DEPARTMENT OF THE INTERIOR—U. S. GEOLOGICAL SURVEY

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THE

GEOLOGY OF THE ROAD-BUILDING STONES OF MASSACHUSETTS

WITH

SOME CONSIDERATION OF SIMILAR MATERIALS FROM OTHER PARTS OF THE UNITED STATES

BY

NATHANIEL SOUTHGATE SHALER

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INTRODUCTION.

The Annual Report of the Director of the United States Geological Survey for the fiscal year 1893–94 contains a memoir by the writer concerning the geology of the highways and the highway materials of this country.[1] The object of this memoir was to present in a general way the conditions of surface and understructure so far as they affect the building and maintenance of good carriage roads. In the following report an effort is made to show the nature of the work which may be carried on, with the end in view of securing such geological information as may be serviceable to the highway boards of Massachusetts.

It is well to state to the reader the conditions under which this report has been prepared; they are as follows: The Commonwealth of Massachusetts began, in the summer of 1894, the construction of a system of main roads which are to be built and maintained at the cost of the public. The experience of the first year of this work, the results of which have been carefully tabulated, makes it plain that true economy requires a systematic exploration of each proposed route with reference to the value of the road-building materials that may be obtained near by the way. As the amount of stone used in macadamizing a road a mile in length, having a width of 15 feet, is not far from 3,000 tons, the cost of the transportation of material for any considerable distance is necessarily a large part of the expense which is incurred in the constructive work. In many cases the proportion of this cost has amounted to more than 40 per cent of the whole expenditure. It is therefore plainly of first importance to take careful account of the stone which may be had near the roadside. Even where the rock is from its nature unfit for use in forming the actual surface of the way, it may still, in many cases, be made to serve as a foundation, on the top of which there may be placed a layer, having a depth of 2 or 3 inches, of broken stone, if need be, of a

[1] Preliminary report on the geology of the common roads of the United States, Fifteenth Annual Report United States Geological Survey, pp. 255–306.

kind which has to be brought from a distance. This combination of low-grade material, which may be made to unite in a substantial manner, but which may be unable satisfactorily to resist the tread of the wheels and the feet of draught animals, with a harder overlying coating will often cheapen the cost of roads, as the experience of the Massachusetts highway commission shows, in the amount of from 20 to 30 per cent of the expenditure.

The results submitted in the tables and descriptions contained in this report are due in the main to cooperative work, in which the United States Geological Survey, the highway commission of Massachusetts, and the engineering laboratory of the Lawrence Scientific School of Harvard University have each had a share. The Federal Survey has furnished the general direction, and has borne the greater part of the cost of the field work. The State commission has provided for the pay of the officer who has been engaged in making the physical experiments, the results of which are set forth, while the Lawrence School has afforded the laboratory and the considerable pieces of apparatus, as well as the dynamic power required for the work. The field work has been so arranged that, while it might serve the immediate needs of the particular way which was under consideration, it has also been of a nature to throw light on the more general question as to the serviceableness of the various kinds of stone for use on roads. The results, as given in the appended tables, show in a general way that the information thus gained may be taken as affording a fair measure of the utility of the several petrographic groups of rocks for road making. As is noted in the text, the experimental results which are set forth in the following pages have been in many instances verified by the tests of practical experience, and many of the varieties of stone have been long used as sources of macadam and their general value has, in a rude but effective way, been tested, and the judgment of roadmasters concerning them has been made up. Others have been tried for a short period on the State roads which were constructed in 1894 and have been several months in use. These last-named trials, though they have been in process for only a few months, are valuable, for the reason that they were made under standard conditions as regards methods of construction and have been subjected to the criticisms of skilled engineers. This very practical study of the problem is one of the many advantages which have occurred through the connection of this inquiry with the labors of the Massachusetts highway commission.

In the preparation of this report I have had the valuable assistance of Mr. Logan Waller Page, who has had charge of the work of collecting during a portion of the time employed in gathering the data, and who has personally, under my direction, carried on the experiments which are set forth in the appendix; and of Mr. Frank Charles Schrader, who, during the present fiscal year, has been employed in the task of obtaining materials and determining their distribution. I have

also to acknowledge the frequent and kind assistance of Mr. William Edward McClintock, C. E., member of the State highway commission, in devising the methods of the experiments, and also in determining the value of the various stones, as shown by his long practical experience in road building.

SYSTEM OF TESTING.

As the value to highway engineers of the matter set forth in the following pages depends in large measure on the methods employed in the investigation, it is necessary to state in some detail the system which has been pursued in gathering the materials and in conducting the tests to which they were subjected. This account is made the more extended for the reason that, so far as I have been able to find, work of this nature has not hitherto been done in this country. It is therefore desirable so to set forth the plan of operations as to make it possible for inquirers to criticise the procedure or to adopt it with such improvements as their better skill or experience may dictate.

As an introduction to the account of the methods employed, it may be well to note that the adequate study of road-building materials is a task of much difficulty. At first sight it may seem best to make a practical test by using the stone in question on a roadway and for such a time as will give, in an absolutely certain manner, the endurance value of the material. The apparent simplicity and effectiveness of this method of dealing with the problem is delusive. A practical trial of a variety of rock can not be made in an efficient manner without laying a road with it for a length of several miles. Moreover, such a road should, in its circumstances of exposure to the weather and to traffic, be exposed to the same range of conditions as would be found in the case of other roads on which the material might be employed. Furthermore, such a road would, during the period of trial, have to be subjected to a very careful study in order to determine in an accurate manner the amount of traffic which it was required to bear. Experience has shown that such a census of the traffic tax on a road can not be attained within the limits of error which would give the results any definite value. Practical experiments of this nature are certain to be very costly, and are sure to be misleading.

The plan of having large practical tests of road-building stones may be subjected to the further criticism that such tests demand a method of work which in all other departments of engineering, where the resistance of materials to strain is a matter of importance, has been found utterly unsatisfactory. No one would think of trying a particular kind of iron, steel, timber, or architectural stone in such a manner. The tests are always made in the laboratory, though the data thus obtained may be criticised by the results of experience, and the methods of the laboratory may be bettered by such criticisms, as they have been and will be in the progress of this inquiry.

METHOD OF COLLECTING.

The materials which have been tested were, with few exceptions, when they came from beyond the limits of Massachusetts, obtained in the following manner: The quarry stone was, so far as possible, taken from faces sufficiently far from the outcrop surface to avoid the effects of weathering. When the deposit had not been quarried, efforts were made to obtain such a fresh face by blasting or by the use of the sledge hammer. In practice it has been found very difficult to secure materials fit for testing in cases where the outcrop had not been the seat of quarry work. This difficulty has limited the range of the study, and probably has resulted in leaving unexamined many good varieties of road-building stones in various parts of Massachusetts.

Of each deposit which has been examined, samples were selected intended to represent the average character of the material there found, and a lot of about 25 pounds was taken to be used in the experiments to determine the resistance of the stone. This was collected in bits of from 1 to 3 cubic inches in bulk, so as to obtain a better average of quality. At the same time specimens were chosen for display in a cabinet and for the study of the petrographic character of the stone.

Where the material consisted of glacial bowlders and pebbles, which in a large part of Massachusetts afford the only conveniently accessible road stone, an effort was made to obtain an average sample which would fairly illustrate the quality of the material that must be employed in road construction. Experience has shown that while it would be possible by the exercise of moderate care in selecting the bits greatly to improve the quality of the erratics used in the crushers which supply the broken stone, it is difficult to induce the men who are employed in the work to take the needed pains.

TESTS.

When the material is prepared for the tests it is broken to about the average size of the fragments used in road making. These bits to the weight of 11 pounds are then placed in the rattler or drum, so hung as to be overturned at the rate of 33⅓ revolutions per minute, which in its overturning has each end alternately lifted and lowered, so that the fragments not only rub over one another but are tossed from one end to the other of the hollow cylinder. The drum is provided with an indicator, so that at the end of 10,000 revolutions, in five hours, its motion is arrested and the abraded material is carefully separated from the remaining solid portion. Each of these parts is then weighed, so as to determine the amount of the charge which has been brought into the state of dust.

The test above described is in all essential features the same as that which has been adopted by the highway engineers of France. As the body of data gathered by those engineers is much the largest and the best ascertained that exists, it has seemed well to make this trial in accordance with the established French method, and not to make changes which have been suggested, even where they have appeared in other respects desirable, because the results would not be intercomparable with those obtained in other countries.

In addition to the abrasion test, studies have been made to determine the value as a cement of the dust that is worn from the fragments of stone. The energy with which this fine material holds the fragments together determines one of the features that it is necessary to ascertain concerning the value of macadam which is made from any particular kind of rock. It has proved difficult to devise a proper instrument for this inquiry. The ordinary tools, known as cement testers, do not give data of value as regards the peculiar pounding action that is effected by the feet of draft animals, for the reason that they determine the resistance of the material to a steadily applied force. On this account a piece of apparatus has been devised which enables us to determine in an accurate manner the amount of the blow that is required to break up the bond in a briquet formed from the dust.

Still another test has been found necessary, though as yet it has been incompletely applied. This is designed to show the recementation value of the powdered rock when the bond which it forms in setting is again and again broken, as it is apt to be by the rude usage to which the superficial materials on the roadway are subjected. To obtain a basis of judgment in this regard the powdered rock is allowed to cement, and after becoming as hard as may be the material is broken to the state of powder; the briquet is then remade and the test repeated.

Although the studies embodied in this report have not as yet attained to anything like completeness, it will be well now to consider their probable relative value in determining the utility of different kinds of rocks to be used in making roads. A careful inspection as to the effect which horses and vehicles have on road stone, an inspection which the writer has made in what seems to him to be a sufficient manner, shows that the damage which traffic does to a road varies somewhat with the nature of its construction. Where the wheelway is paved with blocks of stone, the pieces being fitted closely together, resting on a firm foundation and with the interspaces properly filled with asphalt or other material that will prevent the motion of the separate stones, the damage to the roadway is limited to the result of the blows of shod hoofs and of the compressive and shearing motion of the wheels combined with the stroke which the tires deliver as they come against the edges of the block. Observation shows that the stones used in block pavements wear but little in the central portion of their exposed faces, the greater part of the abrasion taking place on the edges, where the percussive action of the horses' feet and of the tires, as well as the shearing work, is most effective.

Where the stones are used in the cheaper and therefore more generally available methods of macadam, the conditions that determine the endurance of the pavement differ much from those which obtain in the system of block construction. The reasons for this difference are as follows: In a macadam pavement, the stone being rolled down to a smooth surface, the shearing action of the wheels, except under rare conditions, is slight, there being no considerable intervals between the crowns of the separate bits to serve, as in the case of the block pavement, to bring about a sliding motion of the tires. Thus the effect of the traffic on the actual surface is principally wrought by the blow of the horses' feet and the compressive effect of the weight of the vehicles applied through the small field of the tires which actually rest on the roadway. The other differences arise from the dependence of the macadam method on the measure in which the bits of stone are held in their bed places. This holding is in small part brought about by the packing of the stones together under the treading action of the roller. As may be ascertained by inspecting a macadam road where stones, say 2 inches in diameter, have been rolled until they are as firmly compacted as possible, these bits, though they may appear to be firmly held, are not really well fixed in their positions. If the experiment is made before the material has been wetted, it will be found that the bits readily separate from the mass. Such a road, after a little travel, becomes a mere rubble. If, however, the surface is covered with dust—or what comes to the same thing, with fine stone, which is rolled until it is in a powdery state—and especially if this powder is wetted and forced into the underlying mass by the roller and the roadway is then allowed to dry, the separate fragments of stone, if the material be good, will remain in place until they have been completely worn away by the action of the wheels. It is thus evident that the cementation value of the powder produced by grinding the stones is a matter of much importance. The recementation value, or the capacity of the material again to set with many repetitions after it has been broken up, is of value for the reason that it determines the extent to which fragments that have from time to time become loosened may again be bound together into the solid mass of the road by the reuniting of the powder when it is wetted by the rain. Moreover, where the powdered stone has a high recementing capacity it tends to form a somewhat enduring coating on the surface of the road, which in a measure protects the firm-set underlying bits from the blows of the horses' feet and such shearing action as the wheels may apply. Thus a macadam road whose material passes into a powder which does not recement in an effective manner will have its dust quickly blown away and will wear much more rapidly than a road which is made of a stone whose detritus continues to cake in a firm manner, however often it be ground to the powdery state.

The foregoing brief account of the conditions which determine the endurance of a street pavement will serve as a foundation for the consideration as to the value of the experiments which are set forth in the later sections of this report. It will be observed that these experiments do not give any tests having for their purpose the determination of the elasticity of the stone, or in other words, of the extent to which it will sustain weight without going to pieces. The reasons for the omission of this test are as follows: In the first place, save under very unusual conditions of traffic, the amount of weight which is applied by the heaviest loaded vehicles to a roadway is likely to be well within the limits of the elasticity of any stone which a discreet roadmaster would undertake to use in any highway work. It may be assumed that, save in cases of error as to the choice of material, the masses used either in block or macadam work will, if properly bedded, be relieved from the danger of crushing from compressive strains. It may furthermore be said that no apparatus has as yet been contrived which will give, except at very great expense, any proper measure as to the average elasticity of the stone—information which would be of service to the roadmaster. It is true that in the case of architectural stone, where the masses are carefully selected, tests as to elasticity are of great value and can be obtained at a cost which is not disproportionate to the advantage that is gained. But with road stones, where the material has to be taken with little or no selection, it would require an averaging of scores, if not hundreds, of trials to give results of an indicative value.

The test by the abrasion of the stone in the revolving drum is, as may readily be seen, not closely like that to which the material is exposed on the surface of the roadway. The weight of the masses which are moved over one another and the nature of the movement alike differ in a very important way from the conditions which affect the roads. It would be desirable, though as yet it appears to be impracticable, to construct apparatus which would imitate the action of the wheels and horses' feet. It is doubtful, indeed, if by any method short of building a considerable road so arranged that all the materials abraded by traffic could be preserved and weighed any satisfactory determination would be possible. The method used rests upon the assumption that the wear inflicted on the fragments of stone by the rotation of the drum bears a definite ratio to that imposed by the more powerful action of the wheels operating on the roadway. It is highly probable that within the limits required by the road-builder's art the abrasion rate of stone is proportional to the amount of energy applied to grinding off particles from its surface. The French, who invented and have for a long period made use of this test, are content with the results. We may therefore assume that, for the present at least, they may fairly be made use of in this country.

The cementation and recementation tests appear to be sufficient for the end in view. They certainly give a basis for the determination as to the firmness of the bond which unites the bits of the macadam together. They show also, in a general way at least, the extent to which the powdered rock is likely to remain on the surface of the road as a protective coating. Moreover, these experiments indicate that it may be desirable in certain cases, where a stone otherwise suitable for macadam purposes does not afford from its powder a good cement, to cover the road with dust made by grinding some other variety of stone which will afford a firmer bond. It may also be said that these experiments on the binding value of the powdered rock add to the other considerations which lead us to believe that we can not well trust to the formation of rock powder between the bits of stone through the action of the roller in grinding the fragments together, but that experiments should be made looking to the introduction of such powder between the stones before the rolling is begun. An inspection of a section through a newly rolled road shows that the amount of finely divided rock in the lower part of the section is generally insufficient to insure effective cementation. At present the trust is in applying "fines" to the surface, the material being crushed by the roller and, when wetted, worked down into the interspaces between the stones. As the voids in the lower part are imperfectly filled the adhesion in that zone is weak, and the interspaces are apt to gather water, which in freezing disrupts the roadbed.

It should be said that the tests made upon building stones have to be estimated, as regards their value in reference to a particular piece of road construction, by the peculiar conditions of traffic to which the road is to be subjected. Thus, experience shows that where a road receives only a moderate amount of wear, where the teams which pass over it are not numerous and bear no very heavy burdens, the harder traps are likely to prove rather less serviceable than the softer materials. It is, indeed, not improbable that in certain parts of the State, where the traffic is light, it may prove a better policy to use the soft rocks, such as the mica-schists, rather than the more resisting materials. In such cases it will be found that an equation has to be made of the hardness and of the cementing value of the substance. Where the two tests both show as low, it may be assumed that the material is unfit for service in any form of highway construction. Where, however, the binding power is high, though the resistance to abrasion is not so, it will often happen that the rock is worth consideration, especially where a substitute would have to be brought from a considerable distance.

The importance of the considerations just above noted may be reckoned from the experience which has been had in this and other countries in using coral rock in highway construction. Stone of this nature is very soft. It readily pulverizes under the wheels, but the powder thus formed, having the property of binding after having been wet and dried, forms a coating which serves very well when not subjected to the weight of heavy vehicles.

GENERAL ACCOUNT OF THE ROAD-BUILDING MATERIALS OF MASSACHUSETTS.

In the following pages a description will be given of the various classes of rocks occurring within the limits of Massachusetts which may be advantageously used on highways. Incidentally reference will be made to materials which may be made to serve on the less-traveled traffic ways and on sidewalks. Although the account of the materials suitable for road making within the limits of Massachusetts will be set forth mainly according to their regional distribution, it will be necessary to consider the superficial accumulations of glacial waste somewhat apart from the other materials, after which a general account will need be given of the dike stones, to be followed by that of the bedrocks.

ROAD-BUILDING MATERIALS OF GLACIAL ORIGIN.

Although the thickness and character of the glacial drift in Massachusetts varies much in the different parts of its area, no portions of its surface except those which are water covered, those occupied by bogs, and those formed by recent accumulations due to water or wind action, such as the alluvial terraces, the sand spits, and dunes, are quite without glacial débris. In more than nine-tenths of the area of the State the glacial deposits are worthy of search as sources of road-building materials. It is therefore necessary to preface the general account of these ice-made accumulations by some statement as to the circumstances of their origin and distribution.

The greater part of the glacial waste found in Massachusetts, whether measured by area or by quantity, consists of what is known as till or bowlder-clay, a kind of waste composed of fragments of stone varying in size from the largest bowlder, which may contain many thousand cubic feet, downward in size to the very fine bits which are commonly known by the name of clay. These diverse materials are found forming in general a confused coating, which varies in thickness from a few inches to a hundred feet or more. The fragments of this till were worn from the rock by the passage of the ice over the surface; they were commingled with the mass of the glacier, and when it melted away they were dropped upon the surface where they now lie.

It is easy to see that the fragments in the till have been subjected to a rude testing which determines their relative strength at the time when they were broken from the bed-rock. The evidence goes to show that these bits were subjected to yet further stress while they were in the ice, the irregular motion of that mass serving to grind the fragments against one another. In this way it has come about that in a mass of till the pebbles and bowlders, which often constitute by far the larger part of its bulk, are, or at least were immediately after their separation from the bed rock, the harder parts of the material. All the weak bits are likely to have been reduced to the state of powder. On this account the bowlders of the till are, except where they have been long exposed to the weather, prevailingly of a more uniformly solid nature than are the quarry rocks from the same sources of supply.

Next after the till, both in volume and in area of distribution, come the deposits of washed drift, i. e., of glacial waste which has been subjected to the action of streams of water which poured forth from beneath the ancient glaciers and flowed for great distances both beneath the ice and beyond its front. In general, this washed drift contains a much less amount of pebbly and bowldery materials of a nature to be serviceable for use as road-building stones than does the till. Where pebbly the fragments are usually of small size, and in most cases the flinty matter (that is, of material on the whole unsuited to road making because of its brittleness and the lack of binding power in the powder which it makes) predominates. Here and there, at points where the current action was particularly strong, the fragments may be of considerable size. This is especially the case in those accumulations which were formed in the caverns that afforded ways for the subglacial rivers. At many points in New England and elsewhere the ancient subglacial arches are still traceable through the extensive deposits of detritus which have been accumulated in them. (See Pl. XVIII.) Owing to the fact that the subglacial streams generally flowed with great energy, the masses of rock which these deposits contain are often of large size. Not infrequently the greater part of the accumulation is made up of bowlders averaging more than a foot in diameter.

As might be inferred from their history, the fragments in the washed drift are usually of more durable nature than those found in the till. It needs, however, to be noted that in this waste the materials of a quartzose nature are more apt to survive the stresses to which they have been subjected than are those of the other species of rocks. As will be seen from the tests, the slight binding power of quartz dust and the ease with which the material is fractured make this species essentially unfit for use in the construction of macadam roads. It may be further remarked that, except in the deposits which were made in the old ice caves, the washed drift generally yields pebbles of small size, usually so small that they can not be profitably employed for making crushed stone. Where the accumulations were formed at a considerable distance in front of the glaciers from which the streams came forth the pebbles are commonly less than an inch in diameter and are thus worthless in road making.

The third group of glacial deposits which deserves attention here is that formed in front of the ice, having the character generally denoted by the term frontal moraine. Although these accumulations commonly contain a considerable amount of till and of washed detritus, they are characteristically composed of stones, often of large size, which were pushed forward by the ice or dropped along the margin of the glacier in consequence of its melting. These masses of stone are often accu-

CROSS-SECTION THROUGH A SERPENT KAME OR ESKER; WESTON, MASSACHUSETTS.

mulated without order and with many interspaces, the whole bearing the aspect of a ruined wall of cyclopean masonry. (See Pls. XIX, XX.) Such deposits often afford great accumulations of stone which are as convenient for the quarryman's use as they would be if they lay in their original bed places. Not infrequently in New England they have been used as sources of building stone.

The value of the drift deposits as sources of rock to be used in crushed form depends to a great extent on the amount of decay to which they have been subjected since they were brought to the position which they now occupy. Although it has been but a few thousand years, possibly not more than ten or twelve thousand, since the glaciers disappeared from New England, and perhaps not much longer since they passed away from the more western portions of the United States, the amount of decay which has taken place in these originally very solid bowlders and pebbles is, though variable, often very great. In many cases it makes the materials essentially unfit for road building. It is therefore important to note certain features in the distribution of this decay as regards the kinds of rocks, their relations to the surface, and their areal distribution.

In general it may be said that the smaller bowlders, other than those of quartz, which have lain on the surface of the ground since glacial time, have, by decay, often been rendered unfit for use on highways, except where they can be placed in the substructure. When broken they are too soft to resist the action of the wheels or of the horses' feet. Both on the surface and underground the decay is greatest in those rocks which contain considerable amounts of iron in other than the form of magnetic oxides and those which are made up in considerable parts of the species of feldspar which readily pass into the state of kaolin. In almost every part of New England a close observer will note places where large bowlders presenting these conditions have so far fallen to pieces that masses originally solid, having a content of 200 or 300 cubic feet, have broken down until they form low mounds of rubble.

The decay of rocks on or near the surface is often much hastened by the action of the roots of trees, which penetrate the crevices, carrying with them the conditions of chemical change. There is also a general opinion in New England that the splitting of bowlders is often brought about by the action of lightning. I have been shown a number of instances of this sort in which it was difficult to explain the rending of the masses, appearing as if done by the action of gunpowder, by any other supposition than that of a heavy electrical discharge, which, by vaporizing the water along the rift planes of the mass, had, in a manner, exploded it.

The amount of decay in the superficial drift in New England decreases in an evident way as we go from the southern border of that district northwardly. It is thus much more evident in southeastern Massachusetts than in New Hampshire. It appears to me more distinct in the southern portion of the last-named State than along the border-line of Canada. This, it may be remarked in passing, is one of the evidences that the ice endured in the northern part of this country longer than it did in the southern part.

The maximum of decay is exhibited by the bowlders which lie on the surface of the ground; the action diminishes with the depth of burial down to the level to which the process of oxidation has penetrated. In cutting through a considerable section of drift materials, it will be observed that the upper portion always shows the effect of the changes brought about through the action of the atmosphere and of water. The depth of this changed zone varies in a great measure according to the character of the fields, as affecting the penetration of the oxidizing agents, and their distance back from the ice front. Thus in southern New England the alteration is visible to the bottom of the deepest section of washed drift and may be traced in the till deposits to the depth of from 16 to 20 feet, the difference being due to the relative porosity of the materials. In northern New England the penetration of decay is, in the till at least, much less evident, the zone of decay not usually extending to the depth of more than 4 or 5 feet in the till, while the washed drift occasionally shows apparently unchanged condition at the depth of 20 feet below the surface. In general it may be said that the materials from the washed drift are of a less satisfactory nature, on account of the decay to which they have been subjected, than those from the till.

Owing to the prevailingly open nature of the materials accumulated in the frontal moraines, where, as before noted, there are often interspaces between the fragments of the débris, as well, perhaps, as to the fact that the stones have more commonly been transported in the upper parts of the ice, the decay of the fragments is often much greater than that exhibited in the other classes of glacial waste. (See Pl. XX.)

Experience in highway construction shows, at least so far as New England is concerned, that the surface bowlders of small size are in general so far decayed that, whatever their original constitution may have been, they are not now in a suitable condition for road making. It is usually possible, by a careful selection, to pick out the useful from the useless mass, but this discrimination can rarely be exercised in a profitable way. As it may in some instances be useful, and indeed necessary, to make the effort to effect this separation, a description of a simple test may well be given. This can be made in the following manner: Taking a light sledge hammer, the inquirer should proceed to break in succession, on a line across the field from which the stone may be obtained, bowlders to the number of, say, one hundred. Where these stones crumble under the stroke, falling into numerous bits, and at the same time the fragments are readily powdered by light blows of the hammer, the bowlder may be regarded as worthless. Where the breakage occurs along one or two distinct planes and the pieces are not

VIEW OF A FLAT-TOPPED MORAINE; DOGTOWN COMMONS, CAPE ANN, MASSACHUSETTS.

in turn easily broken, it may be assumed that decay has not materially harmed the stone. After a few tests, the observer will learn to know by the sound of the hammer the condition of the bowlder; he need not, indeed, be at the trouble of breaking it.

If, with the use of the test above described, 90 per cent of the field stone proves to be in sound condition, the source of supply may be deemed fit. Care, however, should be taken to enforce on the men who collect the stone caution in their work. This is most readily accomplished by rejecting decayed stone which has been brought to the crusher. With a very little practice the most untrained eyes and hands can learn, without the use of the hammer, to know the difference between a fragment which is sound and one that is worthless.

In certain instances, as in the roads on the island of Marthas Vineyard and on Cape Cod, where the traffic is light, and where good road-building stones would have to be transported from great distances and at great cost, the Massachusetts highway commission has deemed it best to macadamize the road with stone taken from the fields or moraines. Experience has shown that much of this stone breaks into fine bits in the process of crushing; in fact, the amount of the fines thus produced is much greater than the share of the material which can be employed in surfacing the roads. It has been found, however, that this fine stone can advantageously be used in place of gravel in covering the shoulders of the highway.

It will occasionally be found advisable to use "field stone," even where it is much decayed, and this with the expectation that the repairs are likely to be rather frequent. In such cases computation as to the relative cost of good and poor stone, the reckoning extending over a term of years, is necessary to insure a wise determination of the question.

In determining by a rough mineralogical inspection the relative value of bowlders, or, as they are well called, field stones, it may be assumed that those in which feldspar is the predominant mineral are of the better sort, and this for the reasons that the material is relatively not very brittle and that the dust which it forms has a considerable coefficient of cementation. Where hornblende or the related augite exists in considerable quantity the hardness of those minerals is advantageous, and though their direct cementing value is small, the iron which they contain serves indirectly as a binding material.

Where, as is often the case, the rock is micaceous, it is always, and in proportion to the amount of that substance, less valuable than it would otherwise be, for, although the mica does not rapidly grind up under the wheels, in a state of dust the small flakes of it are readily blown or washed away. Wherever the rock contains a large amount of ordinary quartz it thereby falls into the lower grade of value, for the reason that this mineral is very brittle and the particles of its dust are without cementing value; they are, moreover, relatively light and are easily borne away by a current of air or water.

There is a certain measure of damage consequent upon the use on roads of macadam derived from field stone, which is due to the variable hardness of the fragments, arising from the usually great variety in the mineral character of the bits. In practice it is found that some of the stones always prove relatively soft, and thus wear out under the impact of the wheels and the feet of draft animals, leaving small depressions, which, if not promptly repaired, are apt rapidly to extend. Other very hard bits are left projecting as the softer material wears down, and these, for lack of adequate support, are sure to work out and encumber the way. Both these processes hasten the wearing of the road. This evil can be in a great measure reduced by the use of a large share of the "fines" or gravel-like material produced in the process of crushing. This detritus is generally formed in such quantity during the preparation of the first coat of macadam that enough remains over, after applying a top dressing of proper thickness, to recoat the road for several years after its construction. Experiments made by the Massachusetts highway commission in 1894–95 indicate that the production of fines is so abundant that the surplusage beyond that required properly to complete the road is likely to be sufficient, where the macadam is made from field stone, to resurface the road in a complete manner on three or four occasions.

Where possible, as it often is, to make a selection of varieties of field stone which are to be used in road building, it is desirable to use each class separately for macadam purposes, by constructing the road in distinct sections, each being built of the fragments obtained from one kind of rock. In this way the difficulties arising, as above noted, from the varying hardness of fragments is avoided, and at the same time an excellent experiment is instituted as to the relative values of the different grades.

SYSTEMATIC DESCRIPTION OF THE DRIFT MATERIALS IN MASSACHUSETTS IN RELATION TO THEIR USE IN ROAD BUILDING.

We now have to consider the distribution of the drift materials in Massachusetts so far as that feature relates to road-building problems. This relation is established in two ways: In the first place, by the character which the drift coating may give to the foundations of the road, and, in the second place, by the nature of the supply of material used in the manufacture of macadam which may be obtained from the glacial detritus. It will be proper to make the statement concerning the road-constructing value of the drift pebbles and gravel in most detail for those sections of the State where it will be necessary to use the products of the glacial deposits in road construction, and this for the reason that bed-rocks of the nature to afford good varieties of road stones are not economically accessible.

Before entering on the description of the drift of Massachusetts by areas it will be well to examine briefly the main causes which have

ORDINARY FORM OF MORAINE; DOGTOWN COMMONS, CAPE ANN, MASSACHUSETTS.

served to determine the considerable and, from our point of view, very important differences which exist in this débris in the several natural divisions of the State lying between its western boundary and the extremity of Cape Cod.

The differences in the character of the drift pebbles in the sections which we are about to consider depends in part on the nature of the subjacent rock in each field, on the distance of carriage of the débris, and on the nature of that conveyance, whether by ice or by subglacial streams. These complicated conditions will be taken into account only so far as is necessary to give a profitable meaning to the economic points which are to be dealt with in this report.

The State of Massachusetts is, as regards the distribution of its drift deposits, as well as its other geological features, divided into the following distinct regions: The Berkshire district, including the region from the margin of the Hudson Valley to that of the Connecticut Valley; the Connecticut Valley, a broad interval of lowlands lying between the Berkshire district and the central portion of the State; the Worcester district, or central highlands, occupying the area between the western margin of the Connecticut Valley and the eastern border of the coastal lowlands, or extending in general to a north-and-south line drawn through the towns of Pepperell, Ayer, Marlboro, Hopkinton, Milford, and Blackstone; the eastern lowland, comprising an area underlain by the ancient hard rocks, extending to the shore, along the coast between Newburyport and Duxbury; and, finally, an eastern lowland and peninsular district, including the greater part of Bristol and a portion of Plymouth counties, as well as all of Cape Cod and the adjacent islands, in which the ancient hard rocks lie, so far as known, altogether below the level of the sea, and where the supermarine strata are composed mostly of glacial drift and certain soft rocks of Cretaceous and Tertiary age.

BERKSHIRE DISTRICT.

This portion of the State is occupied by a series of mountain ranges which are the southward continuation of the Green Mountain system. As will be noted more particularly in the statements concerning the quarry stones of the State, the rocks of this district are prevailingly either too soft, too brittle, or of too little binding power to make them well suited for use as broken stone. As the drift of this district has evidently been transported from a much less average distance than that which occurs in the lower-lying parts of the State, the pebbles and bowlders are likewise rather unsatisfactory sources from which to obtain stone to be used in road making. Nevertheless, for reasons previously given (see page 291), these pebbles afford in most cases a source of better supply than can possibly be obtained from the quarry rocks.

The greater part of the drift in the Berkshire section is of the till type, and practically all of the glacial waste above the floors of a few main valleys, such as the Housatonic, the Westfield, and the Deerfield rivers, is of this nature. These fields of till offer the most troublesome districts in the State for the construction of roads, and this for the reasons that the foundation for the roadbeds is poor and the materials for construction to be obtained from the till are of rather unsatisfactory quality. Owing to the extreme coldness of winter and the rather limited snowfall, frost penetrates to a great depth. The glacial detritus, which generally covers the country to the depth of 10 feet or more, is of a very clayey nature, holding such an amount of water that the heaving action of the frost is sufficient, each time a thaw occurs, to break up the foundations of any road which is not well drained.

As the pebbles and bowlders which occur in the Berkshire district are formed from rocks which are generally quite accessible to decay, the surface or field stones are, on the whole, not of good character, their long exposure to the agents of decay having caused them to rot very generally to a depth of some inches below the surface. It is therefore désirable, where pebbles or bowlders are used, to obtain the masses from a depth of 2 or 3 feet, at least, below the surface. In most parts of this district these larger fragments are relatively of such infrequent occurrence in the finer and unserviceable materials that it will rarely be profitable to sort the materials of the pit in order to obtain a supply for the crusher. Here and there, however, small fields of a somewhat morainal nature, though of a till-like character, afford a plentiful share of fragments.

In many parts of the Berkshire area which are otherwise unprovided with suitable stone, resort may be had to the beds of the streams where long-continued torrent action has separated quantities of the harder bowlders from the till débris, leaving these well-selected fragments in a condition which is tolerably well suited for use in the crusher. In most cases these torrent pebbles do not lie convenient for exploitation, but in many instances, especially where brooks with steep beds enter larger streams having a less rate of fall, the accumulation of such pebbly matter is very large. Unfortunately, in nearly all instances this store of water-assorted waste is so placed that the macadam prepared from it has necessarily all to be hauled up the grade in order to find its place in the roadway. Notwithstanding this inconvenience the detrital cones of these torrents will be found in many cases to afford the best sources of supply.

The stream deposits above alluded to occur most abundantly in the brook beds which extend from south to north. They are very scantily developed in those valleys where the streams flow southward. The reason for this peculiarity of distribution of the bowlders is to be found in the fact that since the Glacial period this region has been tilted up to the northward to such an extent that the rate of fall of the streams is so far lessened that they can not keep their beds clear, while in the case of the streams that flow southward the descents have been materially increased, with the result that the pebbles are driven forward for an indefinite distance. In the beds of the northward-flowing streams the accumulation of bowlders often exceeds 15 feet in depth, and the alluvial plains which they form are not infrequently 100 feet or more in width.

The washed gravels of the Berkshire district are, as before noted, essentially limited to the greater valleys; they particularly abound in those of the Westfield and Greenfield rivers. In both of these valleys pebbly stream deposits, as well as pebbly kames or eskers, where the fragments are large enough to be advantageously used in the crusher, so abound that rarely is it necessary to go a greater distance than a mile in order to find a tolerable supply of such materials, which, by mere sifting, may be made ready for use in the crusher. In these valleys, however, it is in most cases best to resort to the river beds, where it will be found that the waters have effected a concentration of the washed drift substantially like that above described as brought about in the torrents by the wearing away of the till deposits. The Massachusetts highway commission has constructed in the town of Shelburne a considerable section of road of which the macadam was formed from the so-called "hardheads," or water-rounded bowlders of glacial origin, obtained from the bed of the Deerfield River.

On the sand plains which occupy the lowlands of the greater valleys the foundations for roads are generally good. In some cases, however, river-made clays lie very near the surface, as in a great part of the way between North Adams and Williamstown. In yet other cases, during the times when the streams are full these sands become so surcharged with water that they almost become true quicksands, and therefore afford very unsatisfactory foundations.

The local variations in the glacial deposits in the Berkshire district are considerable. Thus, in the till material along a line from the eastern portal of Hoosac Tunnel southward to the Connecticut line the pebbles and bowlders are, to a considerable extent, made up of débris from the granitic gneiss which outcrops in a belt lying generally to the westward of the line above noted. So far as the drift contains these pebbles, which it often does in a large proportion, the fitness of the material as a source of stone for use in the crusher is distinctly increased.

Along the limestone belt which lies to the westward of the Housatonic Valley and has a northward continuation about North Adams, crystalline limestones occur plentifully. The drift materials from these rocks are naturally of a soft character, and have in most cases been considerably affected by decay. They are quite unfit for use in the crusher.

Throughout the greater portion of the Berkshire area the rocks are mica-schist or of a very gneissic character, materials which are equally poor for road making. As before remarked, the pebbles and bowlders are better than the bed-rocks, and on this account alone are worth attention. Unfortunately, in this field of the Berkshire Hills trappean rocks, which occur plentifully in the same ranges in Vermont, are singularly lacking. There are a few dikes, but these occupy such a small area that they make no noticeable contribution to the drift.

CONNECTICUT VALLEY.

The drift deposits of this valley to a considerable extent consist of materials which have been arranged by river action since the ice-sheet retreated to the north of the Massachusetts line. Where these fluviatile deposits occur they are generally of sand or of clay, and not only afford a bad foundation for roads but fail to furnish any materials which may be employed in their construction. Probably not more than one-tenth of the lowlands of this area is occupied by till or by coarse materials, such as are deposited beneath the ice arches in the manner noted on page 292. By far the greater part of the pebble-yielding drift lies on the flanks of the valley, where the river plains and terraces pass into the hill country. On these slopes the till is often quite thick and contains excellent materials for use in road making. It may be said, in a word, that the pebbles and bowlders which they afford have a value at least 50 per cent greater than that of any which can be found in working quantities within the Berkshire district.

The reason for the better character of the drift materials in the Connecticut Valley is to be found in the existence beneath this basin of two groups of rocks which, when they underwent glacial abrasion, yielded material of a peculiar character, of a kind suitable for use on roads. These deposits consist of widespread conglomerates, which abound in this field, and of trap rocks, which likewise are widely distributed and are of excellent quality for service in the construction of highways.

On some accounts the most serviceable deposits of pebbles and bowlders are those which occur in the form of deltas or detrital cones lying where the streams from the highlands, particularly from the eastern side of the valley, debouch upon the lowlands. On the western border these detrital cones are in the main made up of the waste from rather soft rocks, those which outcrop in the Berkshire district. On the eastern side the materials are, to a considerable extent, fragments which were carried up into the Worcester highlands from the valley by the ice and have afterwards been recarried back toward their place of origin. The fitness of these materials for road building increases southwardly from Turners Falls toward the Connecticut line.

The kame and esker bowlders of the Connecticut Valley are of relatively small importance, the greater portion of such deposits having been covered by the river sands and clays, although the accumulations of this nature which exist in the valley have much scientific interest.

They, as well as the till materials, are of little economic value, for the reason, as will be noted in the account of bed-rocks, that the traps are so abundant and so widely distributed within the area.

THE WORCESTER HIGHLANDS.

This district lies between the Connecticut Valley and the coastal lowlands. Like that of the Berkshire Hills, it is, to a great extent, deeply covered with till deposits, but, unlike the last-mentioned area, the bowldery material has generally been derived from a considerable distance to the northward, largely from beyond the confines of the State. In the section between the western margin of this district and the neighborhood of Worcester the drift is, to a great extent, made up from the waste of schistose rocks, the material being in general of low value for use on roads. By careful and systematic culling, field stones in suitable constitution for road making can be gathered to the amount of about one-third of the bowlders exposed to view. Where the whole of the material is used, the roads can not be expected to endure a heavy traffic in an advantageous manner. In this portion of the district a considerable part of the till is contained in those curious lenticular hills known to geologists as drumlins and locally called "hogbacks." These deposits, each an unstratified mass of clay, sand, pebbles, and bowlders, often attain a thickness of 100 feet or more.

It is characteristic of the drumlins about Worcester, as well as of those which occur in other fields, that the fragments of rock contained in them have often been brought from very much greater distances than those which are found in the till. Thus, in the lenticular hills which we are now considering the bowlders are, to a great extent, from tolerably hard rocks lying in New Hampshire. Not only are these bowlders of the drumlins of originally better constitution for the purpose we have in view than those which are commonly found in the field, but where they are taken from below the surface they are much better preserved from decay. The result is that where, as is sometimes the case, these lenticular hills contain a large proportion of bowlders, their deposits may be advantageously worked as a source of supply for the crusher.

In the region immediately about Worcester there appears a set of hard quartzites and gneisses, apparently highly metamorphosed rocks of Carboniferous or earlier Paleozoic age, which are the source of drift material better suited for road making than any occurring in the western part of the field. Experience, however, shows that these pebbles, when crushed, yield an excessive amount of very finely divided material—much more, indeed, than can possibly be used as the top coating of a road composed of coarser bits of crushed stone.

From Worcester eastward to the ill-defined border of the district the quality of the pebbles contained in and on the hills, as well as in the local modifications of the mass in the drumlins, steadfastly improves, the gain being due to the rapid diminution in the quantity of the schistose element in the underlying rock and to the gradual introduction of the harder granitic, gneissic, and quartzitic rock, as well as to the coming in of trappean materials, which were lacking in the western portion of the field. Thus it arises that the eastern section of the Worcester district affords tolerably good field stone.

The washed gravels of the Worcester district are considerable in extent, mostly occupying the valleys of the streams, though in the region to the northwest of Worcester they have gained a noteworthy extension in the upland country. In every town in this section of the State there occur in greater or less development eskers or elongated ridges of detritus which, as before remarked, were laid down in the old subglacial river channels. For some reason not yet determined these singular ridges are more abundant in the Worcester district than in any other tolerably high part of this country. To a considerable extent these eskers are made up of coarse pebbles and bowlders which have been derived from the New Hampshire rocks. Such deposits, where they lie convenient for use on roads, may well afford material which, after proper screening, will be suitable for use in the crusher. In all the instances known to me the stone in these eskers is very much better in quality than that which can be obtained in the open field. Not only when crushed will the amount of "fines" be relatively small, but the roads built from this source of supply will most likely prove nearly twice as enduring to heavy traffic as those which are made from ordinary field stones. This difference will probably far more than repay the cost of extracting and sifting the material, at least in those instances where the transportation is not a matter which needs to be taken seriously into account.

In certain portions of the Worcester field, particularly on its eastern margin, the local concentration of the bowldery materials effected by the action of torrents is so considerable as to deserve the attention of roadmasters. As a whole, these torrent concentrations are of less importance than they are in the Berkshire district, but in many places, especially where the small streams enter considerable valleys, they have accumulated deposits which are likely to prove of value in road making.

COASTAL LOWLAND.

This section of the State is not clearly delimited from that on the west. It is composed of the low hilly country which rather gently passes into the Worcester highlands on the one side and beneath the sand accumulations on the east and southeast. It attains the shore along the western portion of the field which lies on Buzzards Bay, and again between Plymouth and the mouth of the Merrimac River. In this part of the State, for the reason that the surface is very irregular and the bed-rock extremely varied in character, the nature and local conditions of the drift are much more varied than in any other part of

Massachusetts. In general it may be said that about two-thirds of the surface is occupied by till and the greater part of the remainder by washed drift. There are also considerable areas that have a true morainal character.

The till of the lowland terrace is so varied in constitution that no single statement concerning it can be made which will apply to all parts of the field. It may in general be said that its composition is extremely varied, a given cubic yard of the mass often containing fragments which range in quality from the very best to the very poorest that can be used in road making. In this portion of the State more than in any other district a deliberate and painstaking choice of the pebbles which are to be crushed is most necessary. In general it may be said that the quality of these detrital materials improves as we pass to the eastward. On the western border, where a large part of the detritus has come from the Worcester district, the amount of rejectable matter is decidedly greater than in fields far enough away to have escaped contributions from that area.

In the section about the Blue Hills and on the island of Cape Ann the till is very largely composed of the granitic rocks commonly known as syenite. In these areas selection is hardly to be attained, so uniformly is the rock of granitic nature. Fortunately, although this material is almost too poor for use on roads which are to bear a heavy traffic, the areas are in positions favorable for obtaining a supply of good road materials from no great distance.

The eskers in this district are, as in the case of the Worcester field, remarkably abundant. They very generally contain a large proportion of bowldery matter; in some cases the proportion is more than half of the whole mass. The pebbles and bowlders from these ridges are commonly of excellent quality, representing the better class of building stone which occurs in this part of Massachusetts and in southern New Hampshire. It is owing, apparently, to the relatively great strength of the streams which flowed beneath the glacier that the eskers of this system contain a very large amount of bowldery material, the proportion being exceeded only in some of the most southern districts of the State.

In this portion of the State morainal deposits, which are very indistinctly developed in the more western portions, are found in tolerably characteristic forms. They generally occur in belts extending mainly in an east-and-west direction, and on which lie rude hills of no great height, composed in great part of large, rather angular bowlders. The most characteristic deposit of this nature is that which occupies the central portion of the island of Cape Ann and a section of the mainland extending a few miles west of the fiord which separates that area from the body of the State. Where these bowldery masses occur the fragments are likely to be much decayed; on Cape Ann, owing to their considerable exposure at the surface, many large masses have crumbled into the state of coarse sand and small, angular pebbles. Below the level where the stones are directly exposed to the action of the atmosphere their condition of preservation is generally good, and as the process by which they have been brought to their present position is one which has accomplished a certain selection of the harder materials, the buried portions of these moraines often afford very good varieties of rock for use as crushed stone. In this district, however, the opportunities of access to the deeper-lying bed-rock of excellent constitution for use on roads are such that the morainal heap will rarely be called on as a source of supply.

SOUTHEASTERN DISTRICT.

This field includes the greater part of Bristol and Plymouth counties and the whole of Barnstable, as well as the neighboring islands. In this portion of the State, as the bed-rocks do not rise above the level of the sea, or at least are not exposed in that position except in the case of certain soft beds of Cretaceous and Tertiary periods which have no value in road building, the glacial deposits afford the only sources of road-building materials, except those which may be drawn upon in the other parts of the country. It will therefore be well to consider the nature and distribution of the pebbly and bowldery deposits in this district in a somewhat more detailed manner than has been essayed in treating of the other divisions.

The most noticeable peculiarity of the drift of this section is the relatively great importance of the morainal deposits, which are more extensive and are built along a greater number of lines than in any other part of New England. Except in the case of Long Island and New York, they occupy a greater share of the area than in any other portion of eastern United States. The moraines in southeastern New England are characteristically made up of materials which have been gathered over a wide field. A tolerably careful examination of the stones indicates that the average distance of carriage exceeds 20 miles, and much of the materials which they contain appears to have come from twice that distance. For the reason that the understructure of the country from which the débris has been conveyed is generally exceedingly varied, the rocks of these moraines are in most cases of a very diversified quality, admitting of a considerable selection for the purposes of road construction.

The main moraine of this district extends from near Plymouth southward to the head of Buzzards Bay, thence along the western coast of that bay and along the Elizabeth Islands to Cuttyhunk, the southernmost of those islands. At its northern end, in Manomet Hill, the ridge attains a height of about 370 feet above mean tide, and there are considerations which lead us to believe that the base of the accumulation is from 100 to 200 feet below the sea-level. Thus, at this point the moraine has the greatest altitude of any known east of the Mississippi River; it is, indeed, possible that in this regard it is the greatest of all the American ice-front accumulations. From Manomet southward the morainal deposits, though never attaining to anything like the height at the first-mentioned point, are, with slight interruptions, continued as far as Woods Hole. On the Elizabeth Islands the deposits are relatively scanty, the greater portion of these detached lands being made up of sand and gravel laid down before the last ice advance. In the portions of this moraine north of the town of Bourne, the fragments of rock of sufficient size for use as sources of crushed stone are mostly of a granitic nature, and are tolerably well adapted for road building. A small percentage of the rock consists of Carboniferous sandstone, which is worthless for the use here in view. This material, however, is readily separated, even by an uneducated person, for when found it is commonly so far decayed as to be evidently unfit for service. South of Bourne a considerable proportion of the débris is Carboniferous sandstone and conglomerate. Granitic materials, however, remain as the largest element. As a whole, the moraine above described affords an excellent source whence may be obtained road-building stones of the second grade of value.

Extending from the general north-and-south line of the Plymouth range, as above described, there is a morainal belt which forms the central portion of Cape Cod as far to the eastward as the town of Dennis. This mass is of variable width and height. On the whole the mass is much less wall-like than the Plymouth moraine. It is, however, a vast accumulation, the base of which everywhere rests below the level of the sea.

The Barnstable moraine, as we may term that which forms the backbone of Cape Cod, is composed of much more diversified materials than that last described. In the main, especially in its western section, more than half of the bowlders and pebbles which have a size great enough for use in the crusher are granitic, but are of a very firm variety of that kind of rock. This is shown by the fact that scarcely any of these fragments, though they have been much longer exposed to the weather than those of Cape Ann, exhibit any signs of decay to the naked eye. The subsidiary materials, which in the very easternmost portion of the moraine is occasionally the greater part of the mass, consist of volcanic rocks, partly dike stones and lavas, and partly indurated ash beds, doubtless derived from an extensive field of volcanic rocks which evidently lay beneath the waters of Massachusetts Bay. This last-named group of materials is of excellent quality. At certain points, particularly in the eskers, pebbles of these materials so abound that it will not be a difficult matter to sort them from the others for use on the roads.

The Barnstable moraine lies in a favorable position to afford the whole of the county good road-building stone which can be transported to the point of use by the existing railways, except in the broad fringe of sand plains which occupies the southern portion of the cape. In portions of that field it may be necessary to haul the crushed stone for a distance of 3 or 4 miles to the place of use. In this connection it should be noted that this moraine declines rather gently to the southward, its lower portions being covered by a thin mantle of sands. It is likely that a careful search by borings may disclose various available sections of the bowldery deposits quite near to the southern shore.

On the island of Marthas Vineyard there are several important lines of moraine, of which the most important and characteristic is that which extends, with varied conditions, from near the West Chop, Vineyard Haven, to the peninsula of Gay Head. The bowlders in this moraine are mostly of granitic rock, with a small admixture of conglomerates and sandstones from the district about Dighton. Granitic bowlders, even those on the surface, are in a tolerable state of preservation, and afford as a test, both in the laboratory and in the field, a very fair road stone, the principal objections to the material being that it yields in the crusher a considerably larger amount of "fines" than can be profitably used in the first building of the road, though probably not more than can be advantageously applied to its surface between the time of original construction and that when it will be necessary to reconstruct the way.

There are two other morainal masses on the island, each of considerable extent, one occupying the central portion of the western half, between the Tisbury and the Tiasquan rivers, and the other parallel to the southern portion of the shore of the island, between the village of West Tisbury and Squibnocket Pond. There are several other inconspicuous detached morainal masses on the island, but these have no considerable importance from the point of view of road building.

Although the island of Marthas Vineyard is, throughout a great part of its extent, abundantly supplied with glacial waste of an excellent quality for road building, its area yet contains the largest district in Massachusetts which is quite without suitable road stone. In the southeastern portion of the island there is a field having an area of near 40,000 acres, where the surface is very level and where it is unusual to find a pebble having a diameter of more than 3 inches. This great plain, which was constructed by the washed sands poured into the sea from the streams which flowed beneath the glacier, may afford, as was suggested in the case of the similar area on Cape Cod, occasional buried masses of débris sufficiently coarse to serve for use in the crusher. Deposits of this nature are faintly indicated in certain slight elevations which occur at considerable distances south of the evident moraine. At present, as this plain is quite untilled, the maintenance of good roads over it is a matter of small importance, but in time, as it becomes settled, in order to avoid the great cost of transportation of road stone, it will be desirable to search out these buried deposits of pebbles.

On the island of Nantucket the only morainal mass is that which is contained in the elevated lands known as Sauls Hills. This accumulation is relatively of small extent, and lies near the eastern margin of the island. So destitute of stone are the central and western portions of the area that it has seemed to the Massachusetts highway commission necessary to import the material for the construction of the first 2½ miles of the way between the village of Nantucket and Siasconsett. It is proposed to build the remaining 3½ miles of the road out of stone obtained from Sauls Hills. In this field the detritus, though in good part granitic, is of a tolerably solid nature, and yet is mingled with a mixture of volcanic rock, considerable in amount.

Extending to the westward from the line of the Plymouth moraine, across the western portions of Plymouth County and Bristol County, there are two or three very faintly indicated morainal belts, which are so irregularly distributed and of such slight value as sources of road-making stone that they need not be further considered in this writing.

The deposits of bowlders in the kames and eskers of the southern district of Massachusetts merit some attention. Accumulations of this nature are mainly confined to Plymouth and Bristol counties; they are scantily found in Barnstable, and are barely indicated in the island districts. The number of the ridge-like eskers in Plymouth and Bristol is so considerable, and their distribution as yet so little worked out, that only a general account of them can be given in this report.

In this portion of New England the accumulations of drift which were formed beneath and in front of the glacier by the action of the under-ice rivers are more characteristic than elsewhere in New England. As a knowledge of the facts concerning these accumulations is likely to prove helpful to those who are seeking for road-making materials, a very brief account of the conditions will here be given.

Throughout Plymouth and Bristol counties a large part of the surface is made up of sand plains, each of these plains being an area of characteristic form, from a few hundred to a few thousand acres in extent. On the southern margin of the plain the field is wide, the border is lobated, and the edge slopes down rather steeply to the outer margin. Following it northward, the plain is observed to rise upward and laterally to narrow, until it terminates at or near the southern end of a more or less distinct esker. The natural history of the structure appears to have been as follows: At the close of the Glacial period, when the ice retreated step by step to the northward, great volumes of water were discharged at the front of the glacier from these under-running rivers. The discharge appears to have been into the sea, which, during the declining stages of the ice epoch, had its level much higher than at present. The coarse material, pebbles and bowlders, borne along by the swift subglacial current lodged near the mouth of the ice caves, where, owing to the ease of escape, the opening was widened and the speed of the water diminished. Beyond the mouth of the arch the velocity of the currents was gradually reduced until the motion was so slight that the sand which they contained was deposited in the great plains, the mud being borne away by the marine currents to a much greater distance.

So far as the observations of the present writer go, all the plains in the counties last mentioned terminate to the northward in more or less important esker accumulations, which are always more or less commingled with the indistinct moraines. The clue thus given may serve as a guide to those who are seeking deposits of coarse pebbles of hard rock which may serve well in road making. In Barnstable, and in the island counties to the southward, eskers, which are the natural associates of moraines, appear commonly to be lacking. The fact is that, owing to the foundation of the moraine being below the level of the sea, the deposits which accumulated beneath the ice, or just at the mouths of the under-ice streams, have in a most complete way been sheeted over by the later-formed masses of sand. In searching for these eskers, which, as observation shows, are in some cases but slightly buried, sometimes at no greater depth than 3 or 4 feet, the observer should select those points of the plain which are opposite the breaches or very low points in the frontal moraine. In practically all cases these breaches correspond to the point of emergence of a subglacial stream, and the appropriate place for the corresponding esker is on the line of that low depression in the morainal wall.

In many cases, especially where the subglacial stream was large, the esker corresponding to a breach in the moraine is found to the northward, beyond the accumulation of large bowlders which was formed at the front of the ice.

As before remarked—and the statement can be made with even greater emphasis with reference to southeastern Massachusetts—the pebbles contained in the eskers are generally very well fitted for use in road making, for the reason that they are bits which have survived the rudest use to which the rough treatment of the ice could expose them. In most cases they were first torn from the bed-rock by the glacier and then subjected to great strains in the rude mill which exists at the bottom of moving ice. Afterwards they were taken by the under running water and urged in the most violent manner for many miles through the irregular pipes in which the subglacial stream flowed. It is easy to see that only the most resisting bits of stone would be likely to survive so rude a trial.

The till deposits of southeastern Massachusetts are of relatively slight extent, occupying probably not more than one-fifth of its surface. Here the accumulations of this nature are, in most of the fields, not so readily distinguishable from the morainal and ordinary wash drift as is the case in the other parts of the Commonwealth. Almost everywhere the till is sandy; the proportion of clay is small, and the bowlders have a more waterworn character than we are accustomed to see in accumulations of this nature. The fact is that in this section the advance and retreat of the ice have been so frequent that the same fragments are likely to have been again and again alternately affected by the action of the ice and by that of the subglacial streams. At the same time the

BOWLDERY SHORE, THE STONES BEING DERIVED FROM THE WASHING AWAY OF TILL; SCITUATE, MASSACHUSETTS.
From Gardner Collection of Photographs, Lawrence Scientific School, Harvard University

number of these subglacial streams has been so numerous that nearly all the bits of rock have had their share of subglacial wearing in the streams, excepting those that happened to gain an elevated position in the ice and thus were unaffected, and so remained until they attained a position in the moraine.

A result of this action has been to diminish the number and to decrease the size of the pebbles in the till, and at the same time to improve their quality for use as road-building materials. Except within the limits of the Narragansett coal field, which occupies nearly the whole of Bristol County, the field stones which are obtained from the till deposits are, on the whole, of decidedly better quality than those which can be obtained from the same deposits in any other part of the State.

SEASHORE ACCUMULATIONS.

There remains to be noticed an interesting, though on account of its limited range a not very important, group of road-building stones, occurring where pebbly or bowldery drift has been subjected to the assaulting action of the sea waves. Deposits of this nature exist in considerable quantities along the greater part of the mainland coast-line of Massachusetts. In less extent they occur also on the islands. It may be noted that there are two somewhat distinct positions in which these sea-worn deposits of glacial pebbles are found. Most commonly they occur at or about low tide, lying on a rather flat portion of the bared sea bottom next the shore. The greater part of the masses commonly have the proportions of small bowlders, which by their rounding show that they have been subjected to considerable wave work. Stones less than 6 inches in diameter are not commonly found in this position unless they are firmly wedged in between others of larger size. Deposits of this nature appear to occur along about two-fifths of the coast-line of Massachusetts which faces the open sea or the wider bays. So far as observed by the writer, they are not found where the waves attain a less altitude than about 6 feet, a condition that exists only along the coast-line which received in good measure the ocean swell. (See Pl. XXI.)

The other group of sea-washed pebbles is found along the beaches, particularly those portions which receive the name of wall beaches. Usually these accumulations lie on the upper margin of the section, which is beaten by the waves in times of storm. There they form a strip having usually a width of from 30 to 60 feet, and a depth of from 1 to 10 feet. These pebble beaches are less common than the bowlder platforms; probably not more than one-fifth of the sea front of Massachusetts is bordered by them. Yet the aggregate extension of the deposits probably amounts to not less than 75 miles of that portion of the coast-line which receives the impact of the ocean surges. The pebbles in this shore deposit rarely exceed 6 or 8 inches in their greater diameter, but the major portion of them are large enough for use in a crusher. (See Pl. XXII.)

These wall beaches occur only where the conditions are such as to afford the waves a plentiful supply of fragments which are not too large to be readily swept about. In general the accumulations have been brought to their present position by the action of sea weeds, particularly kelp and rock weed, which fasten upon bits of stone that lie on the bottom at a distance from the shore-line, and have by the process of growth finally exercised such a pulling action on the fragment that it has been lifted into the control of the wave and thus brought to the shore. These wall beaches in Massachusetts are common along the shore from the mouth of the Merrimac River to Plymouth Harbor; they are lacking around the shores of Cape Cod except in its western portion; they occur again along the north shore of Marthas Vineyard, and thence westward to the Rhode Island line. The amount of material contained in these beach walls is so great that they could supply stone for all roads which are to be built that are near enough to render them accessible, the material being, because of the careful sorting out of the weak fragments which has been effected by the waves, of excellent quality for road-building uses. It should be noted, however, that where these beaches lie against bluffs of a soft nature they are often valuable elements in the defenses of the shore, and their complete removal necessarily leads to the exposure of the coast-line to the destructive action of the waves. In most instances these beaches are undergoing a constant increase in volume by importation through the action of sea weeds, as above described, so that withdrawal of the materials, such as would be made in their use for road building, is not likely to prove harmful.

In this connection it may be said that along the shores of the greater lakes there often are accumulations of pebbles which have been extracted from the drift by the action of the waves and left in the form of beach accumulation. Owing, however, to the fact that almost all the fresh-water basins of this State have had their water levels raised by artificial dams, the greater number of these accumulations are now inaccessible. Moreover, owing to the slight amount of wave action which takes place in these limited basins, the destruction of the weak fragments is so slightly effected that the remaining pebbles are but little better than those which may be obtained from the ordinary washed deposits of glacial material.

The foregoing account of the superficial deposits which owe their origin directly or indirectly to glacial action is sufficient to show that the most accessible and, on the whole, the most valuable road-building materials of Massachusetts are to be found upon the surface of the country, in a quarried state, so to speak. It may be noted that there is a collateral advantage arising from the use of these erratics, which consists in the fact that, so far as the fragments occur in the form of field stones, they are at present an incumbrance to the earth—an obstruction to the tillage of the fields. A large part of the agricul-

WALL BEACH COMPOSED OF PEBBLES; SCITUATE, MASSACHUSETTS.

From Gardner Collection of Photographs, Lawrence Scientific School, Harvard University.

tural labor which has been expended in Massachusetts has been given to the task of gathering these pebbles and bowlders from the ground to be tilled, the materials thus removed being accumulated in the stone walls and heaps which make so conspicuous a feature in the farming districts of most glaciated areas. So far as this waste can be utilized in road building, the process is beneficial to the conditions of the fields and helpful to the interests of the agricultural class. At least three-quarters of the stone walls in Massachusetts have not been built with the object of dividing the tillage areas, but to get the stones out of the way of the plow. These fences are, indeed, a very general obstruction to the economical care of the earth. If the plan is adopted of converting this obstructive glacial waste into road material, and the method is followed for a century to come, the result will be a noteworthy increase in the value of the farm lands in the Commonwealth.

The importance of field stone as a source of road-building material makes it desirable that the persons engaged in road construction should bring much care to the system of selection of the fragments, which has been advised in the earlier part of this report. An indiscriminate use of this source of supply is likely to lead to much disappointment; deliberate and careful choice and manipulation of the materials is likely to bring about the very general application of such stone to the requirements of the roadmaster. The experience gained by the Massachusetts highway commission indicates that the difference between the first cost of constructing roads with quarry stone and with that from the field, which is of glacial origin, is likely on the average to amount to not less than 35 cents a ton. Allowing that in each twenty years the average amount of stone used upon a road is about 2,000 tons to the mile, the saving in each mile of way will be $700. Within the State the total length of roadways which within the next fifty years are likely to be macadamized is not less than 10,000 miles. This would mean an aggregate saving of somewhere about seven million dollars in each twenty years in the life of the roads. As essentially the same conditions prevail throughout the larger part of the glaciated areas of this country, the importance of this problem is manifest, even if we leave out of view the incidental benefit to the fields arising from the removal of the stones from the surface.

BEDDED ROCKS.

Under this title we shall consider the stratified rocks which are found in the several districts of the State, including in the class all deposits that originally were stratified, however great the changes in condition which the under-earth processes have wrought upon them. Thus the gneisses, although they often have an appearance which would lead to the supposition that they had not been stratified, can, in most instances, be shown to have been originally formed by the action of water; i. e., laid down as sediments on the sea floor. It should also be noted that many, if not all, of the materials which have come to their present positions in the molten state very likely had in the remote past been in the condition of ordinary sediments. In the classification here adopted the discrimination is, in effect, between the rocks which have retained something of their original bedded character and those which, whatever their ancient history may have been, have come to their present sites in the state of igneous fusion.

BERKSHIRE DISTRICT.

The first group of bedded rocks to be noted in this district are the limestones, which constitute an extensive series of deposits occurring along the western flanks of the Housatonic Valley, and the northward extension of the same great trough, in which flows the upper waters of the Hoosac, and thence westerly to the New York line. These limestones are of a crystalline nature, and thus deserve the name of marbles. In general they are remarkably pure lime carbonates, the proportion of clay which they contain being quite small.

Tests of this stone, those both of the laboratory and of the field, go to show that in the uncombined state it is essentially unfit for use in road building. On account of its crystalline structure the material is very brittle; it quickly goes to pieces, and the powder, because perhaps of the crystalline character of the bits of which it is composed, does not readily form a cement, but tends to blow or wash away. It is not unlikely that if this material is burnt into quicklime it will prove useful as a binder, to serve in combination with some of the stones hereafter to be described from the same district, especially those known as quartzites. It seems probable also that this limestone may be made serviceable by covering the roads which are built of it with a thin layer of the low-grade iron ores which are commonly found in connection with it, usually in the form of an irregular cap on the surface of the uppermost members of the limy series. Owing to the fact that good road-building stones are lacking in this district, it is worth while to essay experiments in the combination of these limestones with other materials.

Rocks of a quartzitic character, originally sandstones which have been recomposed into a compact form, abound in this district, especially in the region lying to the west of the main valley, which extends by North Adams and Pittsfield. These materials are defective in the manner of all quartzose rocks—they are both brittle and destitute of binding power. If they prove at all serviceable it will be in conjunction with the limestones, the lime being used in its burnt form as a cement. An experiment made by the Massachusetts highway commission in constructing in the town of Lee a road of which the macadam was formed of the Berkshire quartzite has shown that even when treated in the most systematic way rock of this kind can not be made to bind in the manner required to make a good road, for, although upon the application of the roller the fragments appear to cohere, the effect is altogether temporary, a very slight amount of travel serving to reduce the road to the state of a sandy rubble.

In the central portion of this district, in a belt of country extending from the Vermont line southwardly to that of Connecticut, through Hoosac Mountain on the north and Chester and Granville on the south, there is a belt of gneissic rock which promises to have a considerable value for road-building uses. These gneisses are prevailingly of a feldspathic nature. They contain only a moderate share of mica; they are not very crystalline. They possess, in a fair degree, the requisite hardness and toughness for road building, but their cementing quality is less than is demanded for a good road-building stone. Practical experiments with the material have yet to be made, but the laboratory inquiries indicate that, used alone, this rock will make roadways of the second order of value, and that for all except the upper 2 or 3 inches it will serve quite well in the construction of broken-stone roads.

The group of mica-schists and related rocks of a schistose nature occupies by far the larger part of this field; probably not far from nine-tenths of the surface is underlain with rocks of this general nature. So far as has been determined by field or laboratory experiments this group of rocks is of very doubtful utility for use in road building. The material quickly comes to the state of powder, the disruption being made easy by the irregular layers of mica which abound in it. There is an almost total lack of binding quality, so that unless the roadbeds which may be built of it are made extraordinarily thick they are likely to be disrupted by frost action.

Unfortunately the hill district which lies between the Housatonic Valley and the Connecticut Valley is mainly occupied by schistose rock, so that, notwithstanding the very poor character of the stone, many of the roads, because of the great cost of transporting better materials, will have to be built of it. It appears desirable that these constructions should be made of the bowlders rather than of the bedded rocks, and that where possible the surface of the road should be covered with materials taken from the vein deposits hereafter to be described, which occur in some abundance in many parts of this field.

CONNECTICUT VALLEY.

In this section of the State the bedded rocks consist practically of three groups—shales, sandstones, and conglomerates. The shales, those of the New Red sandstone (Rhætic) group, are unfit for use on main highways. They may be made to serve as a road covering on ways which have the smallest amount of traffic. The sandstones may be dismissed as quite unserviceable. They quickly grind to powder. Except for use as foundation in telford construction, they have no possible value in road making. The conglomerates of this field, which in many points contain very massive beds, would, in default of better material, afford tolerably good road stones. Their pebbles are prevailingly hard, having been subjected to a severe test by water action and perhaps, at an earlier stage of their history, by the ruder ice work. Owing, however, to the fact that this section of the State superabounds in good traps, decidedly the best group of rocks for use as broken stone, it is not worth while to consider further the conglomerates or other stratified rocks of the area.

WORCESTER DISTRICT.

The bedded rocks of this field, though varied in character, are prevailingly of low value for road-making use. On the eastern margin of the area, in the obscure border between this district and the shore-land field, there are some limestones, which are best exhibited in Bolton, Stowe, and Chelmsford. These limestones occupy very much less area than those in the western part of the State—they are, in fact, but detached remnants of originally extensive deposits which are probably of the same age as those above noted in the Berkshire district. Although these limestones are very crystalline, some portions of the beds which contain materials that will pass into the state of clay may have a limited value for local use in road making. In the region about Worcester, and to the southward, there are some gneissic rocks lying on the boundaries of the Carboniferous basin, which occupies the central portion of this district, that may have a value in road building, at least for the coarse layers of broken stone. The distribution of these rocks is not yet well ascertained. It is known, however, that they are most abundant and of the best quality in the portion of the district which is nearest to the Rhode Island line.

The greater portion of the Worcester district is occupied by schistose rocks of the same general character and probably of the same age as the deposits which make up so large a part of the Berkshire Hills. In the Worcester field, as in the western part of the State, it may be necessary to use the materials from these schists in road construction at places remote from the railroad, where the cost of bringing in good stone would be too great. In these cases it will be best to take selected bowlders rather than the bed-rocks. Where the latter are chosen, a search should be made for ferruginous bands, which occur plentifully in the schists of this district and are most abundant in the western portion of the field, particularly so in and about the town of Barre. Except in cases of exigency, the use of these schists can not be recommended in any part of this area. In the greater portion of the area the road construction should be effected by the use of traps brought in from the eastern and Worcester districts or by using the field stones.

COASTAL PLATEAU.

In this section of the State the bedded rocks which are in some measure fit for road building are much more abundant and in greater variety than they are in any other. They consist of quartzites, clay-slates, gneisses, conglomerates, and certain varieties of schistose rock. Owing to the fact that this section of Massachusetts contains a large share of good trap stone, the deposits of which can be readily distributed by railways to almost every point, so that the stone will not need to be wagoned for any great distance, the use of these stratified deposits is likely to be very limited. They will, therefore, be but briefly mentioned in this report, the mention being rather in the way of warning and with a view to check the injudicious use of these varieties of stone.

The commonest and so far the most used of the stratified rocks in the coastal plateau are the clay-slates. These abound in many portions of the district, particularly in the section immediately west of Boston. They occur in considerable variety, ranging from relatively soft materials, which have been but little changed by the metamorphic agents, to those which have been greatly hardened—some, indeed, brought almost to the condition in which our quartzites occur. Occasionally, indeed, they appear to have been altered to the state of bedded felsites.

In general, it may be said that these clay stones, however much altered, are essentially unfit for use on the highways except for telford subconstruction. The material rapidly goes to pieces under the action of the wheels, and the dust has very little cementing value; it fails to bind the fragments together; it quickly blows or washes away. Yet because of a lack of understanding which may be fairly termed stupidity, a great amount of road construction has been done with this essentially worthless rock. The waste arising from its use may safely be reckoned as having amounted during the last thirty years to somewhere near a million dollars. This waste still continues, although the relative worthlessness of the clay stones as compared with the traps of the neighborhood is now well known.

Where the clay stones have, by the change-bringing action, become in part crystalline, the road-building value of the material is enhanced to the point where it might be profitable to make use of it in cases where better rock is not obtainable; still, these rocks have to be reckoned as of a distinctly low grade.

In the central portions of this field conglomerates abound. This is especially the case in the region immediately west of Boston. These conglomerates are commonly associated in beds which occupy the same formation and often alternate with the clay-slates. Where the conglomerates afford pebbles exceeding 3 inches in diameter they may be used in road making. The trouble is, however, that the pebbles are rarely large enough to afford good road-building stone when broken up in the crusher. A large portion of the product retains the original smooth surface of the pebbles, a fact which causes a failure of the binding action which is the basis of the macadam system of construction. Moreover, the pebbles, though often hard and of good binding quality when broken into bits, are mingled in their beds with a large amount of sand. In part this sandy matter goes to pieces in the crusher and is separated by the screens of the apparatus; where this occurs, the waste of material at the breaker is likely to amount to as much as a quarter of the material quarried for use. In other cases the sandy matter remains firm enough to pass into the "grades" of stone which are to be used on the road, and if so used it is likely seriously to weaken the construction. On these accounts the conglomerates of what is commonly known as the Boston Basin are not to be commended as sources of road stone.

In the southern portion of the district, particularly in Norfolk and Bristol counties, there are extensive conglomerates of the age of the Coal Measures and of rather better quality than those which lie to the northward. The pebbles in this southern field are harder, the mass often more metamorphosed. Still, in view of the more desirable kinds of rock which exist within easy access of this portion of the field, the use of the conglomerates is not to be commended.

The gneisses and the other more or less schistose rocks of this district are in general of undesirable quality. In only one district, that including the shore towns between New Bedford Harbor and Narragansett Bay, does it seem desirable to resort to the bed-rocks of this nature as sources for road material. In the towns just noted, for the main highway between New Bedford and Fall River, the Massachusetts highway commission has, after much consideration, determined to recommend the use of a very granite-like gneiss as a source of the broken stone. This choice has been made for the reason that the field stone is in the main from the Coal Measure field which lies to the northward, and is prevailingly poor, and the cost of bringing in better rock by rail or water, supplemented by wagon transportation, would be very great. Moreover, on this line of road, ledges rising well above the way are immediately adjacent to it, and an arrangement was made with an existing electric tramway, which is to carry broken stone to within a few feet of the places where it is to be deposited on the road. Under these conditions, and with the guiding plan of adapting the materials in the best way to the economic situation, the use of this gneiss is clearly to be reckoned as advantageous.

SOUTHEASTERN DISTRICT.

In this field the deposits below those of Glacial age are essentially without value for use in road construction. Some of the clays have been made to serve in hardening roads, and the benefit which these materials afford when applied to the sand is temporarily great, but the endurance of the beneficial effects is so slight that it is not worth while to incur the cost of the work. Here and there other deposits, such as bog-iron ores, are found, as they are in other portions of the Commonwealth, which may in case of need serve to give a temporary hardness to the way.

At many points along the shore, from the northern side of Boston Harbor to Narragansett Bay, there occur beneath the tidal marshes and the mud flats great areas which below the water level are occupied sometimes to the depth of 8 or 10 feet by beds of oyster shells. Although these shells are somewhat decayed and do not have the toughness which makes them so serviceable as a covering for highways which have to endure but a small amount of wearing, it seems likely that the cheapness with which the material can be won by dredging may in the end commend it to extensive use, particularly on private roads and on highways which, though of importance, are traversed only by light vehicles. Where the oyster beds occur the material can often be lifted by the steam dredge or the hydraulic excavator at a cost not exceeding 15 cents per ton. At anything like this price the material is worth attention, not only for use on light-traffic roads, but also for the manufacture of lime to be used in the ground state as a fertilizer. Lime prepared from this source has a considerably greater agricultural value than that which is obtained from the crystalline limestones of the Atlantic Coast, such as those which afford at Rockport, Me., the largest supply that is used in New England.

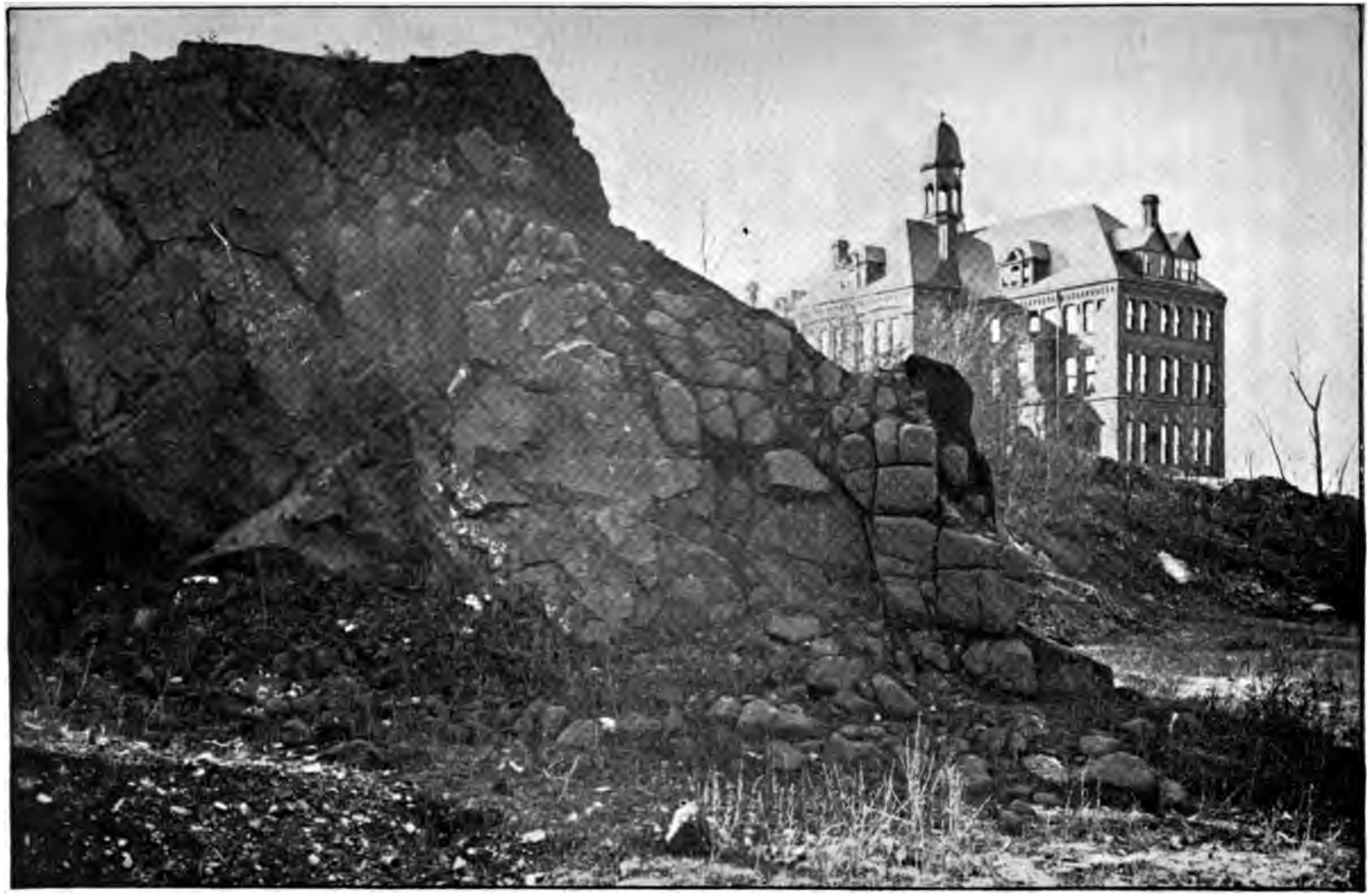
In the greater part of the swamps of New England, particularly in those which occupy the southern portion of the area, there occur considerable deposits of bog-iron ore. These vary in thickness from a few inches to 3 feet, and in character from ocherous sands to very firm deposits containing from 30 to 40 per cent of the bog iron. Wherever accessible this bog ore is likely to have value as a top covering for roads which are not to be macadamized in the strict sense of the term, or for those which are to be covered with broken stone of which the quality is defective as regards cementation value of the material. On this account it is desirable to make some statements concerning the distribution of this group of deposits, which in the last century were the basis of a considerable industry in iron production and which may now be looked to for subsidiary use in road making. As the conditions under which these bog-iron ores are produced are peculiar and throw much light on the positions in which they may be found, a brief statement as to the steps of their formation will not be out of place. All of the large amount of iron oxide contained in the swamps of the glacial belt has been formed in the manner which will now be described.

The greater part of the drift of New England is derived from rocks which contain a considerable amount of ferruginous matter. This material is particularly abundant in the crystalline deposits which abound throughout this area. Penetrating through these drift materials, the surface waters, considerably charged with carbonic acid gas derived from the decaying vegetation, take up a share of these iron oxides and bear them on toward the sea. Where the waters enter a swamp and the ferruginous matter comes in contact with the partly decayed vegetable remains, the charge of iron oxide is likely to be precipitated; owing to its weight it finds its way to the bottom of the soft marsh and there agglomerates in the form of a more or less distinct sheet, which often takes on a curious stalactitic form. In those places where the surface water draining into a swamp passes through ordinary sand the contribution of ferruginous material is usually small, and thus the bog-iron ore never attains any considerable development. Where, however, the drainage is from a region occupied by till, partly for the reason that the water passes more slowly through beds of that nature, but mainly because the till is apt to contain a considerable amount of iron oxides, the opportunity for the growth of bog-iron ores in the neighboring swamps is likely to be great. So far as the observations of the writer have gone, these deposits are more common in the portions of the State lying to the west of the coastal plateau; they are relatively rare in a utilizable quantity in the southeastern district. Nevertheless, in Plymouth and Bristol counties deposits of this kind have been found with a thickness of 18 inches, and this without any extended search for them. Further inquiry concerning these materials is to be desired.

DIKE AND VEIN STONES.

The dike stones of this country have been found to afford the best materials for road construction, especially for use on ways which are necessarily the seat of a heavy traffic. With them may be classed the related volcanic rocks which have come forth in the form of flows and not been intruded between the walls of fissures, as in the case of true dike materials. For the purpose of this report it will not be necessary to make scientific discrimination between the many varieties of these igneous rocks; the differences between them in many cases rest upon very recondite features, such as can not well be taken into account in writings which are meant to be of general utility.

In the Berkshire district of Massachusetts, though numerous dikes occur in that field, the deposits of a kind to be useful in road making, so far as known, are all rather small, and are in positions which make them unworkable. Although a more careful study of this district may possibly reveal dike stones of value, the habit of the country is clearly against the probability of the occurrence of the deposits in utilizable quantities. In this district, however, ordinary veins, such as are deposited by the ascent of heated waters through fissures, occasionally occur, especially in the eastern portion of the field. Although no careful study has been made of these veins, some of them have been found to be large, and on account of the economic minerals which they contain have been extensively worked. Thus, in the town of Rowe, in the northern part of Franklin County, a vein of iron pyrites has been for many years the seat of considerable production, and in the town of Chester vein deposits of emery have likewise been extensively worked. In and about the town of Goshen there are extensive veins that are likely to be exploited as sources of lithia; this is contained in the mineral termed spodumene, which occurs as crystals in the deposits.



TRAP DIKE. SOMEWHAT DECAYED, SHOWING THE CONDITION OF THE WALL ON ONE SIDE; BRIGHTON, MASSACHUSETTS.

From Gardner Collection of Photographs, Lawrence Scientific School, Harvard University

The waste accumulated in working the vein deposits of the Berkshire district is likely to prove of much better quality for use on roads than the ordinary rock of the country, and in time to come it may at some points be profitably applied to the construction of local ways.

CONNECTICUT VALLEY.

In the Connecticut Valley is found the most extensively developed deposits of igneous rock having the general character of trap which exist in New England. These great accumulations abound in Massachusetts and Connecticut. They occur here and there throughout its extent from the mouth of the Deerfield River to Long Island Sound. In age and character they are the same as the traps of the Palisade district on the Hudson and of New Jersey. Their fitness for road building has been very extensively tested and amply proved. As regards their origin, these traps are to a great extent true lava-flows which were poured out upon the floor of the shallow sea, the sheets sometimes attaining a thickness of 100 feet or more. Although in all cases they were buried beneath subsequently accumulated strata, they have, by faulting, uptilting, and wearing away of the covering, been not only disclosed but placed in convenient conditions for working.

The condition of the traps of the Connecticut Valley is such that not only is that section of Massachusetts and Connecticut in which they lie so well provided with good road material that other sources of supply need little consideration, but the greater portion of the country on either side of the Connecticut River within a distance of 100 miles is, where near railways, able to look to this store of natural road material for better and, in a long view, a cheaper source of road stone than the local rocks afford. With the progressive extension of steam and electric railways it is not unlikely that the use of the local road-building stones in the Berkshire and Worcester districts will be abandoned, except in the case of those towns which are remote from such means of transportation.

WORCESTER DISTRICT.

The general resemblance of the Worcester district to that of the Berkshire Hills, which has already been noted as regards the bed-rocks, is found also in the relative absence of igneous materials in this area. A tolerably careful search has failed to show the existence of any utilizable dike stones or lava-sheets in this portion of the State. The harder vein stones are equally rare. No deposits of this nature have been found that are likely to prove sufficiently valuable in road making to deserve notice.

COASTAL PLATEAU.

In this district the igneous rocks exist in greater variety than in any other portion of the Commonwealth. Such great lava-flows as exist in the Connecticut Valley are lacking here, but in their place there is a great array of injected and ejected rocks which have come into their position in a heated state.

First among the igneous rocks of this district, as regards the quantity of the material, we may reckon the granitic masses, such as those which occur in the Quincy and neighboring fields at Cape Ann and in a local and less extensive way in other portions of the area. These granitic masses have broken through, displaced, and in part probably flowed over the older rocks throughout regions which aggregate some hundreds of square miles in area. They evidently came into their position not on the surface but at a great depth within the crust of the earth. From the point of view of road making, the granitic rocks, though they vary somewhat in quality, are generally of inferior grade. They usually contain a large amount of quartz, and their very crystalline structure causes them readily to go to pieces when placed on the roads. Where, as is sometimes the case, there is a considerable proportion of mica in these rocks, the destruction is yet more rapid. Thus, while the granites of this district are commendable on account of their hardness and their fair cementing properties, their brittleness and the crystalline nature of the fines which they produce when ground make them unfit for use on roads where better materials can be obtained.

In certain parts of this district, particularly along the northern shores of Boston Harbor and Massachusetts Bay, there occur extensive deposits of what are termed felsite-porphyries, which seem to have been formed somewhat after the manner of lavas, but probably as horizontal flows within the rocks themselves. The igneous rocks of this group are fairly serviceable in road making. They are rather brittle, and the binding power of their powder is not great. They would be valuable in many parts of the Worcester district, but in this, which abounds in good road materials, they are not to be commended.

The ordinary dike stones of eastern Massachusetts are abundant, and generally of an excellent quality. It is to be noted that these dikes often appear to be much decayed on and near the surface, as is shown in Pl. XXIII. Rarely, however, does this decay extend to a considerable depth, so as to limit the value of the stone for road use The number of the deposits is surprisingly great. There are a few parts of the world where, over equally extensive fields, the number of fissures filled with these originally molten rocks is as great. Thus, on the island of Cape Ann, an enumeration of the dikes measured along the narrow strip of the coast-line, where they are exposed to view, gave a total of about four hundred of these fissures. Within the area of the coastal plateau the number of the separate crevices is probably to be reckoned by tens of thousands. Their general aspect when exposed in quarrying is approximately indicated in Pl. XXIV, in which are depicted a trap sheet which has been forced between layers of slate, and an ordinary fissure dike which intersects the strata.

The dikes of this district increase in number in a progressive manner from its western border toward the shore-line. They are more common

INTRUSIVE SHEET OF TRAP CUT BY DIABASE DIKE; SOMERVILLE, MASSACHUSETTS.
From Gardner Collection of Photographs, Lawrence Scientific School, Harvard University.

in the originally deep-seated rocks, such as the granites, than in the newer formations, such as the Carboniferous. The evidence goes to show that their formation was attendant on the development of much volcanic activity in the regions lying immediately to the east of the Massachusetts shore and southward of the coast of Maine. In connection with these dikes, on the coast-line at Cohasset and elsewhere, there are deposits of volcanic ash, which are doubtless more centrally developed beneath the neighboring sea. At certain points on Cape Cod the drift is largely made up of dike stones and other igneous rocks, which serves to show the great extent of these submarine volcanic beds.

The greater part of the dikes of eastern Massachusetts are narrow, few of them exceeding 20 feet in width. In order that a deposit of this nature may afford a valuable quarry for road-building materials, it is necessary that it be large. In general, it may be assumed that a fissure should have a width of not less than 50 feet and a length of several hundred, and that it must lie in a position, as in the escarpment of a hill, which will permit the development of working faces having a height of 20 feet or more. So far as observations go, the number of dikes which afford these conditions in eastern Massachusetts does not exceed a dozen. Of these, two, one in Salem and another in Waltham, have already been extensively used as sources of road-building stone. There are others in the region about Newburyport, their nature having been disclosed in the search for silver-bearing ores which was made in that section about a quarter of a century ago. Yet another lies on Houghs Neck, Quincy, on the shores of Boston Harbor, in an advantageous position for working.

Just beyond the boundaries of Massachusetts, in Rhode Island, there are two admirably placed deposits of dike stones, which are mentioned here for the reason that, while they are not within the boundaries of the State, they are advantageously situated for supplying the Worcester district, where, as before remarked, there is a lack of good road materials. One of these is a true dike trap, which is situated on the left-hand bank of the Blackstone River, just above Woonsocket, R. I.; the other is the well-known deposit of magnetic iron ore in the town of Cumberland, R. I. This mass contains in the aggregate several million tons of a particularly hard and tough rock which appears to be very well adapted for road making. It is true that the powder of the material has only a moderate cementing power, but the dust is so heavy that it is not likely to be removed from the road by the action of water or of air. Unfortunately both of the localities above mentioned are somewhat inconveniently placed; that on the banks of the Blackstone River may have to be approached by a bridge across that stream or by a spur from the New York and New England Railroad, while to obtain access to the Iron Hill deposit, in Cumberland, it will be necessary to construct a branch railway for the distance of about 1½ miles.

In the district lying between Canton Junction and Wrentham, in Bristol County, there are numerous extensive extrusions of trappean materials, or those which for the present purpose may be thus classed, that may afford a valuable source of supply of road-building stones for the county in which it lies and for the neighboring portions of Massachusetts and Rhode Island. Here also, unfortunately, a mile or two of railway will have to be constructed in order to gain access to the field. There are a number of other promising localities where the dike masses appear to exist under conditions which are favorable for production, but these conditions are not as yet well enough known to enable the writer to commend them to those who are engaged in the search for good localities in which to establish crushers for the immediate supply of the general market.

SUMMARY CONCERNING ROAD-BUILDING STONES.

The foregoing account of the road-building stones of Massachusetts serves to show that this State is, on the whole, very well placed for access to good materials for highway construction. It is, moreover, perhaps the best field in this country in which to institute an extended system of experiments intended to determine the relative value of these materials and the proper method in which to use them in diverse conditions and combinations. In this State, though it has an area of only 8,200 miles, there are at the present time, exclusive of city streets, about 10,000 miles of way which should be macadamized, and which will, presumably, be thus constructed before the middle of the next century. The actual cost of this work for the stone alone will probably be between $50,000,000 and $60,000,000, and the annual replacement of the macadam materials will probably involve a cost not far from $3,000,000. It is thus evident that the expense of the road work in this State is to be a considerable tax upon the earning powers of the people, though the profit will doubtless very much exceed the cost of the undertaking. In this State, as in the other parts of the country, it is clearly a sound policy to make the considerable saving which may be won through a thorough-going study of the nature and methods of use of every variety of stone that is likely to be drawn upon for the needs of road building.

ON THE TOPOGRAPHIC CONDITIONS OF MASSACHUSETTS AS AFFECTING ROAD BUILDING.

It seems proper to supplement the foregoing account of the highway materials of Massachusetts by a statement, necessarily brief, as to the form of the surface, so far as the form affects the construction of the roads.

Although the area of Massachusetts is relatively small, and the relief in maximum height not great, the surface presents what is perhaps a greater combination of difficulties in the construction of roads of proper grade than exists in any other equally extensive field of this country outside of the Cordilleran region. In the Berkshire district we find an elevated field, having somewhat the aspect of a table-land, intersected by deep valleys. The same deeply incised topography is to a considerable extent presented in the Worcester district, and traces of it are to be found in the coastal plateau. Thus the grades which are due to the understructure of the country give rise to many difficult problems, which have to be met by those who plan public ways. The principal difficulty, however, that which is due to the topography of the country, is attributable to the very irregular character of the drift accumulations. The aggregate slope imposed upon the highways of the State by these irregularities, though none of the slopes are of great altitude, is probably much greater than that due to the more extensive elevation of the mountainous areas.

The effect of the drift accumulations, owing to the extreme irregularity of their forms, is to bring about the existence of many hundred lakes of considerable size, and a yet greater number of swamps which originally had a lacustrine character. The result is that in planning the original highways of the State quite without a map the roadways were laid out in an exceedingly clumsy way. Here and there we may detect in the choice of the position of the ways evidence that they were planned by persons of unusual natural ability as engineers; but at least nine-tenths of the road mileage of Massachusetts has been located without a proper study of the country, and by men who had no sense of the gravity of the task which they undertook. Although the tax which arises from the inadequate character of the roadbeds of the Commonwealth is very great, it seems to the writer that the evils which are due to defects of location are yet more serious, and, of course, are likely to be much more permanent.

The only way to provide against the extension of this evil, in case the road should have to be reconstructed, and for its proper remedy by the relocation of ways, is through a provision in the form of high-grade maps which shall display the topography of the country, in both its horizontal and its vertical elements, in a manner sufficiently accurate for the roadmaker's use. The map of the Commonwealth made a decade ago by combination of the work of the United States Geological Survey and that of the topographical survey of the Commonwealth will, to a certain extent, serve this need. By careful use of these charts it is possible, as experience shows, to make a preliminary project concerning a road in a tolerably effective manner. But to do the work thoroughly this system of mapping should be completed in such shape as to give sheets which, at least in the office form, will be on the scale of 1 foot to the mile. These sheets should be colored to indicate both the nature of the soil and surface deposits and that of the underlying rocks.

Although it might not be considered advisable to undertake the preparation of maps on this scale with reference alone to the construction of roads, the task is warranted by the fact that no district which is so densely inhabited as is this State can organize its system of land taxation, of water supplies, of drainage, etc., without large-scale maps. Thus, while such charts are demanded with reference to transportation routes, they are necessary for many other branches of public service. It may, moreover, be said that the enlightened use of the road materials demands that maps be prepared on a scale sufficiently large to indicate the sources and quantities of these materials. Proper indications for guiding this work can not be given on the small-scale maps which now exist.

THE BRICK-MAKING CLAYS OF MASSACHUSETTS.

In the modern development of carriage-ways there has come about a considerable extension in the use of the method of paving with burnt brick. This method originated in Holland, and it has been maintained in that part of Europe for some centuries. It has been in a very limited way applied to the roads of this country within the last twenty years, but it has met with such approval that the clays of any district which are suitable for making paving brick of a quality which may serve for wheel-ways must be counted as among its important highway resources. Therefore, though as yet no such paving bricks have been made in Massachusetts, it seems fit that an account of the deposits which may be made to serve this purpose should be given in this report.

So far as the writer has been able to determine by an examination of the clays which are useful in making paving brick suitable to be placed on highways, there is demanded material which combines silica and alumina with the minimum of potash, soda, or other substances which may be calculated to make the brick flux or attain the state of glass when heated in the process of burning. At the same time it is necessary that at a given high temperature a slight liquefaction or softening of the quartz should take place, in order that the particles may become welded together. So far as experiments have gone, it has not as yet proved possible to determine by analysis, or even by laboratory tests in burning, whether a given clay will prove to be suitable for the use which we are considering, and this for the reason that much depends on the mechanical conditions of the mass. Among these conditions we may note the necessity of having the fragments which are to be bound together individually hard and rather coarse. To this requirement is due the fact that it is in general most profitable to make the clay from which the bricks are to be produced by grinding up somewhat hard and coarse-grained shales, rather than to use the ordinary finely divided clays.

Among the deposits which exist in Massachusetts of a nature to warrant experiments with a view to producing high-grade paving brick, we may note the following: In the Berkshire district, especially in the region in and about the town of Blandford, there are extensive deposits of clays, the finer of which, under the name of kaolin, are to a considerable extent carried to distant markets. These clays have properties which will make them, when mingled in the pug mill with ground-up fragments of quartzite, a possible resource in road-brick making. The finer variations may prove too valuable for such use, but the coarser, which are not suitable for exportation, might be made to serve in the manner above indicated.

In Bristol County the Coal Measures, which are there extensively developed, afford many beds of indurated shale, which, when ground and perhaps mixed in some measure with clays from deposits of the Glacial age, will be likely to yield high-grade paving brick. In this connection it may be noted that some of the most successful establishments engaged in the manufacture of such brick in Illinois obtain the material from deposits of Carboniferous age. It may also be said that the coal beds of the Narragansett basin, which have as yet been but little worked, bid fair to afford a tolerable material for burning bricks. It is not likely that these coals could be used for that purpose in their raw state, but if converted into water gas they would probably serve quite as well as does petroleum for use in the kilns.

On the island of Marthas Vineyard there exists an area about 50 square miles in extent underlain by Cretaceous and Tertiary clays and sands, where almost any desired quality of material for brick making can be obtained by mixing the product of different beds. In the present conditions of this island the clay deposits, though near the sea, are not approachable through good harbors. At the cost of a few thousand dollars, however, probably for less than $10,000, a very good port for vessels drawing not more than 10 feet of water could be made by cutting through the beach which separates Menemsha Pond from Vineyard Sound. It is likely that if such provision for transportation is ever made the clays of this district will come to be used for the production of paving brick.

The glacial clays of Massachusetts are extensively distributed, and frequently occur under conditions which make it seem likely that they may serve, when mixed with other materials, for the manufacture of paving brick. In the Berkshire district these clays of good quality are rarer than elsewhere in the State. They are, moreover, rather too fusible for this use, owing to the fact that the schists afford minerals that are rich in lime and soda, which give the resulting clays a tendency readily to pass into the state of glass.

The river clays of the Connecticut Valley appear to be promising for experiments in the production of paving brick, but so far as is known to the writer there are no conveniently accessible deposits of the hard rocks which are suitable to be used in the mixture, unless the trap stones should prove fit for such use.

In the Worcester district the clays are prevailingly too fusible for use in any mixtures where the object is to produce a hard burning of the material with only a semiliquefaction. So far as is known to the writer, there are no deposits in this section of the State which are worth attention from those who are seeking brick-making clays.

In the region of the coastal plateau the glacial clays are relatively abundant and of varied quality. The experience of the brick-makers shows that in general the hard burning can be induced without excessive production of glass in the bricks, and though in all cases these clays will need to be mixed with some form of ground hard rock, there is reason to suppose that with such treatment they will serve the end which is here in view. The brick clays of this district, or at least all of those of this nature which are worth considering, are found in the lowlands of the river valleys, or adjacent to the seashore. They are well developed in the Merrimac Valley below Lowell, in that of the Charles and the Mystic, and they occur plentifully in the eastern portion of Bristol County and in the valley of the Taunton River. Taken together, the area of deposits of this nature which is accessible for working probably exceeds 25 square miles, though throughout the greater portion of this extent the layers of clay are covered by a coating of sand having a depth of from 1 to 10 feet.

Among the varied rocks of this district which may be used for mingling with the glacial clay to give it the texture that appears to be necessary for making paving brick, we may note the several species of stone. Perhaps the best suited to this end are the felsites and porphyries, and along with these may be classed the darker-colored dike stones, which are used as road material. Of these the felsites are most easily ground. Some of the very indurated felsites and quartzites may be made to serve the same purpose. The granitic rocks, where they are not micaceous, are likely also to prove useful in supplying the necessary kind of admixing material.

It should be clearly understood that the statements here made concerning the possible resources for the production of paving brick are mere suggestions, and are not to be taken as the basis of any economic work. Those who intend to inquire further into the matter should submit the materials to careful trial in a somewhat extensive way. Owing to the fact that the demand for paving brick promises to be quite large in the near future, these trials may be recommended, especially as, in the present condition of the market, the nearest source of supply of brick of high grade is in Illinois. If, by the proper treatment of the materials found in Massachusetts, bricks of equally good quality can be produced at anything like the cost at which they are made in the Mississippi Valley, the undertaking should prove remunerative.

ROAD-MAKING GRAVELS.

It has long been the custom in Massachusetts, as elsewhere within the glaciated district of this country, to cover highways with a coating of gravel, the layer being put on to the depth of from 6 inches to 1 foot. At the present time the greater part of the length of the fairly well-made highways in this State have been constructed in this manner. The success of this method has been extremely varying. In many cases the gravel thus used has been found to compact after the manner of macadam rock, the road remaining smooth and tolerably enduring when subjected to a moderate amount of traffic. In other instances—much the greater portion of the whole—the material, even when brought into position by the use of the roller and well underdrained, has failed to unite into a solid mass and has quickly been reduced to an incoherent state.

The experience which has been gained in Massachusetts is to the effect that, save under rarely occurring conditions, the use of gravel in the construction of roads is not to be recommended, and this for the reason that the rate of wear of the material is in general so rapid that the cost of repairs, when capitalized, makes highways of this description more expensive than are those which are constructed of macadam. On this account it does not seem desirable to give any extensive description of the road-making gravels of this area. The statements made below are intended for the guidance of those roadmasters who may be inclined to maintain a method of road building which in the present condition of the art can not be deemed sound practice.

The road-making gravels of Massachusetts which can be trusted to form a tolerably firm bed depend for their satisfactory qualities on one or more of the following conditions: They are composed of pebbles derived from rocks which have a high cementation value; they contain a considerable admixture of iron oxides; or they have, on account of their deeply covered position, remained in the condition in which they were immediately after their formation. In general, it may be said that the first-named class of road-making gravels is the most serviceable, the deposits belonging to the other groups being of relatively rare occurrence.

As regards the distribution of the road-making gravels, it may be said that no deposits of good quality are as yet known in the portion of the State lying to the west of the eastern margin of Worcester County. In the Berkshire district the larger valleys, particularly west of the Deerfield River, contain deposits which have a certain cementation value, this feature being due to the fact that a considerable proportion of the pebbles have been derived from the harder rocks of Vermont. As a whole, it may be said that these gravels are of an inferior quality.

In the region east of Worcester County, owing in the main to the large amount of trappean deposits and to the greater survival of the pebbles derived from these rocks, the gravels are, from the point of view of the road-maker, at their best. In the county of Essex deposits of this nature occasionally afford materials which can be used, after careful screening, with almost the same advantage that would be obtained from the ordinary grades of macadam rock.

In what is commonly known as the Cape district, i. e., the section lying to the south and east of a line drawn from Plymouth to Marion, road-making gravels appear to be entirely wanting. The pebbly beds are composed mainly of quartz, and the fragments of other rocks are commonly so much decayed that they are unfit to serve as a binding material to unite the other portions of the mass.

It seems not unlikely that the deposits of gravel in Massachusetts may in many instances prove useful as foundation materials on which is to be placed a superstructure of macadam rock. By this method of construction it is possible somewhat to reduce the total thickness of the macadam layer. As yet careful experiments looking toward this form of construction are lacking.

STATISTICS CONCERNING THE RESISTANCES TO WEAR OF ROAD-BUILDING STONES.

The following tables represent the results of the tests which have been applied to samples of road-building stones. These results were obtained by Mr. L. W. Page, geologist of the Massachusetts highway commission, by the method described on page 286 of this report.

ABRASION TESTS OF ROAD-BUILDING STONES.

[The first Arabic numeral following the name of the locality indicates the sheet of the U. S. Geological Survey map of Massachusetts; the Roman number, one of the nine sections into which the map is divided; the number and letter in curves, the exact location whence the specimen came. In this last method of indicating, each section of the map is divided vertically into twenty-six divisions, designated by the letters of the alphabet, and horizontally into thirty-four divisions, which are indicated by numbers. Although it has proved impracticable to have a detailed map of Massachusetts accompany this report, it has seemed well to retain these note-book indications, for the reason that they afford a tolerably accurate and quite permanent record as to the site of the specimens which have been tested.]

No. 1.—Locality of stone: Lee, Berkshire County, Mass. 2, IX (15—Z). Name of stone: Marble. Coefficient of wear, 2.85.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams....	4,131.82	153.81	7.01	0.77	5.54	10.63	92.14	584.63	13.65	700.72
Ounces...	145.44	5.41	.25	.03	.19	.37	3.24	20.58	.48	24.67
Per cent.....	82.64	3.08	.14	.02	.11	.21	1.84	11.69	.27	14.01

REMARKS.—Although the binding power of this stone is high, it is so soft and has such a tendency to crumble that it would be worthless as a road metal. It might possibly be used to advantage as a binder in surfacing roads. Selected specimens could be obtained at the same quarry which would stand a higher test than this.

No. 2.—Locality of stone: Lenox. Berkshire County, Mass. 2, VII (24—Q). Name of stone: Mica schist. Coefficient of wear, 8.04.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams....	4,700	42.97	3.94	0.38	2.31	5.80	30.97	205.52	8.11	248.92
Ounces...	165.44	1.51	.14	.01	.08	.20	1.09	7.23	.28	8.76
Per cent.....	94	.86	.08	.01	.04	.11	.61	4.11	.16	4.98

REMARKS.—This rock is very heterogeneous; it contains a great deal of quartz and mica. Its only value as a road metal is its resistance to decay. It would probably do well as a foundation material for roads.

Abrasion tests of road-building stones—Continued.

No. 3.—Locality of stone: Pittsfield, Berkshire County, Mass. 2, VII (28—D). Name of stone: Limestone. Coefficient of wear, 9.38.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams....	4,695.74	82.83	1.65	2.55	13.95	7.82	20.90	166.28	8.28	213.15
Ounces...	165.29	2.92	.06	.09	.49	.28	.74	5.85	.29	7.50
Per cent....	93.91	1.66	.03	.05	.28	.16	.42	3.33	.17	4.26

Remarks.—This stone is of a light-gray color, and rather hard for limestone. It would undoubtedly make a good road if not subjected to heavy traffic.

No. 4—Locality of stone: Duxbury, Plymouth County, Mass. 44, III (26—L). Name of stone: Hornblende-granitite. Coefficient of wear, 13.46.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams....	4,777.27	65.19	0.21	0.23	3.99	4.20	17.07	122.84	9.00	148.54
Ounces...	168.16	2.29	.01	.01	.14	.15	.60	4.32	.32	5.23
Per cent.....	95.54	1.62	.004	.004	.07	.08	.34	2.46	18	2.97

Remarks.—This rock gives a very high coefficient for one of its class. It was considerably weathered, which may possibly account for it It is difficult to say just what its results on a road would be.

No. 5.—Locality of stone: Waltham, Middlesex County, Mass. 26, VIII (23—V). Name of stone: Hornblende-granitite. Coefficient of wear, 12.16.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams....	4,789.96	33.52	0.42	0.54	6.55	5.25	17.02	134.70	12.04	164.48
Ounces...	168.61	1.18	.01	.02	.23	.18	.60	4.74	.42	5.79
Per cent.....	95.80	.67	.01	.01	.13	.11	.34	2.69	.24	3.29

Remarks.—This rock has been used a great deal in road making, and its results have been very good for a rock of its class.

No. 6.—Locality of stone: Salem, Essex County, Mass. 37, VI (31—F). Name of stone: Augite-diorite. Coefficient of wear, 15.55.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams....	4,840.91	22.32	0.39	0.38	2.74	2.94	11.64	110.51	8.17	128.60
Ounces...	170.40	.79	.01	.01	.10	.10	.41	3.89	.29	4.53
Per cent.....	96.82	.40	.01	.01	.05	.06	.20	2.21	.16	2.57

Remarks.—This stone has been used very extensively throughout eastern Massachusetts, and its results have been most satisfactory.

Abrasion tests of road-building stones—Continued.

No. 7.—Locality of stone: Tomkins Cove, N. Y. Name of stone: Limestone. Coefficient of wear, 6.31.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams....	4,613.64	68.35	0.85	2.20	21.20	9.30	32.40	251.16	.90	317.11
Ounces...	162.40	2.41	.03	.08	.74	.33	1.14	8.84	.03	11.16
Per cent.....	92.27	1.37	.02	.05	.42	.19	.65	5.02	.02	6.34

REMARKS.—This stone would make a good binder for surfacing a road.

No. 8.—Locality of stone: Somerville, Middlesex County, Mass. 31, V (7—M). Name of stone: Slate (probably Cambrian). Coefficient of wear, 8.48.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams....	4,719.13	29.93	0.74	2.54	19.67	10.70	31.40	170.75	15.14	235.80
Ounces...	166.11	1.05	.03	.09	.69	.38	1.10	5.98	.53	8.15
Per cent.....	94.38	.60	.01	.05	.39	.21	.63	3.41	.30	4.72

REMARKS.—This stone has been used for some time in road making. Its results are very poor; it soon grinds to powder, and makes a great deal of mud and dust.

No. 9.—Locality of stone: Lee, Berkshire County, Mass. Name of stone: Quartzite. Coefficient of wear, 11.65.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams....	4,773.84	47.75	0.32	0.14	1.34	2.96	19.45	147.46	6.74	171.67
Ounces...	168.04	1.68	.01	.005	.05	.10	.68	5.19	.24	6.04
Per cent.....	95.48	.95	.01	.003	.03	.06	.39	2.95	.13	3.43

REMARKS.—This stone, though extremely hard, has no binding power or toughness. It would probably not be very satisfactory except in the foundation of a road.

No. 10.—Locality of stone: Northampton, Hampshire County, Mass. Name of stone: Hornblende-granitite. Coefficient of wear, 10.69.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams....	4,771.06	34.21	0.28	0.96	6.82	5.75	18.60	154.71	7.61	187.12
Ounces...	167.94	1.20	.01	.03	.24	.20	.65	5.45	.27	6.59
Per cent.....	95.42	.68	.01	.02	.14	.11	.37	3.10	.15	3.74

REMARKS.—This stone would give only fair results, as it contains a high per cent of quartz, which renders it very brittle.

Abrasion tests of road-building stones—Continued.

No. 11.—Locality of stone: North Attleboro, Bristol County, Mass. Name of stone: Field stone (erratics). Coefficient of wear, 9.09.

	Size of mesh.								Loss.	Under $\frac{1}{8}$ in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams....	4,756.88	15.80	1.78	23.37	33.51	11.80	40.35	109.28	7.23	220.09
Ounces ...	167.44	.56	.06	.82	1.18	.42	1.42	3.85	.25	7.75
Per cent.....	95.14	.32	.04	.47	.67	.24	.81	2.19	.14	4.40

REMARKS.—This stone varies so much in character that its results on the road would be only fair. It is not weathered so much as field stone generally is, which may account for its rather high coefficient.

No. 12.—Locality of stone: Whitman, Plymouth County, Mass. Name of stone: Field stone (erratics). Coefficient of wear, 5.93.

	Size of mesh.								Loss.	Under $\frac{1}{8}$ in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams....	4,482.51	175.86	0.87	28.97	17.37	13.45	42.99	233.76	4.22	337.41
Ounces ...	157.78	6.19	.03	1.02	.61	.47	1.51	8.23	.15	11.88
Per cent.....	89.65	3.52	.02	.58	.35	.27	.86	4.68	.08	6.75

REMARKS.—This stone varies so much in character and is weathered to such an extent that it would be of little value as a road metal.

No. 13.—Locality of stone: Mattapoisett, Plymouth County, Mass. Name of stone: Field stone (erratics). Coefficient of wear, 8.78.

	Size of mesh.								Loss.	Under $\frac{1}{8}$ in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams....	4,699.42	70.60	0.47	11.27	23.10	14.47	26.40	151.48	2.79	227.69
Ounces ...	165.42	2.49	.02	.40	.81	.51	.93	5.33	.10	8.01
Per cent.....	93.99	1.41	.01	.23	.46	.29	.53	3.03	.06	4.55

REMARKS.—This stone is somewhat weathered and varies much in character.

No. 14.—Locality of stone: Everett, Middlesex County, Mass. 31. VIII (6—N). Name of stone: Olivine-diabase. Coefficient of wear, 13.87.

	Size of mesh.								Loss.	Under $\frac{1}{8}$ in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams....	4,845.83	5.24	0.22	25.35	23.06	7.45	16.99	71.07	4.79	144.14
Ounces ...	170.57	.18	.01	.89	.81	.26	.60	2.50	.17	5.07
Per cent.....	96.92	.10	.004	.51	.46	.15	.34	1.42	.10	2.88

REMARKS.—This rock is rather coarse grained, which probably accounts for the rather low coefficient for a rock of its kind. It has been used in road making, and its results are fairly good.

Abrasion tests of road-building stones—Continued.

No. 15.—Locality of stone: Revere, Suffolk County, Mass. 31, VII (26—T). Name of stone: Felsite. Coefficient of wear, 13.21.

	Size of mesh.								Loss.	Under 1/16 in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or 1/16 in.	0.13 cm. or 1/20 in.	0.064 cm. or 1/40 in.	0.042 cm. or 1/60 in.	0.031 cm. or 1/80 in.	0.025 cm. or 1/100 in.		
Weight:										
Grams....	4,775.59	68.65	0.53	1.37	4.70	7.66	22.26	114.94	4.30	151.46
Ounces ...	168.10	2.42	.02	.05	.17	.27	.78	4.05	.15	5.33
Per cent.....	95.51	1.37	.01	.03	.09	.15	.45	2.30	.09	3.03

REMARKS.—This rock is extremely hard, but very brittle. It is probably too brittle to give very good results.

No. 16.—Locality of stone: West Springfield, Hampden County, Mass. 12, II (25—R). Name of stone: Olivine-diabase. Coefficient of wear, 15.60.

	Size of mesh.								Loss.	Under 1/16 in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or 1/16 in.	0.13 cm. or 1/20 in.	0.064 cm or 1/40 in.	0.042 cm. or 1/60 in.	0.031 cm. or 1/80 in.	0.025 cm. or 1/100 in.		
Weight:										
Grams....	4,840.26	26.61	0.65	0.98	3.27	2.77	8.98	111.55	4.93	128.20
Ounces...	170.38	.94	.02	.03	.12	.10	.32	3.93	.17	4.49
Per cent.....	96.80	.53	.01	.02	.07	.06	.18	2.23	.10	2.56

REMARKS.—This stone has been used in road making, and its results have been very satisfactory.

No. 17.—Locality of stone: Meriden, Conn. Name of stone: Augite-diabase. Coefficient of wear, 12.50.

	Size of mesh.								Loss.	Under 1/16 in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or 1/16 in.	0.13 cm. or 1/20 in.	0.064 cm. or 1/40 in.	0.042 cm. or 1/60 in.	0.031 cm. or 1/80 in.	0.025 cm. or 1/100 in.		
Weight:										
Grams....	4,803.53	31.92	0.63	1.26	4.13	4.37	9.70	139.87	4.59	159.96
Ounces ...	169.08	1.12	.02	.04	.15	.15	.34	4.92	.16	5.63
Per cent.....	96.07	.64	.01	.03	.08	.09	.19	2.80	.09	3.20

REMARKS.—This rock has been used extensively in Connecticut for road building, and its results are said to be good. The specimen received of this stone was a poor one.

No. 18.—Locality of stone: Holden, Worcester County, Mass. Name of stone: Field stone (erratics). Coefficient of wear, 6.58.

	Size of mesh.								Loss.	Under 1/16 in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or 1/16 in.	0.13 cm. or 1/20 in.	0.064 cm. or 1/40 in.	0.042 cm. or 1/60 in.	0.031 cm. or 1/80 in.	0.025 cm. or 1/100 in.		
Weight:										
Grams....	4,658.49	30.88	0.12	0.23	2.34	6.00	31.27	263.95	6.72	303.91
Ounces ...	163.98	1.09	.004	.01	.08	.21	1.10	9.29	.24	10.70
Per cent.....	93.17	.62	.002	.004	.05	.12	.63	5.28	.13	6.08

REMARKS.—There were several varieties of stone in this test, all of which were weathered considerably. Only a poor result can be expected from this stone.

Abrasion tests of road-building stones—Continued.

No. 19.—Locality of stone: Newton, Middlesex County, Mass. 31, II (32—L). Name of stone: Trachyte. Coefficient of wear, 20.79.

	Size of mesh.								Loss.	Under 1/16 in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or 1/16 in.	0.13 cm. or 1/20 in.	0.064 cm. or 1/40 in.	0.042 cm. or 1/60 in.	0.031 cm. or 1/80 in.	0.025 cm or 1/100 in.		
Weight:										
Grams....	4,890.52	12.20	0.49	0.50	4.18	4.01	12.52	74.49	1.09	96.19
Ounces...	172.15	.43	.02	.02	.15	.14	.44	2.62	.04	3.39
Per cent.....	97.81	.24	.01	.01	.08	.08	.25	1.49	.02	1.92

Remarks.—This stone is exceedingly hard and tough. Its coefficient shows it to be of an excellent quality. It has been used in road making, and its results are excellent.

No. 20.—Locality of stone: Newton, Middlesex County, Mass. 31, III (1—V). Name of stone: Conglomerate. Coefficient of wear, 8.67.

	Size of mesh.								Loss.	Under 1/16 in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or 1/16 in.	0.13 cm. or 1/20 in.	0.064 cm. or 1/40 in.	0.042 cm. or 1/60 in.	0.031 cm. or 1/80 in.	0.025 cm. or 1/100 in.		
Weight:										
Grams....	4,657.84	106.80	0.46	0.85	12.65	10.20	32.27	174.21	4.72	230.64
Ounces...	163.96	3.76	.02	.03	.45	.36	1.14	6.13	.17	8.12
Per cent.....	93.16	2.14	.01	.02	.25	.20	.65	3.48	.09	4.61

Remarks.—The stone used in this test was considerably weathered; so much so, that the pebbles had a tendency to separate from the matrix. This stone has been used in road making, and its results are only fair.

No. 21.—Locality of stone: Brookline, Norfolk County, Mass. 31, VI (5—B). Name of stone: Hornblende-diorite. Coefficient of wear, 11.40.

	Size of mesh.								Loss.	Under 1/16 in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or 1/16 in.	0.13 cm. or 1/20 in.	0.064 cm. or 1/40 in.	0.042 cm. or 1/60 in.	0.031 cm. or 1/80 in.	0.025 cm. or 1/100 in.		
Weight:										
Grams....	4,808.26	10.78	1.05	1.40	6.92	7.41	20.85	137.75	5.58	175.38
Ounces...	169.25	.38	.04	.05	.24	.26	.73	4.85	.20	6.17
Per cent.....	96.17	.22	.02	.03	.14	.15	.42	2.75	.11	3.51

Remarks.—The stone used in this test was very much weathered. It has a high cementing value, and is quite hard, and would undoubtedly make an excellent road material.

No. 22.—Locality of stone: Quincy, Norfolk County, Mass. 32, VII (3—P). Name of stone: Hornblende-granitite. Coefficient of wear, 10.16.

	Size of mesh.								Loss.	Under 1/16 in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or 1/16 in.	0.13 cm. or 1/20 in.	0.064 cm. or 1/40 in.	0.042 cm. or 1/60 in.	0.031 cm. or 1/80 in.	0.025 cm. or 1/100 in.		
Weight:										
Grams....	4,735.37	63.10	2.56	3.60	31.70	10.19	26.36	122.39	4.73	196.80
Ounces...	166.69	2.22	.09	.13	1.12	.36	.93	4.31	.17	6.93
Per cent.....	94.71	1.26	.05	.07	.63	.20	.53	2.45	.09	3.94

Remarks.—This stone contains a high per cent of quartz, which renders it very brittle, too much so for a good road material.

Abrasion tests of road-building stones—Continued.

No. 23.—Locality of stone: Nantucket, Nantucket County. Mass. Name of stone: Field stone (erratics). Coefficient of wear, 9.47.

	Size of mesh.								Loss.	Under 1/16 in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or 1/16 in.	0.13 cm. or 1/20 in.	0.064 cm. or 1/40 in.	0.042 cm. or 1/60 in.	0.031 cm. or 1/80 in.	0.025 cm. or 1/100 in.		
Weight:										
Grams....	4,741.52	43.48	1.26	0.84	9.90	6.73	27.12	165.42	3.73	211.25
Ounces ...	166.90	1.53	.04	.03	.35	.24	.95	5.82	.13	7.44
Per cent.....	94.83	.87	.02	.02	.20	.13	.54	3.31	.07	4.22

REMARKS.—Consists chiefly of a variety of granites, in various stages of decomposition. Its coefficient is rather high for field stone, and fair results may be expected in a road subjected to light teaming.

No. 24.—Locality of stone: Quincy, Norfolk County, Mass. 38, III (30—K). Name of stone: Diabase Coefficient of wear, 15.21.

	Size of mesh.								Loss.	Under 1/16 in.
	6.31 cm. or 2½ in	3.18 cm. or 1¼ in.	0.16 cm. or 1/16 in.	0.13 cm. or 1/20 in.	0.064 cm. or 1/40 in.	0.042 cm. or 1/60 in.	0.031 cm. or 1/80 in.	0.025 cm. or 1/100 in.		
Weight:										
Grams....	4,859.45	7.20	0.12	0.48	4.46	5.60	13.77	107.01	1.91	131.44
Ounces ...	171.05	.25	.004	.02	.16	.20	.48	3.77	.07	4.63
Per cent.....	97.19	.14	.002	.01	.09	.11	.28	2.14	.04	2.63

REMARKS.—This stone is very hard and tough, and will undoubtedly make a good road metal.

No. 25.—Locality of stone: Somerville, Middlesex County, Mass. 31, V (14—T). Name of stone: Diabase. Coefficient of wear, 9.28.

	Size of mesh.								Loss.	Under 1/16 in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or 1/16 in.	0.13 cm. or 1/20 in.	0.064 cm. or 1/40 in.	0.042 cm. or 1/60 in.	0.031 cm. or 1/80 in.	0.025 cm. or 1/100 in.		
Weight:										
Grams....	4,778.82	4.85	0.57	1.10	10.93	7.04	18.26	177.60	0.83	215.50
Ounces ...	168.21	.17	.02	.04	.38	.25	.64	6.25	.03	7.59
Per cent.....	95.58	.10	.01	.02	.22	.14	.37	3.55	.02	4.31

REMARKS.—This stone has considerable binding power, but it is very coarse grained and has a tendency to crumble. It would not make a good road metal.

No. 26.—Locality of stone: Medford, Middlesex County, Mass. 31, IV (31—N). Name of stone: Diabase. Coefficient of wear, 15.82.

	Size of mesh.								Loss.	Under 1/16 in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or 1/16 in.	0.13 cm. or 1/20 in.	0.064 cm. or 1/40 in.	0.042 cm. or 1/60 in.	0.031 cm. or 1/80 in.	0.025 cm. or 1/100 in.		
Weight:										
Grams....	4,855.23	16.60	0.49	0.70	4.67	3.78	12.55	104.28	1.70	126.47
Ounces ...	170.90	.58	.02	.02	.16	.13	.44	3.67	.06	4.45
Per cent.....	97.10	.33	.01	.01	.09	.08	.25	2.09	.03	2.53

REMARKS.—This rock has been used as a road metal, and very good results have been obtained.

Abrasion tests of road-building stones—Continued.

No. 27.—Locality of stone: Lynn, Essex County, Mass. 38, I (12—C). Name of Stone: Diabase. Coefficent of wear, 19.77.

	Size of mesh.									
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.	Loss.	Under $\frac{1}{16}$ in.
Weight:										
Grams....	4,884.80	10.72	0.14	0.24	2.89	2.42	8.39	87.06	3.34	101.14
Ounces...	171.94	.38	.005	.01	.10	.09	.30	3.06	.12	3.56
Per cent.....	97.70	.21	.003	.005	.06	.05	.17	1.74	.07	2.02

REMARKS.—This stone is very hard and tough, and will undoubtedly make an excellent road metal.

No. 28.—Locality of stone: Lynn, Essex County, Mass. 38, I (16—D). Name of stone: Diabase. Coefficient of wear, 20.37.

	Size of mesh.									
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.	Loss.	Under $\frac{1}{16}$ in.
Weight:										
Grams....	4,896.07	1.92	0.14	0.91	2.64	2.42	9.02	83.06	3.82	98.19
Ounces...	172 34	.07	.005	.03	.09	.09	.32	2.92	.13	3.46
Per cent.....	97.92	.04	.003	.02	.05	.04	.18	1.66	.07	1.96

REMARKS.—This stone is exceedingly hard and tough, and will beyond doubt make an excellent road metal.

No. 29.—Locality of stone: Saugus, Essex County, Mass. 31, VII (21—Y). Name of stone: Diabase. Coefficient of wear, 16.08.

	Size of mesh.									
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.	Loss.	Under $\frac{1}{16}$ in.
Weight:										
Grams....	4,870.29	3.93	0.32	0.36	3.44	2.65	12.11	105.48	1.42	124.36
Ounces...	171.43	.14	.01	.01	.12	.09	.43	3.71	.05	4.38
Per cent.....	97.41	.08	.01	.01	.07	.05	.24	2.11	.03	2.49

REMARKS.—Very good results should be expected from this stone.

No. 30.—Locality of stone: Brookline, Norfolk County, Mass. 31, VI (7—B). Name of stone: Olivine-diabase. Coefficient of wear, 14.71.

	Size of mesh.									
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.	Loss.	Under $\frac{1}{16}$ in.
Weight:										
Grams....	4,833.20	26.41	0.87	0.82	6.37	6.31	13.95	107.65	4.42	135.97
Ounces...	170.13	.93	.03	.03	.22	.22	.49	3.79	.16	4.79
Per cent.....	96.66	.53	.02	.02	.13	.13	.28	2.15	.09	2.72

REMARKS.—The stone in this test was very much weathered; a fresh specimen from the same ledge would give a better result. It should make an excellent road metal.

Abrasion tests of road-building stones—Continued.

No. 31.—Locality of stone: Lynn, Essex County, Mass. 38, I (12—K). Name of stone: Felsite. Coefficient of wear, 14.66.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams...	4,802.57	56.77	2.48	1.20	12.85	8.12	22.71	89.08	4.22	136.44
Ounces..	169.05	2.00	.09	.04	.45	.29	.80	3.14	.15	4.80
Per cent....	96.05	1.14	.05	.02	.26	.14	.45	1.78	.08	2.73

REMARKS.—This stone is of a good quality, and very fair results should be expected from its use.

No. 32.—Locality of stone: Saugus, Essex County, Mass. 31, VII (24—W). Name of stone: Diabase. Coefficient of wear, 16.02.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams.....	4,868.93	2.79	0.35	0.45	6.01	5.80	21.34	90.87	3.46	124.84
Ounces....	171.39	.10	.01	.02	.21	.20	.75	3.19	.12	4.39
Per cent....	97.38	.06	.01	.01	.12	.12	.43	1.82	.07	2.50

REMARKS.—The stone in this test was somewhat weathered; it should make a good road metal.

No. 33.—Locality of stone: Gloucester, Essex County, Mass. 43, II (28—U). Name of stone: Hornblende-granitite. Coefficient of wear, 11.03.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight										
Grams....	4,806.21	8.05	0.06	1.56	29.92	7.75	21.00	121.08	4.37	181.37
Ounces...	169.18	.28	.002	.05	1.05	.27	.74	4.26	.15	6.38
Per cent.....	96.12	.16	.001	.03	.60	.15	.42	2.42	.09	3.63

REMARKS.—This stone contains too much quartz to be a very good road metal.

No. 34.—Locality of stone: Lynn, Essex County, Mass. 38, I (12—N). Name of stone: Felsite. Coefficient of wear, 12.30.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams....	4,821.61	10.32	0.32	0.60	5.03	5.36	22.52	128.70	5.54	162.53
Ounces...	169.72	.36	.01	.02	.18	.19	.79	4.53	.20	5.72
Per cent.....	96.43	.21	.01	.01	.10	.11	.45	2.57	.11	3.25

REMARKS.—This stone is rather brittle, but it should give fair results.

Abrasion tests of road-building stones—Continued.

No. 35.—Locality of stone: Saugus, Essex County, Mass. 31, VII (20—V). Name of stone: Diabase. Coefficient of wear, 18.25.

	Size of mesh.								Loss.	Under 1/16 in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or 1/16 in.	0.13 cm. or 1/20 in.	0.064 cm. or 1/40 in.	0.042 cm. or 1/60 in.	0.031 cm. or 1/80 in.	0.025 cm. or 1/100 in.		
Weight:										
Grams....	4,878.09	6.97	0.17	0.61	3.08	3.43	13.01	89.29	5.35	109.59
Ounces...	171.71	.25	.01	.02	.11	.12	.46	3.14	.19	3.86
Per cent.....	97.56	.14	.003	.01	.06	.06	.26	1.79	.11	2.19

REMARKS.—This stone should give excellent results.

No. 36.—Locality of stone, Lynn, Essex County, Mass. 38, I (10—C). Name of stone: Diabase. Coefficient of wear, 18.17.

	Size of mesh.								Loss.	Under 1/16 in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or 1/16 in.	0.13 cm. or 1/20 in.	0.064 cm. or 1/40 in.	0.042 cm. or 1/60 in.	0.031 cm. or 1/80 in.	0.025 cm. or 1/100 in.		
Weight:										
Grams....	4,891.03	3.90	0.11	0.26	2.41	2.61	11.30	83.41	4.97	110.10
Ounces...	172.16	.14	.004	.01	.08	.09	.40	2.94	.17	3.88
Per cent.....	97.82	.08	.002	.005	.05	.05	.22	1.67	.10	2.20

REMARKS.—This stone is rather coarse grained, but very hard and tough. It should give excellent results.

No. 37.—Locality of stone: Gloucester, Essex County, Mass. 43, II (32—F). Name of stone: Augite-nepheline-syenite. Coefficient of wear, 12.63.

	Size of mesh.								Loss.	Under 1/16 in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or 1/16 in.	0.13 cm. or 1/20 in.	0.064 cm. or 1/40 in.	0.042 cm. or 1/60 in.	0.031 cm. or 1/80 in.	0.025 cm. or 1/100 in.		
Weight:										
Grams....	4,826.69	9.23	0.17	1.05	22.63	7.08	20.27	107.22	5.66	158.42
Ounces...	169.90	.32	.01	.04	.80	.25	.71	3.78	.20	5.58
Per cent.....	96.53	.18	.003	.02	.45	.14	.41	2.14	.11	3.17

REMARKS.—This stone, though somewhat brittle, should make a fairly good road metal.

No. 38.—Locality of stone: Saugus, Essex County, Mass. 31, VII (12—W). Name of stone: Hornblende-granitite. Coefficient of wear, 8.99.

	Size of mesh.								Loss.	Under 1/16 in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or 1/16 in.	0.13 cm. or 1/20 in.	0.064 cm. or 1/40 in.	0.042 cm. or 1/60 in.	0.031 cm. or 1/80 in.	0.025 cm. or 1/100 in.		
Weight:										
Grams....	4,724.44	48.48	0.44	0.96	14.40	6.30	25.42	174.97	4.59	222.49
Ounces...	166.30	1.71	.02	.03	.51	.22	.89	6.16	.16	7.83
Per cent.....	94.49	.97	.01	.02	.29	.13	.51	3.50	.09	4.45

REMARKS.—This stone is very coarse and brittle, which renders it rather poor for use on roads.

Abrasion tests of road-building stones—Continued.

No. 39.—Locality of stone: Newbury, Essex County, Mass. 36, VI (32—G). Name of stone: Olivine-diabase. Coefficient of wear, 20.40.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams....	4,891.92	6.48	0.02	0.28	2.34	2.15	10.80	82.46	3.55	98.05
Ounces...	172.20	.23	.001	.01	.08	.07	.38	2.90	.12	3.45
Per cent.....	97.84	.13	.0004	.01	.05	.04	.21	1.65	.07	1.96

Remarks.—This stone is exceedingly hard and tough, and excellent results should be expected from it.

No. 40.—Locality of stone: Saugus, Essex County, Mass. 31, VII (16—V). Name of stone: Diabase. Coefficient of wear, 21.22.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams....	4,895.35	5.66	0.23	0.22	1.35	1.54	9.23	81.68	4.79	94.25
Ounces...	172.32	.20	.01	.01	.05	.05	.32	2.88	.17	1.89
Per cent.....	97.91	.11	.01	.004	.03	.03	.18	1.63	.09	3.31

Remarks.—This stone is exceedingly hard and tough, and excellent results should be looked for from it. It has the highest coefficient of wear obtained up to this date.

No. 41.—Locality of stone: Tisbury, Dukes County, Mass. Name of stone: Field stone (erratics). Coefficient of wear, 8.88.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams....	4,685.69	84.89	0.34	0.50	11.38	5.27	23.13	184.75	4.05	225.37
Ounces...	164.94	2.99	.01	.02	.40	.19	.81	6.56	.14	7.93
Per cent.....	93.71	1.70	.01	.01	.23	.10	.46	3.69	.08	4.51

Remarks.—Slightly weathered. Fair results should be expected.

No. 42.—Locality of stone: Plymouth, Plymouth County, Mass. Name of stone: Field stone (erratics). Coefficient of wear, 10.10.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams....	4,745.46	52.15	2.50	0.86	12.93	10.13	24.85	146.84	4.28	198.11
Ounces...	167.04	1.84	.09	.03	.46	.36	.87	5.17	.15	6.97
Per cent.....	94.91	1.04	.05	.02	.26	.20	.50	2.94	.09	3.96

Remarks.—The stone used in this test was, for field stone, very well preserved. Consists chiefly of granite. Fair results should be expected.