

**MOLDING SANDS  
OF MICHIGAN**

STATE OF MICHIGAN  
DEPARTMENT OF CONSERVATION

GEOLOGICAL SURVEY DIVISION

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**MOLDING SANDS OF MICHIGAN**

AND

**THEIR USES**

BY

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UNIVERSITY OF MICHIGAN



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LETTER OF TRANSMITTAL

*To the Director, and the Board of Commissioners of the Department of Conservation of the State of Michigan:*

P. J. Hoffmaster, Director

Wm. H. Loutit, Chairman

Philip Schumacher

Harry H. Whiteley

M. J. Fox

Philip K. Fletcher

Joseph P. Rahilly

Wm. J. Pearson

Wayland Osgood, Secretary

Gentlemen: I have the honor to submit herewith a report entitled "The Foundry Sands of Michigan", and recommend that it be published and bound as Publication 41, Geological Series 35, of the Geological Survey Division, Department of Conservation.

This report represents several years of field work and laboratory study and testing by Dr. George G. Brown of the University of Michigan, and a great many analyses and tests at the University of Cornell, New York, and the Bureau of Standards, Washington, D. C., under the direction of Dr. H. Ries, head of the Department of Geology, Cornell University, with the financial assistance of the American Foundrymen's Association. The report adequately answers the demand of the foundry sand industry for a comprehensive discussion of the molding sands of the State, and may well stimulate a revival of the molding sand industry in Michigan.

The report contains a discussion of the sands of the State, and the results of an exhaustive study of the bond in foundry sands. The investigation of sand localities proved that although the deposits are very large, very few are deposits of naturally bonded sand. The cost of importing bond sand from such localities as the Albany Molding Sand district of New York, and the resultant lagging of the foundry sand industry in Michigan far behind the progress of the iron and steel industries, led to a laboratory search for a synthetic molding sand. Laboratory experiments conducted in the University of Michigan Laboratory, under the direction of Dr. Brown, by Dr. C. C. DeWitt, now professor of chemistry at the Michigan College of Mines, were highly successful in producing a synthetic bonded sand from unbonded sands in the State, and a simple and cheap method for the manufacture of the artificial sand was developed. This discovery may prove revolutionary and develop the large resources of sand in Michigan.

The report thus fulfills the requests of an important industry and opens the way for future development of a once despised resource.

Very truly yours,

R. A. SMITH,  
State Geologist.

## TABLE OF CONTENTS

|                             | Page No. |
|-----------------------------|----------|
| Letter of Transmittal ..... | 3        |
| Preface .....               | 13       |

### PART I.

|   |    |
|---|----|
| Chemical and Physical Properties of, and Cause of Bond in Sands ..... | 15 |
|---|----|

#### Chapter I.

|  |    |
|--|----|
| Origin of Sand .....                           | 17 |
| Definition .....                               | 17 |
| General .....                                  | 17 |
| Foundry Sands .....                            | 17 |
| Molding Sands .....                            | 17 |
| Core Sands .....                               | 17 |
| Origin .....                                   | 18 |
| Disruption or Disintegration .....             | 18 |
| Glacial Decomposition .....                    | 18 |
| Transportation .....                           | 19 |
| Glacial .....                                  | 19 |
| Streams .....                                  | 19 |
| The Wind .....                                 | 19 |
| Deposition .....                               | 20 |
| Glacial Deposits .....                         | 20 |
| Stream Deposits .....                          | 20 |
| Deposits in Glacial Outwash .....              | 21 |
| Deposits along abandoned Drainage Lines .....  | 22 |
| Deposits along Present Lines of Drainage ..... | 22 |
| Lucustrine or Lake Deposits .....              | 22 |
| Glacial Lakes .....                            | 22 |
| Present Lakes .....                            | 23 |
| Eolian Deposits .....                          | 23 |
| Consolidated Deposits .....                    | 24 |
| Sylvania Sandstone .....                       | 24 |
| Secondary Changes in Sand Deposits .....       | 24 |
| Summary .....                                  | 27 |

#### Chapter II.

|                                       |    |
|---------------------------------------|----|
| Prospecting and Excavating Sand ..... | 28 |
| Exploration of Deposits .....         | 29 |
| Mapping .....                         | 29 |
| Economic Factors .....                | 30 |
| Drainage .....                        | 30 |
| Overburden .....                      | 30 |
| Markets and Transportation .....      | 30 |
| Recovering or Producing Sand .....    | 30 |
| Stripping of Overburden .....         | 31 |
| Excavation .....                      | 31 |
| Transportation .....                  | 32 |
| Treating .....                        | 33 |
| Mixing .....                          | 33 |
| Washing .....                         | 34 |
| Screening .....                       | 34 |
| Stationary Screens .....              | 34 |
| Revolving Screens .....               | 34 |
| Electric Vibrating Screens .....      | 35 |
| Drying .....                          | 35 |
| Shipping .....                        | 36 |

|  | Chapter III. | Page No. |
|--|--------------|----------|
| Chemical Properties                                |              | 37       |
| Minerals in Sand                                   |              | 37       |
| Quartz   |              | 37       |
| Feldspar   |              | 37       |
| Orthoclase   |              | 38       |
| Plagioclase  |              | 38       |
| Mica   |              | 38       |
| Muscovite  |              | 38       |
| Biotite  |              | 38       |
| Amphiboles   |              | 38       |
| Pyroxene   |              | 38       |
| Iron   |              | 39       |
| Magnetite  |              | 39       |
| Ilmenite   |              | 39       |
| Hematite   |              | 39       |
| Limonite   |              | 39       |
| Siderite   |              | 40       |
| Pyrite   |              | 40       |
| Calcite  |              | 40       |
| Calcium Carbonate of Limestone                     |              | 40       |
| Dolomite   |              | 40       |
| Magnesite  |              | 40       |
| Gypsum   |              | 41       |
| Clay   |              | 41       |
| Kaolinite  |              | 41       |
| Hallosite  |              | 41       |
| Significance of Color                              |              | 42       |
| Chemical Composition of Sand                       |              | 42       |
| Silica   |              | 43       |
| Alumina  |              | 43       |
| Lime   |              | 43       |
| Alkalies   |              | 43       |
| Sulphur  |              | 43       |
| Water  |              | 43       |
| Analysis of Sand                                   |              | 44       |
| Rational Analysis                                  |              | 44       |
| Colloidal Material                                 |              | 46       |
| Determination                                      |              | 46       |
| Dye Adsorption Test                                |              | 46       |
|  | Chapter IV.  |          |
| Physical Properties of Sand                        |              | 48       |
| Texture or Fineness                                |              | 48       |
| Methods of Determining                             |              | 49       |
| Sense of Touch                                     |              | 49       |
| Screen Analysis                                    |              | 49       |
| Ritinger Series                                    |              | 49       |
| Mesh   |              | 50       |
| A. S. T. M. Method                                 |              | 50       |
| A. F. A. Fineness                                  |              | 51       |
| Procedure—no bond                                  |              | 51       |
| Procedure—bonded                                   |              | 52       |
| Interpretation of Screen Analysis                  |              | 53       |
| Cumulative   |              | 54       |
| Fractional   |              | 54       |
| Probability of Plot                                |              | 58       |
| Fineness Index                                     |              | 58       |
| A. F. A. Grain Fineness                            |              | 59       |
| Method of Determining                              |              | 60       |
| Grain Fineness Classification                      |              | 60       |
| Ritinger Fineness Index                            |              | 61       |
| Simple Series                                      |              | 61       |
| Extended Series                                    |              | 62       |
| Relation between Ritinger Index and Albany Numbers |              | 64       |

|  | Page No. |
|--|----------|
| Size Distribution                                | 65       |
| Methods  | 65       |
| A. F. A. Grain Size Distribution                 | 65       |
| Ritinger Grain Size Distribution                 | 68       |
| Shape of Grain                                   | 68       |
| Composition of Grain                             | 69       |
| Adsorption                                       | 69       |
| Dye Adsorption Test                              | 70       |
| Electrotypes                                     | 70       |
| Dye  | 70       |
| Dye Concentration                                | 70       |
| Used Sands                                       | 70       |
| Interpretation of                                | 71       |
| Permeability                                     | 71       |
| Shape of Grain                                   | 72       |
| Definition                                       | 72       |
| Methods of Tests                                 | 73       |
| Sand Rammer                                      | 74       |
| Procedure  | 75       |
| Preparation of Sample                            | 75       |
| New Sands  | 75       |
| Moisture   | 75       |
| Ramming  | 76       |
| Calculation                                      | 76       |
| Base Permeability                                | 76       |
| Test Method                                      | 77       |
| Grain Size on                                    | 78       |
| Grain Shape on                                   | 78       |
| Bond Strength                                    | 78       |
| Indirect Methods                                 | 78       |
| Touch  | 79       |
| Clay Content                                     | 79       |
| Dye Adsorption & Vibratory Test for Clay Content | 79       |
| Direct Methods                                   | 79       |
| Shear Test                                       | 79       |
| Transverse Test                                  | 80       |
| A. F. A. Cohesiveness                            | 80       |
| Compression Tests                                | 83       |
| Tensile Strength Test                            | 85       |
| Comparison of Bond Strength Tests                | 88       |
| Automatic Precision Strength Tests               | 88       |
| Machine  | 91       |
| Calibration                                      | 91       |
| Rammer   | 92       |
| Procedure  | 93       |
| Accuracy   | 94       |
| Cause of Bond in Molding Sands                   | 94       |
| Clay and Silt                                    | 94       |
| Moisture   | 95       |
| Mulling  | 95       |
| Colloidal Iron Oxide                             | 97       |
| Analytical Determination of                      | 97       |
| Fresh Sand                                       | 98       |
| Natural Base Material                            | 100      |
| Natural Base Sand                                | 101      |
| Results  | 102      |
| Synthesis of Bonded Sand from Unbonded           | 103      |
| Silica   | 104      |
| Kaolin   | 104      |
| Iron Hydrosol                                    | 104      |
| Adsorption of Iron Hydrosol                      | 105      |
| Synthetic bonded Materials                       | 105      |
| Synthetic Bond No. 1                             | 105      |
| Bond No. 2                                       | 105      |
| Base Material No. 1                              | 105      |
| Base Material No. 2                              | 106      |

|   | Page No. |
|---|----------|
| Synthetic Molding Sands .....                             | 107      |
| Bonded Sand No. 1 .....                                   | 107      |
| Bonded Sand No. 2 .....                                   | 107      |
| Bonded Sand No. 3 .....                                   | 107      |
| Properties of Synthetic Molding Sands .....               | 107      |
| Effect of Heating .....                                   | 108      |
| Bond in Molding Sands .....                               | 110      |
| Bonded Molding Sands from Unbonded Materials .....        | 110      |
| Silica .....  | 111      |
| Silica Base Material .....                                | 111      |
| Silica and Kaolin .....                                   | 112      |
| Silica Base Material and Kaolin .....                     | 112      |
| Silica Base Material and Bond .....                       | 115      |
| Results .....   | 115      |
| Sand .....  | 115      |
| Green Bond .....  | 117      |
| Dry Bond .....  | 118      |
| Relation between Green and Dry Bond .....                 | 118      |
| Durability of Bond .....                                  | 120      |
| Methods of Tests .....                                    | 120      |
| Heat Test .....   | 120      |
| Rehydratability .....                                     | 121      |
| Comparison .....  | 123      |
| Cause of Failure .....                                    | 124      |
| Experimental Data .....                                   | 125      |
| Discussion .....  | 126      |
| Green Strength .....                                      | 126      |
| Dry Strength .....  | 129      |
| Refractoriness .....                                      | 129      |
| Definition .....  | 129      |
| Importance .....  | 130      |
| Test for .....  | 130      |
| Effect of Clay and Colloidal Bond .....                   | 131      |
| Effect of Treatment .....                                 | 132      |
| Ramming .....   | 134      |
| Tempering or moisture content .....                       | 135      |
| Chapter V.  |          |
| Sand Control and Reclamation in Foundries .....           | 138      |
| Control of Physical Properties .....                      | 138      |
| Moisture Content .....                                    | 138      |
| Control of Ramming .....                                  | 140      |
| Reclamation and Improvements in Physical Properties ..... | 140      |
| New Sand Additions .....                                  | 140      |
| Mulling .....   | 141      |
| Strength and Bond .....                                   | 141      |
| Grain Size .....  | 142      |
| Permeability .....  | 142      |
| Clay Additions .....                                      | 143      |
| Clay Alone Inadequate .....                               | 144      |
| Dry Strength Important .....                              | 144      |
| Use of Impure Clays .....                                 | 145      |
| Sand Handling in Foundries .....                          | 145      |
| Synthetic Sands .....                                     | 146      |
| Chapter VI.   |          |
| Classification of Sands .....                             | 147      |
| Molding Sands .....                                       | 147      |
| Physical Properties .....                                 | 147      |
| Fineness or Grain Size .....                              | 147      |
| Clay Substance .....                                      | 148      |
| Durability .....  | 148      |
| Uses .....  | 150      |

|  | Page No. |
|--|----------|
| Other Foundry Sands .....                        | 151      |
| Core Sand .....                                  | 151      |
| Bond .....                                       | 152      |
| Testing .....                                    | 152      |
| Steel Sand .....                                 | 152      |
| Fire Sand .....                                  | 153      |
| Parting Sand .....                               | 153      |
| Other Uses of Sand .....                         | 153      |
| Structural Sand .....                            | 154      |
| Building Sand .....                              | 155      |
| Concrete Sand or Fine Aggregate .....            | 155      |
| Screen Analysis .....                            | 155      |
| Organic Matter .....                             | 155      |
| Sand for Brick Mortar .....                      | 156      |
| Plastering Sand .....                            | 156      |
| Screen Analysis .....                            | 156      |
| Paving Sands .....                               | 157      |
| Sands for Concrete Pavements .....               | 157      |
| Screen Analysis .....                            | 157      |
| Sands for Asphaltic or Bituminous Pavement ..... | 157      |
| Screen Analysis .....                            | 158      |
| Grouting Sand .....                              | 158      |
| Screen Analysis .....                            | 158      |
| Sand for Sand Bed or Cushion .....               | 158      |
| Sand for Cement Mortar Bed .....                 | 159      |
| Glass Sands .....                                | 159      |
| Physical Properties .....                        | 159      |
| Screen Analysis .....                            | 160      |
| Shape of Grain .....                             | 160      |
| Chemical Properties .....                        | 160      |
| Engine Sand .....                                | 161      |
| Abrasive Sand .....                              | 162      |
| Stone Sawing Sand .....                          | 162      |
| Glass Grinding Sand .....                        | 163      |
| Banding Sand .....                               | 163      |
| Sand Paper Sand .....                            | 164      |
| Stone and Marble Grinding Sand .....             | 164      |
| Sand Blast Sand .....                            | 164      |
| Fineness Grades .....                            | 164      |
| Shape of Grains .....                            | 165      |
| Filter Sand .....                                | 166      |
| Grain Size and Shape .....                       | 166      |
| Chemical Properties .....                        | 167      |
| Special Sands .....                              | 168      |
| Potters Sand .....                               | 168      |
| Roofing Sand .....                               | 168      |
| Flooring Sand .....                              | 169      |
| Sand for Chemical Products .....                 | 169      |
| Sand for Sand Lime Brick .....                   | 170      |
| Sand for Oxysulfate Cement .....                 | 170      |
| Summary .....                                    | 171      |

**PART II.**  
**TESTS OF MICHIGAN SANDS**

| Chapter VII.                            |      |                                |      |
|---|------|--------------------------------|------|
|   | Page |                                | Page |
| Tests of the Michigan Sands.....        | 175  | Methods of Sampling .....      | 175  |
| Explanatory Statement .....             | 175  | Methods of Testing .....       | 176  |
| Maps .....                              | 175  | Method of Reporting Tests..... | 176  |
| Description by Counties.....            | 175  | Significance of Tests .....    | 177  |
| Chapter VIII.                           |      |                                |      |
|   | Page |                                | Page |
| The Southern Peninsula.....             | 178  | Lake County .....              | 210  |
| Sands of and development by counties    |      | Lapeer County .....            | 210  |
| Alcona County .....                     | 178  | Leelanau County .....          | 211  |
| Allegan County .....                    | 179  | Lenawee County .....           | 211  |
| Alpena County .....                     | 181  | Livingston County .....        | 212  |
| Antrim County .....                     | 182  | Macomb County .....            | 213  |
| Arenac County .....                     | 183  | Manistee County .....          | 214  |
| Barry County .....                      | 183  | Mason County .....             | 214  |
| Bay County .....                        | 184  | Mecosta County .....           | 215  |
| Benzie County .....                     | 185  | Midland County .....           | 215  |
| Berrien County .....                    | 185  | Missaukee County .....         | 216  |
| Branch County .....                     | 190  | Monroe County .....            | 217  |
| Calhoun County .....                    | 191  | Montcalm County .....          | 218  |
| Cass County .....                       | 191  | Montmorency County .....       | 218  |
| Charlevoix County .....                 | 192  | Muskegon County .....          | 218  |
| Cheboygan County .....                  | 192  | Newaygo County .....           | 219  |
| Clare County .....                      | 193  | Oakland County .....           | 219  |
| Clinton County .....                    | 194  | Oceana County .....            | 222  |
| Crawford County .....                   | 195  | Osceola County .....           | 222  |
| Eaton County .....                      | 195  | Oscoda County .....            | 223  |
| Emmet County .....                      | 196  | Otsego County .....            | 223  |
| Genesee County .....                    | 197  | Ottawa County .....            | 224  |
| Gladwin County .....                    | 198  | Presque Isle County .....      | 225  |
| Grand Traverse County .....             | 198  | Roscommon County .....         | 225  |
| Gratiot County .....                    | 199  | Saginaw County .....           | 226  |
| Hillsdale County .....                  | 200  | St. Clair County .....         | 227  |
| Huron County .....                      | 201  | St. Joseph County .....        | 229  |
| Ingham County .....                     | 201  | Sanilac County .....           | 230  |
| Ionia County .....                      | 205  | Shiawassee County .....        | 231  |
| Iosco County .....                      | 205  | Tuscola County .....           | 232  |
| Isabella County .....                   | 205  | Van Buren County .....         | 234  |
| Jackson County .....                    | 206  | Washtenaw County .....         | 235  |
| Kalamazoo County .....                  | 208  | Wayne County .....             | 237  |
| Kalkaska County .....                   | 208  | Wexford County .....           | 241  |
| Kent County .....                       | 209  |                                |      |
| Chapter IX.                             |      |                                |      |
|   |      |                                | Page |
| The Northern Peninsula                  |      | Iron .....                     | 248  |
| Sands of and Development of by Counties |      | Keweenaw County .....          | 248  |
| Alger County .....                      | 242  | Luce County .....              | 249  |
| Baraga County .....                     | 242  | Mackinac County .....          | 249  |
| Chippewa County .....                   | 242  | Marquette County .....         | 251  |
| Delta County .....                      | 243  | Menominee County .....         | 252  |
| Dickinson County .....                  | 246  | Ontonagon County .....         | 253  |
| Gogebie County .....                    | 246  | Schoolcraft County .....       | 253  |
| Houghton .....                          | 247  |                                |      |

| Fig. No.  | Page No.  |
|---|-----------|
| 1. Screen analysis plotted on probability coordinates to show distribution of grain sizes according to Rittinger numbers .....  | 55        |
| 2. The same Screen Analysis as in Fig. 1 plotted on rectangular coordinates .....   | 56        |
| 3. The same screen analysis as in Figs. 1 and 2 plotted solely from fractional weight percentages on rectangular coordinates .....  | 57        |
| 4. Rittinger Index as related to Albany Sand Scale .....  | 63        |
| 5. Rittinger Index as basis for Rittinger Scale or slightly raised Albany Scale ..  | 64        |
| 6. Permeability Tester and Rammer .....   | 72        |
| 7. Improved method of connecting rammed sample to permeability tester .....   | 73        |
| 8. Dietert Hydraulic Compression Tester .....   | 82        |
| 9. Construction Dietert Hydraulic Compression Tester .....  | 82        |
| 10. Construction of Rammer for Compression Tests .....  | 82        |
| 11. Construction of Mold for Ramming Compression Test Specimens .....   | 83        |
| 12. Grubb Tension Cylinder for making Tensile Strength Tests .....  | 84        |
| 13. Apparent Relation between Compressive and Tensile Strength of Green Sand ..   | 86        |
| 14. Construction of Automatic Testing Machine .....   | 89        |
| 15. Automatic Test Machine for Precision Strength Tests .....   | 89        |
| 15 a. Rammer used for preparing specimens for strength tests .....  | 92        |
| 16. Compressive Strength as a function of Water Content .....   | 98        |
| 17. Permeability as a function of Water Content.....  | 99        |
| 18. Diagram of Scheme for Hot Dialysis of Ferric Hydrosol .....   | 102       |
| 19. Dialysis Battery for preparing Colloidal Ferric Hydrate .....   | 103       |
| 20. Compressive Strength of Materials used in Synthesis of Bonded Molding Sand...   | 113       |
| 21. Permeability of Synthetic Materials .....   | 114       |
| 22. The effect of Heat on Compressive Strength of various Synthetic Materials .....   | 116       |
| 23. Effect of Water Content (Moisture) on Dry Strength, Permeability, and Green strength .....  | 119       |
| 24. Effect of Heating on Properties of a Zanesville Sand .....  | 121       |
| 25. Effect of Heating to 600 F. on Compressive Strength and Permeability of two Michigan Iron Bonded Sands .....  | 128       |
| 26. The Relation between the Fusion Temperature of Sand-clay Mixture and the percent of Clay in the Mixture.....  | 131       |
| 27. The effect of Method of Treatment on Physical Properties. Solid lines (A) represent riddled sample. Dotted lines (B) represent milled sample.....   | 133       |
| 28. The effect of Ramming and Moisture on Permeability using same relative energy of ramming on different sized specimens. ....   | 135       |
| 29. The Relation between Casting Loss and Dry Strength of Sand.....   | 136       |
| 30. Pit of Garden City Sand Co., Showing top foot of clay loam, as indicated by shovel, over brown sand and clay (Sample 37) .....  | 186       |
| 31. Pit of Garden City Sand Co. Showing clay loam thrown into bottom of dug over pit in foreground of right digging; the brown sand, indicated by shovel, (Sample 37) and the white sand (sample 41) at bottom of pit ..... | 186       |
| 32. Sand Bank in Pit of Burt Core Sand Co. Showing layers of clay and rust in top of yellow sand stratum under the top soil .....   | 202       |
| 33. Steam Shovel loading dinky cars at Burt Core Sand Company's pit near Vassar ..  | 202       |
| 34. Method of screening and loading from dinky cars into railroad cars—Burt Core Sand Co. ....  | 202       |
| MAPS Map of Sand Areas of Northern Peninsula .....  | In Pocket |
| Map of Sand Areas of the Southern Peninsula .....   | In Pocket |

## TABLES

| Table No.   | Page No.       |
|---|----------------|
| 1. Chemical Analysis of Typical Sands .....   | 44             |
| 2. Rational Analysis of Molding Sands .....   | 45             |
| 3. Comparison of Screen Sizes or "Mesh" .....   | 51             |
| 4. Fractional and Cumulative Screen Analysis of St. Joseph County, Michigan. Core Sand. Sample No. 222. (Lab. Sample No. 2108.) .....                   | 54             |
| 5. Calculation of Rittinger Average Fineness Index of St. Joseph County, Michigan. Core Sand Sample No. 222. (Lab. Sample No. 2108.) .....              | 61             |
| 6. Calculation of Rittinger Average Fineness Index of St. Joseph County, Michigan. Core Sand Sample No. 222. Equivalent Arithmetical Method .....       | 62             |
| 7. Calculation of A.F.A. Grain Size Distribution of St. Joseph County, Michigan. Core Sand, Sample No. 222 .....  | 66             |
| 8. Calculation of Rittinger Grain Size Distribution of St. Joseph County, Michigan. Core Sand. Sample No. 222 .....                                     | 67             |
| 9. Base Permeability of Different Sized Mixtures .....  | 77             |
| 10. The Effect of Silt on Base Permeability .....   | 77             |
| 11. Effect of Grain Size and Grain Shape on Base Permeability .....   | 78             |
| 12. Properties of the Natural Molding Sand .....  | 97             |
| 13. Properties of the Natural Base-Material .....   | 100            |
| 14. Properties of the Natural Base-Material .....   | 101            |
| 15. Analysis of Natural Bond Material .....   | 105            |
| 16. Properties of Synthetic Base Material No. 1 .....   | 106            |
| 17. Properties of Natural Base sand plus 1% Hydrated Iron Oxide, Synthetic Base Material No. 2 .....  | 106            |
| 18. Properties of Synthetic Molding Sand No. 1 .....  | 107            |
| 19. Properties of Synthetic Molding Sand No. 2 .....  | 107            |
| 20. Properties of Synthetic Molding Sand No. 3 .....  | 108            |
| 21. Properties for Natural Albany Molding Sand Heated to 600° F. for three hours .....  | 109            |
| 22. Properties of Synthetic Molding Sand No. 1 (Natural Base Material plus Synthetic Bond No. 1, heated.) .....   | 109            |
| 23. Properties of Synthetic Molding Sand No. 2 (Synthetic Base Material No. 2 plus Synthetic Bond Material No. 1 heated.) .....                         | 109            |
| 24. Properties of Synthetic Molding Sand No. 3 (Synthetic Base Material No. 2 plus Synthetic Bond Material No. 2 heated.) .....                         | 110            |
| 25. Properties of Crushed Fused Silica used as Base for Bonded Systems .....  | 111            |
| 26. Properties of Silica Base Material (Base Silica plus 1% Hydrated Iron Oxide.) ..  | 112            |
| 27. Properties of Silica—Kaolin Mixture .....   | 112            |
| 28. Properties of Silica Base Material plus 15% Kaolin .....  | 112            |
| 29. Properties of Silica Base Material plus 15% Kaolin, Containing 0.44% Iron Oxide as Hydrated Iron Oxide .....  | 115            |
| 30. Properties of Michigan City Sand Base Material plus 15% Kaolin Containing 0.44% hydrated Iron Oxide .....   | 117            |
| 31. Properties of Beach Sand (Michigan City) Base Material plus 15% Kaolin Containing 0.44% Hydrated Iron Oxide heated to 600° F. for three hours ..... | 117            |
| 32. Comparison of Laboratory Casting Rehydrability and Heating Tests for Durability .....   | 123            |
| 33. Properties of the (Silica Base Material) plus Kaolin Containing 0.44% Iron Oxide, as Hydrated Iron Oxide, heated to 600° F. for three hours .....   | 125            |
| 34. Properties of Silica Base Material Heated to 600° F. for three hours plus 15% Kaolin containing 0.44% Iron Oxide as hydrated Iron Oxide .....       | 126            |
| 35. Properties of Silica Base Material plus 15% Kaolin containing 0.44% Hydrated Iron Oxide, heated to 600° F. for three hours after mixing .....       | 126            |
| 36. The effect of Centrifuging on Moisture Content .....  | 139            |
| 37. Effect of Mulling on Various Sand Mixtures .....  | 141            |
| 38. Specified Composition of Glass Sands .....  | 161            |
| 39. Screen analysis of sand blast sand .....  | 165            |
| 40. Physical properties of Michigan sands .....   | After page 254 |
| 41. Physical properties of out state sands used in Michigan .....   | After page 254 |
| 42. Summary of Tests of Michigan sands by Ries and Rosan .....  | After page 254 |

## PREFACE

This investigation was started largely at the suggestion of the American Foundrymen's Association, and foundrymen of Michigan, to locate, if possible, any usable molding sand in the State of Michigan. Although there seemed little chance of finding any appreciable deposits of such material, definite results of either positive or negative nature were considered important as a complement to the report of Foundry Sands by Ries and Rosen published in 1908 as part of the Michigan Geological Survey Report for 1907.

As indicated, this report deals mainly with molding sand, but because many Michigan sands are more readily adapted to other uses, at least brief descriptions of the properties necessary and desirable in sand used for other purposes have been included. It is thought that the inclusion of this information may prove of use to those residents of Michigan who wish to estimate the possible economic value and uses of various sand deposits occurring within the State, as well as aiding those foundrymen and other commercial users of sand who wish to find new deposits, within the State, of materials adaptable for their purpose.

The field work was started in the summer of 1923 in conjunction with other field work. Practically no field work was done the following year due to the press of work completing the report\* on Clays and Shales of Michigan. During the summer of 1925 the field work was completed with the assistance of Dr. C. C. Furnas, now professor of chemical engineering at Yale University.

As there are few deposits of naturally bonded sands within the State, investigation was conducted in the laboratory to determine, as far as possible, the fundamental factors responsible for the bond in natural bonded sands with the idea of indicating how such sands might be prepared synthetically from the unbonded sands so common in Michigan. This investigation was successfully conducted by C. C. DeWitt, now professor of chemistry at the Michigan College of Mines and Technology, Houghton, Michigan, during the years 1925 and 1926.

The first part of this bulletin includes a discussion of the physical and chemical properties of sand and the results of this investigation of the cause of bond in naturally bonded sands.

The second part is a detailed description of the sand areas and deposits throughout the State with a complete table giving all of the properties of the sands which have been tested. This description is arranged alphabetically according to counties for the Southern and Northern Peninsulas respectively. By comparing the specifications required of sand to be

\*Pub. 36, Geol. Ser. 30, Mich. Geol. Surv. Div. Dept. Conservation, 1926.

used for different purposes as given in the first part of the report with the tabulated physical properties of the sand in the second part, an approximate idea of the possible economic uses of the various sands may be readily obtained.

With the increasing recognition of the advantages of synthetic or artificial bonded sands for use in foundry practice, it seems reasonable to expect that some of the unbonded sands of the State may, in the not far distant future, be used in preparing bonded sand for molding purposes. This conclusion seems the more probable because of the high freight charges paid in importing sand from other districts, frequently as far as the Albany Molding Sand Districts in New York. It seems reasonable to expect that high quality artificial molding sands may be prepared at a cost (exclusive of digging or recovering the sand) less than the freight differentials between points in Michigan and the present shipping points of molding sand from without the State.

With a few exceptions of suspicious ignorant folk, everyone throughout the State cooperated fully in supplying information that is essential to a report of this kind. A number of the samples collected, during the summer of 1923 were tested under the auspices of the American Foundrymen's Association at Cornell University and at the Bureau of Standards. In some cases duplicate samples were also tested in the University of Michigan in Ann Arbor, for purposes of comparison.

The cooperation of many persons throughout the State and of the American Foundrymen's Association in testing about one hundred and fifty samples is gratefully acknowledged. In addition to those mentioned, Dr. A. R. Carr, now Dean of Engineering in Wayne University, helped with the field work during the summer of 1923; Dr. G. G. Lamb, now assistant professor of chemical engineering, New York University, made the routine physical tests of the Michigan sands not done through the cooperation of the American Foundrymen's Association, and prepared the tabulation of the physical properties. The work was originally conceived, promoted, and finally carefully reviewed by Dr. R. A. Smith, State Geologist. Without his patient effort this bulletin would never have been prepared.

GEO. GRANGER BROWN.

June 25, 1928, Nov. 28, 1934.  
Ann Arbor, Mich.

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PART I. CHEMICAL AND PHYSICAL PROPERTIES OF, AND  
CAUSE OF BOND IN SANDS

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## Chapter I

### ORIGIN OF SAND

#### DEFINITION

##### GENERAL

Sand is the general name applied to comparatively finely divided, unconsolidated grains of rock, minerals, or slag. For this report only the naturally formed product will be considered. Although this report is concerned primarily with foundry sand, it is perhaps well to consider briefly other important uses of sand. Concrete, plaster and similar sands used in construction represent by far the largest consumption of sand. Foundry sands rank next to construction sand in volume of output. For steel work a high silica content is essential for proper refractory qualities. Some molding sands for the non-ferrous metals contain not more than sixty or seventy percent of silica. Sands used for other purposes such as: the manufacture of glass, engine sand to prevent slipping of locomotive wheels, abrasive in grinding operations, filter sand at municipal water filtration plants, fire or furnace sand for lining the bottom of furnaces, as well as sand for other special uses will be discussed briefly as references to them occur in the text.

#### Foundry Sands

A definition of foundry sands will include many sands which cannot be regarded as ideal, but which are profitably and satisfactorily used by the foundries.

**Molding Sand.** Any material which when moist can be formed into a mold from which usable metal castings may be made is known as molding sand.<sup>1</sup> This definition includes the natural-bonded molding sands which are mixtures of sand, clay and colloidal matter occurring in Nature, and similar artificial mixtures generally referred to as synthetic molding sands.

*Core sands* used in preparing cores are lacking in bond or strength and are always bonded by the mixture of some additional agent, which supplies the strength to the sand so that the prepared mixtures can be molded into the large core which then possesses the required strength to secure a satisfactory core for the casting. *Core sands* may then be defined as sand which can be artificially bonded and used in the preparation of satisfactory cores.

<sup>1</sup>M. S. Littlefield, Bulletin No. 50, State Geological Survey, Illinois, page 20.

## ORIGIN

The difference between core and molding sands is essentially the absence of bonding material in the core sands, and the presence of clay and colloidal matter in the bonded or molding sands which gives them the desired property of having strength or cohesiveness so that no artificial bonding agent is necessary in preparing molds for metal castings.

In addition to these forms of unconsolidated sand deposits, there is a large group of consolidated deposits, classed as sandstone and quartz or silica rock, which are crushed and provide a very satisfactory clean sand for use in preparing cores and other artificial sand mixtures for foundry use.

All of the unconsolidated sands of Michigan are, geologically speaking, young, being of the glacial or Pleistocene Age.

The natural processes by which the sand was formed from the bed-rock and then transported and deposited during the glacial period were perhaps somewhat different in degree from the similar processes occurring today but undoubtedly identical in principle. These processes should be considered under four heads:

1. Disruption or disintegration
2. Transportation
3. Deposition
4. Secondary changes

## DISRUPTION OR DISINTEGRATION

The primary source of all sands is pre-existing rock. The disruption or disintegration of this rock may have been accomplished by *chemical means* such as solution in rain water, or *mechanically* by the breaking of the rock into fragments either by changes in temperature causing alternate expansions and contractions of the rock itself and by the freezing of water in the pores and cracks of the rock, or by the growth of vegetation in and through the cracks ultimately breaking the larger rocks into small pieces; by wind through abrasion of sand grains on exposed rock surfaces or through the uprooting of trees growing on rocks; or by glaciers moving over the surface.

*Glacial Decomposition and Solution* are active on the more soluble rock minerals, reducing the original rock to an insoluble residue termed clay, the dissolved mineral salts being carried away by water. This form of decomposition produced sand particles only when the minerals of the original rock contained at least one widely different and relatively insoluble mineral substance.

The relatively large amount of soluble material contained in any sand deposit indicates that chemical decomposition has been much less im-

portant than mechanical disruption. Chemical decomposition continues in such sands after deposition and in some deposits decomposition locally has been an important factor in the production of natural-bonded sands.

Coming down from the north bearing a tremendous load of rock debris scored from the surface of Canada, the ice completely covered the State of Michigan and most of the area north of the Ohio and Mississippi rivers. When the ice sheet retreated this debris composed of boulders, sand, and clay was deposited on the surface of Michigan either as a direct deposit from the glacier or as a material transported from the ice sheet in streams of water issuing therefrom, or deposited by water in glacial lakes. These water deposits are classed as glacial outwash, fluvial and lacustrine deposits.

## TRANSPORTATION

*Glacial.* If the material furnished by the ice sheet had simply been deposited as glacial debris on the surface of the earth without any further transportation or classification, it would not be satisfactory material for any foundry use without expensive artificial separation and classification. Glaciers transport all sizes of material without sorting.

*Streams,* on the other hand, move gravel, silt, clay, and dissolved salts, but with a given velocity they can pick up and carry sediment only up to a certain size, all larger fragments being left behind. An ordinary sluggish creek may pick up and carry gravel and sand during a flood, but as the flood stages retire only the fine sand and silt can be carried, while at the still lower stages of the creek only clay can be transported. Finally at low water the stream will be clear, its velocity being too low for it to carry sufficient clay to make the water roily. The sorting action of streams in transporting material is very delicate and in direct contrast to that of glacial transportation.

*The wind* generally picks up and transports only sand, silt, and clay when such material is loose, dry, and unprotected by vegetation. Its tendency to sort this sediment into different grades of sizes is pronounced, but less so than that of streams.

Transportation in streams and by the wind is now taking place in Michigan in much the same manner as occurred immediately after the glacial period. The shifting sand dunes along the east shores of Lake Michigan are a clear example of present transportation by wind. Every stream and river in the state is continually transporting boulders, sand, silt, and clay, and depositing this material in the same manner as has been done for ages.

## DEPOSITION

*Glacial deposition* is due largely to the melting of the ice and the consequent releasing of the inclosed rock material. The term glacial drift is applied to all such deposits. If for a time the melting of the ice front progresses at the same rate as the forward ice movement of the ice across the country, much of the material carried along in the ice is deposited in a relatively narrow belt along the ice front. The glacial debris is deposited very unevenly, resulting in a hilly, hummocky, or knobby surface, with many deep depressions called "kettles." Such belts or areas of glacial deposits are called *moraines*. They are composed chiefly of a heterogeneous and variable mixture of boulders, pebbles, sand, and finely ground rock particles. The term *boulder clay* or *till* is applied to the unsorted mixture of glacial material. Locally the material is water-sorted, resulting in "pockets" of sand and gravel in the moraines.

If the melting back of the ice margin is faster than the forward movement of the ice the deposits are spread out in the form of gently undulating plains. These deposits are largely of debris carried along beneath the ice or in its lower portion. The term *ground moraine* or better *till plain* is applied to such deposits. Some of the material is sorted in the channels of streams beneath the ice and left in the form of ridges of sand and gravel, called *eskers* or *hogbacks*. Except for the hogbacks deposited along subglacial stream channels, very little sand or gravel occurs within till plain deposits, but in many places these sheets of till are thin and lie on deposits of sand and gravel belonging to an earlier sheet of glacial material.

Both the morainic and till deposits are of widespread occurrence in Michigan. They are conspicuous for the predominance of unsorted material.

Deposits of usable foundry sand in the moraines are generally confined to the flanks of knobs. The thickness of the sand is usually greater at the base and thins upward, grading into sharp sand and gravel at the top. The deposits are generally very small and vary rapidly in grain size. In eskers, the deposits of sand and gravel show rapid variation within very short distances vertically and horizontally, indicating rapid changes in velocity of the sub-glacial stream. Morainic or till deposits are unfavorable sources of satisfactory foundry material and demand the best experience and pit management to produce even a fairly uniform grade of sand.

## River or Stream Deposits

*Fluvial deposition* tends to sort the sediment into size grades, and for this reason offers greater promise in the production of commercial material. If a rapid stream carrying sediment generally decreases in velocity

down stream the gravel and then coarse sand are dropped first, followed progressively by finer material, until in almost still water silt and mud or clay are deposited. But the completeness of the sorting or separation of the different sizes of materials at any one point depends upon the rate of decrease of velocity. It is clear that uniform fineness in a deposit must be dependent upon constant conditions of deposition over a considerable time, as were maintained for considerable periods in those streams which flowed rapidly from the terminals of the glaciers and carried with them some of the material deposited by the ice sheet, as it melted.

Simultaneous deposition of sand and clay without fine sand and silt is an impossibility. There is a remote possibility that alternate layers of sand and of clay might be deposited in such a proportion that the resulting section could yield a satisfactory molding sand composed of sand and clay without large amounts of fine sand and silt. For this reason, the actual formation of a bonded sand containing sand particles and clay without large quantities of fine sand and silt is usually dependent upon secondary changes occurring in the sand after deposition.

*Deposits in Glacial Outwash:* During the period that the Great Ice-sheet retreated northward across Michigan extensive plains of gravel and sandy material were deposited by the many streams which issued from the melting ice front. Some of these deposits are spread out like large aprons or fans. Others form relatively narrow belts marking the channels of former streams, as in the case of deltas. This type of deposit is characterized by the flat nature of its topography. The outwash trends roughly southward from the terminal moraines.

In many places the deposits of outwash streams were fairly well sorted and the sharp sand is of a fairly uniform size. However, the possibility of depositing clay with this sand to form naturally bonded sand is so small that we seldom find any naturally bonded sand in glacial outwash aprons.

If any bonded sand is in these deposits it is very probable that it has been developed by secondary changes after the deposition of the sand. *Weathering*, the process of producing secondary changes, seems to take place best on the large flat areas and is aided to some extent by the covering of vegetation which furnishes organic acids which help in the solution and decomposition of the sand particles forming clay and colloidal matter which supplies the bond in the sand.<sup>2 3</sup> The sand of the Albany district is composed entirely of quartz or chert grains which are very insoluble under ordinary weathering conditions. The grains are coated with a strong type of clay which does not extend below the zone of weathering

<sup>2</sup>D. H. Newland Albany Molding Sands, New York, New York State Museum Bulletin 187, 1916.

<sup>3</sup>C. M. Dennen Albany Molding Sands of the Hudson Valley, New York State Museum Bulletin 273, pp. 19-20, 1925.

or the level of ground water where sharp sand or gravel is encountered. Clay bond in these deposits has been formed by the weathering of the soluble minerals out of the sand particles. Other examples of this type of deposit are found in extensive outwash flats south of Burlington, Wisconsin, and in similar outwash plains in southwestern Michigan.

*Deposits Along Abandoned Drainage Lines.* Occasionally the streams flowing from the ice deposited much sand and gravel in the valleys through which they were flowing. Such streams often clogged the valley with sediment to such an extent that the stream was frequently forced to find another course. Abandoned drainage lines leave filled valleys with no permanent or persistent streams flowing through them.

In numerous places the deposits of old glacial streams are sufficiently well sorted to yield satisfactory foundry material. In such deposits the sands are usually found under flat top terraces where a relatively thin deposit may be sufficiently well bonded to serve as satisfactory molding sand.

*Deposits Along Present Lines of Drainage.* In areas of deposits by the old glacial streams, a smaller stream frequently persists after the retreat of the glacier. These later, present streams cut through the old deposits leaving the sand as terraces above the bed of the stream.<sup>4</sup>

The last deposition on the top of these terraces is frequently bonded molding sands, as in the Zanesville, Ohio, district, where the currents and the material supplied by the streams were favorable for depositing essentially the proper mixture of sand and clay to form a molding sand. Below the molding sand cover there is usually a much greater thickness of sharp sand and gravel. The "Red Flint" blast sand produced at Eau Claire, Wisconsin, comes from such a terrace which was made by the Chippewa River cutting through the sand previously deposited by the old glacial river.

#### Lacustrine or Lake Deposits

*Glacial Lakes.* Locally the old glacial streams or rivers flowing from the terminal of the glacier were dammed by a large deposit of material dropped by the streams or by the edge of the glacier forming a temporary dam across the valley in which the stream was flowing. The sediment, varying from the coarse sand to fine clay, carried by the streams running into these lakes spread over the lake bottom. The coarser material was deposited near the shore where wave action worked it over into sandy beaches or beach deposits and the finer material was carried further out into deeper and more quiet water. Many such deposits are found in Michigan along the old beaches and lake bottoms of the glacial lakes.

<sup>4</sup>J. A. Bownocker, Muskingum County, Sand and Gravel. Geological Survey of Ohio, Fourth Series, Bulletin 21, p. 341, 1916.

David W. Traynor, Jr.,<sup>5</sup> reports an analysis of the clay contents of the sand in the old lake bed at varying distances from the old beach ridge formed by the glacial lake Jean Nicolet in the Berlin District of Wisconsin. On the beach the sand had a clay content of 0.74 percent, two-tenths of a mile from the beach ridge the sand showed a clay content of 4.56 percent; the molding sand in the second foot below the surface and about one hundred feet further away from the beach ridge than the last sample showed a clay content of 30.66 percent; and a sample taken a quarter of a mile from the beach ridge showed 47.42 percent of clay.

In these lake deposits it is reasonable to expect that the natural bonding material was deposited simultaneously with the sand grains using the term "simultaneous disposition" in a geological sense.

Because lake deposits may have been formed in this way and contain sand of the proper size grade deposited with clay bond as molding sands, in which the development of the bond is not necessarily dependent upon weathering, we may expect to find molding sand or naturally bonded sand in lake deposits independent of the penetration of weathering, or other secondary changes in the deposit.

*The Deposits Along the Shores of Present Lakes.* The processes described above are actually occurring at the present time in many of the large lakes of this country which have marked shore currents.

Lake Michigan is a notable example of this sorting action of shore currents. The bluffs along the lake shore vary in height from a few feet to over a hundred feet near St. Joseph and are composed of glacial material consisting principally of sand and clay. The waves working on the bluffs sort this material, carry the clay out into the deeper portions of the lake and deposit the sand along the shore. The south-moving current along the west or Wisconsin shore of Lake Michigan caused by the northeast winds in this section cut into the shore line carrying the sand southward. This is evidenced in the large deposits of sand found piled up on the north side of any artificial or natural obstruction on the west side of the lake.

#### Eolian Deposits

After sediment has been picked up by the wind its place of deposition will depend in a large part upon the size of the sediment and upon its weight. The light particles will be blown higher and carried further than the heavier particles. With certain wind velocity the coarse sand may move by short leaps, the finer sand by longer leaps, and the clay remains in suspension in the air for long distances.

That size which moves very slowly is concentrated into dunes, the finer

<sup>5</sup>Geology of Molding Sand Deposits. The Transactions of the American Foundrymen's Association. Vol. 33, p. 707.

material is winnowed up and carried away. Sand dunes, therefore, occur very close to the source of the sand or sediment picked up by the wind. Because of the high effectiveness of the wind in sorting sediment according to sizes the sand contained in a dune is well sorted and generally of a uniform fineness. The finer windblown sediment which is removed from the sand deposited in the dunes is carried further and deposited later on the bluff or the rim of the valley wall.

This fine material of silt and clay and very fine sand distributed by winds over the country, is known as *loess* and is found in the Central Mississippi Valley especially in the states of Iowa, Kansas and Nebraska covering thousands of square miles. The thickness of the loess is not great varying usually from ten to twenty feet. It is generally supposed that this very fine material which in some cases carries small fossil shells has been blown into its present place from the surrounding flat country and was originally rock flour ground up very finely by the glacier and spread over the country. It is quite variable, sometimes showing more clay matter in places and even a great amount of lime in others.

Loess deposits have been used for stove plate casting at several places especially at the stove foundries in Quincy, Illinois.

Loess deposits are almost lacking in Michigan. The soil, however, throughout the state carries a small amount of wind-deposited material which has rendered extensive districts in the southern part of the lower peninsula somewhat loamy that would otherwise be sandy.

The dune sands along the southern and eastern shores of Michigan are particularly important as a source of core sand. This sand has been well sized by the wind which in places near the mouths of the principal rivers has heaped the sand to heights of one hundred and fifty to two hundred feet above the level of the lake. The high dunes, however, are confined to within one or two miles of the shore of Lake Michigan.

#### Consolidated Deposits

*Sylvania sandstone* at the top of the upper Silurian series and varying from about thirty to three hundred feet in thickness, is present in the southeastern part of the state. Locally the *Sylvania* sand is practically pure silica rock and is mined by two companies near Rockwood and Steiner. When crushed and cleaned this material makes excellent core sand and base for steel sand in making steel castings, as well as being adapted for high grade uses as a glass sand.

#### SECONDARY CHANGES IN SAND DEPOSITS

It has been shown that it is improbable, except in rare cases, for sand and clay to be deposited simultaneously in the same place without the inclusion of very fine sand or silt. As many natural bonded molding

sands are a mixture of sand and clay without fine sand and silt, obviously processes additional to those already considered must have operated on such deposits.

Most of the sand deposits were produced by mechanical disruption or by glacial action. Chemical decomposition and disruption of the sand particles may proceed after this sand has been deposited, as the soluble matter in the rock and mineral particles has not been removed by weathering or chemical action.

Continual leaching of the sand deposits by rain water and by ground water, particularly when they contain some absorbed carbon dioxide from the atmosphere, removes the soluble part of the sand grains, causing a disruption of the grain. The insoluble residue formed by chemical action is left in the interstices between the grains as a deposit of clay. The insoluble particles of sand and mineral matter are left behind as sand grains.

Solution of soluble matter under these conditions in a practically neutral solution favor the formation of colloidal solutions and colloidal particles which are readily absorbed on the surfaces of the sand grain and on the surface of the clay. In this way a deposit of well sorted sand originally without bond, under favorable conditions of weathering may become a well bonded usable molding sand.

Molding sand formed in this way is generally the most valuable sand, as the action of the ground water removes practically all of the lime from the limestone, the alkali from the feldspar, and to a large extent the excess of iron that may be present, leaving the sand behind as essentially silica sand particles and a residue of clay, or aluminum silicate, between the grains.

Chemical disruption of the sand grains is very appreciably aided by organic acids contained in the water. For this reason a growth of vegetation over a sand deposit is an important factor not only in holding in place the deposit and preventing further transportation and sorting of the sand according to size, but also in supplying the chemical means for the continued disruption and solution of the sand grains. This weathering action tends to increase the refractoriness of the sand by the removal of lime, alkali, and some of the iron.

J. E. Fletcher<sup>6</sup> calls attention to the fact that the English molding sands are more ferruginous than those found in America. He credits this high iron content as being the cause of the greater durability of the English sand. In England the highly ferruginous sands are found on the outskirts of the coal measures where red sandstone comes into contact with the coal measures. Wherever there is any trail of volcanic action in these deposits, molding sand is found. When many of the American

<sup>6</sup>Transactions of American Foundrymen's Association, Vol. 33, page 793.

molding sands are burned or heated, they resemble in condition the naturally bonded English sand. Most of the Michigan sands that possess natural bond take on a dark red or brown color when heated to temperatures of 1000 to 1200 degrees F. The importance of colloidal ferric hydrate in a bond and the durability of the molding sands will be discussed later.

The action of weathering begins at the top of a deposit and causes a formation of clay in the upper layers. This heavy layer, as it is called by a producer of molding sands, may be a single thick horizontally continuous layer or it may be a series of thin horizontal layers from an inch or less to over a foot thick separated by somewhat thinner layers of sharp, clean sand. Upon casual inspection it might be supposed that these more or less horizontal layers of high clay content were due to stratification in the deposition of the sand. But this is not the case. In many deposits, such as wind blown or dune sands which are uniformly sorted from top to bottom, the clayey bands are found bearing no relation to the depositional stratification. In other deposits several stratified layers of different fineness may be included in a single clayey band. In general these deposits exhibit four distinct layers as follows:

- (1) At the top a loam or reduced clay supporting vegetation.
- (2) Below this a layer of medium fine sand containing some clay running into
- (3) Sands of high clay content which are separated by a sharp sand usually coarser than found above the clay band, and
- (4) below the clay band the sharp core sand continues as a uniform deposit practically free from bond.

Although these distinct layers are not always in evidence, owing to the fact that the Michigan deposits are still so young as not to have shown clearly the result of the weathering, in general, these four different layers are present or in the process of formation. In the deposits of uniform fineness the clayey bands run parallel to the top of the sand deposits and in their initial stages begin within a foot of the surface.

In Illinois where the sand deposits are considerably older than in Michigan weathering has continued in many places until the sands have merged into a thick heavy layer from five to fifteen feet thick.<sup>7</sup> The core sand deposits near Juniata, Tuscola County, contain only one or two clay bands. In these deposits which are the remains of old glacial lake beaches still relatively young compared to those found in southern Illinois, the weathering has not proceeded sufficiently to develop an appre-

<sup>7</sup>M. S. Littlefield in Bulletin 50, State Geological Survey of Illinois, Natural Bonded Molding Sand Resources of Illinois, page 60.

ciably high clay content. Apparently these deposits represent core sand, at present, or molding sand in the making.

Generally clay bands are more pronounced in the higher deposits above the level of ground water, and seem to be found only in those deposits covered by a surface of soil or some form of vegetation.

Exactly what causes the formation of these clay bands is not clear, but it seems reasonable in view of the facts mentioned that the clay deposited in these sands is obtained originally from the upper part of the deposit either by weathering action or directly from the soil on top of the deposit. A reasonable theory is that the protective action of the vegetable emulsoids on the colloids in the leaching water tends to hold the clay formed in the upper part of the deposit or picked up in the soil in suspension in a flocculated state. Water then descending through the deposit carries this clay with it until the unstable vegetable emulsoids are decomposed or oxidized on reaching the lower sand. This decomposition of the vegetable protective colloid causes deflocculation of the colloidal matter and the deposition of clay.

Within the clayey band all of the coarse grains are usually coated with limonite which suggests that the formation of ferric hydroxide or limonite in the sand deposits may have some influence on the deposition of the clay in the band.

#### SUMMARY

Uniform deposits of well sized material are to be expected only in the sand dune areas and in the deposits known as glacial outwash. Natural bonded sands may be found in small deposits along river terraces generally close to the river banks or in slope mantels formed by wind, or in strictly glacial deposits as at the lower part of the shoulder of drumlins, or in terminal moraines, but in general such deposits are small, variable and unsatisfactory. The best and most valuable natural molding sand is usually found in weathered dune areas or in glacial outwash aprons or in weathered deposits of uniformly sized materials produced by other means.

In Michigan, the sands are still young and generally have not been sufficiently well weathered to produce a satisfactory, durable sand for molding purposes.

## Chapter II

## PROSPECTING AND EXCAVATING SAND

To anyone superficially familiar with the surface geology of Michigan, prospecting for sand would seem an easy task, as sand or sandy soils seem to be almost everywhere in Michigan. Through the central part of the Southern Peninsula large areas which are composed of outwash plains left by the ice sheet offer vast deposits of well classified unbonded sand. The relative abundance of unbonded sands and lack of well classified bonded sands is reason for making a major attempt to locate possible sources of natural bonded or molding sand.

The better deposits of molding sand are most likely to be found in well weathered glacial outwash plains or in similar deposits of well classified or sized sand which have been exposed to the action of surface water for a relatively long time. A careful search through most of the glacial outwash plains of Michigan indicates, however, that these deposits have not been weathered sufficiently to form well bonded sand. In fact, the only areas which show any appreciable natural bond in Michigan are those areas indicated as moraines. These areas may have been subjected to some weathering, or washing by waters of lakes, ponds or streams, which helped to carry some of the clay bond from its original position to other nearby areas which may have contained fairly well classified sand.

It seems, therefore, that the only probable localities containing usable amounts of molding sand are the old lake beds in which the sorted material may have been mixed later with a clay bond, or in small areas of moraines. In such deposits it is not to be expected that any appreciable thickness of molding sand of uniform quality will be found. Somewhat similar deposits may have been formed in small inland lakes from moraines, the material being mixed and sorted by the streams running into these small lakes. There is also a possibility that small pockets of molding sand may be found in the moraines. These pockets will usually be found on the flanks of the knobs or drumlins, usually showing a greater thickness at the base and grading upwards into sand and gravel. Unfortunately the weathering process of the dune sand deposits of glacial outwash plains has not progressed to that degree necessary to form reasonably thick deposits of molding sand. In many of these beach deposits some clay bands have been observed indicating that the weathering process is under way.

Because of these conditions we may expect to find the best deposits of core sand or unbonded well sized sand in the sandy outwash plains, the

lake deposits or beaches of old glacial lakes, and most important, in dune sands particularly along the eastern shore of Lake Michigan.

## EXPLORATION OF DEPOSITS

When a deposit of sand has been located, the thickness, extent and character may be determined by thorough field examination. Because deposits of sand vary rapidly both horizontally and vertically it is important that careful test pitting or boring be done at short distance intervals over the entire deposit. Auger borings are the most convenient to determine carefully the thickness and character of overburden, the thickness and general character of the bonded sand if present, and any changes in color or character of the sand as the borings are extended to greater depth.

Samples representative of different strata found in the deposits should be collected and a careful record taken of the thickness of each stratum represented by the sample. It is far better to keep the samples of the different layers separate and to combine them proportionately in the laboratories to represent an average sample, than to try to collect an average sample in the field, as frequently the real value of the deposit cannot be determined unless the different layers are kept separate.

A satisfactory auger for drilling sand deposits may be readily and cheaply made by welding a two inch carpenter's auger to a short length of three quarter inch pipe. By using a number of three or four feet sections of pipe which may be screwed in as the depth of the hole increases and a "T" to make a handle, the auger may be run down to a depth of thirty feet or more without trouble if the sand does not cave into the hole. If the sand possesses sufficient bond, this caving does not occur. But if the hole tends to fill up, it is possible to keep the sand out of the hole by driving down a larger pipe and working the auger through the large pipe. Where a large sample is desired, particularly, at limited depths, a post-hole auger or digger may prove more satisfactory than the small auger described.

## MAPPING

The data obtained by means of boring is best coordinated by means of a large scale map of the deposit, the distance between borings being posted, and each line of boring paralleling the preceding lines of boring. The borings identified by numbers can then be compared with notes made in the field, for a preparation of a profile of the deposits through the different lines of holes.

A comparison of this profile with a large scale map, and the result of the tests on the various samples collected, will give an approximate idea as to the amount of sand of the desired quality contained in the deposit.

Because the small quantity of sand taken in this way may not be representative of the different layers of the deposit, pits should then be sunk through the supposedly workable sections of the deposits, and at least fifty pound samples obtained by mixing and quartering several hundred pounds of sand taken from this section of the deposit. Care must be taken in sampling to include no surface clay or soil but only that sand from the workable section. A number of samples taken in this way and tested by standard methods should give a satisfactorily accurate idea of the quantity of sand of the desired grade that may be recovered.

### ECONOMIC FACTORS

#### DRAINAGE

Drainage of the deposits may in rare cases offer a serious problem, but generally sand deposits, at least in Michigan, are underlain by sand, so that the drainage occurs naturally without artificial means.

#### THE OVERBURDEN

The overburden, or the soil covering the sand has to be thoroughly removed before the sand can be recovered, in its clean state. For this reason, consideration of the extent and nature of the overburden are important in estimating the value of the sand deposits. The inclusion of unusable sand in an otherwise satisfactory deposit must also receive careful consideration as such inclusions must be avoided in digging.

#### MARKETS AND TRANSPORTATION

Core sand is a very cheap commodity usually selling for less than one dollar and at times as low as fifteen cents, per ton, f.o.b. For this reason, it is important that transportation facilities be readily accessible to the deposits and that the deposits be located at least reasonably near the large markets, so that the possible profit in working the deposits is not entirely consumed in transportation costs.

Molding sand, being a rather scarce commodity in Michigan, is frequently imported from New York or Ohio, with high transportation charges, so that in the case of a natural bonded sand it is not quite so important that the deposit be located close to the large markets.

#### RECOVERING OR PRODUCING SAND

As practically all structural sands as well as foundry sands, are recovered from unconsolidated deposits, the term mining or quarrying hardly applies in the usual sense. Perhaps digging or excavation is a better term for describing the methods used to recover or produce sands.

Methods of working or excavating depend on the character and locality of the sand bed or sand bank, the output or capacity, and whether or not the sand requires subsequent treatment such as washing or cleaning.

In general, the producing of sand may be divided into the following five steps: Stripping, digging or excavating proper, transporting, treating, and shipping.

#### STRIPPING OF OVERBURDEN

Stripping may be done by hand, drag scrapers, or steam shovels depending upon the thickness of the overburden and the size of the working. Small wayside pits have practically been abandoned in favor of large efficiently equipped plants for the production of structural sand. This change has been brought about by the insistence of engineers and builders upon the use of tested sands, as well as the decreased cost of production when operations may be conducted on a large scale. When good grades of suitable material are readily obtainable near at hand, local producers still get large amounts of sand from small pits.

Frequently it is possible to use the overburden as fill for the excavated deposits. If possible filling is always advisable as it eliminates the expense of transporting the overburden and finding a place for its disposal. Because molding sand is usually found under an overburden of soil thereby underlying agriculturally valuable land, the overburden of soil must be replaced after the molding sand is removed. This is accomplished by opening a long pit and removing the sand along the whole length of the pit before a new cut is made. The overburden is removed by hand-shoveling and thrown back into the bottom of the worked out pits. The average thickness of overburden of this kind is not more than about a foot and the thickness of the molding sand layer seldom exceeds two or three feet in Michigan.

In the case of core sand the soil overburden is very thin, and the land is generally of no agricultural value so that it is customary in many core sand pits to remove the entire deposit from the surface down and pass overburden and sand through the screens which are relied upon to remove whatever sticks and grass may have been picked up by the scrapers or by the small power shovel.

#### EXCAVATION

In extensive workings the sand is generally excavated and loaded with steam or electric shovels in cars of the industrial or standard railway type. This method of operation demands a fairly thick bank, or bed, of sand of considerable horizontal extent and a comparatively dry floor on which the shovel may travel.

If the sand is wet or is obtained from river bottoms or bars, a drag

line or some form of dredge will take the place of the steam shovel. Suction dredges have proved satisfactory in excavating under-water deposits where the proportion of gravel to sand is low and the pebbles are not too large to be pumped successfully. Otherwise some form of ladder or bucket dredge is generally used.<sup>1</sup>

The power shovel is a flexible unit which can be readily moved to different parts of the base of the deposit, if the quality is variable, to load the desired grade. It also has the advantages of handling large boulders and coarse gravel. Although railroad type shovels are occasionally used, the revolving type mounted on caterpillar trucks are more flexible and eliminate the laying of heavy planking or rails.

In some of the smaller workings, horse drawn scrapers are used to recover the sand and transport it to the shipping or treating station. It is necessary to resort to scrapers or hand digging if the deposit is relatively thin.

Core sand will not bear the expense of hand digging. For this reason core sand is usually recovered by means of horse drawn scrapers, or by some mechanical diggers such as a small steam or gasoline shovel.

In recovering molding or naturally bonded sand, hand shovelling is necessary in most cases because of the need for rather accurate selection of the parts of the section to be included. The use of scrapers in stripping or removing the overburden is uncommon as the sand surface must be finally cleaned of the overburden by hand shovelling and because the overburden is generally spread evenly over the floor of the excavated part of the pit in order that the agricultural value of the land may be retained.

If the molding sand deposit is very uniform, it is possible to adapt some mechanical digger for recovering the sand. Under these conditions the use of a small steam shovel for thick sections of uniform sand is entirely possible. The use of a machine commonly used for digging ditches has proved satisfactory in a number of cases in which the machine is run up and down along the face of the bank.

The sand dug by any of the methods described above must be cleaned to remove pieces of wood, whatever large stones may have been picked up, and any pieces of metal that may be included in the sand. In the case of structural and core sand this is frequently the only treatment it receives before being loaded on cars for transportation to the market or foundry.

#### TRANSPORTATION

In the pit operated by Fred Black at Juniata, Tuscola County, the sand is recovered by horse drawn scrapers which are dragged up an incline and dumped into a hopper which feeds a belt carrying the sand

<sup>1</sup>W. M. Weigel, Technology and Uses of Silica and Sand, U. S. Dept. of Commerce, Bureau of Mines, Bulletin 266, 1927.

to a rotary screen over the flat car in which the sand is loaded. The belt conveyor and rotary screen are driven by a Ford motor which is the only power equipment required.

Molding sand is usually shoveled into carts and drawn to the screens, or in some cases loaded directly into the trucks.

In some of the larger pits such as that of the Rochester Sand and Brick Company, Oakland County, a steam shovel is used to load a number of small cars on a narrow gauge track which are drawn by horse power or a small gasoline engine to the cleaning and screening plant from which the sand is dumped into the railroad cars.

#### TREATING

In recovering molding sand it is frequently necessary to mix different amounts of the heavy or highly bonded sand found near the upper part of the deposit with the sharp unbonded sand found below, in order to supply the different bonded sands demanded by different purchasers. Adequate mixing demands that before being loaded into the freight car the sand be *mulled* or passed through roll crushers after the desired proportion of the heavy sand and the sharp sand is loaded into small wagons or wheelbarrows.

#### Mixing

Mixing is usually done by loading the desired amounts of sand from the two different sections on the same cart and depending upon mulling and screening to complete the mixing during loading. Although this mixing of molding sand from two different sections of the deposit or from two different deposits in the same district may develop certain desirable properties in the mixed sand, generally the gain in one physical property is certain to be attended by the loss in some other desirable physical property. It seems that whenever mixing must be done it can be done to better advantage by the foundryman than by the producer of the sand, because the foundryman has the immediate objective of the mixing in view.

The manner in which the sand is handled in the pit, may have a very marked influence on the quality of the sand shipped. Occasionally some of the overburden, particularly if it is clayey, is mixed with the sand to increase the bond. This practice may introduce considerable silt or extremely fine sand with the clay, particularly if the clay is water laid or wind-blown material, and not a product of decomposition of the sand particles. The silt has no use or purpose in the molding sand, except in those sands used for very small castings. In this case high permeability to the gases given off during casting and high strength of the sand are not necessary as the castings are small and light and do not generate

large volumes of gas. In molding sands to be used for more exacting purposes, the silt simply clogs up the pores in the sand, preventing free escape of the gases and does not contribute to the strength or bond in the molding sand.

On the other hand, it is customary to mix sharp sand or clean unbonded sand with the heavy bonded sand to produce what is known as a lighter molding sand. In this mixing process the chances are that the clay does not become properly bonded with the sharp sand because the colloidal conditions necessary for the development of its full bond strength do not exist. Mixing of sharp sand under these conditions would tend to increase the permeability of the sand but also to greatly weaken its bond or strength.

#### *Washing*

In preparing structural sand for the market it is frequently necessary to wash the sand to remove most of the clay and silt. The simplest washing method is to excavate the sand by pumps and discharge the wet sand into bins or scows. Passage through the pump and pipe line tends to scour the sand and break up lumps, and the water overflowing from the bins or hoppers carries away the excess clay and silt. Regulation of the depth of water between the overflow and the sand allows the amount of very fine sand remaining to be controlled<sup>2</sup> to a limited extent.

If the sand contains over-size material which must be removed or foreign substances such as roots or pieces of buried wood, the sand must be screened before it may be washed. Very few sands are clean or uniform enough to need no screening.

#### *Screening*

Stationary screens must be given enough slope to clear themselves of over-size. Shaking or oscillating screens need have relatively only a slight slope.

Revolving cylindrical screens in which the axis is placed on a slight angle from the horizontal so that the material will constantly move forward, and conical screens in which the shaft may be horizontal, the slope being obtained by the angle of the cone, are found in many pits. Increasing the slope of these screens spreads out the material in a thinner layer and passage of the fines through the screen is more rapid.

Sand, or gravel and sand, in which the percentage of gravel is low cannot be screened efficiently on stationary screens. For material of this kind the vibrating screens are generally considered more successful. Shaw<sup>3</sup> describes the use of the various types of screens in detail.

<sup>2</sup>Edmund Shaw, The Design of Sand Plant, Rock Products, 25, page 89, December 30, 1922.  
<sup>3</sup>Shaw, Screens for Washing Plants, Rock Products, 25, page 18, October 21, 1922, page 32, November 4, 1922, page 15, November 18, 1922, and page 17, December 2, 1922.

*Stationary screens* may be kept at such an angle with the horizontal to give the most screening with the least tendency to blending. The pitch varies with the kind of fabric used, size and nature of the material to be screened. The apertures of the screen should be slots and not round or square holes, the length of the slot being in the direction of travel of the grain. This allows for the trajectory of the grain. The screen area should be much greater for the fine mesh than for the coarse mesh screen. Short and wide screens are much more efficient than long and narrow screens. To do the best work the long narrow screens should be broken up into sets of short wide screens with baffles to check the speed of the grain.

*Revolving screens* of the ordinary conical and cylindrical forms are specially adapted to washing plants, as it is not only a good screen but a good washer and scrubber as well. For large screens with heavy duties, the trunion type of the cylindrical screen is the best. Screens with central shafts and spiders are preferred to lighter screens with ordinary duty. The slope of the revolving screen is important, a common error being to set them with too little slope. Generally the best slope is from ten to fourteen degrees or two to three inches per foot. The correct speed is equally important and poor work can be sometimes bettered by increasing or decreasing the speed of rotation.

Generally, revolving screens are used in washing plants, as revolving screens are always to be preferred with limited amounts of water. Stationary screens may be used if accompanied by plenty of water and fine screening is not desired.

*The electric vibrating screens* seem to be preferred for fine screening. If electric current is not available there is a wide range of screens which are agitated by mechanical means.

In some installations sizing of the sand is accomplished in settling tanks. Tanks do not size sand as positively as screens but their initial cost is low, and, requiring no power and few repairs, are economical when satisfactory results can be obtained by this method. All washed sand, or sand that has been settled by hydraulic means, requires to be de-watered or dried before shipment.

#### *Drying*

Drying is frequently accomplished in a Lewiston type of steam dryer but there seems to be a tendency in the newer plants to use rotary driers fired by coal or oil. The direct fire driers are without doubt better regarding fuel efficiency, but steam driers may have the advantage of keeping the sand clean and freer from contamination.

Steam driers usually consist of a brick bin with a V-shaped or hopped

bottom discharging onto a belt conveyor. Running lengthwise of the bin are tiers of pipes supported on steel angles through which live steam is circulated. The usual arrangement from the top down, is about seven tiers of two-inch pipes below which at the bottom are two tiers of one-inch pipes, staggered and placed close together. The top of the drier is opened and forms a hopper into which the wet sand is discharged. In practice the wet sand is piled upon the pipes covering them completely. As the sand dries, it falls down between the pipes into the hopper and is discharged onto the conveyor. Circulation of air is maintained through the drier by an exhaust fan connected to an exhaust pipe near the top of the drier on one side. The dimensions of these driers are usually about eight feet wide and six to eight feet high above the hopper bottom, with lengths up to about sixty feet. Each drier section, about twenty feet long, is usually estimated to have a capacity of about two hundred to three hundred tons of sand for twenty-four hours. The dry sand usually contains ten percent, or slightly more, of moisture.

#### SHIPPING

Shipments of the lower grade sands, such as the structural and foundry sands, are usually made in open cars. As these sands have not been especially prepared or dried, little damage is done by exposing them to the elements in shipping. However, rains sometimes have a tendency to wash the clay from the molding sand, particularly if exposed for an appreciable time. Such sands as glass sand, which are carefully prepared and dried, are almost invariably shipped in box cars.

## Chapter III

### CHEMICAL PROPERTIES

Although the physical properties of foundry sand are far more important from all considerations than the chemical properties, the latter must be considered because of their importance in determining the physical properties of the sand. In the final analysis all physical properties may be regarded as outward evidence of chemical conditions existing in the sand.

#### MINERALS IN SAND

The result of a thorough investigation into the mineral composition of sands<sup>1</sup> identified a large number of minerals. Among those found, the following should be mentioned:

#### QUARTZ

*Quartz* ( $SiO_2$ ) is one of the most abundant minerals occurring in nature. Its hardness, insolubility, and lack of cleavage render quartz almost indestructible, and make it the main constituent of sand and gravel.

The principal source of quartz is granite and other igneous and metamorphic rocks, in the formation of which quartz is the last constituent to crystallize during cooling. For this reason quartz grains frequently contain inclusions of minerals that solidified earlier. Hair-like rutile crystals, rods of apatite, and dust particles of other minerals are common and can be readily seen under the microscope. Liquid and gas inclusions are also characteristic of quartz.

Surface water may leach out these soluble inclusions in the quartz, which thereby afford a means for the disruption of otherwise almost indestructible quartz crystals.

If the sand has been formed by weathering of rock in place, the grains are generally angular. In sedimentary deposits, which are generally used in the northern states for sand, the grain has become rounded by being rolled and ground while washed along the stream or by the waves on the beach before being deposited in more quiet water.

Quartz has a hardness of 7, being harder than glass which varies from about 4.5 to about 6.5.

#### FELDSPAR

The *feldspars* occur in different crystal forms and of different compositions. They are all complex aluminum silicates with calcium, sodium,

<sup>1</sup>Dale Condit, Transactions of the American Foundrymen's Assn. Vol. 21, pages 21-27.

or potassium silicates. *Orthoclase*  $KAlSi_3O_8$ , and microcline having the same composition are two different crystalline forms of the same chemical compound. *Plagioclase feldspars*, mixtures of albite, the sodium aluminum silicates, with anorthite, are identified as *oligoclase* and *labradorite*.

The feldspars are probably next to quartz in abundance and distribution in sands. They have a prominent cleavage in two directions inclined at or near  $90^\circ$ . The color of feldspar varies from white, to pink, to gray. In sand, grains of feldspar are often seen that are made up of alternating layers of orthoclase and plagioclase.

Feldspar exposed to weathering in a moist climate undergoes relatively rapid decomposition; the potash, soda and lime bases being leached out, leaving kaolinite, the aluminum silicate which forms the basis of clay. Feldspar fuses at a temperature of about 310 degrees C. corresponding to Cone 9, but different species vary greatly in this property, those containing lime and soda fusing at lower temperatures than the orthoclase. Feldspar is softer than quartz, and is more readily broken down by solution or chemical action.

## MICA

*Mica* exists in a number of species of rather complex compositions, of aluminum silicate with other bases.

*Muscovite* or *white mica* has a formula corresponding to  $H_3KAl_3(SiO_4)$  and occurs in glassy plates which are fairly resistant to decomposition by weathering. For this reason the thin scaly particles of muscovite are frequently evident in sand. *Biotite* or *black mica* is a complex silicate containing potash, and magnesia or iron, with the aluminum silicates common in all mica. Biotite is seldom found in molding sand as it readily alters to chlorite and limonite on weathering. All micas tend to lower the refractory quality of sand and for this reason are generally disadvantageous.

## AMPHIBOLES

*Amphibole*. This group of variable composition, includes *hornblende*, *actinolite*, and *tremolite*, as in the more common varieties. They are all silicates of magnesium, iron, aluminum and lime.

As fusion is not difficult, the presence of the compounds tend to lower the fusing point of the sand which is not then good for heavy work.

## PYROXENE

The pyroxene series is similar to the amphibole series in chemical composition, and has much the same properties of fusion, and ease of weathering, so that they are not common except in recent sands derived

from glacial drift. The series include *diopside*, a silicate of lime and magnesia, *augite*, a complex silicate containing lime and alumina, enstatite, and hypersthene, which are silicates of magnesia and iron.

## IRON

*Iron* is present in sand in a large number of minerals. In addition to those mentioned above, in which iron is found as a part of a complex silicate, the following minerals containing iron without the presence of other metals may be considered as a group:

*Magnetite* ( $Fe_3O_4$  or  $Fe_2O_3FeO$ ) is the black magnetic oxide of iron. This oxide does not weather readily when exposed to water, but when acted upon by organic acids it decomposes to *hematite* and *limonite*. Magnetite is common in sands and in many molding sands. It is present in recent sands either as free grains or as inclusions in other minerals.

*Ilmenite* ( $FeTiO_3$ ) is a black magnetic oxide of iron and titanium and is a common associate of magnetite in sands. It is very refractory and is used in the preparation of linings of puddling furnaces.

*Hematite* ( $Fe_2O_3$ ) is the red oxide of iron. Both hematite and magnetite have a hardness of about 6 on Moh's scale.<sup>2</sup> Although hematite itself is very refractory, when present in large amounts in molding sand and used in the presence of excess iron which is poured into the mold, the iron oxides are frequently reduced to the ferrous condition in which form they slag readily with other minerals, particularly silicates which are always present in sand. For this reason a high iron content in the sand may in some cases cause the sand to fuse and stick to the casting, particularly if the casting is poured at a fairly high temperature.

Like magnetite, hematite is readily dissolved in water containing organic acids. As the water percolates down through the sand, the iron is precipitated as a hydrated oxide, *limonite*, on the sand grains. Apparently this precipitate is largely colloidal in nature due to the protective action of the organic acids. It seems that the presence of limonite deposited in this way on the surface of the sand grains is an important factor in developing a durable bond in the molding sand. The grains of most high grade molding sands are rather thickly coated with limonite in a colloidal condition.

*Limonite* is the hydrated ferric oxide formed by the solution and hydration of magnetite or hematite. It is yellow brown in color and reverts back to the dehydrated form, hematite, when heated to reasonably high temperatures. It is this action which explains the red character of the

<sup>2</sup>A scale of hardness with a diamond 10, corundum 9, topaz 8, quartz 7, orthoclase 6, apatite 5, fluorite 4, calcite 3, gypsum 2, talc 1.

molding sands<sup>3</sup> found in England wherever they have been exposed to volcanic action. The same change in color from yellow or brown to red upon heating of American sands has been noted.

*Siderite* ( $FeCO_3$ ) or iron carbonate, weathers to limonite in much the same way as hematite except that oxidation as well as hydration is involved. Because of the ease of weathering of siderite it is seldom found in sand deposits. It is frequently observed in a deeper, blue layer of clay in a clay bed. As weathering of clay proceeds more slowly than the weathering of sand, because of the open structure of the sand which allows free passage of water and oxygen, siderite is seldom found in molding sands. The color of this blue clay, frequently erroneously called "fire clay", underlying the red clay which has been weathered near the surface, is usually due to the presence of siderite which has not yet been converted into limonite.

*Pyrite* ( $FeS_2$ ), the iron sulphide, has a yellow metallic luster ("fool's gold"), is readily weathered by hydration and oxidation to the sulphate or to limonite. For this reason pyrite is not common in sand derived from surface deposits but is frequently found in the deeper workings of quarries.

#### CALCITE

*Calcium carbonate* ( $CaCO_3$ ) or *limestone* is frequently found as small particles in sand derived from glacial drift, or in recent deposits of sand in glacial outwash, or deposits which have not been thoroughly weathered or leached. It has a hardness of three and a specific gravity of about 2.72. It is generally colorless, white, or amber, with a vitreous or glassy lustre. It dissolves readily in weak acids and is rapidly weathered by surface waters particularly those containing carbon dioxide. Lime acts as a fluxing agent, and is undesirable in sands used for many purposes as well as in foundry sands. It not only tends to lower the fusing point of the sand, but in case of core sand it reacts frequently with the core oils used to create the bond in forming the cores. It also seems to have a deleterious action on the durability of the bond in molding sands.

*Dolomite* is a calcium magnesium carbonate ( $CaMgCO_3$ ) slightly harder and heavier than calcite and is less readily soluble in water and weak acids.

*Magnesite* ( $MgCO_3$ ). Magnesium carbonate, is very similar to dolomite, being somewhat harder, 4 to 5, on Moh's scale and with a specific gravity of about 3.1.

<sup>3</sup>Fletcher loc. cit. see Chapter I.

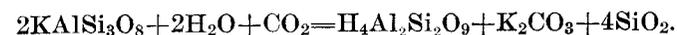
*Gypsum* ( $CaSO_4H_2O$ ) is hydrated calcium sulphate and may be found in recent sands or clays which have not been exposed to thorough weathering.

#### CLAY

In addition to these minerals mentioned above which are found strictly as grains in the sand, or on the sand particles, we have a large group of hydrous aluminum silicates which represent the clay present in the sand. These minerals are always of secondary origin, in most cases probably derived from feldspar, or other similar minerals. Because of the importance of the hydrous aluminum silicates in forming the bond in molding sands, the following should be mentioned:

*Kaolinite* ( $H_4Al_2Si_2O_9$  or  $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$ ), corresponds to a composition of silica ( $SiO_2$ ) 46.6 percent; alumina ( $Al_2O_3$ ) 39.8 percent; water ( $H_2O$ ) 13.9 percent. It is soluble in hot sulphuric acid and in sodium carbonate. When wet it is slightly plastic. It is pearly white, and crystallizes in the monoclinic system in small hexagonal plates with a hardness of 2-2.5 (Moh's scale) and a specific gravity of 2.2-2.6. Its index of refraction (1.56) is the same as that of *Canadian balsam*, and its optical behavior is very similar to that of *muscovite* so that it can be distinguished from colorless mica only by analysis to prove the absence of alkali. When stained with methylene blue the crystals are lamellar and exhibit a zonal structure parallel to the edge.

Kaolinite is always of secondary origin, in most cases probably derived from feldspar. Although chemically possible, its derivation from minerals other than feldspar has never been proved. It may be formed from feldspar according to the equation:



Pure kaolinite is very refractory but a small addition of impurity decreases its refractory properties.

*Halloysite* is closely related to kaolinite, having the same relative amounts of alumina and silica but a greater amount of water, and an amorphous structure. Halloysite is massive, like clay, has a conchoidal fracture, and shows little or no plasticity. Its hardness is 1 to 2 and specific gravity 2.0 to 2.20. Its color is white, frequently with a gray, green, yellow or red cast, with a pearly luster to waxy dull. When placed in water it swells and falls to a powder. It is translucent to opaque, sometimes being even transparent in water with an increase of one-fifth in weight.

Halloysite found in a deposit five miles southwest of Aurora, Missouri, and somewhat stained by yellow clay fused completely at cone 15 (2600 degrees F.) and has the following composition:

|  |        |
|--|--------|
| Silica (SiO <sub>2</sub> )                     | 44.12% |
| Alumina (Al <sub>2</sub> O <sub>3</sub> )      | 37.02  |
| Ferric Oxide (Fe <sub>2</sub> O <sub>3</sub> ) | .33    |
| Lime (CaO)                                     | .19    |
| Alkalies (Na <sub>2</sub> O K <sub>2</sub> )   | .24    |
| Water (H <sub>2</sub> O)                       | 18.48  |

which agrees closely with the theoretical composition as given.

Other less important minerals or mineral substances found in sand are tourmaline, zircon, apatite, rutile, garnet, corundum, chlorite, serpentine, epidote, spinel, indianite, pholerite, allophane, rectorite, newtonite, pyrophyllite, etc. Some are complex silicates and others are oxides. Several of the last mentioned above are hydrated. The combined water in these hydrated minerals does not evaporate on drying, but is driven off as steam only at relatively high temperatures, usually about 650-750 degrees C.

#### SIGNIFICANCE OF COLOR

In most sands weathering has proceeded to such an extent that only those minerals which resisted weathering to relatively high degree are left. Quartz, being practically unaffected by the ordinary agents of weathering, is by far the most abundant mineral in sands used for foundry purposes, constituting in most cases 50 to 70 percent of the entire content. Color is of importance in indicating the nature of the accessory minerals. The white molding sands have, in addition to quartz, such minerals as feldspar, mica, calcite, dolomite, and hydrous aluminum silicates. The carbonates—calcite, and dolomite,—show distinct cleavage and effervesce in hydrochloric acid. Mica has a flaky characteristic silvery appearance. The feldspars are generally partially or completely altered into hydrous aluminum silicates.

Olive green or bluish green coloring is usually due to the presence of ferrous magnesian minerals and their alteration or decomposition products of which chlorite and serpentine and the hydrated magnesium silicates are the most common. Their derivation is chiefly by alteration of olivene, amphibole, pyroxene, epidote, and biotite.

Rusty yellow, reddish brown and chocolate colors in the sand are due to iron oxide. Generally, the yellow reddish sands are considered best for molding purposes as the presence of colloidal iron oxides on the surface of sand grains seems to indicate the desirable bonding properties in natural-bonded sands.

#### CHEMICAL COMPOSITION OF SAND

The oxides determined in sand analysis may serve to give some idea concerning the fusibility of the sand, and suggest some of the minerals which may be present. But, in general, a chemical analysis of sand is of

far less value than direct tests of its physical properties, as the physical properties are those that determine the actual value of the sand, and it is much better to determine the desirable properties directly than to try to estimate them by indirect means as through chemical analysis.

In the ultimate analysis of sand the following oxides are usually determined:

#### SILICA

*Silica* is the most important oxide and practically all of it is supplied by either quartz grains or by the hydrous aluminum silicates in the clay, the rest of the silica being accounted for by mica, or feldspar.

#### ALUMINA AND IRON

*Alumina* is present in the clay or to a slight degree in amphibole, pyroxene or *mica*, when present. *Iron* is usually present as oxides in the form of limonite, hematite or possibly magnetite or siderite. There is also a small amount of iron in other minerals such as chlorite, epidote, and some varieties of amphibole, and tourmaline.

#### LIME

*Lime* or calcium oxide enters into the makeup of a number of the minerals, principally the calcite, dolomite, and some of the feldspars. Many of the Michigan sands contain relatively large amounts of lime, indicating that they are only recently derived from the glacial deposit, as weathering would tend to leach out the lime.

#### ALKALIES

The *alkalies*, soda and potash, may be present in the micas, and in sands recently derived from glacial drift in undecomposed feldspars.

#### SULPHUR

*Sulphur* is usually present only in very small amounts and may be due to pyrite or to some sulphate.

#### WATER

*Water* is almost universally present as moisture, but may also be present in the hydrated minerals, particularly the hydrated aluminum silicates making up the clay substance in the molding sand. The hydrated iron oxide, limonite, chlorite and moscovite, mica, also have water in chemical combination which is given off on ignition.

## ANALYSES OF SAND

Hanley and Simons give analyses of typical sands used in foundry work as in Table I.

TABLE I.—Chemical Analyses of Typical Sands\*.

|   | Medium Molding Sand | Coarse Core Sand | Facing Sand | Fire Sand | Gravel | High Silica Steel Sand | Parting |
|---|---------------------|------------------|-------------|-----------|--------|------------------------|---------|
|   | %                   | %                | %           | %         | %      | %                      | %       |
| Loss on Ignition.....                                 | 3.05                | .75              | 2.00        | 1.14      | 1.34   | .45                    | .45     |
| Silica (SiO <sub>2</sub> ).....                       | 82.10               | 95.25            | 88.52       | 94.00     | 84.18  | 97.55                  | 98.01   |
| Iron Oxide (Fe <sub>2</sub> O <sub>3</sub> ).....     | 5.23                | 1.45             | 5.69        | 2.15      | 3.02   | 1.00                   | 30      |
| Aluminum Oxide (Al <sub>2</sub> O <sub>3</sub> )..... | 7.70                | .50              | 2.47        | 2.45      | 7.95   | .61                    | .85     |
| Calcium Oxide (CaO).....                              | .63                 | 1.01             | Trace       | Trace     | .44    | .15                    | .10     |
| Magnesium Oxide (MgO).....                            | .13                 | .42              | .23         | .08       | .37    | .21                    | .06     |
| Sodium Oxide (Na <sub>2</sub> O).....                 | Trace               | .15              | .06         | Trace     | .07    | Trace                  | Trace   |
| Potassium Oxide (K <sub>2</sub> O).....               | 1.15                | .10              | .85         | .05       | 2.51   | Trace                  | Trace   |

\*Foundry, Vol. 48, p. 742.

## RATIONAL ANALYSIS

Rational analysis a method for conducting a rational analysis of molding sand has been outlined by Field.<sup>4</sup> In this method, the sand is regarded as being composed of quartz, feldspar and clay substance. The method of analysis consists of digesting one gram of sand previously ground to one hundred mesh and dried at 100 degrees C. for one hour, with sulphuric acid for a period of about twelve hours. It is then filtered.

The filtrate, containing the sulphuric acid solution and carrying the iron and alumina of the clay substance, is oxidized with bromine and precipitated with ammonia to determine the amount of iron and alumina in the clay substance.

The precipitate is then digested with a ten percent solution of sodium hydroxide solution, filtered, washed with water, then with 1 to 3 hydrochloric acid, and again with water until the filtrate is free from chlorites. The residue after being ignited to constant weight in a platinum crucible, represents the weight of quartz plus feldspar. This weight subtracted from the original weight of the sample gives the weight of the clay substance. The quartz plus feldspar residue is then fused with five times its weight of sodium carbonate in a platinum crucible to determine the alumina present. The alumina determined in this way represents the alumina of the feldspar, which can then be calculated on the assumption of the formula for feldspar Al<sub>2</sub>O<sub>3</sub>, K<sub>2</sub>O, SiO<sub>4</sub> which has an alumina content of 18.34.

Analyses made in this way on a number of sands showed quartz varying from 45 to about 88 percent, usually between about 78 percent and 67 percent. The clay substance was found to vary from about 9 to about

<sup>4</sup>Transaction of the American Foundrymen's Association, Vol. 21, page 85.

32 percent usually between the limit of 13 and 30. Feldspar varies from about 2.5 to 30 percent.

An average of the rational analyses of the sands from various parts of this country and Europe may be of interest in indicating the results of this method of analyzing sands.<sup>5</sup>

TABLE II.—Rational Analysis of Molding Sands.<sup>6</sup>

| Region                         | No. of Samples | Quartz Percent | Clay Substance Percent | Feldspar Percent |
|--------------------------------|----------------|----------------|------------------------|------------------|
| Albany.....                    | 23             | 58.82          | 18.99                  | 22.16            |
| Kentucky.....                  | 13             | 64.53          | 24.77                  | 10.69            |
| Ohio.....                      | 14             | 71.02          | 23.79                  | 5.17             |
| New Jersey.....                | 4              | 81.38          | 15.49                  | 3.13             |
| Pennsylvania.....              | 9              | 67.21          | 21.99                  | 10.79            |
| Missouri.....                  | 10             | 64.10          | 24.36                  | 11.54            |
| Illinois.....                  | 1              | 70.82          | 16.65                  | 12.53            |
| Georgia.....                   | 1              | 77.37          | 17.94                  | 4.69             |
| Tennessee.....                 | 1              | 74.53          | 21.11                  | 4.36             |
| American Average.....          |                | 65.53          | 21.73                  | 12.74            |
| French sand, Paris region..... |                | 84.45          | 10.68                  | 4.69             |
| German Sands:                  |                |                |                        |                  |
| Bransenburg.....               |                | 87.31          | 10.19                  | 2.50             |
| Freyenwalde.....               |                | 58.63          | 15.77                  | 25.23            |
| Lueneburg.....                 |                | 85.72          | 7.71                   | 6.89             |
| Hanover.....                   |                | 86.57          | 7.52                   | 6.44             |
| British Sands:                 |                |                |                        |                  |
| Workshop.....                  |                | 74.01          | 12.60                  | 8.88             |
| Mansfield.....                 |                | 73.36          | 5.90                   | 12.39            |
| Erith.....                     |                | 73.47          | 14.48                  | 11.40            |
| Kiddemaster.....               |                | 74.40          | 7.71                   | 13.28            |
| Stourbridge.....               |                | 64.76          | 10.53                  | 23.46            |
| South Staffordshire.....       |                | 77.21          | 6.99                   | 13.03            |
| Clyde.....                     |                | 78.23          | 7.03                   | 12.80            |
| Glasgow.....                   |                | 89.47          | 4.70                   | 4.18             |
| Wordsley.....                  |                | 73.34          | 11.76                  | 11.12            |

<sup>6</sup>Moldenke, Principles of Iron Founding, p. 285.

A glance at the figures given in the table above shows that there are wide variations in the composition of molding sands. Decomposed feldspar, which is fusible at high temperatures such as exist when iron is molten, as computed from this method of rational analysis runs as high as 22.16 percent in the Albany sands. This fact may account for the almost universal use of the Albany sands for light work in which the iron sets almost as poured, and hence the fusibility of the feldspar has no chance to come into play.

In order to see if the grain size had any effect on the rational analysis of the sand, samples were classified into three groups: fine sand, more than 90 percent smaller than 100 mesh; medium sand, 80 to 90 percent smaller than 100 mesh; and coarse sand, less than 80 percent under 100 mesh. A tabulation of the quartz, clay substance and feldspar throughout these three different size classifications indicates that, with few exceptions, whether a sand be coarse or fine, it seems to carry the same pro-

<sup>5</sup>Moldenke, Transactions of the American Foundrymen's Association, Vol. 23, page 692.

portion of these materials, depending only upon the deposit from which it was obtained.

#### COLLOIDAL MATERIAL

The importance of colloidal material in natural bonded molding sands is generally recognized. There can be little doubt but that the natural bond in sand is due largely to a colloidal or a surface condition of the sand particles in relation to the "clay substance", which is a general term used by foundrymen to include all of the very fine particles and various colloidal oxides as well as clay.

*The presence of water is necessary* for the proper development of the bond strength in molding sand, and it is also necessary to the development of the colloidal condition, either as a hydrosol or as a hydro-jell. Heating these colloids dehydrates them and in many cases causes some change in their structure which prevents the later absorption of water and the reforming of the original colloid. Heating the sand to high temperatures also destroys the natural bond. A careful study of the colloids contained in natural bonded molding sands and the relation existing between these colloids and the bond, is of fundamental importance to an understanding and accurate knowledge of molding sand.

In the last analysis colloid is probably a physical condition of a chemical substance, and is therefore, on the border line between a chemical property and a physical property.

*Determination.* Methods of determining the amounts of colloids in molding sands have not been sufficiently developed to give any certain degree of accuracy. Physical tests such as measurement of bond strength, or compression tests, are neither accurate nor direct measures of colloidal matter, but are simply the measurements of the physical properties, which are assumed to be dependent upon the colloidal matter in the sand.

Eighteen possible methods under eight distinct headings have been listed for measuring the colloidal contents of soils. The fact that so many different methods have been proposed indicates that no satisfactory test exists for this purpose. Of all these methods<sup>7</sup> the *dye adsorption test* is frequently considered the best. Many investigators object to the use of the dye-adsorption test as a measure of colloidal matter, because, being an equilibrium reaction the result depends on the amount of surface of the sand exposed and the concentration of the dye in solution just as much as upon the colloidal matter present.<sup>8</sup>

It seems that the dye adsorption test might indicate difference in the amount of colloids present in a given particular sand, as changes brought

<sup>7</sup>Estimation of Colloidal Material in Soils by Adsorption, U. S. Department Agriculture Bulletin, 1193, 1924.

<sup>8</sup>C. M. Nevin, Transactions of the American Foundrymen's Association, Vol. 33, page 763.

about by heating. The surface of the sand itself, under these conditions would remain practically constant but the surface of the colloid would change markedly, as the dehydration caused by the heating would cause the colloids to contract and prevent them from adsorbing the amount of moisture originally contained in the hydro-sols and the hydro-jells of the sand.

Work done by William M. Saunders and reported by C. M. Nevin<sup>9</sup> in which this method of determining the presence of colloid matter in various sands was used, seems to indicate that the dye-adsorption test may be used with satisfactory results to indicate the destruction of colloidal matter in a given sand when heated to different temperatures under different conditions. But in using the dye-adsorption test to determine the presence of colloid in sands of different grain size and from different deposits, inherent limitations in this method must be kept in mind if accurate conclusions are to be drawn from the results of the test.

<sup>9</sup>Transactions of the American Foundrymen's Association, Vol. 33, page 793.

## Chapter IV

## PHYSICAL PROPERTIES

The economic value of a sand depends upon its physical properties. The physical properties which are of value in evaluating sands depend in a large measure upon the uses to which the sand is to be subjected. However, there are a number of tests which are used to determine the most important physical properties for all purposes. These tests are of general value, and a number of them are recognized as standard tests.

## TEXTURE OR FINENESS

Fineness or texture of the sand is its most important single property, not only in itself, but also because texture determines to a large extent the degree of the other important physical properties. For this reason, sands are usually classified according to the fineness of the constituent particles. This customary classification of foundry sands is also based on the fact that a coarse sand when molded gives a surface of much coarser texture than does a fine sand. In this way the surface of the resulting casting is dependent very largely upon the texture or fineness of the molding sand used. This same relation also applies to core sands and other sands.

This difference in the texture of the sand is readily recognized without making any special tests and is determined by experienced molders from their sense of touch. This practice has given rise to the term "*relative fineness*" which does not recognize differences in the size distribution of the particles but simply the general fineness or coarseness of the sand.

The degree of sorting or the *size distribution* of the constituent grains or particles of the sand may differ greatly in sands which seem to the eye and hand to be of the same relative degree of fineness. Such variations in the size distribution of the particles affects the permeability and the bond strength to a considerable extent but in itself does not generally affect the suitability of molding sands for a given use. Because this fact has not been generally recognized in the past, particularly by the practical foundrymen, the belief has arisen that every molding sand is a law unto itself and that scientific methods of control are difficult of application.

Recognition, however, of the fundamental factors determining the important physical properties of molding sand clearly indicates the importance of determining *size distribution* as well as *relative fineness*. If sands of spherical particles are perfectly sorted into uniformly sized grains the void in the sand is independent of the grain size. However, if the size distribution is not uniform the percent of void will in no case

be constant, as small particles contained in a sand composed of large grains tend to fill up the void space between the large grains.

## METHODS OF DETERMINING FINENESS OR TEXTURE

*The sense of touch* is reasonably accurate when applied to the determination of the relative fineness of sand, very little experience is necessary to enable one to distinguish correctly between sands differing slightly in fineness grades when the sands are placed side by side for direct comparison. But it requires long and continuous experience to develop anything approaching accuracy in judging the absolute fineness of sands and it is impossible to convey this individual experience to others. It is essential that some more finite method of determining absolute fineness be applied in order that the fineness scale shall be fixed or stabilized for it to become generally useful.<sup>1</sup>

The Albany Grading Scale originally depended solely upon the sense of touch and is still in effect upon this basis, with little evidence of being superseded by any other method. In spite of its crude basis the Albany Grading Scale is quite definite to those few individuals of long experience who supervise the production and loading of the major portion of the Albany sand. The scale becomes less and less definite, however, as the sands are removed from these supervisors until at the extreme end of the handlers among the foundrymen the scale is rather hazily indefinite.

Hansen has shown that this method of grading sands on the basis of size bears a direct relation to the size of the sand particles determined by screen analysis, which is the only commonly accepted scientific method of determining the fineness, and size distribution of sand.

## Screen Analysis

*Rittinger Series*: The fundamental basis upon which American Standard Testing Screens were designed was originally proposed by Professor Rittinger,<sup>2</sup> about 1868. The Rittinger series represents a geometric series in the area of the rectangular spaces between the woven wires constituting the screens, such that the area of any one opening was twice that of the next finer one in the series, or the distance between wires composing the mesh vary in the successive screens as the square root of two, or 1.414.

Later Professor R. H. Richards proposed a similar geometric series containing twice this number of screens, in which the ratio between the sieve openings was the 4th root of 2 or 1.189. This series is sometimes referred to as a *double Rittinger ratio*, and has the advantage of providing an increased number of sieves particularly in the finer sizes.

<sup>1</sup>C. A. Hansen, The Grading of Molding Sand. Transactions of the American Foundrymen's Association, Vol. 24, page 375.

<sup>2</sup>Proceedings the A. S. T. M., Vol. 13, 1913, page 1068.

If the screens are carefully selected and carefully used the single Rittinger ratio series is amply accurate for most practical purposes. Screens, however, are frequently abused in such a manner as to destroy the initially uniform weaves, and when this uniformity of weave is destroyed the screens are very far from being efficient tools. The greater the number of screens, the less important becomes one or more inaccurate screens in the series. Furthermore, the inaccurate screens are conspicuously indicated in the results obtained, so that they can be weeded out and discarded. For these reasons, the *Richard Series* based on the ratio of the 4th root of 2 is generally preferable in making analyses of fineness of sands.

*Mesh:* Although the area of the opening in the wire mesh is the determining factor in sizing, unfortunately the sizes of the various screens have become known in terms of mesh, or the number of openings per linear inch, which bears no direct relationship to the size of the opening unless the size of the wire used in weaving the screen is also specified. As there are at least two important series of testing screens using different sized wire for the same screen openings, this custom of referring to size of materials in terms of mesh has caused needless confusion.

If we follow the suggestion of Hansen<sup>3</sup> and substitute for the conventional *mesh* as designating the size of the screen, a series of serial numbers constituting a rationally uniform scale on which the serial numbers in arithmetical progression represent the area of the openings in the screens taken in geometric progression, these apparent differences in the screen series disappear. Table III indicates that a serial number, as given in the first column with the corresponding opening in the screen reported in the second column in inches, is, according to the double Rittinger or Richard's series, based upon the fourth root of 2. The succeeding columns three and five, give the corresponding number of the screen and actual aperture in the Tyler Series, and columns four and six give the corresponding screen number and aperture in the Bureau of Standard Series.

*A.S.T.M. Method of Mechanical Analysis.* The American Society for Testing Materials method D, 7-27,<sup>4</sup> for making a screen analysis of sand for highway material, requires a representative test sample aggregate weighing fifty grams dried to constant weight at a temperature not exceeding 110° Centigrade, (230° F.). The sample is then passed through each of the following sieves from the Bureau Standards Series: 10, 20, 30, 40, 50, 80, 100, and 200 mesh. The percent by weight retained on each sieve is determined and the sieving on each sieve is to be continued until

<sup>3</sup>Transactions of the American Foundrymen's Association, Vol. 34, page 376.  
<sup>4</sup>A. S. T. M. Standards, 1927, Part II, page 479.

TABLE III.—Comparison of Screen Sizes or "Mesh".

| N—<br>(Rittinger<br>Scale N) | Rittinger<br>Formula<br>Aperture<br>Requirement<br>in Inches.<br>.00102 x 2 <sup>N</sup> | Corresponding<br>Mesh (Linear) |   | Opening in<br>Inches |                                  | Settling Rate<br>in Water,<br>Feet per<br>Minute for<br>largest Grains<br>passing<br>Tyler<br>Screens |
|------------------------------|--|--------------------------------|---|----------------------|----------------------------------|---|
|                              |  | Tyler<br>Series                | Bureau of<br>Standards<br>Series<br>Nominal<br>Mesh | Tyler<br>Series      | Bureau of<br>Standards<br>Series |   |
| 10                           | 1.04448  |                                |   | 1.050                |                                  |   |
| 9.75                         | .877312  |                                |   | .883                 |                                  |   |
| 9.5                          | .7384  |                                |   | .742                 |                                  |   |
| 9.25                         | .62094328  |                                |   | .624                 |                                  |   |
| 9                            | .52224   |                                |   | .525                 |                                  |   |
| 8.75                         | .438656  |                                |   | .441                 |                                  |   |
| 8.5                          | .3692  |                                |   | .371                 |                                  |   |
| 8.25                         | .31047164  | 2.5                            | 2.5   | .312                 | .315                             |   |
| 8                            | .26112   | 3.                             | 3.  | .263                 | .265                             |   |
| 7.75                         | .219328  | 3.5                            | 3.5   | .221                 | .223                             |   |
| 7.5                          | .1846  | 4.                             | 4.  | .185                 | .187                             | 1.002   |
| 7.25                         | .15523582  | 5.                             | 5.  | .156                 | .157                             |   |
| 7                            | .13056   | 6.                             | 6.  | .131                 | .132                             | .872  |
| 6.75                         | .109664  | 7.                             | 7.  | .110                 | .111                             |   |
| 6.5                          | .0923  | 8.                             | 8.  | .093                 | .0937                            | .756  |
| 6.25                         | .07761792  | 9.                             | 10.   | .078                 | .0787                            |   |
| 6                            | .06528   | 10.                            | 12.   | .065                 | .0661                            | .603  |
| 5.75                         | .054832  | 12.                            | 14.   | .055                 | .0555                            |   |
| 5.5                          | .046153  | 14.                            | 16.   | .046                 | .0469                            | .520  |
| 5.25                         | .03880896  | 16.                            | 18.   | .039                 | .0394                            |   |
| 5                            | .03264   | 20.                            | 20.   | .0328                | .0331                            | .408  |
| 4.75                         | .027416  | 24.                            | 25.   | .0276                | .0280                            |   |
| 4.5                          | .0230765   | 28.                            | 30.   | .0232                | .0232                            | .308  |
| 4.25                         | .01940448  | 32.                            | 35.   | .0195                | .0197                            |   |
| 4                            | .01632   | 35.                            | 40.   | .0164                | .0165                            | .226  |
| 3.75                         | .013708  | 42.                            | 45.   | .0138                | .0138                            |   |
| 3.5                          | .01153825  | 48.                            | 50.   | .0116                | .0117                            | .164  |
| 3.25                         | .00970224  | 60.                            | 60.   | .0097                | .0098                            |   |
| 3                            | .00816   | 65.                            | 70.   | .0082                | .0085                            | .114  |
| 2.75                         | .006854  | 80.                            | 80.   | .0069                | .007                             |   |
| 2.5                          | .00576912  | 100.                           | 100.  | .0058                | .0059                            | .0764   |
| 2.25                         | .00485112  | 115.                           | 120.  | .0049                | .0049                            |   |
| 2                            | .00408   | 150.                           | 140.  | .0041                | .0041                            | .0496   |
| 1.75                         | .003427  | 170.                           | 170.  | .0035                | .0035                            |   |
| 1.5                          | .00288456  | 200.                           | 200.  | .0029                | .0029                            | .0310   |
| 1.25                         | .00242556  |                                | 230.  |                      | .0024                            |   |
| 1                            | .00204   |                                | 270.  |                      | .0021                            | .0196   |
| .75                          | .0017135   |                                | 325.  |                      | .0017                            |   |
| .5                           | .00144228  |                                |   |                      |                                  | .0162   |
| .25                          | .00121278  |                                |   |                      |                                  |   |
| .0                           | .00102   |                                |   |                      |                                  | .0096   |

less than one percent of the weight retained on each sieve passes through the sieve during the last minute of sieving. The results so obtained are reported as percent passing 200, 100, 80, 50, — — — mesh.

The A.S.T.M. procedure for making sieve analysis for aggregates of concrete, C 41-24, is somewhat similar to the method described above.

*The A.F.A. Fineness Test.* The methods for making screen analyses adopted as standard by the American Foundrymen's Association in December 1926, were used on the tests herein.

*Procedure for Molding Sands Containing No Clay or Bonding Substance:* One hundred grams of sand dried for at least one hour at a temperature of 105°C, with a tolerance of 5°C, are transferred to the first of a series of sieves, U. S. Bureau of Standards Nos. 6, 12, 20, 40, 70, 100, 140, 200 and 270<sup>5</sup> and placed in a RO-tap testing-sieve shaker. This

<sup>5</sup>The fineness test may be graphically expressed by plotting sieve numbers as abscissa against the grain remaining on each sieve calculated as the percent of 50 grams.

machine is run for thirty minutes, and the amount of sand remaining on each sieve is weighed and expressed in percentage. The portion passing the No. 270 sieve is known as No. 270 minus.

Series of Sieves, U. S. Bureau of Standards

| Sieve Number | Sieve Opening Millimeters | Sieve Opening Inches | Wire Diameter Millimeters | Wire Diameter Inches | Tolerance in Average Opening | Tolerance in Wire Diameter | Tolerance in Maximum Opening |
|--------------|---------------------------|----------------------|---------------------------|----------------------|------------------------------|----------------------------|------------------------------|
| 6            | 3.36                      | .132                 | 1.02                      | .040                 | ± 3%                         | +30%                       | 10%                          |
| 12           | 1.69                      | .0661                | .69                       | .0272                | ± 3%                         | 30%                        | 10%                          |
| 20           | .84                       | .0331                | .42                       | .0165                | 5%                           | 30%                        | 25%                          |
| 40           | .42                       | .0165                | .25                       | .0098                | 5%                           | 30%                        | 25%                          |
| 70           | .210                      | .0083                | .140                      | .0055                | 6%                           | 35%                        | 40%                          |
| 100          | .149                      | .0059                | .102                      | .0040                | 6%                           | 35%                        | 40%                          |
| 140          | .105                      | .0041                | .074                      | .0029                | 8%                           | 35%                        | 60%                          |
| 200          | .074                      | .0029                | .053                      | .0021                | 8%                           | 35%                        | 60%                          |
| 270          | .053                      | .0021                | .041                      | .0016                | 8%                           | 35%                        | 60%                          |

*Procedure for Molding Sands Containing Clay or Bond Substance:* Fifty grams<sup>6</sup> of molding sand, dried for at least one hour at a temperature 105°C, with a tolerance of 5°, are put into a standard one-quart preserving jar, having a smooth side with no sharp shoulders in the neck to prevent the sand from being easily removed with a small stream of water. 475 cc water and 25 cc standard solution of sodium hydroxide (made by dissolving 10 grams of sodium hydroxide in 1,000 cc water) are added, and the jar filled to base of neck is covered and securely sealed. Instead of the usual rubber ring, a rubber disc is employed, which fits into the inside of the glass cover. The receptacle is then placed in a shaking machine, making about 60 revolutions per minute, in such manner as to allow it to be up-ended at each revolution. At the end of one hour the receptacle is removed, the cover unsealed, and the sand adhering to the cover is washed into the receptacle.<sup>7</sup> The receptacle is then filled with water, permitting the stream to stir up the contents, and allowed to stand for 10 minutes, when by means of a siphon extending to within 2.5 centimeters of the bottom of the receptacle, the water is siphoned off. More water is added, filling the receptacle, and at the end of 10 minutes siphoned off. Water is added again, and at the end of 5 minutes siphoned off. The process of 5 minutes' standing and siphoning is repeated until the water remains clear at the end of the 5 minutes' period. By this means the clay substance is separated from the grain, and may be collected in suitable containers and recovered by the addition

<sup>6</sup>Since a 100-gram sample involves so many siphonings as to make the test prolonged, a 50-gram sample is more convenient to use.

<sup>7</sup>The disintegration of the sand in the revolving shaker requires an hour. At the suggestion of H. W. Dietert, the use of a motor-driven milk-shake stirrer in the place of the rotary shaking apparatus is also approved, which accomplishes a satisfactory disintegration in five minutes, thereby saving 55 minutes of the time required to make the fineness test.

of acid to neutralize the sodium hydroxide.<sup>8</sup> The committee on Standard Tests, Trans. A.F.A. 37. (1929) page 554 recommends the following modification. "The minimum internal diameter of siphoning tube shall be 6 m.m.; the bottom of the tube shall be placed one inch from bottom of jar, and the lower end of the tube shall be curved upward being bent with a half inch radius to prevent suction of settled grains from bottom of jar. The tube is placed in jar just prior to siphoning. The outer leg of siphoning tube is to be 2 inches longer than inner leg."

The grain remaining in the bottle or jar is washed on to a filtering paper, in a 9 cm Buchner's funnel, is drained by means of suction, then wet with alcohol, and transferred, together with the filter-paper, to a large glass, and dried for one-half hour at 105°C., with a tolerance of 5°. The dried grain is weighed,<sup>9</sup> and the difference between its weight and that of the original 50 gram sample is ascertained to determine the clay substance.

The dried grain is then subjected to a screen analysis as for unbonded sands, except that the RO-tap machine is run for fifteen minutes instead of thirty minutes.

As both the Tyler Series and the Bureau of Standard Series are based upon an opening of .0029 inches corresponding to the 200 mesh screen, when made with wire of .0021 inch diameter, the Rittinger scale number as given above (Table III) can be used with either series without error.

Unfortunately this particular selection of screens originally recommended by the joint committee on Molding Sand Research<sup>10</sup> does not constitute a uniformly graduated series, as is evident from Table III. The rhythm of the Rittinger Series was sacrificed apparently for the sake of some slight economy in the purchase of screens. This lack of rhythm introduces some error in the interpretation of the screen analysis, and tends to conceal a fairly simple symmetrical distribution of grain sizes which definitely characterizes a large majority of all molding sands. For this reason in the tests conducted for the present investigation a more complete series of screens was used for making these fineness tests.

This lack of rhythm was recognized by the Sand Test Committee of the A.F.A.\* and the U.S.B. of S. mesh screens, 50, 30, 16, and 8 were added since this work was completed.

*Interpretation of Screen Analyses.* The function of screen analysis is to determine the distribution of grain sizes in sand. There are two generally used methods of tabulating the data so obtained, the fractional

<sup>8</sup>For practically all known American molding sands this treatment is satisfactory. There are some foreign sands that are alkaline, and require an acid treatment, in which case tannic acid may be used.

<sup>9</sup>The filter-paper may be disposed of, after drying, by burning, as it lies on top of the sand sample.

<sup>10</sup>Transactions of the American Foundrymen's Assoc., Vol. 31, page 725.

\*Report at Phila. Convention, May 1928.

method commonly used by American Foundrymen's Association, involving tabulation of the weight percentage trapped between each successive pair of screens; and the cumulative method, widely used in Europe and by the mining engineers the world over, involving tabulation of the cumulative percentages coarser than the successive mesh openings. The two methods, are equally legitimate when properly used; the choice between them being mainly the matter of personal opinion.

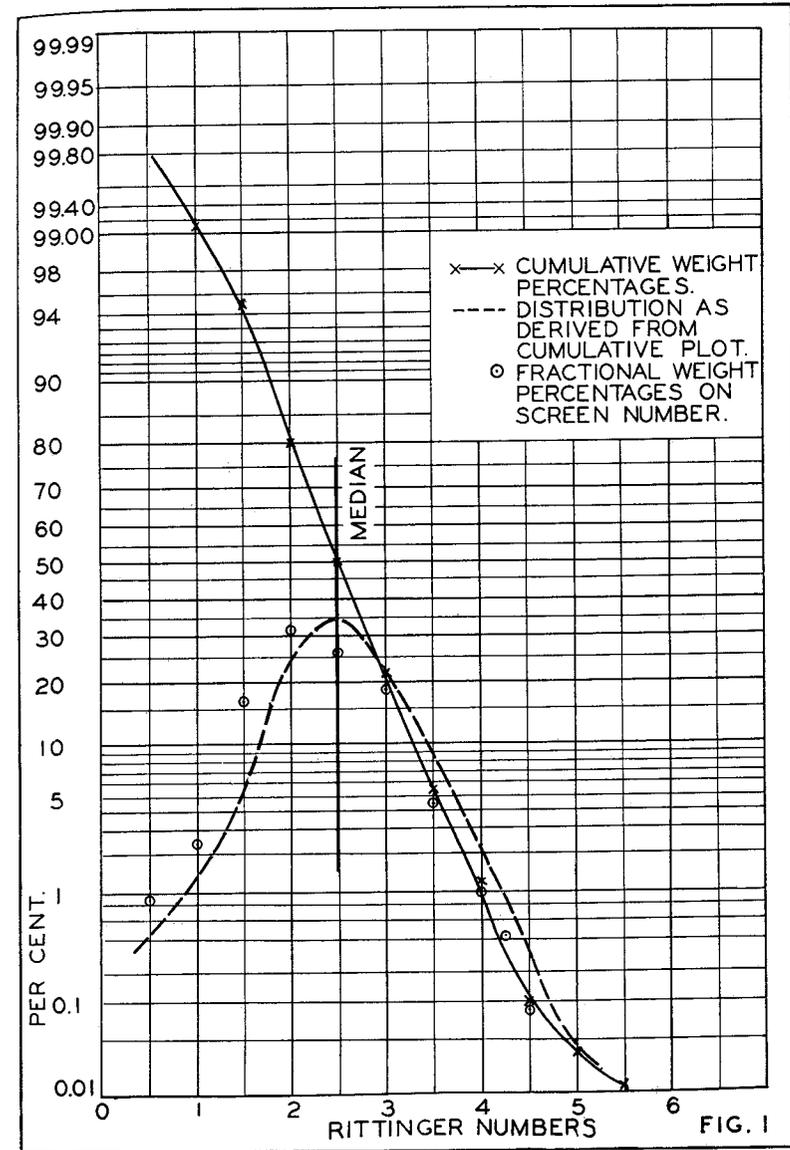
The data obtained in a screen analysis (Table IV) may be shown very satisfactorily in graphical plots, such as Figures 1, 2, and 3. Many graphical methods which do not take full recognition of the rhythm possessed by the Rittinger Series frequently yield grossly distorted pictures of the size distribution they are intended to portray.

*Cumulative:* The solid curves in Figures 1 and 2 are plotted from cumulative percentages. This method of plotting involves but one assumption which can affect its accuracy, that the distribution is continuous or that all intermediate grain sizes are present in the sample as well as those represented by the mesh of the screen on which the fractional part of the sample is retained. The cumulative plot establishes a definitely fixed relation between weight and dimension.

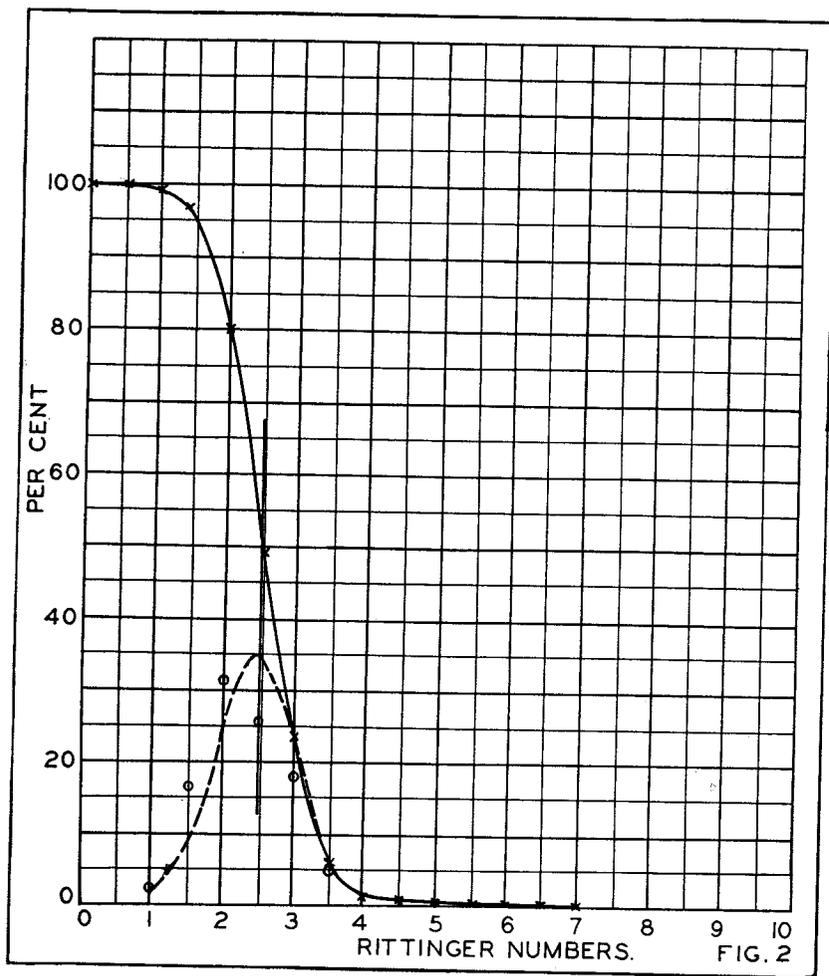
TABLE IV.—Fractional and Cumulative Screen Analyses of St. Joseph County, Michigan Core Sand No. 222 (Lab. No. 2108).

| Rittinger No. | U. S. Bureau Standards Nominal Mesh | Fractional Weight Percent |                 |                   | Cumulative Weight Percent |                 |                   |
|---------------|-------------------------------------|---------------------------|-----------------|-------------------|---------------------------|-----------------|-------------------|
|               |                                     | Rittinger Ratio 1.41      | A. F. A. Series | Rittinger Ratio 2 | Rittinger Ratio 1.41      | A. F. A. Series | Rittinger Ratio 2 |
| 7             | 6                                   | 0                         | 0               | 0                 | 0                         | 0               | 0                 |
| 6.5           | 8                                   | 0                         | 0               | 0                 | 0                         | 0               | 0                 |
| 6             | 12                                  | 0                         | 0               | 0                 | 0                         | 0               | 0                 |
| 5.5           | 16                                  | 0                         | 0               | 0                 | 0                         | 0               | 0                 |
| 5             | 20                                  | 0.03                      | 0.03            | 0.03              | 0.03                      | 0.03            | 0.03              |
| 4.5           | 30                                  | 0.08                      | 0.08            | 0.03              | 0.11                      | 0.03            | 0.03              |
| 4             | 40                                  | 1.02                      | 1.10            | 1.10              | 1.13                      | 1.13            | 1.13              |
| 3.5           | 50                                  | 4.42                      | 5.55            | 5.55              | 5.55                      | 5.55            | 5.55              |
| 3             | 70                                  | 17.81                     | 22.23           | 22.23             | 23.36                     | 23.36           | 23.36             |
| 2.5           | 100                                 | 25.45                     | 25.45           | 25.45             | 48.81                     | 48.81           | 48.81             |
| 2.0           | 140                                 | 31.37                     | 31.37           | 31.37             | 56.82                     | 56.82           | 56.82             |
| 1.5           | 200                                 | 16.63                     | 16.63           | 16.63             | 80.18                     | 80.18           | 80.18             |
| 1.0           | 270                                 | 2.30                      | 2.30            | 2.30              | 96.81                     | 96.81           | 96.81             |
| .5            | Pan                                 | 0.89                      | 0.89            | 0.89              | 99.11                     | 99.11           | 99.11             |
| 0             |                                     |                           |                 |                   | 100.00                    | 100.00          | 100.00            |
| Totals.....   |                                     | 100.00                    | 100.00          | 100.00            | 100.00                    | 100.00          | 100.00            |
| Clay.....     |                                     | 0.20                      | 0.20            | 0.20              | 0.20                      | 0.20            | 0.20              |

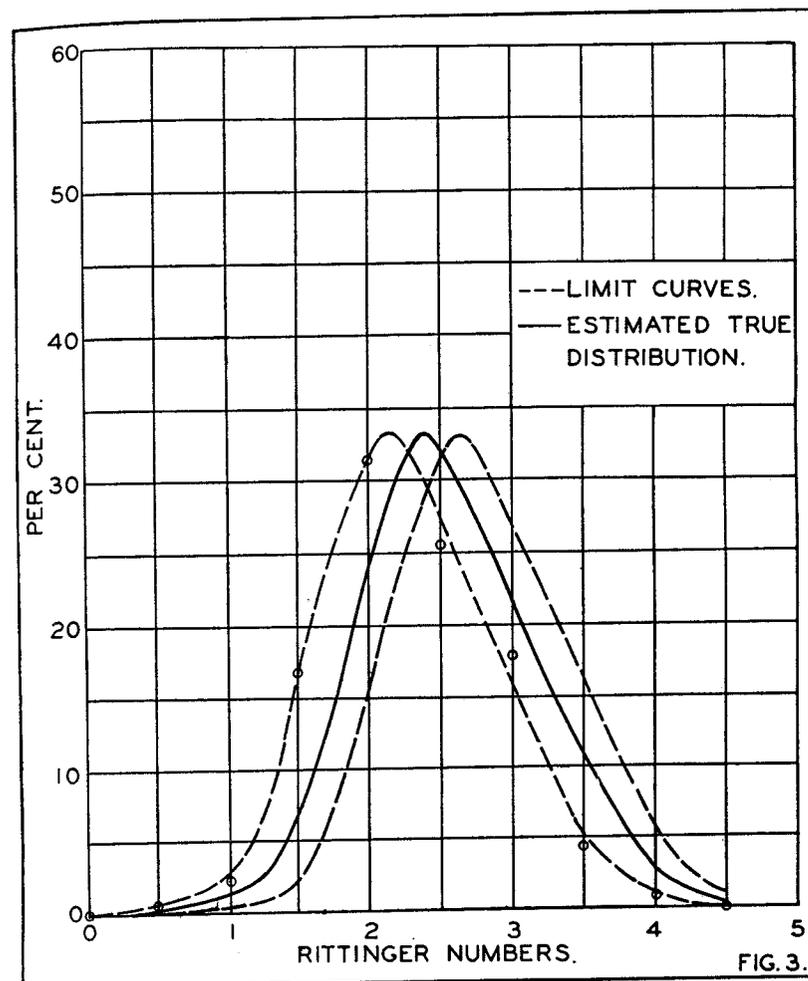
*Fractional:* The fractional data are somewhat less acceptable as a basis for plotting curves, as the data plot merely indicates that a definitely determined weight of material is finer than one and coarser than the other of the two limiting mesh openings. This means that the distribution curve must lie between the determined limits, but its exact



Screen analysis plotted on probability coordinates to show distribution of grain sizes according to Rittinger numbers.



The same screen analysis as in Figure 1, plotted on rectangular coordinates.



The same screen analysis as in Figures 1 and 2 plotted solely from fractional weight percentages on rectangular coordinates.

position is rather difficult to determine, as in Figure 3 the estimated distribution curve is indicated by the solid curve intermediate to the two limiting curves.

In Figure 2, the cumulative data have been used while in Figure 3, dependence has been placed entirely upon the fractional screen analysis.

*Probability Plot applied to Size Distribution:* The coordinate system used in Figure 1 was proposed by Whipple<sup>11</sup> for plotting the probability function and has been used by Hansen<sup>12</sup> in plotting cumulative and fractional screen analysis data, as the distribution of grain sizes in sand should properly come within the scope of probability laws. Sands are deposited in Nature subject to classification by wind and water, conditions that are not sharply selective but still favor the deposition of a specific grain size in any particular deposit. The relative frequency of deposition of other grains should diminish fairly regularly as the deviation from the favored grain size increases, and the distribution of grain sizes should be more or less symmetrical to the selected or favored grain size. If this assumption is true, the Whipple probability coordinate combined with a correctly selected dimensional scale should give a straight line plot of a cumulative screen analysis. The slope of the line would indicate the exactness of the classification, or the uniformity of the grain size.

The advantages of such a plot are obvious, as the curve being nearly a straight line or a rather weakly flexed curve may be quite accurately drawn from relatively few determined datum points. This makes it unnecessary to have a complete set of screens in order to determine the size distribution and serves as a very satisfactory check on the accuracy of the screens used in the making of the tests.

The broken curve in Figure 1 is the distribution curve of fractional data, derived from the cumulative plot. Although this coordinate system is peculiarly adapted for use in plotting screen analyses, several more readily available types of coordinate papers may be used to yield practically the same results. Figure 2 is an example of such a plot on rectangular cross-section paper.

#### FINENESS INDEX

For purposes of grading the fineness of sand, it is convenient if not actually necessary to adopt a single number as the criterion of the fineness or texture of the sand. The conventional numbers used in grading Albany Sand are based upon the texture of the sand as determined by the sense of touch of an experienced foreman.

<sup>11</sup>The Element of Chance in Sanitation, Journal of the Franklin Institute, Vol. 182, p. 205.  
<sup>12</sup>Transactions of the American Foundrymen's Association, Vol. 34, 1926, p. 379.

A fairly rational fineness index may be derived from these cumulative curves as shown. Half of the sand by weight is certainly finer and half coarser than that screen size corresponding to fifty percent on the cumulative curve. The fifty percent dividing line of a probability function would be its axis of symmetry or the median. This median may be adopted as the index of the fineness or texture of the sand.

Another fairly rational fineness index may be derived from the distribution curve plotted from the fractional data. One particular grain size contributes more than any other to the total weight of the sand, that grain size corresponding to the apex of the distribution curve may be called the predominant grain size. This is frequently the same as the median index, as they should be according to the assumption of continuous distribution of the particles throughout all sizes.

These fineness indexes calculated on the basis of the graphical method, are interesting and valuable, but are not well suited as a basis for the exact grading of deliberate mixtures of essentially dissimilar sands. Such mixtures are very seldom, perhaps never, found in nature but they are fairly common in the foundry and are quite frequently prepared by sand producers to blend over-bonded fine sand with coarser weakly bonded sand. For such mixtures the median index loses significance in that it is no longer an axis of symmetry. Likewise the predominant grain size loses significance in that there may be several equally predominant grain sizes. Under these conditions the interpretation of the graph depends entirely upon the personal opinion of the investigator, and different results may be expected by different investigators on the same material.

Similar graphical methods applied to very fine sands which have half or more of their weight beyond the capacity of our finer screens are also rather unsuitable as a basis for exact grading, since the personal equation enters to a large extent in extrapolating beyond the range of easily determined fineness.

For these reasons, it is considered preferable to use arithmetically calculated fineness indexes for exact standard grading of the fineness of sands. Even arithmetical fineness indexes of deliberate mixtures of dissimilar sands are somewhat arbitrary, but at least they possess the merits of being strictly definable so that all who apply the formulated method of calculation will at least reach the same conclusion.

#### A. F. A. Grain Fineness

The Grain Fineness Number of sand, adopted as tentative standard by the American Foundrymen's Association, is defined as "approximately the number of mesh per inch of that screen which would just pass the sample of sand if its grains were averaged in size. It is approximately

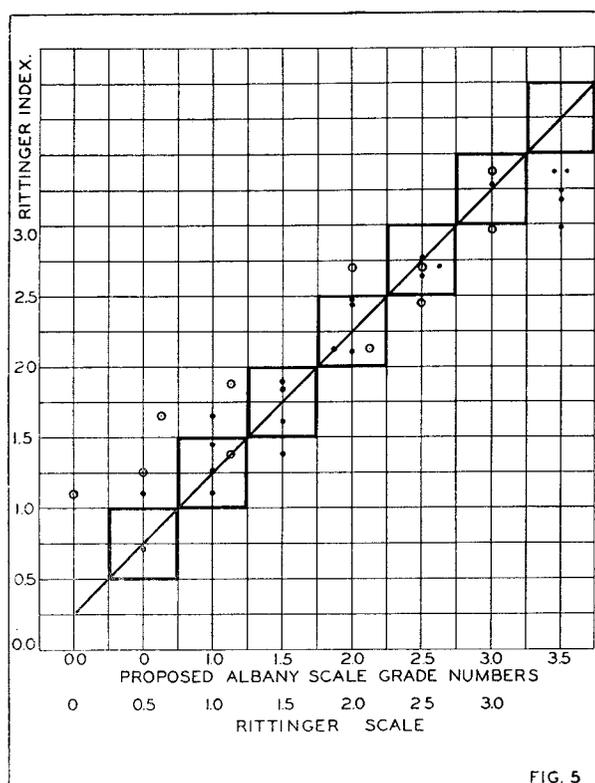




### The Relation Between Rittinger Indexes and Albany Grade Numbers

Hansen<sup>14</sup> has compared the Albany grade numbers of over three hundred sands with the Rittinger Fineness Index as computed by the method described above.

Grouping the sands according to the producers grade numbers as taken from shipping memoranda the average fineness index for grade groups is found to be as indicated by the plot in Figure 4, in which Rittinger Index is plotted along the ordinate and the Producer's Grade Number, the Albany Scale, along the abscissa. The relation between Rittinger Fineness Index and Albany Grade Number seems to be approximately linear for grades 0 to 3 inclusive.



Rittinger Index as basis for Rittinger Scale or slightly raised Albany Scale.

The Rittinger Index for any given sand is a finite number while 'grade' inherently implies a limited range of fineness. Grades must necessarily

<sup>14</sup>Transactions of the American Foundrymen's Association, Vol. 34, page 386.

overlap so long as sand continues to be graded commercially by purely touch sense. Sixty percent of the sands in each producer's grade group fall within the fineness limit indicated by the rectangles in Figure 4.

It is to be noted that grade 00 and 3.5 are essentially identical with grades 0 and 3 respectively both in regard to average fineness and to range of fineness. As a matter of fact, there are no commercially available sands in the Albany District finer than No. 0 or coarser than No. 3, as these grades are defined in Figure 4. Grade 00 and 3.5, or occasionally 4 and 5 are thus of value as selling points rather than as descriptions of the fineness of Albany Sand.

Because of the essentially linear character of the relation between Albany grades and the Average Rittinger Index, Hansen proposes that molding sands and core sands be classified into "Rittinger Fineness Grades" according to Rittinger Fineness Indexes, as shown in Figure 5. The same relation can be extended indefinitely to cover the coarser sands used anywhere in the foundry. This proposed grade classification is essentially that of classifying the fineness of a sand according to the nearest half unit of the Rittinger Fineness index having a numerical value below that of the Rittinger Index. Such proposed grades differ but slightly from the present Albany Sand grades and offer the advantage of close agreement with the size grade now in common use throughout foundry industry.

#### SIZE DISTRIBUTION

Sand of uniform grain size has quite different characteristics from a sand of the same average grain fineness but of a wide range of grain size. The latter packs more densely with the small grains tending to fill the spaces between the larger ones, giving a sand of lower permeability and generally higher green bond strength. At present there is no standard method for expressing grain distribution numerically.

*Methods:* A uniformity coefficient used in connection with classifying filtering sands is determined by dividing the dimension of the screen opening which will pass sixty percent of the samples by the dimension of the screen opening that will pass ten percent of the sample.

*The A.F.A. Grain Size Distribution.* Another method suggested by A. A. Grubb, chairman of the Sub-Committee of Grading,<sup>15</sup> is to divide the average mesh as determined by Ries and Rosen,<sup>16</sup> by the A.F.A. grain fineness number. Ries' method divides the amount of sand retained on each screen by the same number as used for a multiplier in A.F.A. grain fineness number, and divides the total sum of the quotients so obtained

<sup>15</sup>Transactions of the American Foundrymen's Association of America, Vol. 35, 1927.  
<sup>16</sup>Michigan Geological Survey, Annual Report, 1907, page 50.

by the amount of sand used in making the test, the final quotient giving the average size of the sand. The reciprocal of this figure representing the average size of the sand, is a figure representing the average mesh of the sand particles. As the multipliers used in A.F.A. grain fineness number, or the divisors used in determining Ries' average particle size, increase with increasing fineness of the particles it is clear that the A.F.A. grain fineness number weighs the fine material while Ries' method weighs the coarse material. If the sand is all of uniform size the A.F.A. grain fineness number is exactly equal to Ries' average mesh, and the grain distribution as determined by dividing the average mesh by the grain fineness number is unity.

This method of indicating the grain distribution takes into consideration the entire screen analysis and is a definite measure of grain distribution based upon unity for a single grain size and correspondingly decreasing numbers for sand possessing a wide range of grain sizes. Table VII shows the method of computing this factor for sample 222.

TABLE VII.—Calculation of A. F. A. Grain Size Distribution of St. Joseph County, Michigan. Core Sand, Sample No. 222.

| Calculation of A. F. A. Fineness Index |        |         |          | Calculation of Ries Fineness Index |        |         |         |
|--|--------|---------|----------|------------------------------------|--------|---------|---------|
| Screen Interval                        | Fact.  | Weight  | Product  | Screen Interval                    | Fact.  | Weight  | Product |
| -6 + 12                                | 5      | x 0.    | = .30    | -6 + 12                            | 1/5    | x 0.    | = .003  |
| -12 + 20                               | 10     | x 0.03  | = .30    | -12 + 20                           | 1/10   | x 0.03  | = .003  |
| -20 + 40                               | 20     | x 1.10  | = 22.00  | -20 + 40                           | 1/20   | x 1.10  | = .055  |
| -40 + 70                               | 40     | x 22.23 | = 889.2  | -40 + 70                           | 1/40   | x 22.23 | = .556  |
| -70 + 100                              | 70     | x 25.45 | = 1781.5 | -70 + 100                          | 1/70   | x 25.45 | = .364  |
| -100 + 140                             | 100    | x 31.37 | = 3137.0 | -100 + 140                         | 1/100  | x 31.37 | = .314  |
| -140 + 200                             | 140    | x 16.63 | = 2328.2 | -140 + 200                         | 1/140  | x 16.63 | = .121  |
| -200 + 270                             | 200    | x 2.30  | = 460.   | -200 + 270                         | 1/200  | x 2.30  | = .011  |
| -270 + Pan                             | 300    | x 0.89  | = 367.   | -270 + Pan                         | 1/300  | x .89   | = .003  |
|  | 100.00 |         | 8571.2   |                                    | 100.00 |         | 1.427   |

|  |   |
|--|---|
| A. F. A. Fineness Index = $\frac{8571.2}{100} = 86.$   | Ries Av. Size = $\frac{1.427}{100} = .01427$ inches |
|  | Ries Av. Mesh = $\frac{1}{.01427} = 70$             |
| Grain Size Distribution = $\frac{\text{Ries Average Mesh}}{\text{A. F. A. Fineness Index}} = \frac{70}{86} = .815$ |   |

Following are four screen analyses, all of the same A.F.A. grain fineness but varying in distribution:

|                         | (1)  | (2)  | (3)  | (4)  |
|-------------------------|------|------|------|------|
| On 6                    |      |      |      | 6    |
| 12                      |      |      |      | 12   |
| 20                      |      |      | 6    | 15   |
| 40                      |      | 5    | 10   | 30   |
| 70                      | 90   | 80   | 60   | 15   |
| 100                     |      | 5    | 9.5  | 10   |
| 140                     |      |      | 4.5  | 2    |
| 200                     |      |      |      |      |
| 270                     |      |      |      |      |
| Pan                     | 10   | 10   | 10   | 10   |
| Clay Substance          | 70   | 70   | 70   | 70   |
| A. F. A. Grain Fineness | 70   | 68.4 | 58.8 | 40.1 |
| Av. Mesh (Ries)         | 1.00 | .98  | .84  | .57  |
| Grain Distribution      |      |      |      |      |

TABLE VIII.—Calculation of Rittinger Grain Size Distribution of St. Joseph County, Michigan. Core Sand Sample 222.

| Rittinger Screen Series—1.41 Ratio  |        |        |                  |
|---|--------|--------|------------------|
| 7.5 — 7.  | 1/7.25 | .1379  | x .0 =           |
| 7 — 6.5   | 1/6.75 | .1481  | x .0 =           |
| 6.5 — 6   | 1/6.25 | .1600  | x .0 =           |
| 6 — 5.5   | 1/5.75 | .1739  | x .0 =           |
| 5.5 — 5   | 1/5.25 | .1905  | x 0.03 = .005    |
| 5 — 4.5   | 1/4.74 | .2105  | x 0.08 = .017    |
| 4.5 — 4   | 1/4.25 | .2353  | x 1.02 = .240    |
| 4 — 3.5   | 1/3.75 | .2667  | x 4.42 = 1.180   |
| 3.5 — 3   | 1/3.25 | .3077  | x 17.81 = 5.475  |
| 3 — 2.5   | 1/2.75 | .3636  | x 25.45 = 9.23   |
| 2.5 — 2   | 1/2.25 | .4444  | x 31.37 = 13.930 |
| 2 — 1.5   | 1/1.70 | .5714  | x 16.63 = 9.49   |
| 1.5 — 1   | 1/1.25 | .8000  | x 2.30 = 1.84    |
| 1 — 0.0   | 1/0.5  | 2.0000 | x 0.89 = 1.78    |
|   |        | 100.00 | 43.187           |
| $\frac{43.187}{100} = .43187$   |        |        |                  |
| Average Rittinger Size = $\frac{1}{.43187} = 2.313$   |        |        |                  |
| Rittinger Grain Size Distribution = $\frac{\text{Average Rittinger Size}}{\text{Rittinger Fineness Index}^*} = \frac{2.313}{2.52} = .918$ |        |        |                  |

| Rittinger Screen Series—2 ratio.                                |       |        |                  |
|---|-------|--------|------------------|
| 8 — 7   | 1/7.5 | .1333  | x 0 =            |
| 7 — 6   | 1/6.5 | .1538  | x 0 =            |
| 6 — 5   | 1/5.5 | .1818  | x 0.03 = .005    |
| 5 — 4   | 1/4.5 | .2222  | x 1.10 = .245    |
| 4 — 3   | 1/3.5 | .2857  | x 22.25 = 6.355  |
| 3 — 2   | 1/2.5 | .4000  | x 56.82 = 22.528 |
| 2 — 1   | 1/1.5 | .6667  | x 18.93 = 12.630 |
| 1 — 0   | 1/0.5 | 2.000  | x 0.89 = 1.780   |
|   |       | 100.00 | 43.543           |
| $\frac{43.543}{100} = .43543$                                   |       |        |                  |
| Average Rittinger Size = $\frac{1}{.43543} = 2.292$             |       |        |                  |
| Rittinger Grain Size Distribution = $\frac{2.292}{2.54} = .904$ |       |        |                  |

\*Tables V and VI.