blast-furnace slag is included as a Group 1 aggregate of the National Board of Fire Underwriters Building Code. The N.S.A. reported that: "Recent tests conducted in the Underwriters Laboratories (sponsored by Portland Cement Association) on a 6-inch reinforced concrete slab and beam floor, using air-cooled slag aggregate, justified a 4-hour fire rating for this section. Results of tests on comparable sections involving traprock, limestone and gravel aggregates justified only a 3-hour rating".

Approximately 18% of the 1968 production was used in bituminous construction such as: sheet asphalt pavement binder course, bituminous concrete base or surface course, bituminous macadam base or surface coarse and bituminous surface treatment. As mentioned previously, slag is hydrophobic and has a natural compatability with bituminous materials resulting in good adhesion. Since a slag bituminous mixture weighs less per cubic foot than that made from heavier natural aggregates, it yields a greater yardage in place for a given unit of weight. Thus, Bureau of Public Roads Specification FP-61 and several states handle this detail by basing payment on an equivalent volume basis. But, the most outstanding characteristic of bituminous slag pavements used for highways is its skid resistance, under wet and dry conditions. For this reason, automobile speedways, and highways such as: Pennsylvania Turnpike Authority and Ohio Turnpike continue using slag aggregate.

Slag base courses are also used in road construction. The texture of slag creates an interlocking action making it stable for base courses - macadam, dense graded aggregate, bituminous stabilized base, or soil-aggregate bases. Its high insulating factor makes it ideal for use in areas of frost thus minimizing heaving. The National Slag Association reports that there "... is almost complete absence of any settlement after initial placement and compaction. Overlying pavements or slabs can, therefore, be constructed without delay".

In 1968, 4,223,000 tons of air-cooled slag, almost 20% of the total domestic production, was used by railroad companies for ballast. The same characteristic as mentioned for base courses also are applicable to railroad ballast. In addition 70-85 pounds of slag normally yields one cubic foot of ballast in place (N.S.A.) as compared to crushed limestone weighing 85-90 pounds per cubic foot (Pit & Quarry Handbook, 1968).

Other uses of air-cooled slag include slag wool insulation, slag roofing, filter media, glass manufacture, agricultural liming, and terrazzo.

Expanded Slag

Both fine and coarse expanded slags are used as an aggregate in the manufacture of lightweight concrete for structural purposes and floor fills, concrete products, and masonry units.

Investigations reported by laboratories of the Portland Cement Association and the National Slag Association have described and established the properties of expanded slag structural concrete such as: strength, unit weight, durability, heat transmission, bond, creep, and alkalai reactivity. The NSA reports that "Actual construction projects where expanded slag lightweight concrete was successfully applied confirm the laboratory studies regarding satisfactory performance".

Structural lightweight concrete made with expanded slag has been used in the construction of Ford Motor Company Central Staff Office Building and the City of Detroit's Cobo Hall.

Expanded slag concrete used in masonry units possesses lightweight (25-33 pounds/8" x 8" x 16" block as compared to natural aggregate block weighing 45 pounds); durability; strength; low shrinkage; highly desirable thermal, sound absorption, noise coefficient; and sound transmission properties; and nailability. Masonry units produced include hollow load-bearing, hollow non-load-bearing and solid load-bearing.

Granulated Slag

Granulated slag is being used as base material for pavements, fill material, pipeline backfill, concrete floor fill, concrete masonry units, landscaping, agricultural liming, and in the manufacture of cement.

All of the granulated slag processed in Detroit is used in the manufacture of cement. It is used as a raw material for Portland Cement as in ASTM C-150 and C-175, by integrading it with portland cement for Portland blast-furnace slag cement, or by adding lime or an air-entraining agent for pozzalanic slag cement.

STEEL FURNACE SLAG

Production

In contrast to iron making, three types of furnaces are being used in the Detroit area to make steel: open hearth, basic oxygen, and electric.

In open hearth furnaces, limestone and scrap steel are charged into a shallow steel-making area or hearth. As the exposed flame of the burning fuel starts to melt the scrap steel, molten iron from the blast furnaces is poured into the open hearth. When tests of samples show the steel to be of a specific chemistry, the tap hole is opened, and the molten contents run into a ladle. The slag, floating on the metal, overflows through a slot at the top of the ladle.

Basic oxygen furnaces will produce up to a 300-ton batch of steel in 45 minutes as against 5-8 hours in the open hearth process. First, the refractory-lined, pear-shaped furnace is tilted and charged with scrap metal. These furnaces are mounted on trunnions and can be swung through a wide arc. Molten pig iron is added and the furnace is then returned to an upright position. A water cooled oxygen lance is lowered into the furnace and oxygen is blown onto the top of the charge at supersonic speed. During the oxygen blow, lime is added as a flux to help carry off the oxidized impurities. After the "heat", the furnace is tilted and the molten steel is poured into a ladle. When the steel has been discharged, the furnace is then tilted approximately 180^o in the other direction where the molten slag is poured into another ladle.

According to "Steelways" magazine, "A long deserved reputation for producing alloy, stainless, tool, and other specialty steel belongs to America's electric furnaces. Operators have also learned to make larger heats of carbon steels in these furnaces; this development helps account for the record tonnage outputs of recent years." The entire top of the furnace is swung to the side and a load of steel scrap is lowered into the furnace. The top is then put back in place and three carbon electrodes are lowered through the roof of the furnace and the electric power is turned on. Electric arcing from one electrode to the metallic charge and from the charge to the next electrode creates intense heat. Limestone is then charged on top of the molten contents. The furnace is tilted slightly and the slag is raked off by means of an opening on the side of the furnace. When the steel meets specifications the furnace is tilted and the molten steel flows into a ladle. Any remaining slag flows out after the steel and serves an an insulating blanket during tapping.

Steel furnace slag which is dumped and allowed to solidify at the furnace site is scraped up and trucked to the nearest processing plant. Steel furnace slag in the molten state is transported to the plants by ladles mounted on railroad cars.

After the slag has cooled sufficiently, any free metal is removed by a crane-mounted magnet. The slag is then crushed, sprayed with dilute sulphuric acid and stockpiled.

Properties

Steel furnace slag is very dark gray with a similar rough vesicular nature as blast-furnace slag. Steel slag is heavier due to higher iron consistency.

Chemically, the main constituents of steel slag are oxides of lime, silica, iron, manganese, magnesia, phosphorous, and alumna. Minor elements include titanium, zirconium, boron, vanadium, sulfur, chromium, and carbon. A comparison of the main chemical compounds in steel and blast-furnace slags as produced by the Michigan State Highway Department's Research and Testing Division shows a substantial 28% reduction of total silica and alumna. This is due to the low content of alumina and silica of the pig iron as compared to raw materials used in the blast-furnaces. Significant percentage increases include lime (3.7%), manganese oxide (7.2%), phosphorous pentoxide (3.4%), and the oxides of iron (about 14%). The presence of the active chemical compounds free lime (CaO), Ferrous oxide (FeO), and manganese oxide (MnO), in an unstable equilibrium, plus its high alkalinity, have importance when considering the uses of steel-furnace slag. Free lime will slake in the presence of moisture, and the other two oxides will oxidize further taking on moisture from the air. These changes result in an increase in volume. The Michigan State Highway Department's Research and Testing Division reports that the high ferrous oxide particle counts as well as the free lime inclusions have resulted in appreciable volume changes of local occurrence causing upheavals or bulges of bituminous pavements.

Another undesirable quality is its high alkalinity which along with the presence of free lime as an activator causes cementation. In fact, the lime-silica ratios approach the composition of portland cement.

The Research Division also reports that there appears to be little danger of deleterious chemical action between steel slag and portland cement concrete from external physical contact. Sulfur content of the slag is negligible, usually less than 0.1%, thus precluding formation of significant amounts of sulphate. While phosphorous pentoxide (P_2O_5) may be present in combination with basic oxides in amounts up to 3.5% they can uncover no evidence to indicate that free phosphoric acid will be formed under the conditions of exposure. In portland cement, it tends to slow up hardening by converting tricalcium silicate to the dicalcium form with release of free lime.

Mineralogy

This author has not found any significant studies conducted on the mineralogy of steel slags to date. Variances due to types of furnaces, varying charges, high temperatures, rates of cooling, and steel qualities results in slags of diverse mineralogical makeup.

COMPOSITION OF OPEN HEARTH AND BLAST FURNACE SLAGS*

Compound	Steel Furnace Range Percent(1)	Steel Furnace Typical Analysis(2)	Blast Furnace(3) Range Percent	Blast Furnace(3) Typical Analysis
SiO_2	16-19	18.4	33-42	36.4
Al_2O_3	2- 3	2.5	10-16	12.8
CaO	40-55	45.0	36-45	41-3
MgO	5- 7	5.9	3-12	5.8
FeO		12.2	0.3-2.0	0.4
Fe_2O_3		3.4		0.5
FeO + Fe_2O_3	10-23	15.6	0.2-1.5	1.4
MnO	6- 5	8.6		1.3
S	0- 1	00.0	1-3	
P_2O_5				

*Compiled by Michigan Department of State Highways, Testing and Research.

(1)"First Helper's Manual". Dolomite Refractories Association, 1956.

(2)"The Making, Shaping and Treating of Steel", J. M. Camp and C. B. Francis, US.S.CO., 1951.

(3)"Iron Blast-Furnace Slag Production, Processing, Properties and Uses", Bulletin 479, U.S. Bureau of Mines, 1949.

Several samples of steel slag were collected at Edward C. Levy's plant No. 3, and thin sections made from them. These thin sections are quite remarkable because all were different in appearance. Dr. Norman E. Wingard of Michigan's Department of Highways, Testing and Research observed several thin sections and reports as follows:

Slag Sample No. 1

"This sample is relatively fine grained. Under plain polarized light there appears to be irregular areas of differential reddish coloration. The boundaries of these areas correspond to the directional orientation of the fibrous appearance of the material. Under crossed nicols the areas of differential color density that appeared under plain polarized light present extinction as optical units. The fibrous appearance may be caused by chemical alteration: either the clear component changing to the reddish or vice-versa. The lineation is consistent within optical units - either linear, radiating or forming an irregular concentric pattern. The outlines of the optically consistent units are very irregular and may be related to flowage effects as crystallization proceeded during emplacement of the slag.

Slag Sample No. 2

"Coarser grained than No. 1. There appears to be three of four components with more distinct grain boundaries than in No. 1. These boundaries are produced by fracturing. Fractures may be parallel to the maximum length of the grains or irregularly distributed. The fractures may be either straight or curved. Many larger fractures cross grain boundaries and are continuous across several grains. Under high magnification a greenish material appears to be the product of partial alteration of the clear material toward a red material. The greenish material shows undulatory and incomplete extinction. The fracturing appears to take place after alteration around centers of expansive reation. Where fractures do not occur the grain boundaries are transitional and indistinct. Several irregularly shaped areas of colorless material display extensive cracking in the interior producing a granular texture. The material is isotropic with its refractive index slightly higher than balsam and is surrounded by a rim of the red material. The interior may be the parent material for the red substance which is forming a reaction rim. Minerals that appear to be present here based on perfunctory optical data are:

- Anorthite
- Pseudowollastonite
- Unknown, cloudy material without identifiable optical properties
- Red material - possible metallic oxide or sulfide.

Slag Sample No. 3

"The blue-green pleochroic grains are uniaxial positive, often clouded, and showing variable extinction. This may be an olivine but no specific identification was made. Black opaque may be metallic iron.

Slag Sample No. 4

"The textural pattern is that of pyrolusite. The non-opaque material is Biaxial negative. Under cross polarized light there appears an irregular linear pattern of optically continuous zones. This may be caused by flowage as the melt crystallized.

Slag Sample No. 5

"Totally opaque except for air voids. These observations illustrate only the extreme variability, both texturally and compositionally of the open hearth slag sources sampled. The data are preliminary and do not constitute a mineralogical analysis."

Uses

Due to certain undesirable chemical properties, steel slag does not have the variety of uses as the more uniform and desirable blast-furnace slag. Most steel slag is used as bases for highway paved areas or other miscellaneous bases, fills, and railroad ballast. In 1968, steel slag sold or used by processors in the United States for these uses amounted to 1,390,000 tons or over 80% of the total. That used for bituminous mixes only amounted to 479,000 tons or 7% of the total.

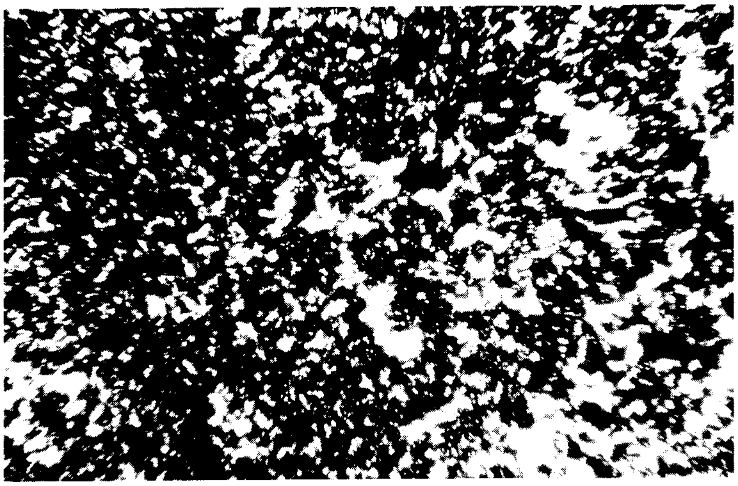
The Edward C. Levy Company has attempted to treat steel slag with dilute sulphuric acid in order to break down the calcium oxide and thus make it more desirable for bituminous aggregate. No official findings have yet been concluded.

It would be safe to say that in the Detroit area more steel slag is produced than can be used.

Peroration

According to "A Dictionary of Mining, Mineral, and Related Terms" published by the U.S. Bureau of Mines, a mineral is defined as: "An inorganic substance occurring in nature . . ." We need not continue. By definition, slag is not a mineral because it does not occur in nature. This puts slag into the category along with cement and lime as a manufactured mineral

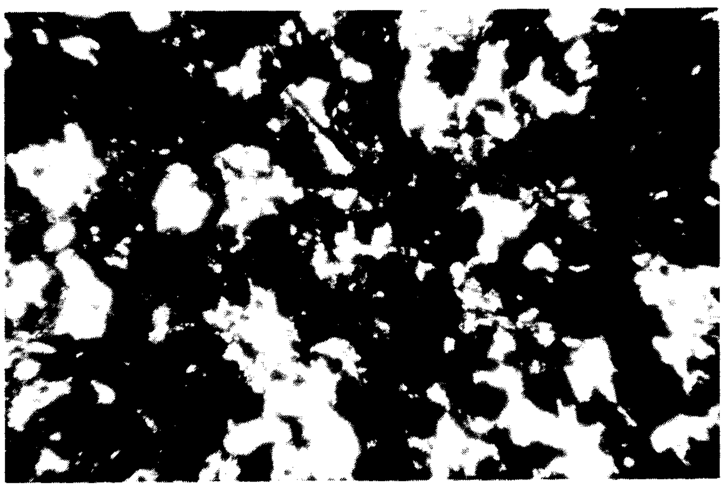
THIN SECTIONS OF STEEL SLAG



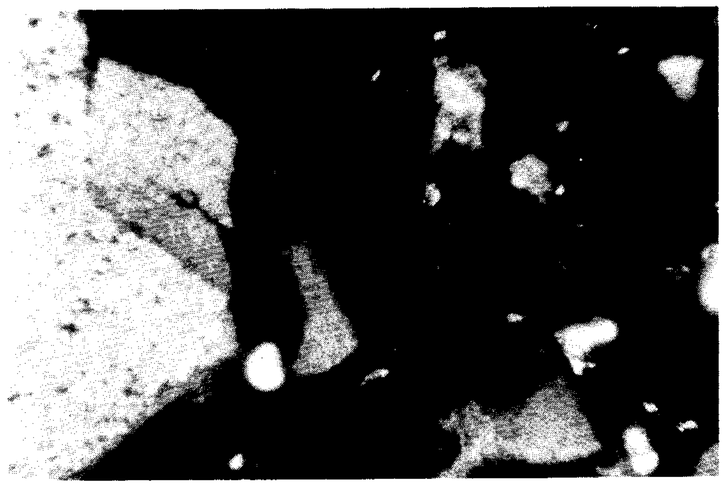
0.1 MM

SCALE
(All Samples)

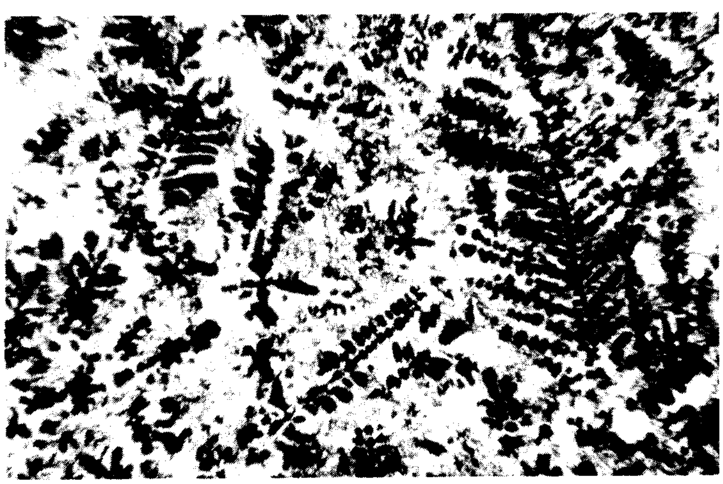
Slag #1



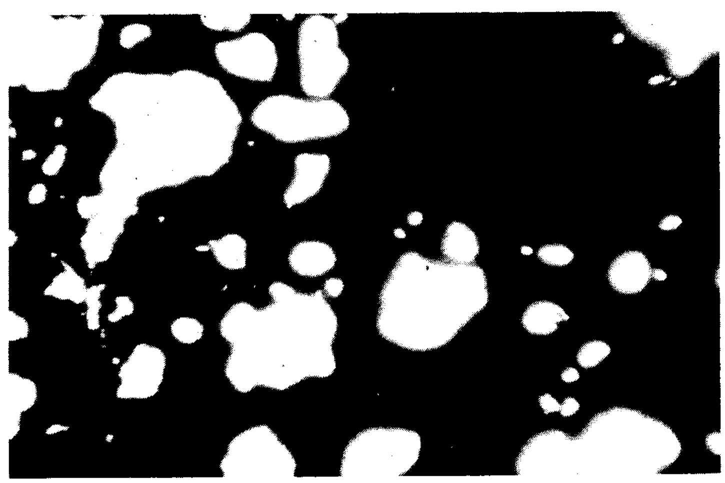
Slag #2



Slag #3



Slag #4



Slag #5

product.

Slag is one of the United States' important mineral products and important enough to be published in the Bureau of Mines annual statistical summary. As long as Detroit and its suburbs continue to grow and the iron and steel makers continue to operate, slag will remain as one of Michigan's all-purpose aggregates.

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RELATIONSHIPS BETWEEN PHYSICAL AND CHEMICAL PROPERTIES OF THE BRASSFIELD LIMESTONE (SILURIAN) IN INDIANA, OHIO, AND KENTUCKY[1]

by

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Abstract

Statistical correlation of 9 physical and 10 chemical properties of 17 samples of the Brassfield Limestone in Indiana, Ohio, and Kentucky found negative correlations between absorption and specific gravity, between soundness loss and $CaCO_3$ content, between abrasion loss and insoluble residue content, and between abrasion loss and sulfur content. Positive correlations were found between P_2O_5 content and soundness loss, between absorption and soundness loss, and between absorption and compressive strength. Other correlations were obtained, but attention was directed to correlations involving abrasion loss, soundness loss, absorption, and specific gravity because these are the primary properties used by the Indiana State Highway Commission to grade the quality of limestone aggregate.

In exploration for quarry sites in the Brassfield Limestone primary consideration should be given to limestones with a high $CaCO_3$ content; however, limestones that contain small amounts of disseminated impurities in the form of pyrite and quartz silt may have more resistance to abrasion loss than have the purer limestones.

INTRODUCTION

This paper attempts to define statistically the relationship between some physical and chemical properties of the Brassfield Limestone. The study was undertaken after French (1967, p. 6) had noted that most of the 22 rock units used for concrete aggregate in Indiana exhibit wide variations in their resistance to standard tests for toughness and soundness. A preliminary survey of data from 311 physical tests performed by the Indiana State Highway Department on rock samples obtained from 112 different locations showed that 18 of the 22 rock units had failed class A specifications in one or more geographic areas. Of the four units that did not fail, one was relatively untested because it had a poor service record, and the remaining three were quarried at a single location. The inconsistencies in test performance prompted us to examine a moderately thin, easily recognizable, and widely distributed rock unit in order to determine the relationships, if any, between the physical and chemical properties of an industrial limestone. We wanted to know if there were any significant correlations in physical or chemical properties of a limestone over a wide geographic area. We also wanted to know if chemical analyses of a limestone could be used as a first step in the determination of the physical properties much as they are used as the first step in mineralogical determinations. This is particularly appealing since published chemical data of limestones are generally more abundant than physical-property data. Also, where samples have limited size, such as may be obtained from small-diameter cores, there may not be enough rock to perform physical tests properly, whereas, the quantity is ample for chemical determinations.

PREVIOUS WORK

Although numerous studies have dealt with the relationship of the physical properties of rock, and to a lesser degree the chemical properties, to the durability of aggregate, little has been published on the interrelationship of physical and chemical properties of rock. In 1960, Price used scatter diagrams to study the relationships

[1]Published with the permission of the State Geologist, Indiana Geological Survey.

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between porosity, quartz content, compaction, and compressive strength of some carboniferous sandstones in England. A short time later, Judd and Huber (1961) investigated the relationship between physical properties of a wide variety of rock types by using scatter diagrams, statistical correlation, and linear regression analysis. Using similar data, D'Andrea and others (1964) extended the study of Judd and Huber by using curvilinear regression analysis. West and Johnson (1965) used multiple regression and correlation analysis to investigate physical properties, and a limited number of chemical properties, of Indiana crushed limestone aggregates. Bundy and others (1965) used a nonparametric rank correlation test to correlate physical and chemical properties of kaolinites with kaolinite starch coatings on paper. Mutmansky and Singh (1968) used factor analysis to study the interrelationship of physical properties of a variety of rock types and to group similar physical properties. Baxter and Harvey (1969) used statistical correlation to study the relationship between sodium sulfate soundness and some mineralogical and chemical properties of limestones from the upper part of the St. Louis Limestone near Alton, Ill.

STRATIGRAPHY

The Brassfield Limestone (Silurian) is a moderately thin, well-defined rock unit that is exposed in many places around the Cincinnati Arch in southeastern Indiana, southwestern Ohio, and northern Kentucky. Locally it is used as a source of raw material for cement, flux stone, road metal, aggregate for concrete and bituminous mixes, agricultural limestone, and other high-calcium products; it has also been used as dimension limestone and as a self-fluxing iron ore.

The type section at Brassfield, Madison County, Ky., described by Foerste (1906, p. 176) consists of 3.5 feet (1.1 m.) of medium-bedded ferruginous calcarenite with abundant crinoid columnals (bead bed), underlain by 12.0 feet (3.7 m.) of medium- and thin-bedded rubbly dolomitic and argillaceous limestone, and 6.0 feet (1.8 m.) of bluish-gray massive dolomitic and argillaceous limestone (Belfast Member).

The type area of the Brassfield was not visited, but two sections near Brownsboro and Mt. Washington, Ky., on the west side of the Cincinnati Arch, were examined and samples collected for testing. In this area, the Brassfield is generally less than 4 feet (1.2 m.) thick, although Rexroad (1967, p. 5) and O'Donnell (1967, fig. 6) recorded sections as much as 22 and 19 feet (6.7 m. and 5.8 m.) thick about 10 miles (16 km.) to the southeast. The bead bed is absent west of the Cincinnati Arch (Rexroad, 1967, p. 5), but the Brassfield retains its salmon-pink to reddish-brown color and coarsely crystalline texture. Rubbly beds 12 to 18 inches (30 cm. to 46 cm.) thick and irregular shale lenses are common, and some sections are moderately dolomitized.

In Adams, Highland, and Clinton Counties, Ohio, the Brassfield is approximately 15 to 51 feet (4.6 m. to 15.6 m.) thick and retains most of the physical characteristics observed in the type section. Thin to medium beds, 4 to 18 inches (10 cm. to 46 cm.), of reddish-brown ferruginous crystalline limestone are separated by irregular partings of calcareous shale. Chert is common in the middle unit, and the Belfast Member is arenaceous and shaly at collecting sites 11 and 12. Northwestward from Wilmington, Ohio, the Brassfield is from 15 to 30 feet (4.6 m. to 5.2 m.) thick and contains appreciably less chert and shale.

In southeastern Indiana the Brassfield is mostly less than 10 feet (3.1 m.) thick and is absent from some exposures in adjacent parts of Ripley, Jennings, Decatur, Jefferson and Scott Counties (Foerste 1897, 1904, 1935; Rexroad 1967). At most exposures in Indiana the Brassfield is a ferruginous reddish-brown or gray limestone, generally glauconitic and coarsely crystalline. Rubbly bedding less than 1 foot (.3 m.) thick is characteristic, but more massive beds are present in places. Shale lenses and chert are not uncommon, but chemical analyses show that the Brassfield is more than 90 percent carbonate rock in most areas.

TEST PROCEDURES

Channel samples of about 50 pounds (22.5 kg.) each were collected at 17 localities in Indiana, Ohio, and Kentucky (fig. 1). In addition to the channel samples, several large pieces were collected at each locality and sawed into 2-inch (5.1 cm.) cubes for the compressive strength tests.

Physical testing followed procedures as outlined by the American Society for Testing and Materials or standard laboratory techniques (table 1).

Spectrochemical determinations of calcium, magnesium, aluminum, iron, titanium, manganese, sulfur, and phosphorus were made with a Jarrell-Ash 21-foot (W) spectrograph. Silica and carbon dioxide determinations were made gravimetrically.

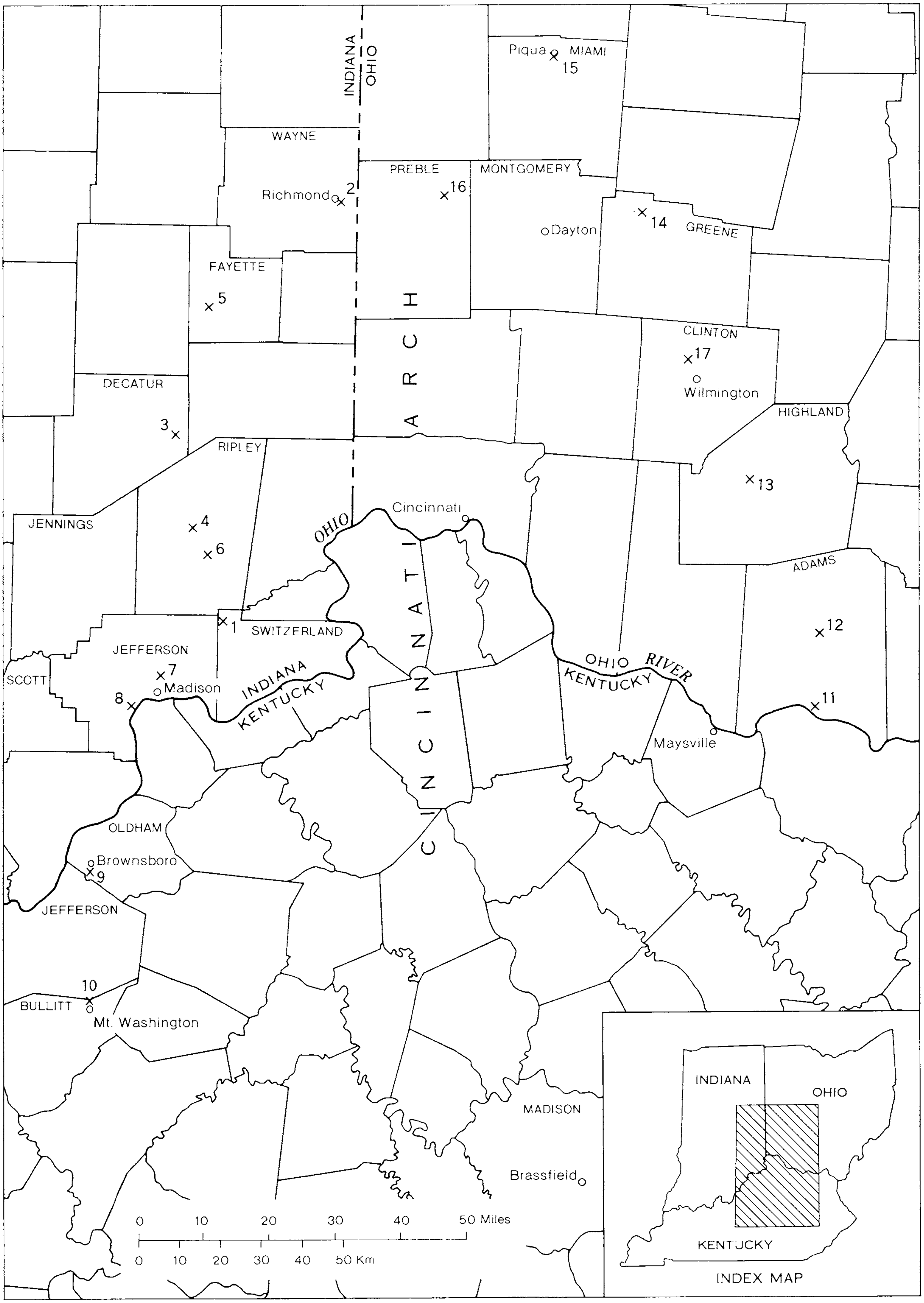

Figure 1. Index map showing location of sampling sites in the Brassfield Limestone in southeastern Indiana, southwestern Ohio, and northern Kentucky.

Table 1. Methods for physical testing of the Brassfield Limestone

Test	Method
	American Society of Testing and Materials (1968)
Los Angeles abrasion loss	ASTM C131-47
Soundness loss	ASTM C88-46T
Absorption	ASTM C127-42
Specific gravity	ASTM C127-42
Compressive strength	ASTM C170-50
	Standard laboratory techniques
Mean grain size	Thin section analysis
Grain sorting	Thin section analysis
Insoluble residues>clay size	Acid treatment
Insoluble residues, clay size	Acid treatment and decantation

RESULTS

Results of the physical and chemical tests are shown in tables 2 and 3. After the data were normalized, Pearson product-moment correlation coefficients (Steel and Torrie, 1960, p. 183-187) were computed for each pair of physical test data and each pair of chemical test data and arranged in separate matrices (figs. 2 and 3). It was necessary to compute separate matrices because of restraints on the data handling capacity of the computer program. Significance levels of 95 percent and 99 percent were arbitrarily selected as being appropriate for this study; these values were obtained from published tables (Steel and Torrie, 1960, p. 453).

	1	2	3	4	5	6	7	8	9	10	11	
Los Angeles Abrasion Loss	1.000	-.279	-.126	.003	-.007	.322	-.457	.258	-.361	.103	.171	1
Soundness Loss		1.000	.572	-.375	.079	-.180	.204	-.159	.399	-.723	-.318	2
Absorption			1.000	-.526	.450	-.229	-.169	-.129	.026	-.353	.228	3
Specific Gravity				1.000	-.274	.019	.197	-.066	.276	.199	-.064	4
Compressive Strength					1.000	-.424	-.144	.089	.028	.061	.358	5
Mean Grain Size						1.000	-.148	.338	-.339	.037	.002	6
Insoluble Residues							1.000	-.104	.844	.138	-.684	7
Grain Sorting								1.000	-.334	.345	.225	8
Clay Content									1.000	-.155	-.651	9
Location East										1.000	.335	10
Location North											1.000	11

EXPLANATION

.061 — $|r| < 0.482$ Insignificant

.572 — $0.482 < |r| < 0.606$ Significant (95% significance level)

.844 — $|r| > 0.606$ Highly significant (99% significance level)

n = 17

Figure 2. Matrix of coefficients of correlation of physical properties of the Brassfield Limestone. Half of the symmetric matrix is shown.

Sample locations were quantitatively determined by superimposing a grid over the map. Each sample location was designated by its distance east and north from a common datum point, and these data were computed with both the physical and chemical data.

Physical Properties

Examination of the physical properties matrix (fig. 2) reveals the following:

1. A significant positive correlation exists between absorption and soundness loss and a significant negative correlation between absorption and specific

	10	11	12	13	14	15	16	17	18	19	20	21	
Location East	1.000	.335	.248	-.286	.030	-.221	-.078	.029	.216	-.372	.053	-.651	10
Location North		1.000	.312	-.194	-.418	-.778	-.315	-.613	-.351	.552	.334	-.555	11
$CaCO_3$			1.000	-.969	-.600	-.708	-.757	-.653	-.653	-.039	.001	-.554	12
$MgCO_3$				1.000	.392	.575	.612	.518	.539	.225	-.010	.443	13
SiO_2					1.000	.672	.836	.706	.718	-.517	.049	.592	14
Al_2O_3						1.000	.651	.846	.558	-.514	-.118	.652	15
Fe_2O_3							1.000	.654	.740	-.232	.208	.608	16
TiO_2								1.000	.716	-.566	.059	.497	17
MnO									1.000	-.226	-.091	.395	18
CO_2										1.000	-.056	-.038	19
S											1.000	-.131	20
P_2O_5												1.000	21

EXPLANATION

.059 — $|r| < 0.482$ Insignificant

.552 — $0.482 < |r| < 0.606$ Significant (95% significance level)

.846 — $|r| > 0.606$ Highly significant (99% significance level)

n = 17

Figure 3. Matrix of coefficients of correlation of chemical properties of the Brassfield Limestone. Half of the symmetric matrix is shown.

Table 2. Chemical analyses of samples of the Brassfield Limestone (weight percent)

Sample	Thickness (ft.)	$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	CO_2	S	P_2O_5
1	11.6	80.4	16.0	1.47	0.64	0.96	nd	0.041	43.8	0.18	0.049
2	8.5	78.6	16.3	2.52	0.65	1.32	0.047	0.030	42.7	0.73	0.046
3	5.1	91.4	6.41	0.92	0.29	0.49	nd	0.022	43.4	0.11	0.067
4	4.0	95.8	0.94	1.42	0.53	0.78	nd	0.023	42.4	0.11	0.062
5	10.4	59.1	28.9	8.22	0.86	2.31	0.047	0.065	44.1	0.18	0.14
6	3.6	93.7	1.08	3.44	0.33	0.90	nd	0.022	42.6	0.055	0.069
7	2.0	78.8	16.2	2.67	0.82	0.96	0.037	0.040	42.9	0.17	0.069
8	1.5	70.7	24.3	2.37	0.88	1.10	0.048	0.046	43.2	0.090	0.052
9	4.0	79.9	13.7	4.02	1.08	0.64	0.065	0.042	41.7	0.016	0.10
10	2.5	53.4	33.3	6.94	2.35	1.92	0.084	0.054	41.9	0.044	0.14
11	22.0	77.3	13.0	5.82	1.51	1.30	0.070	0.048	39.6	0.075	0.044
12	51.0	86.8	3.94	6.62	0.63	1.42	0.042	0.051	40.0	0.33	0.019
13	19.5	94.9	1.21	2.01	0.44	0.86	0.038	0.052	42.7	0.13	0.055
14	29.0	79.8	18.5	0.36	0.14	0.64	nd	0.033	44.0	0.004	0.013
15	26.5	79.6	17.7	1.88	0.13	0.50	nd	0.030	43.9	0.25	0.014
16	18.0	96.5	1.16	1.74	0.094	0.24	nd	0.031	43.5	0.093	0.016
17	26.5	77.4	18.2	2.24	0.49	1.06	0.036	0.046	43.4	0.016	0.007

nd = not detected

Table 3. Physical test data of samples of the Brassfield Limestone

	Sample																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Los Angeles abrasion loss (percent)	34.3	13.1	36.6	48.9	20.7	42.5	37.3	43.1	29.4	33.7	34.5	33.4	30.9	58.4	46.5	47.0	35.6
Soundness loss (percent)	9.4	11.7	6.5	21.0	28.7	4.7	16.8	23.6	16.1	16.7	2.6	1.7	2.2	2.1	2.3	5.8	6.62
Absorption (percent)	1.6	1.1	1.2	1.6	4.2	1.3	3.2	1.2	0.3	0.9	0.6	0.6	0.4	1.4	1.4	1.0	1.6
Specific gravity	2.5	2.7	2.7	2.6	2.6	2.7	2.6	2.6	2.7	2.8	2.7	2.7	2.7	2.7	2.7	2.7	2.6
Compressive strength (psi X1000)	11.3	13.0	11.9	10.9	16.2	11.3	17.9	11.9	9.5	10.1	16.7	5.4	10.6	11.0	13.6	9.1	20.7
Mean grain size (mm)	.074	.077	.213	.079	.039	.186	.054	.255	.034	.017	.083	.189	.099	.173	.043	.068	.031
Insoluble residues (percent)	2.8	4.9	1.4	2.5	4.5	1.5	5.4	6.0	6.4	9.0	10.5	8.6	2.9	0.5	1.3	0.7	4.0
Grain sorting (ϕ)	1.5	1.8	2.0	2.7	1.8	2.0	1.5	1.8	1.4	1.2	2.4	2.2	1.9	2.0	1.2	2.4	1.9
Clay content (percent)	.9	1.7	.2	.4	3.1	.1	2.6	2.9	2.8	6.8	5.0	1.5	.5	.2	.8	.3	1.1

gravity. A highly significant negative correlation exists between soundness loss and location east, which indicates that soundness loss decreases from west to east along the outcrop of the Brassfield Limestone.

2. A highly significant positive correlation exists between amount of insoluble residues and amount of clay present, and they both have a highly significant negative correlation with location north. This suggests that the amount of insoluble residues, including clay, decreases in the samples from south to north along the outcrop of the Brassfield Limestone.

3. Relationships that closely approach significance include: abrasion loss to insoluble residue content and absorption to compressive strength.

Chemical Properties

Examination of the correlation coefficients of the chemical properties matrix (fig. 3) reveals numerous significant and highly significant correlations. In order to compare the chemical and physical properties, we found it necessary first to screen out some of the chemical variables so as to keep within the data handling capacity of our program, which is 14 variables. Because the oxide of aluminum has highly significant and significant positive correlations with the oxides of magnesium, silicon, iron, titanium, manganese, and carbon, we chose to let aluminum oxide stand in for the other oxides in computing the combined matrix.

It should be pointed out that the negative correlation coefficients of the chemical properties may be slightly distorted because these data are variables of a constant sum (each analysis adds to 100 percent). Chayes (1960) pointed out the tendency toward negative correlation among variables, especially when the variables are few. Webb and Briggs (1966) found that for sets of analyses of nine oxides each the distortion toward negative correlation was slight. Because our analyses consist of 10 elements, we also assume the distortion toward negative correlation is slight.

Combined Chemical and Physical Properties

The combined chemical and physical properties matrix (fig. 4) repeats some of the correlations observed in figures 2 and 3. The interrelations between the chemical and physical properties are as follows:

1. A significant negative correlation exists between sulfur and abrasion loss, which indicates that abrasion loss increases in the Brassfield Limestone as sulfur content decreases.

2. A significant negative correlation exists between $CaCO_3$ content and soundness loss, which indicates that soundness loss increases as $CaCO_3$ content decreases.

3. A highly significant positive correlation exists between the oxide of phosphorus and soundness loss, which indicates that the soundness loss increases with an increase in phosphorus content.

4. A significant positive correlation exists between the amount of $CaCO_3$ and grain sorting, which suggests that the samples with a higher $CaCO_3$ content have a more uniform grain size.

5. A highly significant positive correlation exists between Al_2O_3 and the amount of insoluble residues, which reflects the high clay content in the insoluble residues. The expected decrease of calcium carbonate in the more argillaceous limestones is indicated by the significant negative correlation between $CaCO_3$ and the amount of insoluble residues.

	1	2	3	4	5	6	7	8	10	11	12	15	20	21	
Los Angeles Abrasion Loss	1.000	-.279	-.126	.003	-.007	.322	-.457	.258	.103	.111	.347	-.371	-.587	-.449	1
Soundness Loss		1.000	.572	-.375	.079	-.180	.204	-.159	-.723	-.318	-.522	.389	-.008	.690	2
Absorption			1.000	-.526	.450	-.229	-.169	-.129	-.353	.228	-.373	-.075	.039	.342	3
Specific Gravity				1.000	-.274	.019	.197	-.066	.199	-.064	-.031	.266	.015	.114	4
Compressive Strength					1.000	-.424	-.144	.089	.061	.358	-.094	-.115	-.125	-.166	5
Mean Grain Size						1.000	-.148	.338	.037	.002	.321	-.328	-.042	-.271	6
Insoluble Residues							1.000	-.104	.134	-.684	-.530	.832	.088	.334	7
Grain Sorting								1.000	.345	.225	.578	-.315	-.065	-.351	8
Location East									1.000	.335	.248	-.221	.053	-.651	10
Location North										1.000	.312	-.778	.335	-.555	11
$CaCO_3$											1.000	-.708	.001	-.554	12
Al_2O_3												1.000	-.118	.653	15
S													1.000	-.131	20
P_2O_5														1.000	21

EXPLANATION

.061	.572	.832	
$\lvert r \rvert < 0.482$ Insignificant	$0.482 < \lvert r \rvert < 0.606$ Significant (95% significance level)	$\lvert r \rvert > 0.606$ Highly significant (99% significance level)	n = 17

Figure 4. Matrix of coefficients of correlation of physical and chemical properties of the Brassfield Limestone. Half of the symmetric matrix is shown.

INTERPRETATION AND CONCLUSIONS

Previous studies have dealt with a large number of physical properties (table 4); however, most of these studies were concerned with the "engineering performance" of the rock, or in the case of Bundy and others (1965), the performance of kaolinite-starch coatings. The study by West and Johnson (1965) and the present study are more concerned with the "durability" of the rock as an aggregate. We have chosen to restrict our attention to the correlation involving abrasion, soundness, absorption, and specific gravity because these are the primary properties used by the Indiana State Highway Commission to grade the quality of aggregate.

Our findings that a significant negative correlation exists between absorption and specific gravity essentially agrees with West and Johnson (1965, p. 158); however, they found other correlations, such as percent voids (absorption) versus abrasion loss and grain size variation (sorting) versus abrasion loss, that we did not find. This lack of agreement between two studies at first appears to indicate inconsistency of the interrelationships between certain physical properties. It is important to remember, however, that our study was restricted to a single limestone unit but that West and Johnson used data from several limestone and dolomite units of markedly different lithologies. It should be expected that differing results would be obtained when a single lithology is compared to, say, a complete suite of lithologies with a wide variation in physical and chemical properties.

It is difficult to explain why an increase in sulfur content results in a decrease in the amount of abrasion loss in the Brassfield Limestone. A scatter diagram (fig. 5A) suggests a curvilinear relationship between these properties. Thin section analysis indicates that authigenic pyrite is the principal source of sulfur. Pyrite is present in samples of high sulfur content as discontinuous scattered fine (0.2 mm.) euhedral and subhedral crystals and as very fine (0.02 mm.) euhedral crystals that are evenly scattered throughout the specimen. The finely disseminated pyrite make these samples darker. Pyrite is much harder than calcite (6 vs. 3 on Mohs' scale), but it is present in such small amounts, that its apparent effect on abrasion resistance was unexpected. Different results might have occurred if the pyrite had been concentrated rather than disseminated. Some Silurian and Devonian carbonates in southern Indiana that contain pyritic laminations have poor service records when used as concrete aggregate (Patton, 1954, p. 85) as do some Ordovician carbonates in Iowa (Elwell and Lemish, 1965, p. 348-350).

The reason soundness loss increases with an increase in phosphorus content is also an enigma. A scatter diagram (fig. 5B) suggests a linear relationship between these two properties. Thin section analysis reveals that the specimens with high phosphorus content contain only a small quantity of skeletal material. Thus, phosphorus probably is not primarily from the skeletal material of organisms but was precipitated, along with calcite, as a minor constituent from the sea water.

Numerous chemical analyses of limestone rocks in Indiana reveal a remarkable uniformity in phosphorus content over large areas (Richard Leininger, oral communication, 1968). Our data suggest a small increase in phosphorus content from north to south and from east to west along the outcrop of the Brassfield. We believe it only a coincidence that soundness loss increases regionally with an increase in phosphorus content from east to west because this same relationship apparently does not exist from north to south.

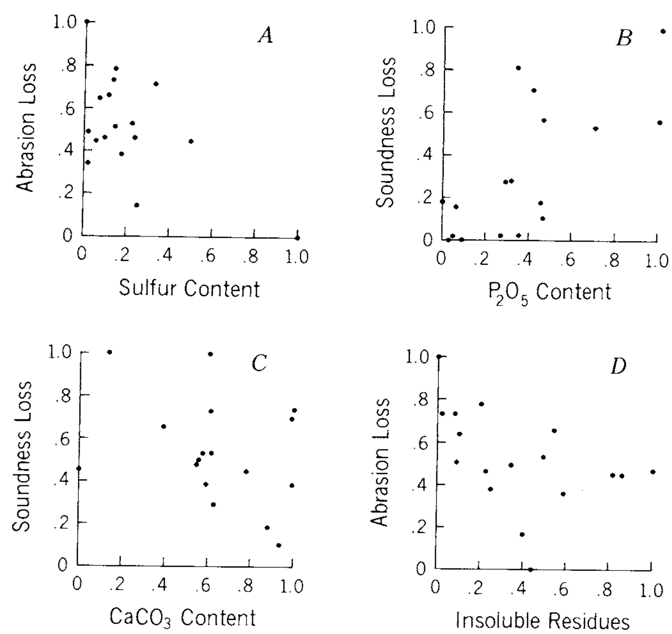

Figure 5. Scatter diagrams of selected physical and chemical properties: (A) abrasion loss vs. sulfur content, (B) soundness loss vs. P_2O_5 content, (C) soundness loss vs. $CaCO_3$ content, and (D) abrasion loss vs. insoluble residues. Data normalized.

Table 4. Physical and chemical properties analyzed in different studies

Judd and Huber (1961)	D'Andrea and others (1964)	Bundy and others (1965)	West and Johnson (1965)	Mutmansky and Singh (1968)	This study
Compressive strength	Compressive strength	Kaolin Properties	Los Angeles abrasion	Compressive strength	Los Angeles abrasion
Young's modulus	Young's modulus		Insoluble residue	Transverse strength	Soundness loss
Modulus of rigidity	Modulus of rigidity	Crystallinity	Percent void	Shear strength	Absorption
Bar velocity	Bar velocity	Particle size	Average grain size	Modulus of elasticity	Specific gravity
Specific gravity	Specific gravity	Surface area	Grain size variation	Density	Compressive strength
Porosity	Tensile strength	Sediment volume	Grain shape	Absorption	Mean grain size
Modulus of rupture	Longitudinal velocity	Shape factor	Grain interlock	Thermal conductivity	Insoluble residues
Impact toughness	Shear velocity	Brookfield viscosity	Specific gravity	Moisture transmission	Grain sorting
Scleroscope hardness	Poisson's ratio	Hercules viscosity	Absorption	Thermal expansion	Clay content
Specific damping capacity		Dispersant level	Soundness loss	Creep at 75% load	$CaCO_3$
		Brightness	Degradation value		$MgCO_3$
		Whiteness	Insoluble residue		SiO_2
		Cation exchange	$CaCO_3$		Al_2O_3
		Chemical composition	$MgCO_3$		Fe_2O_3
					TiO_2
		Coating Properties			MnO
					CO_2
		Brightness			S
		Whiteness			P_2O_5
		Opacity			
		Gloss			
		Smoothness			
		Clay orientation			
		Wet rub resistance			
		Pick			
		Ink gloss holdout			
		Ink receptivity			

Baxter and Harvey (1969, p. 7-9) reported a significant correlation between soundness and Al_2O_3 content, but we failed to find this correlation in our study. This inconsistency apparently indicates that for carbonate rocks with low clay content, the mode of occurrence of the clays is as important as the quantity. Carbonate rocks with clay laminations are generally more susceptible to soundness loss than are carbonate rocks with disseminated clays even though the quantity of clay may be the same in both.

A linear relationship appears to exist between soundness loss and amount of $CaCO_3$ and between abrasion loss and amount of insoluble residues (figs. 5C and 5D). The generalization may be made that rocks having a higher $CaCO_3$ content perform better when subject to the soundness test than rocks having a lower $CaCO_3$ content, and rocks having a higher insoluble residue content are more resistant to loss in the abrasion test than rocks having a lower insoluble residue content. It should be noted, however, that the Brassfield carbonate rocks in this study generally contained less than 10 percent insoluble residues. Different results might be expected for carbonates with a higher insoluble residue content.

The increase in compressive strength with increasing absorption (apparent porosity) is probably due to the very low absorption values of the Brassfield samples, which were generally less than 2 percent. Compressive strength generally increases with decreasing porosity (for example, Judd and Huber, 1961; Price, 1960, p. 290-292), but in the low porosity range this apparently does not hold true.

In conclusion, our study of 19 chemical and physical properties of the Brassfield Limestone was effective in showing certain regional changes in chemical and physical properties, but we were not altogether successful in finding significant correlations between the chemical and physical properties over our study area. Thus, we feel that chemical analyses should be used with caution to predict the physical properties of a limestone. Chemical analyses do not take into consideration the distribution of impurities, which may have a significant effect on physical properties. Our study indicates that an exploration program for limestone aggregate should theoretically search for rock having the optimum $CaCO_3$ and insoluble residue content, because such limestone would have a minimum abrasion loss and a minimum soundness loss. Realistically, however, an exploration program should search for limestones that have a high $CaCO_3$ content because pure limestones have more uses than impure limestones and also because soundness loss generally would be minimized. Even then, it must be remembered that some exceptionally pure limestones are soft and do not make class A aggregate.

ACKNOWLEDGMENTS

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THE CHALLENGE FOR THE GEOLOGIST IN THE EXTRACTIVE INDUSTRY

by

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Abstract

The geologist in the extractive industry is usually a combination of exploration, economic and environmental geologist. Since most of the well-known economic deposits have already been, or are now being, exploited by the extraction industry, the exploration geologist must accumulate old and new information and interpret this information in terms of today's needs and technology. The economic geologist has to be competent not only in technical areas but also in areas of finance, real estate, and law. The environmental geologist has a responsibility to affect multiple land use concepts and to improve the image of the industry. These goals can be achieved by instituting good neighbor practices and by educating local citizens and planners. Industrial geologists are challenged not only to accumulate information, but to apply it as an explorationist, economist, and an environmentalist. Educators are challenged to initiate curriculum changes to include business courses for geology majors. State survey geologists are challenged to tabulate lists of geological theses and university publications.

INTRODUCTION

The extractive industry requires of its geologists expertise in three main areas: exploration geology, economic geology and environmental geology. Often one person assumes the duties and responsibilities for all three of these areas. The extractive industry, as referred to in this text, includes those operations which involve the mining and processing of metallic and non-metallic materials. This forum is intended to inform geologists concerned with the industrial mineral industry. This industry is characterized by high volume, low profit products. However, the basic concepts described in this paper are aimed at the entire extractive industry.

EXPLORATION GEOLOGY

Since most of the obvious and easy to produce deposits have been or are now being exploited by the extractive industry, the exploration geologist must seek new deposits which are less obvious. To do this, he must be familiar with all geologic information, old and new. This is an enormous responsibility and the reason why the role of exploration geologist is the most demanding of the three. The information explosion is a real problem but usually refers to new information. Old geologic studies as sponsored by state surveys, U.S.G.S. and the Bureau of Mines should not be overlooked as information sources. These studies may be outdated in terms of mining techniques and materials requirements but descriptions of mineralogy, occurrence, and analytical chemistry rarely lose validity. Many of the published new studies, and explicitly detailed data are generated at the universities. Therefore, the exploration geologist should maintain contact with university geologists in addition to reading professional and trade journals. There is a continuous change in materials requirements which also demands a total information awareness.

Changes in materials requirements can force changes in exploration attitudes. What was once economic to mine may no longer be a profitable operation because of technological changes, transportation costs and/or world politics. For example, World War II cut our country off from many vital mineral materials and forced us to search for substitute deposits. Another example is the recent announcement by Kaiser Industries (E/MJ p.96) of plans to build a strontium processing facility on Cape Breton Island, Nova Scotia. The major product will be strontium carbonate from processing celestite. This operation undoubtedly will have a large impact on domestic strontium carbonate producers because most celestite is supplied from England, Mexico and Spain. These producers will be forced to search for closer celestite sources in order to compete with Kaiser.

As high grade material sources are depleted, lower grade and more difficult to mine deposits which were previously bypassed or overlooked are reexamined. Therefore, the concepts of geochemistry, petrology, geophysics, and geomorphology are significant to the exploration geologist because to understand the geologic processes of formation is a key to knowing where to look for and how to beneficiate new deposits. This role also demands an awareness of the potential of waste products. There are examples of mine dumps which have reclaimable products. The settling pond area of our sand and gravel processing plant may contain a substantial amount of reclaimable concrete sand.

An exploration geologist must possess realistic optimism and curiosity of the unusual because any place he examines, there have been others before him. This role requires knowledge of permissive geometry, i.e. areal and volumetric requirements that are necessary to satisfy the size of a new deposit. New tools and techniques in the areas of drilling, geophysics and remote sensing are ideas essential to the exploration geologist. He should be acquainted with how data processing can be applied. Computer applications exist in the fields of data calculations, probability models and possibly for mineral resource development and planning as described by Dr. Dunn at the 1969 Forum in Harrisburg, Pa. Dr. Dunn described a pilot program in which computer inputs included regional geology inventory, transportation analysis, development plans, etc.

In summary the exploration geologist is responsible for old and new geologic information; beneficiation and materials requirements changes; geochemistry, petrology, geophysics and geomorphology; computer applications and must possess a unique curiosity and insight.

ECONOMIC GEOLOGY

Economic geology requires technical evaluations and business recommendations. An economic geologist is required to measure quality and estimate quantity of potential new deposits. For existing reserves, he must supply quantitative and qualitative information to effect the most economic mining plan. In the sand and gravel industry for example, this requires knowledge of overburden thickness variations, changes in sand to gravel ratio, changes in thickness of deposit, depth to water table, etc. These technical evaluations represent routine problems for a geologist, because he has been trained in these areas. However, there are tasks that fall within the realm of economic geology which many geologists are not prepared to handle. These tasks are related to business-economic decisions.

Economic geology as taught in university courses is concerned with mineralogy, mineral genesis, occurrence in rock type, major deposit locations, and prices and uses of mineral deposits. All of these concepts are necessary tools for a geologist but do not qualify students for a role of economic geologist. At the G.S.A. meeting in November 1969, Mr. Behre discussed deficiencies in current geology curricula. He described a lack of training in finance, law and professional ethics. An economic geologist may be required to participate in budget planning and analysis, equipment depreciation, investment analysis, market studies, contract and lease negotiations.

The economic geologist also is responsible for knowledge of truck, rail and water transportation rates and practices as they apply to his product and locale. Real estate principles are another concern of the economic geologist, i.e. raw land values, royalty rates, lease prices, option costs and zoning problems. All of these real estate principles relate to land acquisition for future reserves. Land acquisition should be one of the main contributions of a geologist in the extractive industry because reserves govern the life expectancy of a company.

In summary, the economic geologist is required to contribute in technical evaluations which represent routine tasks. He is also often expected to make business recommendations and evaluations which are not routine tasks because he is not trained in these areas.

ENVIRONMENTAL GEOLOGY

The environmental geologist has a responsibility as a public relations man because the extractive industries have earned an image as "rapers of the land". As a result, the industry has received much unfavorable attention from organizations that claim to be conservation oriented. But, as someone once said - many conservationists are preservationists.

Geologists subscribe to the ideas of conservation - the best use for all raw materials which include land, water and mineral materials. The multiple land use concept is the phase of conservation most closely related to our industry. We, of all professionals, must do more than give lip service to this concept. The environmental geologist must know the opportunity of and the responsibility for post-operation rehabilitation because the multiple land use concept then becomes a reality. Detailed rehabilitation plans can best be prepared by landscape architects, but it is up to the geologist to initiate rehabilitation action. The environmental geologist must implement good neighbor practices which should include pre-operation planning. The effects of dust and noise can be minimized through erection of berms and by live plantings.

State conservation departments sell seedlings and assist in plans for planting them. The United States Department of Agriculture Soil Conservation Service also have available free assistance and, at least in Michigan, have seedlings for sale. These agencies will recommend species and planting procedure based on soil type and location.

The environmental geologist must take it upon himself to educate the public. This can be done by talking to individuals or organizations and describing the potential waste of needed materials through confiscatory zoning regulations. Planning agencies are usually very willing to listen and help. However, many lack the initiative to recognize this problem themselves. As an example, there was a substantial planning study made in S. E. Michigan which projected needs and trends for housing and transportation through the year 1990. It was found out that the sand and gravel properties were inappropriately plotted on the map and no additional properties other than those presently existing were allocated. Most of the existing aggregate operations within the study area will be depleted long before 1990. This raised the question - how can growth and plans develop without the materials necessary for the construction industry? This organization and group of planners realized their oversight and were most willing to listen to the ideas of multiple land use. Unfortunately, the final report was already drafted when this error was found out. Therefore, an opportunity for recognition of such a problem was passed, simply because no geologist contacted this organization early in the study.

The problems of zoning fall into the area of responsibility of the environmental geologist. Today, there is real competition for land use. This problem will magnify and become further complicated by zoning regulations. Mr. Dole, who is an assistant Secretary of the Interior for mineral resources, told the Northwest Mining Association (E/MJ p.101) that our nation's mineral requirements are growing ten times faster than the population. These requirements will not be met if the trend of confiscatory zoning laws continues. These laws should embrace the concepts of multiple land use as one means of relieving the stress of competition for land. However, the laws are usually written and enforced at a local level by people who think of the extractive industry as "rapers of the land", and the zoning regulations testify to the fears of the local citizenry.

The following two examples relate to zoning and land use. One illustrates the frustration of our industry; the other illustrates hope. Our company is suing a township in Michigan for permission to mine sand and gravel. The township's zoning ordinance does not provide for mining under any condition. The land which we own is in a very open and rural area which is expected to sustain only slow growth. We had prepared detailed plans for progressive mining to insure progressive rehabilitation and the development of a lake property. These plans failed to change the minds of the local people. The lawsuit was our last resort. We contended that the zoning ordinance was unconstitutional and confiscatory. The case has been tried and the court decided in our favor. But the case was filed four years ago and the decision may be appealed.

Another case of zoning and land use we are involved in exhibits considerable hope for the industry. A state park agency is seeking to expand one of their parks. One of the properties they wanted to buy contained a small gravel deposit on it. The park authority negotiated the purchase of the land but not the gravel rights. By doing this they were able to buy the land at a much lower price. The owner sold the gravel rights to us and through the double sale realized a just price for his land without a court fight. The park wants a lake developed on this property which can be achieved at no cost to them because part of the material to be mined is underwater. These two examples illustrate extremes in terms of attitudes on zoning and land use. The most unusual aspect of these examples are that the two properties are within one mile of each other.

In summary, the environmental geologist must work in the area of public relations and initiate good neighbor practices and rehabilitation programs to improve the image of our industry. However, the largest responsibility is for the education of planners as well as the general public in terms of meeting minerals requirements through multiple land use.

CHALLENGE

So far, this has been a summary of problems and responsibilities of geologists in the extractive industry. But progress is not made in retrospect. With this in mind, the following recommendations are offered in the form of challenges to industrial geologists, educators and state survey geologists.

The challenge for the industrial geologist is not in the accumulation of information in the areas of exploration, economics and environments, for that is the function of libraries, but in the application of this information as an explorationist, economist and environmentalist. This application is necessary for the growth and future of you, your company, the industry and the country.

The challenge to geology teachers is not only to instruct students in the fundamentals of geology and how to search for information, but also to initiate curriculum changes. It should be required that undergraduate geologists receive training in business law, finance, real estate and professional ethics. These changes would benefit both the students and the industries that hire them.

The challenge to the state survey geologists is to encourage research in the areas of beneficiation and waste product utilization. Another challenge is to prepare an annual list of articles (published and submitted), theses and dissertations authored in geology departments of all colleges and universities in the state. This list would serve two purposes. First, it would disseminate new information to those of us who need it, much more quickly and comprehensively. Second, it would serve to give recognition to authors of unpublished articles and theses and wider recognition for published articles.

The challenge for all of us is to describe the need for land use planning and conservation. But, we must do more than tell each other about this need. We need to be heard at any and all levels: write to your congressman; serve on state and national committees; tell your neighbor. Any person or group is a worthwhile audience. In 1966, Dr. Eddy stated the challenge rather well:

"..... regardless where the geologist serves, his foremost professional obligation is seeing that geologic knowledge is unfolded and applied for the betterment of mankind".

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MICHIGAN'S CLAY DEPOSITS AND INDUSTRY

by

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Abstract

This paper is a review of the clay and shale resources of Michigan including past, present, and potential utilization and outcrop localities. Clay and shale suitable for the production of clay products and cement are found in much of the State.

Glacial clays are used in the manufacture of brick, tile, cement, pottery, and lightweight aggregate while undeveloped deposits could be used for pottery purposes such as flower pots, earthenware, and glazed tile. Some may be suitable for special purposes such as slip clay and Fuller's Earth. It is possible that other special uses may be found as the clays are more carefully tested.

Shales of the Traverse Group and the Antrim and Ellsworth formations, all Devonian in age, are used in the manufacture of Portland cement; and shale of the Saginaw Formation of Pennsylvanian Age is used in the manufacture of tile. Other potential shale beds occur in formations of the Ordovician, Silurian, Devonian, and Mississippian periods. There is additional potential in the utilization of these shales in the manufacture of brick, cement, and lightweight aggregate.

INTRODUCTION

In addition to a general review of the clay and shale resources of Michigan, an appendix is included (Tables 3 and 4) showing percent of total alkali (Na_2O+K_2O) and the silica-alumina ratio (SiO_2 / Al_2O_3) for 17 shale and 25 glacial clay deposits. These data should be of value in determining the suitability of the material for use in the manufacture of Portland cement.

History

The manufacture of clay products is one of Michigan's oldest mineral industries. The first plant is believed to have been the Daniel's Brick Company in Detroit, which is reported to have begun production in 1864.

After that date, many brick and tile plants, as well as some pottery plants, were established in and near Detroit and elsewhere in the state where suitable deposits and a market existed. By 1911, as many as 138 plants were operating, but many were closed from 1911 to 1913. In 1926, only 42 plants remained and by the end of World War II the number had decreased to 12. The building boom following the war led to an increase of three brick plants in the period 1945-49, but then the decline resumed. The only new operations in recent years have been two lightweight aggregate plants.

The general distribution of former brick and tile plants in Michigan is shown in Figure 1. Most of the operations were very small and many operated seasonally or only long enough each year to meet demands of the local market.

Developments

Today, clay products are produced on a rather modest scale from clay and shale deposits in Michigan. Present operations include a brick plant in Detroit; tile plants at Tecumseh, Corunna, and Grand Ledge; a pottery plant at Rockwood; and lightweight aggregate plants at Livonia and Grand Haven.

In addition, Michigan clay and shale re-

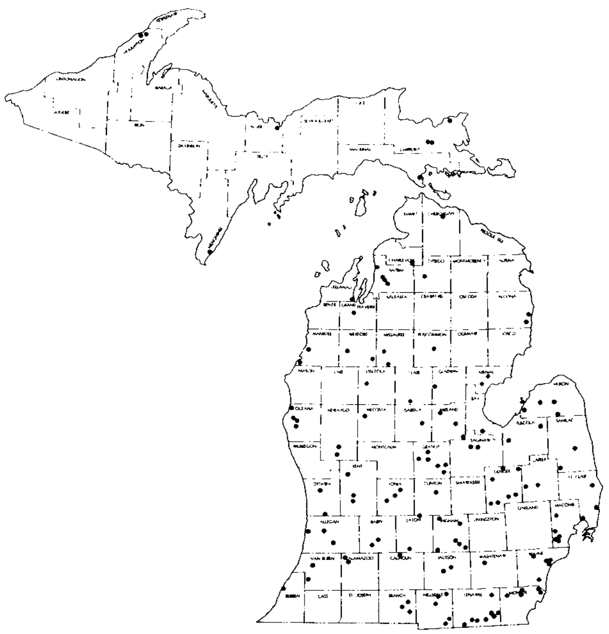


Figure 1. Map showing location of some 133 birch and tile plants formerly in operation in Michigan.

sources are also used by seven cement companies operating nine Portland cement plants. In the manufacture of cement, shale, if readily available and of suitable quality, is preferred to glacial clay. Shale quarries are located: 1 mile south of Ellsworth (for cement plant at Charlevoix); 5 miles west of Petoskey (for plant there); and 10 miles west of Alpena (for plant in Alpena).

All cement plants in the southern part of the state use glacial clay from local or nearby surface deposits. Pits are located at Saginaw (plant at Essexville); 10 miles west and south of Port Huron (plant in Port Huron); Ford Motor Company land in Detroit (2 plants in Detroit); overburden stripped from sandstone quarry at Rockwood; and overburden stripped from limestone quarry at cement plant 2 miles north of Dundee.

Excluding overburden stripping, 5 shale quarries and 7 glacial clay pits are being worked. (See Figure 2.)

Production

Most of the clay and shale produced in Michigan is used in the manufacture of Portland cement. In 1968, 2,394,569 tons of clay and shale were used with 7,844,384 tons of limestone and 258,780 tons of gypsum in the production of 32,368,574 barrels of Portland cement. Clay and shale produced and used in the manufacture of clay products totaled 329,990 tons, or about one-seventh of that amount used for cement.

The 1968 total clay and shale production for the state was 2,724,559 tons valued at $3,038,572. Figure 3 shows clay and shale production and clay products and Portland cement industires developments during the period 1951-1959.

SHALE RESOURCES

Shale from the Traverse Group, Antrim Shale, Ellsworth Shale, and Saginaw Formation accounted for about half of the Michigan's 1969 clay and shale production. Shale also occurs in other Paleozoic formations (See Table 1).

The oldest shales having economic potential outcrop in the Northern Peninsula. These are the Bill's Creek Shale of the Richmond Group and the Point aux Chenes Shale of the Salina Group. The shale beds of most economic value, however, are those of Devonian, Mississsippian and Pennsylvanian ages in the Southern Peninsula. These are the Bell Shale and the "upper blue shale" of the Gravel Point Formation of the Traverse Group; Antrim Shale; Ellsworth Shale, Coldwater Shale; and shale of the Saginaw Formation ("coal measures" of Michigan).

Shale beds, some of appreciable thickness, are common in a number of the predoninantly limestone formations of the Traverse Group. In the Michigan Formation shale is interbedded with gypsum. These shales, however, are restricted in occurrence under relatively thick rock overburden, or too calcareous to be of any present importance. Neither these nor the Bedford or Sunbury shales which do not outcrop in the state will be discussed here because of time limitation. The aerial extent and outcrop areas of shale strata in Michigan are shown in figure 4.

Ordovician

Rocks of the Ordovician Period are predominantly limestones and dolomites. Twelve feet of shale of this formation is exposed for about one mile along the east shore of Little Bay de Noc on the Stonington Peninsula, Delta County (section 14 and 23, T39N, R22W). It consists of thinly-bedded, light gray to dark brown, soft to hard shale. Other exposures are found to the north along Bill's Creek in section 12, T42N, R21W, and along Haymeadow Creek in section 19, T42N, R20W. Total thickness for the Bill's Creek is estimated to be about 70 feet.

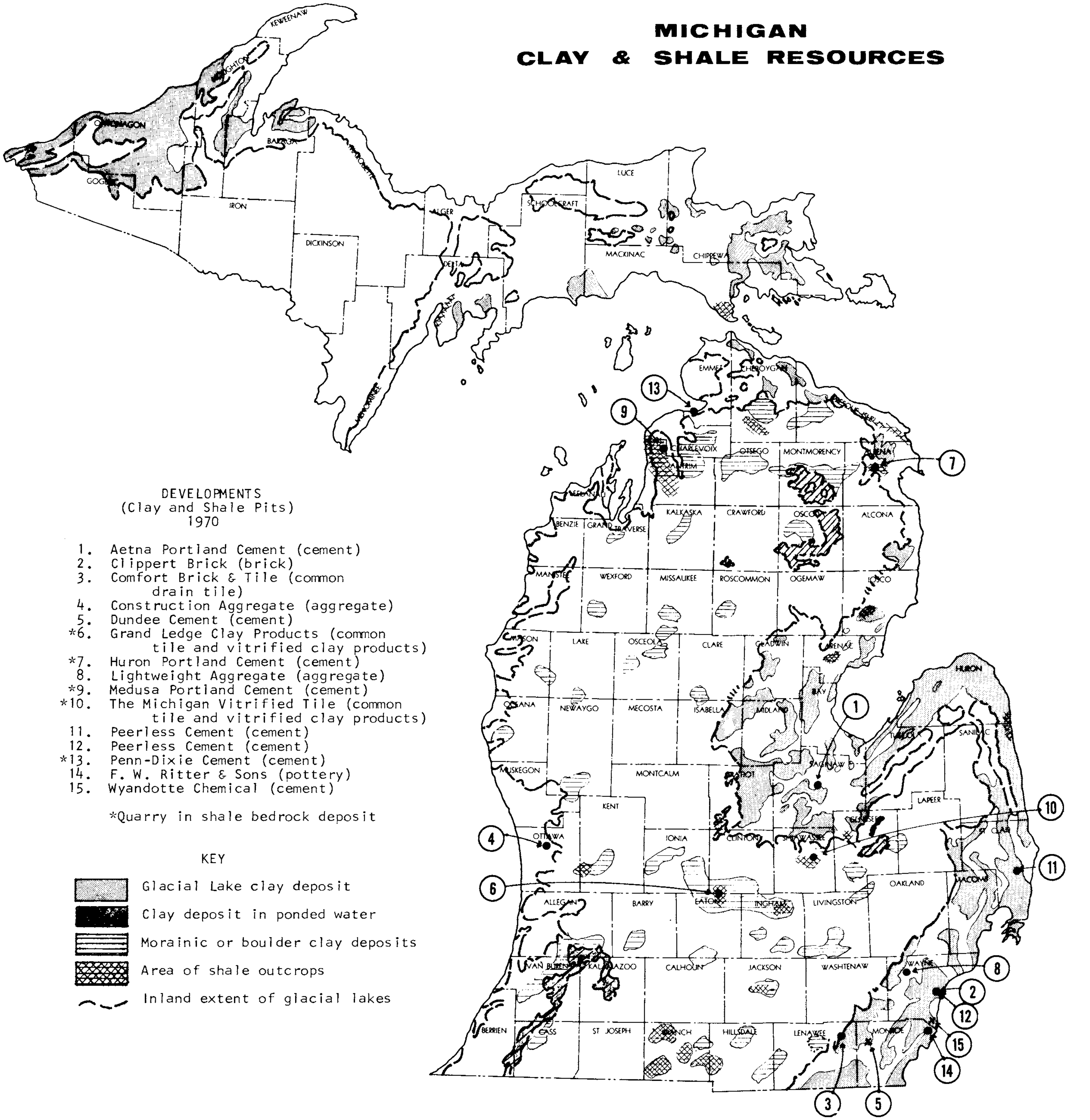


Figure 2. Map showing area of clay and shale deposits and location of clay products and Portland cement clay and shale pit and quarry operations.

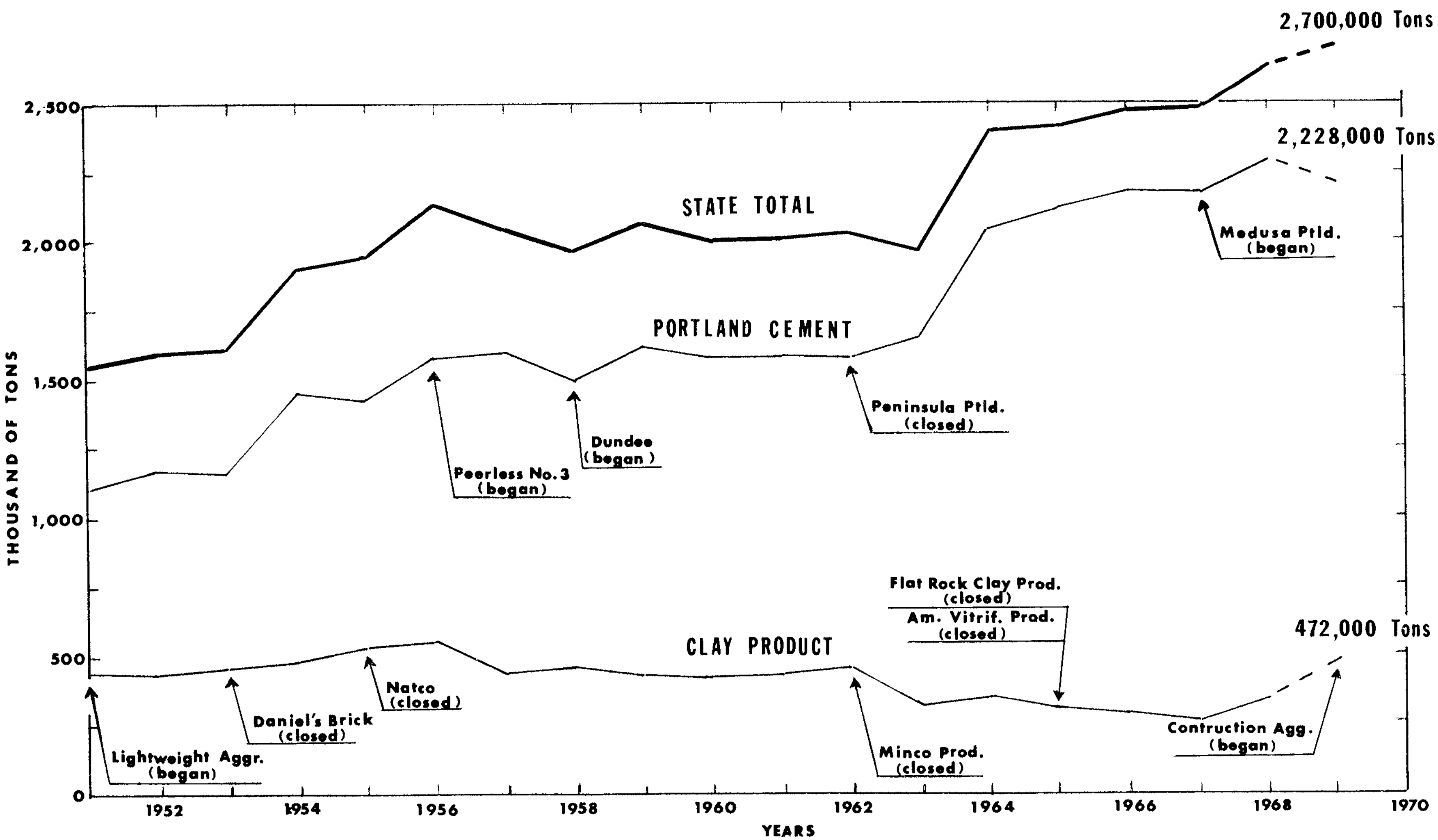


Figure 3. Clay and shale production and development, 1951-1969

STRATIGRAPHIC SUCCESSION IN MICHIGAN

PALEOZOIC THROUGH RECENT

MICHIGAN DEPARTMENT OF CONSERVATION

Ralph A MacMullan, Director

GEOLOGICAL SURVEY

Gerald E Eddy State Geologist

ACKNOWLEDGEMENT Compiled with the counsel of colleagues in this department the U S Geological Survey Michigan's universities other state Geological Surveys, and geologists within Michigan's oil and gas industry Dr Aureal T Cross Department of Geology, Michigan State University, identified rocks of Mesozoic age and suggested provisional age assignments

GEOLOGIC NAMES COMMITTEE

Garland D Ells Chairman, Robert W Kelley, Secretary
Harry J Hardenberg, L David Johnson, Harry O Sorensen

PLEISTOCENE NOMENCLATURE

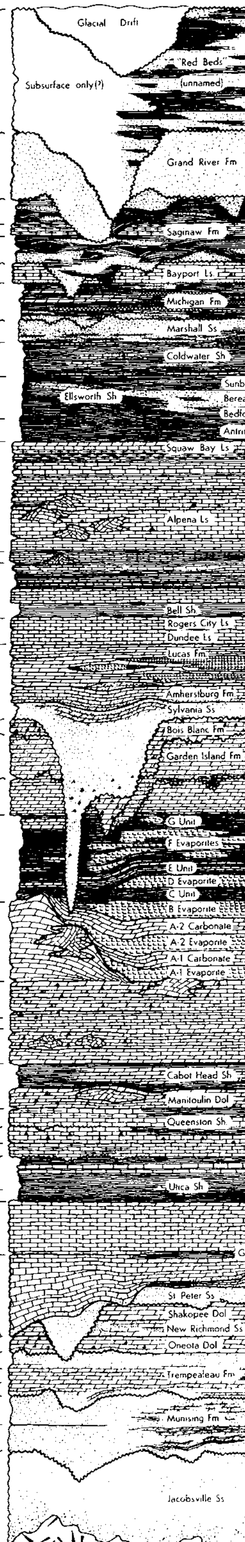
ERA	SYSTEM	SERIES	STAGE	
CENOZOIC	QUATERNARY	RECENT		
		PLEISTOCENE	Wisconsin Glaciation	Valders Stade
				Two Creeks Interstade
				Mankato Stade (Pt Huron?)
				Cary Stade
				Tazewell Stade
			Sangamon Interglaciation	
			Illinoian Glaciation	

OUTCROP NOMENCLATURE / SUBSURFACE NOMENCLATURE

SHALE RESOURCE (present and former uses)

ERA	PERIOD	EPOCH	SERIES	GROUP	FORMATION	MEMBER	Subsurface FORMATION	Subsurface MEMBER	Subsurface GROUP	Approximate maximum thickness, in feet, of rock units in the subsurface (NO SCALE)	SHALE RESOURCE
MESOZOIC	JURASSIC	LATE	KIMERIDGIAN				"Red Beds" (unnamed)			220	
PALEOZOIC	PENNSYLVANIAN	LATE	CONEMAUGH		Grand River Fm	Ionia, Eaton and Woodville Sandstones	Grand River Fm			750	
		EARLY	POTTSVILLE		Saginaw Fm	Verne Ls	Saginaw Fm				X TILE, brick
	MISSISSIPPIAN	LATE	MERAMECIAN	GRAND RAPIDS	Bayport Ls		Bayport Ls		GRAND RAPIDS	160	
					Michigan Fm		Michigan Fm			600	X Brick
		EARLY	OSAGIAN		Marshall Ss	Napoleon Ss	Marshall Ss	Napoleon Ss		330	
			KINDERHOOKIAN		Coldwater Sh		Coldwater Sh			1300	X Brick, cement
	MISSISSIPPIAN-DEVONIAN Unassigned				Ellsworth Sh (Western Michigan)		Sunbury Sh	(Eastern Michigan)		160	
							Ellsworth Sh / Berea Ss			260	X CEMENT, brick
							Bedford Sh			240	
	DEVONIAN	LATE	CHAUTAUQUAN		Antrim Sh		Antrim Sh			660	X CEMENT
			SENECAN	TRAVERSE	Squaw Bay Ls		Squaw Bay Ls		TRAVERSE		
		MIDDLE	ERIAN		Thunder Bay Ls						
					Potter Farm Fm						X Brick
					Norway Point Fm						
					Four Mile Dam Fm						
					Alpena Ls		Alpena Ls		Generally undivided in subsurface	830	X CEMENT
					Newton Creek Ls						
					Genshaw Fm	Killians					
					Ferron Point Fm						X Cement
					Rockport Quarry Ls						
					Bell Sh		Bell Sh				X Brick
					Rogers City Ls		Rogers City Ls			475	
					Dundee Ls		Dundee Ls				
			ULSTERIAN	DETROIT RIVER	Anderdon Fm						
					Lucas Fm		Lucas Fm		DETROIT RIVER	1450	
					Amherstburg Fm		Amherstburg Fm				
					Sylvania Ss		Sylvania Ss				
					Bois Blanc Fm (MACKINAC BRECCIA)		Bois Blanc Fm			800	
		EARLY			Garden Island Fm		Garden Island Fm			100	
	SILURIAN	LATE	CAYUGAN	BASS ISLANDS	Raisin River Dol				BASS ISLANDS	700	
					Put-in-Bay Dol						
					St Ignace Dol (Northern Peninsula)						
				SALINA	Pte. aux Chenes Sh		G Unit		SALINA	3150	X
							F Evaporites				
							E Unit				
							D Evaporite				
							C Unit				
							B Evaporite				
		MIDDLE	NIAGARAN		Engadine Dol		A-2 Carbonate				
							A-2 Evaporite				
							A-1 Carbonate				
							A-1 Evaporite				
				MANISTIQUE	Cordell Dol				NIAGARA	980	
					Schoolcraft Dol				Generally undivided in subsurface		
				BURNT BLUFF	Hendricks Dol	Fiborn Ls					
					Byron Dol						
					Lime Island Dol						
		EARLY	ALEXANDRIAN	CATARACT	Cabot Head Sh		Cabot Head Sh		CATARACT	200?	
					Manitoulin Dol		Manitoulin Dol				
	ORDOVICIAN	LATE	CINCINNATIAN	RICHMOND	Big Hill Fm		Queenston Sh		RICHMOND	950	
					Stonington Fm	Ogontz; Bay de Noc					
					Bill's Creek Sh	Collingwood	Utica Sh	Collingwood			X Brick
		MIDDLE	MOHAWKIAN	TRENTON	Groos Quarry Fm				TRENTON		
					Chandler Falls Fm				Generally undivided in subsurface	1100	
				BLACK RIVER	Bony Falls Fm			Glenwood	BLACK RIVER		
			CHAZYAN				St Peter Ss			260	
		EARLY	CANADIAN	PRAIRIE DU CHIEN	Oneota Dol		Shakopee Dol		PRAIRIE DU CHIEN	425	
							New Richmond Ss				
							Oneota Dol				
	CAMBRIAN	LATE	ST CROIXAN	LAKE SUPERIOR	Trempealeau Fm	Jordan Ss; Lodi; St Lawrence	Trempealeau Fm	Jordan Ss; Lodi; St Lawrence	LAKE SUPERIOR	750	
					Munising Fm	Miner's Castle Ss; Chapel Rock Ss	Munising Fm	Franconia Ss; Dresbach Ss; Eau Claire; Mount Simon Ss		1175?	
		MIDDLE / EARLY			Jacobsville Ss		Jacobsville Ss			1100+	
PRECAMBRIAN											

DOMINANT LITHOLOGY



(x) shale bed locally exposed or near surface to be of potential value for ceramic products and cement use

GEOLOGIC NAMES COMPILATIONS Harry O Sorensen, Cambrian and Ordovician, Robert W Kelley Early and Middle Silurian, Garland D Ells Late Silurian through Detroit River Group of Devonian age Harry J Hardenberg, Dundee Limestone through Traverse Group of Devonian age, L David Johnson, Antrim Shale through the Pennsylvanian System, F Wells Terwilliger, glacial geology of the Cenozoic

TABLE 1

Many years ago, the Bill's Creek Shale was dug from the Stonington Peninsula and skidded across the ice to Escanaba for making bricks. However, the shale is very calcareous and it is doubtful that it has any present value for that purpose, but it could possibly be used in the manufacture of cement.

Silurian

The Silurian rocks are almost entirely dolomites and limestone. The exception is the Point aux Chenes Shale which is exposed at a few places on and along the shore of the St. Ignace Peninsula. The formation in outcrop is a gray-green to red shale with some very thin layers of dolomite. Thickness of the formation is 500 to 600 feet, and individual shale beds may be 20 to 45 feet thick. The Point aux Chenes Shale has not been investigated for its suitability in the manufacture of ceramic products.

Devonian

The Bell Shale, generally 60 to 80 feet thick, is the basal formation of the Traverse Group. It subcrops in a narrow belt extending from the old Rockport Quarry on Lake Huron in the northeast corner of Alpena County (section 6, T32N, R9E), northwestward to Rogers City, then westward into the vicinity of Black Lake in Cheboygan County where it becomes covered by thick glacial drift. Best exposures are in the drainage ditch of the old abandoned Rockport Quarry, a pit on the south edge of Presque Isle Corporation Limestone Quarry near Presque Isle, Presque Isle County (NW corner 11, T33N, R8E); in the overburden stripping of U.S. Steel Corporation Limestone Quarry at Rogers City; and in a small roadside gulley about 2.5 miles southwest of Rogers City (NW¼ Section 29, T25N, R5E). The Bell Shale is a bluish-gray soft shale, generally limey and fossiliferous. It weathers rapidly to a blue plastic clay.

The Bell Shale was formerly dug on a small scale near Presque Isle (SW¼ Section 11, T33N, R8E) for the manufacture of a soft mud brick. It has been found satisfactory in the manufacture of Portland cement, and burning tests indicate it to be of good material for common brick, tile, and some pottery.

In western Michigan, the "upper blue shale" of the Gravel Point Formation contains an 8 to 20 foot bed or bluish-gray, calcareous shale with pyrite crystals and nodules. This shale is best exposed west of Petoskey in the shale pit of Penn-Dixie Cement Company where 20 feet of the rock is quarried (NE¼ section 8, T34N, R6W) and west of Charlevoix on Medusa Portland Cement Company property where some 5 to 10 feet is exposed in a shale pit.

Directly overlying the Traverse Group is the Antrim Shale, a brownish black to black hard fissile bituminous shale about 350 feet thick. In certain zones, numerous anthraconite concretions occur ranging in size up to three or more feet in diameter. Smaller marcasite concretions from the size of walnuts to a foot across are also present but in less abundance.

The best exposure of the Antrim Shale is in the quarry of Huron Portland Cement Company 10 miles west of Alpena where 20 feet is quarried. Other exposures are: three miles south of Afton (NW¼ SE¼ Section 14, T34N, R2W); on the north side of Walloon Lake (Section 36, T34N, R6W); on the north and south sides of Lake Charlevoix; and on the shore of Lake Michigan in a bluff just north and south of Norwood.

In addition to the present utilization in the manufacture of Portland cement, the Antrim Shale was formerly used at a Charlevoix brick plant.

Exposures of the Ellsworth Shale are located in Antrim and Charlevoix counties. The Formation, some 450 feet thick, consists of hard to soft, blue gray to greenish banded shale, contains some calcareous and arenaceous zones, and weathers easily to a gray clay. It is quarried about one mile southeast of Ellsworth (SW¼ Section 24, T32N, R8W) for cement use by Medusa Portland Cement Company in Charlevoix, and was formerly quarried one and a half miles south of Ellsworth (NE¼ Section 26, T32N, R8W) for the plant at Petoskey. About 50 feet of the shale is exposed in the two quarries. At East Jordan, Charlevoix County (NW¼ Section 24, T32N, R7W) the Ellsworth Shale was formerly used for the manufacture of bricks.

Mississippian

The Coldwater Shale, the lowest rock strata of the Mississippian Period, is predominantly a gray to greenish-blue shale. However, certain zones are calcareous or silicious and contain Kidney Ore. The Formation is from 500 to more than 1,000 feet thick. Over 50 feet are exposed in the Lake Huron shore bluff between Forestville and White Rock in Sanilac and Huron counties. Other exposures are in old abandoned quarries near Union City (NE¼ Section 16, T5S, R27W), Coldwater (NW¼ Section 32, T6S, R6W), south of Quincy in the banks of Fisher Creek, and northwest of Reading where

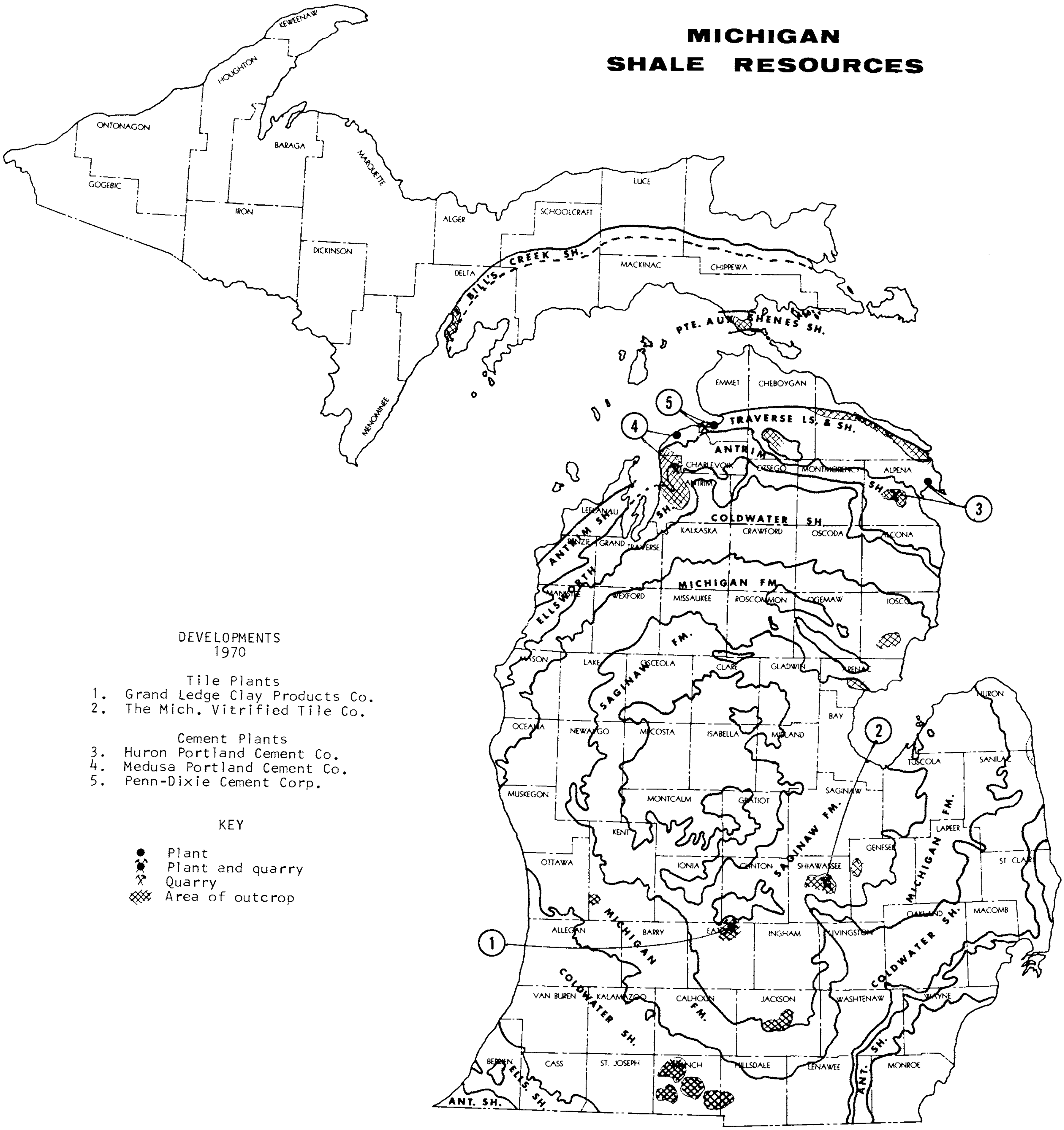


Figure 4. Map of shale bedrock and outcrop areas in Michigan with location of quarry developments.

the shale is exposed in stream cuts. The shale was formerly quarried near Union City and Coldwater and mined near Bronson for the manufacture of cement and near Coldwater it was used for the manufacture of brick. Coldwater Shale has not been utilized for many years, but tests indicate it is excellent material for brick, tile, or almost any vitrified product as well as Portland cement. Large reserves are available in Branch and Hillsdale counties.

Pennsylvanian

Shales of the Saginaw Formation are extensively worked at Grand Ledge in Clinton County for manufacture of drain tile, sewer pipe, septic tanks, flue liners, and other products, and at Corunna in Shiawassee County for drain tile and various fittings.

Deposits of Saginaw Formation shale were formerly used for the following: paving bricks near Flushing (SE¼ Section 22, T8N, R5E) and north of Omer (Section 5, T19N, R5E); face brick at Grand Ledge and Williamston, and sewer pipe at Jackson.

The shale of the Saginaw Formation ranges from light gray to black, is somewhat bituminous, and may contain calcareous and arenaceous zones. Iron carbonate concretions, pyrite, and thin coal beds are usually present.

CLAY RESOURCES

In general, the surface clays of Michigan can be divided into three classes: (1) morainic clays; (2) lake clays; and (3) residual clays. The first two are products of the Pleistocene Age whereas the third, residual clays, represents the weathered shale in areas of shale outcrops and thin glacial drift cover. (See figure 2.)

The morainic clays are confined to the morainic and till plain areas of the State, and therefore, are generally inland away from the present shores of the Great Lakes. These clays are often stoney and sandy and high in lime content.

The lake clays were deposited in water of former glacial lakes or in ponded water in the morainic areas. In the Southern Peninsula, these clays are almost entirely confined to a 40-mile strip running north from the Ohio State Line along the east side of Michigan to the "Thumb Area" around Saginaw Bay and into Alcona County. The glacial lakes were not as extensive on the west side of the State. Lake clays were deposited in narrow strips in a few indentations along the Lake Michigan shoreline, generally extending only one to two miles inland except from Holland northward across Ottawa and Muskegon counties where deposits are encountered 10 to 25 miles inland.

Lake clays cover much of the eastern part of the Northern Peninsula, particularly in Chippewa and Mackinac counties, where thicknesses of 300 to 400 feet have been encountered. Lake clay deposits in the western part are comparatively thin and are mainly confined to areas inland from Lake Superior in Gogebic, Ontonagon, Houghton, and Baraga counties.

Major ponded water clay deposits are in Genesee, Clinton-Gratiot, Oscoda-Montmorency counties and in a strip southwestward from Kalamazoo County through Van Buren and Cass counties. Undoubtedly many of the more plastic, smooth, and gritless clay deposits in the morainic areas of the state are clays of ponded water origin.

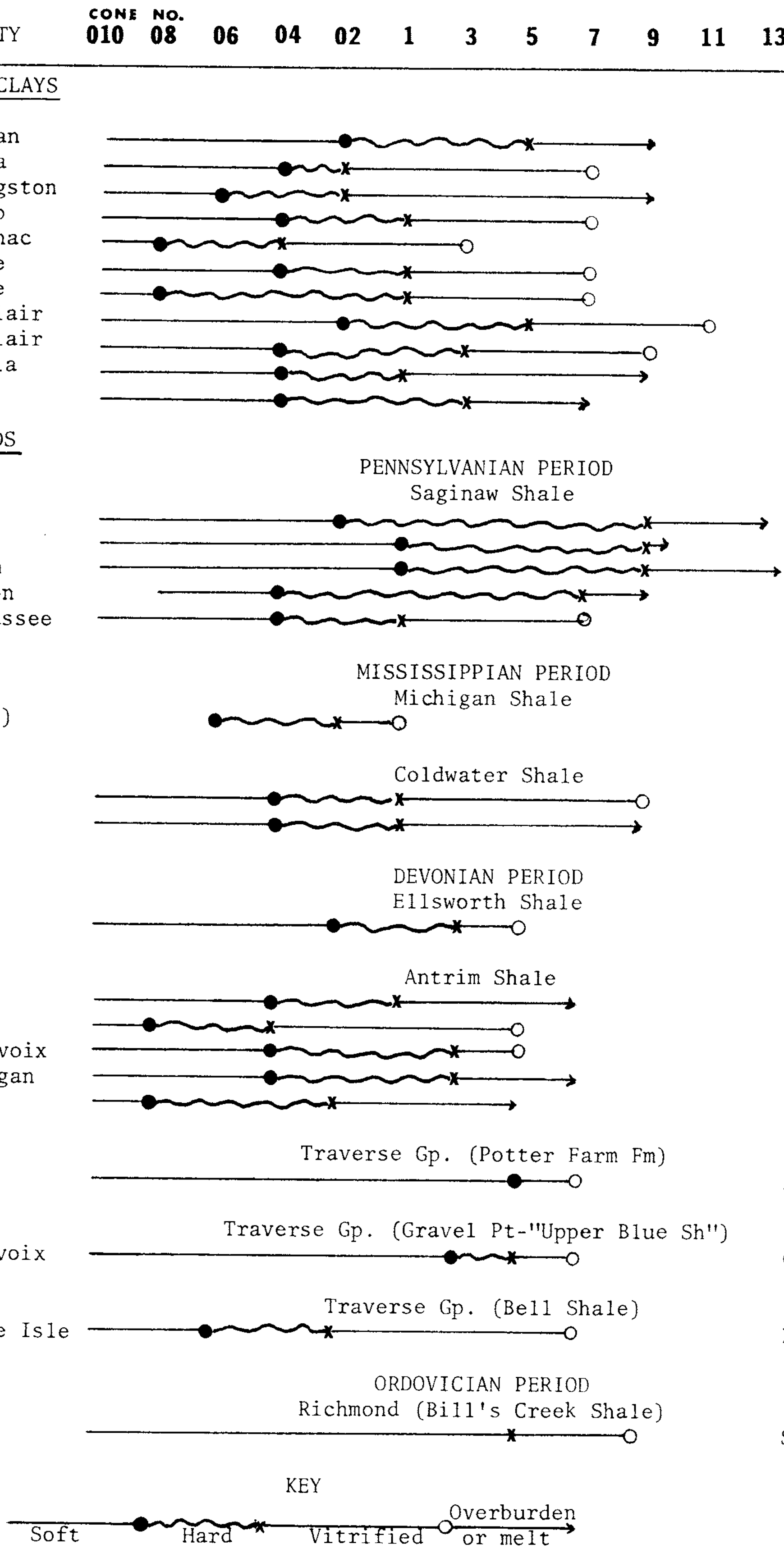
The composition of lake clays is similar to morainic clays, but they generally are free of glacial pebbles and boulders. Lake clay generally covers more extensive areas. Usually the upper 2 to 5 feet are weathered and low in lime, whereas the underlying blue clay may be loaded with lime pebbles. Most of the surface clays presently used by the clay product producers and cement companies in Southern Michigan are lake clays.

The third class, residual clays, is found where the shale bedrock is exposed or under very thin glacial drift cover. In these areas, the shale may be weathered to a depth of three or more feet. Much of the surface clay in Antrim, Charlevoix, and southern Emmet counties may be residual clay formed by weathering of the underlying Antrim and Ellsworth shales. Some of the clay in the Coldwater area of Branch County and St. Ignace, Mackinac County may also be residual of the underlying Coldwater and Point aux Chenes shales. Other areas of residual clays may be present within the belts of shale outcrops.

White burning kaolin clays are not known in Michigan, however, some of the calcareous plastic clays in the State burn almost white, and therefore, might be adaptable for special uses. A blue, very plastic, gritless, calcareous clay deposit on the north limits of Lansing has been tested and burns almost white.

Other clay deposits which may be suitable for special uses have been reported. At Harrietta, Wexford County, an extremely-gritless, fine-grained clay was tested for its Fuller's Earth properties some years ago and was reported to be effective in clarifying oil. A white or nearly white clay from Ontona-

TABLE 2.--BURNING TEST RANGE OF CLAYS AND SHALES FROM SELECTED DEPOSITS IN MICHIGAN
(from Brown, 1926)



COUNTY	Nearest Town	SEC	T	R
SURFACE CLAYS				
1 Allegan	Allegan	32	2N	13W
2 Baraga		31	51N	34W
3 Livingston	Howell	23	2N	4E
4 Macomb	Utica	4	1N	12E
5 Mackinac	Gould City	28	42N	11W
6 Monroe	Azalia	25	5S	6E
7 Monroe	Rockwood	21	5S	10E
8 St. Clair	Avoca	5-8	7N	15E
9 St. Clair	New Baltimore	7	3N	15E
10 Tuscola	Cass City	4	13N	11E
11 Wayne	Flat Rock	30	4S	10E
SHALE BEDS				
PENNSYLVANIAN PERIOD Saginaw Shale				
12 Bay	Auburn	30	14N	4E
13 Eaton	Grand Ledge	3	4N	4W
14 Ingham	Williamston	1	3N	1E
15 Jackson	Jackson	11	2S	1W
16 Shiawassee	Corunna	23	7N	3E
MISSISSIPPIAN PERIOD Michigan Shale				
17 Kent(1)	Grand Rapids	3	6N	12W
Coldwater Shale				
18 Branch	Coldwater	32	6S	6W
19 Huron	White Rock	32	15N	16E
DEVONIAN PERIOD Ellsworth Shale				
20 Antrim	Ellsworth	23	32N	8W
Antrim Shale				
21 Alpena	Alpena	30	31N	7E
22 Antrim	Chestonia	17	31N	6W
23 Charlevoix	Boyne City	25	33N	6W
24 Cheboygan	Indian River	1	34N	3W
25 Emmet	Walloon Lake	36	34N	6W
Traverse Gp. (Potter Farm Fm)				
26 Alpena	Alpena	33	31N	8E
Traverse Gp. (Gravel Pt-"Upper Blue Sh")				
27 Charlevoix	Charlevoix	28	34N	8W
Traverse Gp. (Bell Shale)				
28 Presque Isle	Rogers City	30	35N	5E
ORDOVICIAN PERIOD Richmond (Bill's Creek Shale)				
29 Delta	Stonington	11	39N	22W

gon County about 2 miles southwest of Rockland was formerly used for slip clay in Ohio. A deposit at Crosswell, Sanilac County, has a low melting point (glaze at about 1230° C) and may be suitable for slip clay use.

Some surface clays have a tendency to swell upon burning and may be suitable for lightweight aggregate production. Such a clay exists near Marine City, St. Clair County, and near Farwell, Clare County. A clay from about 10 miles west of Baraga, Baraga County, indicated positive signs of swelling beyond the first stage of vitrification.

BURNING TESTS

The most practical test for determining the suitability of a clay for use as a ceramic product is the burning test. If the temperature from the time the clay becomes hard burned (incipient vitrification) to the point where it becomes viscous and melt exceeds 120° C (6 pyrometric cones), the clay is considered to have a good burning range and may possibly be adaptable for vitrified ware. If less than 6 cones, the clay would only be suitable, at best, for common brick or tile.

Because of the calcareous nature of Michigan surface clays, most have rather narrow burning ranges and will burn to an off-shade red, pink, or salmon color. However, those surface clays that have been subjected to weathering and leached of much of their lime content have better burning ranges, and in many cases, are quite suitable for all kinds of brick and tile and sometimes vitrified products of various kinds.

Burning range spreads for samples from various shale deposits in Michigan and 11 surface clay deposits are presented in Table 2. The table shows that the Bill's Creek Shale (no. 29) in Delta County does not burn hard before vitrification takes place and melt occurs. With a burning range of less than 4 cones (80° C) the shale would not be suitable in the production of vitrified ware. Inability to burn hard suggests a high lime content. The "upper blue shale" (no. 27) of the Gravel Point and Potter Farm (no. 26) formations, Ellsworth Shale (no. 20) and the Michigan Formation shale (no. 17) also have a short burning range, and hence, may be considered almost worthless for production of clay products of any kind.

The Antrim (no. 21-25), Coldwater (no. 18 and 19), and Saginaw Formation (no. 12-16) shales, on the other hand, show very good burning ranges, and being low in lime, are well suited in most instances for all kinds of brick and tile, sewer pipe, and other vitrified products or ware.

The 11 surface clays (no. 1-11) were selected for their long burning ranges and should be suitable for brick, tile, and some vitrified products.

PROSPECT FOR THE FUTURE

In general, Michigan glacial clays (morainic and lake clays) are less satisfactory for ceramic materials than are the Pennsylvanian, Mississippian and Devonian shales, but when leached of lime, the clays are generally satisfactory for brick and tile, pottery, and possibly some vitrified ware.

Possible new uses for the Michigan's clay and shale resources can only be surmised. Preliminary tests made by the U.S. Bureau of Mines during 1966-67 show that the Bell Shale of the Traverse Group will bloat and produce lightweight aggregate material by the rotary-kiln process. Shale from the Michigan Formation showed laminar expansion at 2000° F and warrants further testing. The other shales tested have little promise for lightweight aggregate material although further investigation may prove otherwise. On the other hand, most of the surface clays will cinder when mixed in certain proportions with coke or grounded coal and fired over a cindering grate. More clay deposits than the two presently being worked will undoubtedly be opened for this purpose in the future.

It is possible that some of the undeveloped shale deposits will eventually become valuable in the production of clay products and vitrified ware, as may some of the surface clay deposits having a wide burning range. Some of the very fine-grained, gritless plastic clays in Clare, Sanilac, and Ontonagon counties that show slip clay characteristics may eventually be worked on a small scale for that use. The clay deposit at Harrietta may have a use as a substitute for "Fuller's Earth".

* * *

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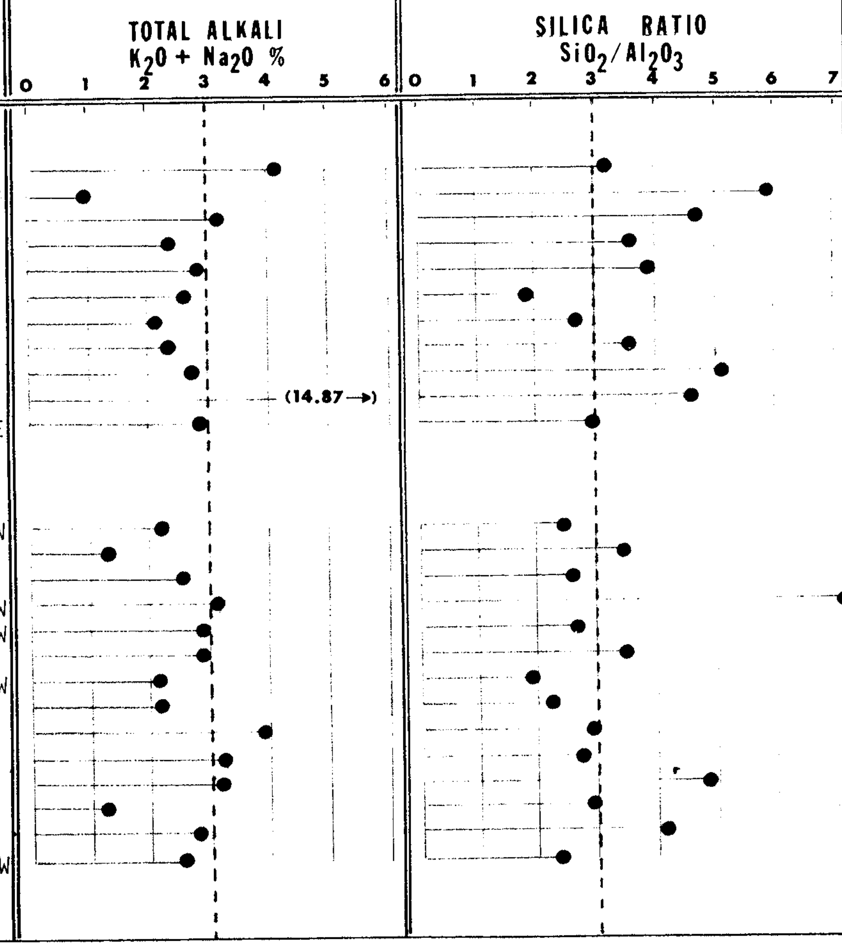
* * *

Note: Appendix consisting of Tables No. 3 and No. 4 follows on pages 154 and 155.

TABLE 3.--ALKALI AND SILICA/ALUMINA ANALYSES OF CLAY SAMPLES FROM GLACIAL DEPOSITS IN MICHIGAN

Note: An alkali content of 3%, or less, and a silica/alumina ratio of 3 or less, suggests clay suitable for manufacturing Porland cement.

(Analyses from Brown 1926)

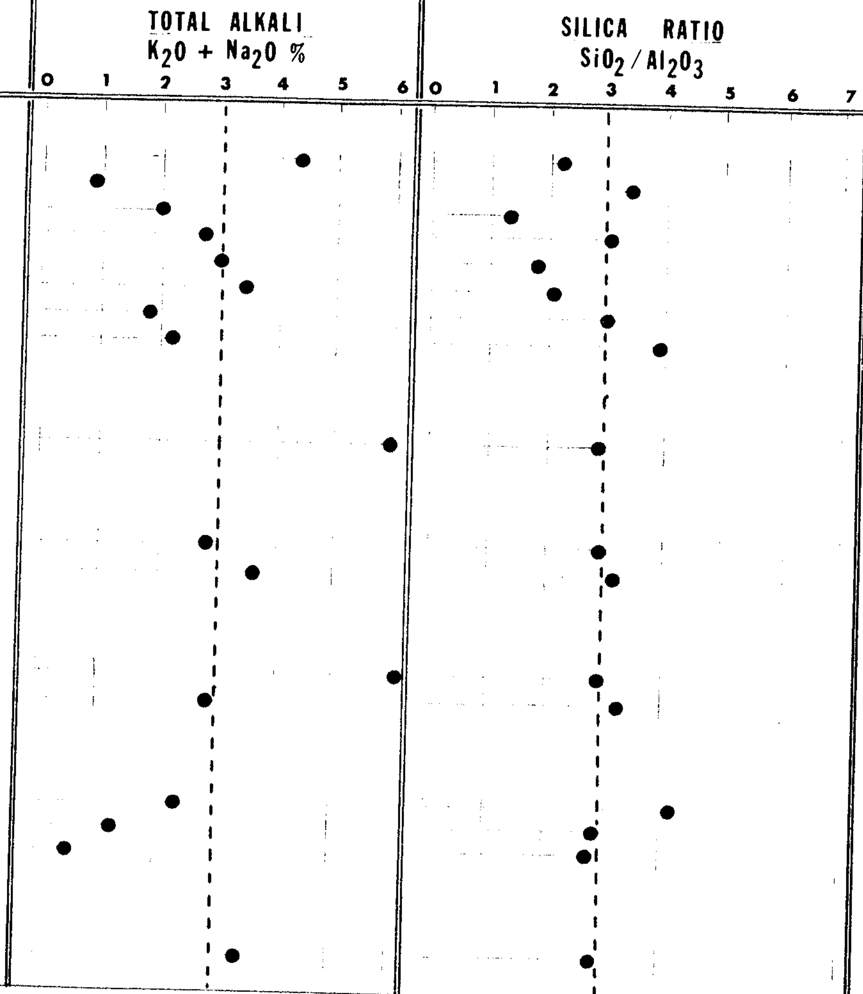


COUNTY	SEC. TWP. RGE.	Common Brick	Drain Tile	Bldg. Tile	Pottery	Cement	REMARKS
BOULDER CLAY							
Allegan	9-10, T1N, R12W						upper 10'
Benzie	30, T26N, R15W						boulder clay
Calhoun	SE 7, T1S, R6W					X	blue clay
Clare	SE 24, T17N, R5W						red clay 12-17' thick
Ingham	NW 14, T4N, R2W	X					blue clay
Ionia	SW 25, T7N, R7W		X		X		upper 20' red clay
Ionia	SW 25, T7N, R7W		X		X		underclay 50-75' blue clay
Isabella	2, T14N, R9W		X				12' of blue clay under 3' gravel
Isabella	30, T15N, R5W						boulder clay
Lenawee	SE 24, T6S, R3E						PRE-WISC. TILL (under 12' cover)
Manistee	11, T24N, R16E						red glacial clay
LAKE CLAY							
Leelanaw	28, T28N, R11W	X					blue clay
Lenawee	NW 14, T8S, R3E	X	X				red clay, 12-15' deep
Macomb	4, T1N, R12E	X					blue and red clay 10-12' deep
Manistee	10, T24N, R16W						blue clay, upper 8'
Manistee	36, T23N, R16W	X	X				blue clay
Monroe	23, T5S, R6E						blue clay, below 12'
Muskegon	SE 14, T12N, R15W	X					blue clay, lower 6'
Oakland	36, T2N, R9E	X		X			blue plastic clay
St. Clair	1, T4N, R16E	X					red clay
St. Clair	SW 18, T4N, R17E	X					plastic gray clay, upper 5'
St. Clair	7, T3N, R15E	X					upper 3' red burning clay
Van Buren	21, T3S, R16W	X	X				upper 6'
Wayne	30, T4S, R10E		X				upper 3'
Wexford	7, T22N, R11W	X					Harrietta clay deposit

TABLE 4.--ALKALI AND SILICA/ALUMINA ANALYSES OF SELECTED SHALE DEPOSITS IN MICHIGAN

Note: An alkali content of 3%, or less, and a silica/alumina ratio of 3 or less, suggests shale suitable for manufacturing Portland cement.

(Analyses from Brown 1926)



COUNTY	SEC. TWP. RGE.	Common Brick	Paving Brick	Sewer Tile	Cement	REMARKS
SAGINAW SHALE						
Bay	NW 4, T14N, R5E					overshale, Winonia Cool Mine (abd)
Eaton	3, T4N, R4W	x		x		mixed shale as used in plant
Eaton	3, T4N, R4W	x		x		black carbonaceous shale
Eaton	3, T4N, R4W	x		x		grey carbonaceous shale
Genesee	22, T8N, R5E		x			upper shale
Ingham	1, T3N, R1E	x				
Jackson	11, T2N, R1W			x		composite sample
Saginaw	6, T11N, R5E					under shale, Standard Cool Mine (abd)
MICHIGAN SHALE						
Kent	2, T6N, R12W	x				above gypsum
COLDWATER SHALE						
Branch	32, T6S, R6W				x	old Wolverine Ptl. Cem. Qy.
Huron	32, T15N, R16E					shore bluff; 50' high
ELLSWORTH SHALE						
Antrim	26, T32N, R8W				x	composite sample, Penn-Dixie Qy.
Antrim	13, T32N, R8W					red. cut, weathered shale
ANTRIM SHALE						
Alpena	30, T31N, R7E				x	upper 5', Payton qy.
Antrim	E 17, T31N, R6W					1.5 mi. N. of Chestonia
Emmet	36, T34N, R6W					N. side Walloon Lake
TRAVERSE & Ferron Pt. Shale						
Alpena	18, T32N, R9E				x	Abd. shale quarry.