AN ECONOMIC STUDY

OF THE PROPERTY OF THE

TIDE WATER TRAP ROCK COMPANY

AT

BRANFORD, CONN.

IRVING E. ADAMS.

INTRODUCTION.

Considering the wealth of triassic trap in the Connecticut Valley and the proximity of Boston and New York markets it seems remarkable, to the superficial observer, that so little stone has been quarried in the past for use as a road metal. The reason, however, is easily discovered. Notwithstanding the universally recognized fact that the more basic igneous rocks furnish the best of road material, they are, at the same time, the hardest and toughest and offer the greatest difficulties in crushing; and it is only when the conditions of deposition are especially favorable and the deposits themselves easily accessible to water transportation that economic exploitation is, as a rule, possible.

Now it so happens that the Connecticut Valley trap, which crosses the state as a series of boldly outcropping north-south ridges, fails in every case but one to quite reach the seaboard. This makes resort to railroad transportation necessary; and, since freight rates are high, and the New York, New Haven, & Hartford Railroad Company are themselves large shippers, there is slight opportunity for the independent quarry-owner to mine at a profit. Moreover, the nearby Palisades deposits have, up to very recent times, adequately supplied the New York market.

The eastern main trap ridge does, however, extend to the Sound; and the Tide Water Trap Rock Company controls its southernmost portion. This ridge possesses certain geological peculiarities, which, aside from their high theoretical interest, greatly reduce the difficulties of mining and crushing the rock. These considerations, coupled with the fact that the Palisades deposits are no longer available as a source of supply, make the future possibilities of this ridge, as a road-metal producer enormous.

This report will deal with some problems involving this property as a future economic factor. Details of plant, present degree of development, financial status of operating company, etc.--details belonging essentially to a stockholders' report,--will not be here touched upon. The cause of the extremely low crushing price will be dealt with at length, since it is at bottom an interesting geological problem. The physical properties of the rock, as determined from an elaborate series of laboratory tests, will be incorporated, together with a discussion of the utility of the various tests, based on collateral reading. Finally, the cause of the abnormally high recementation value will be considered.

LOCATION.

As noted above, the property in question is located about six miles east of New Haven, in the town of Branford, on a boldly outcropping ridge of trap, locally known as "Pond Rock", and, beginning one and one-eighth (1 1/8) miles S-10°-E of the railroad embankment across Lake Saltonstall, extends in a northerly and easterly direction for six miles. The property comprises some fifty-five (55) acres, distributed as indicated on the accompanying blue print.

Sections "C" and "D" on the blue print lie entirely on the ridge, the general direction of which is shown by the contour lines. At one point, "N", the underlying sandstone overlaps for a short distance. The quarry front is at "X", presenting a vertical face sixty feet (60') high. Section "B" represents a stretch of low land; it includes the Company buildings and crushing plant. Section "A" represents some island property on schistose rock, to be later utilized for storage bins. The Company has an option on section "G".

GENERAL GEOLOGY.

The mode of origin and condition of deposition of the triassic strata along the Atlantic border is a much mooted question among geologists. A wholly adequate theory explaining the source of the material forming the sandstone, varying as it does from the finest sand to the coarsest conglomerate, indiscriminatingly mixed; the peculiar lenticular shape of the deposits, requiring such a continual adjustment to sea level conditions; and the complicated structural relations of the accompanying "trap", have never been presented. As pertinent to the subject in hand, we are alone concerned with the question of the origin of the trap.

The formation has been studied in great detail in the Connecticut Valley by several able men, and the facts of structure, as now exposed, worked up very carefully. Nevertheless, in the interpretation of these facts the greatest difference of opinion still prevails. As to whether the trap was erupted "through a series of nearly parallel fissures in the strata, and after their consolidation and subsequent disturbance"; or whether it represents a series of volcanic lavas ejected before the tilting of the strata took place, is still an open question.

It so happens that "Pond Rock",at the southern end of which the quarry is located, possesses a peculiar interest in this connection, since, according to Prof. Davis, it affords the key to the solution of the origin of all the trap ridges of the Valley. According to the latter authority, Pond Rock represents an overflow sheet, the arguments advanced being briefly summed up as follows: the base exhibits little metamorphic action; the back or upper surface is characterized by a decided amygdaloid texture; its structure is brecciated and irregular; the rock is highly altered and hydrated. Mr. E. O. Hovey, on the other hand, in a later, and, for this particular area, more detailed work, has contended that, in the main, these features might obtain if the rock was intrusive in origin; and further advances what he considers positive evidence in the invariably somewhat higher dip of the overlying sandstone.

Since the conclusions reached by these writers, based on structural relations as exhibited over extended areas are so inharmonious, it seemed to me that a careful study of the "trap" itself in a very restricted area, and from as many points of view as possible, might serve to throw some light on this puzzling problem. For if the structural evidence is inadequate, the rock itself should present some features that would indicate its "intrusive" or "extrusive"mode of origin. Further, it appealed to me that too little laboratory work accompanied the reports of these writers.

GEOLOGY OF POND ROCK.

Pond Rock ridge is not continuous throughout. Extensive faulting divides it naturally into three members. The southernmost, and the one to be considered in detail, possesses a general trend of about N-14°-W, and is three-fourths (3/4) of a mile long, terminating just north of the Branford turnpike. The southern end rises abruptly above the older paleozoics, from which it is separated by a stretch of marsh land, to a height of 140' above mean low tide. It diminishes in height and width as we proceed north, until, at its termination, the former reaches 30', while the latter is only 60'. The western slope is steep, the eastern gentle. Sandstone flanks both slopes.

The top of the ridge presents a peculiar and characteristic appearance. The surface soil is extremely thin, the bare trap being quite generally exposed. It is quite universally weathered out as small, angular fragments, tough and undecomposed except along the weathered surfaces. An examination of one of these fragments reveals the presence of numerous steam vesicles, sometimes empty, sometimes filled with secondary calcite or quartz. Nowhere do these vesicles penetrate to a depth of more than a fraction of an inch. Quite often these vesicles are elongate, and resemble more the etchings of acid on a limey rock.

Boulders of sandstone abound along the eastern slope, but no true outcrops were observed; hence it was very difficult to ascertain the dip of the overlying sandstone. By dint of hard search an exposure undoubtedly in place was noted just south of the railroad cut. The soft, rather sandy shale here exposed agreed in character with the boulders strewn along the eastern slope. The contact had a general trend of N-71° -E, and dipped to the east at an angle of 74°.

Several contacts of trap and underlying sandstone are noted as you proceed north along the steep western slope. It is often difficult to know when you have a true contact, since boulders of trap are often engulfed in the sandstone. I obtained an average dip of 60 E, a somewhat higher figure than the one ascertained by Hovey. The strike is N-15° -E. The sandstone is quite generally indurated to a depth of 2'-3', it being otherwise of a loose, shaly texture. Conglomeritic phases were noted at intervals.

The quarry opening is at the extreme southern end, presenting a vertical face 60' high, and clearly revealing the structure of the trap. This structure is peculiar, and from a commercial point of view, highly important. Considered as a unit the mass is remarkable for its homogeneity. Of a rather dark, stony gray color, finely crystalline and very dense in texture, very intricately veined with a whitish mineral, mostly calcite--affording relief to an otherwise sombre surface--it stands unique among most diabase traps of the vicinity. No trace of ophitic structure is visible to the naked eye. The veinlets of calcite vary from a mere thread to a diameter of 1/4", and ramify through the rock in every conceivable direction. They divide the mass, as it were, into numberless small blocks, which fall apart readily in the process of crushing, the blocks themselves, however, being remarkably hard and tough.

An examination of one of these fragments with the aid of a hand lense reveals the presence of abundant shapeless masses of a black mineral, mostly augite, with numerous tiny flecks of a white feldspar. Its microscopic structure will be discussed in detail later.

Along the sides of the opening the trap shows considerable decomposition evidenced by stains of iron oxide, and in some places has progressed enough to yield a muddy red soil. The decomposition has followed the veining, the interior of the fragments being still solid trap. Considered as a whole, however, decomposition has not progressed far, the main mass being well preserved clear to the grass roots. Alteration and hydration have not, on the whole, much affected the crystalline structure of the rock.

CONCLUSIONS.

To deduce a wholly competent theory of structure from the above observed facts, is, to my mind, impossible. The structural relations are too obscure. We must approach the problem from another standpoint. Petrographic evidence should help decide the mode of origin of the rock, and the conclusions derived from such study be correlated with the field observations.

I see little evidence to warrant an extrusive mode of origin for Pond Rock. As stated before, there is comparatively little alteration and hydration of the constituent minerals; the amygdaloidal texture is restricted to a very superficial layer along the back or upper surface, and this might just as well obtain in the case of an intrusive sheet if the overlying sediment was friable or imperfectly consolidated; there is an entire lack of flow structure; induration of adjacent sediments is not restricted to the under surface; the texture is homogeneous throughout, neither true breccia (except in a few contact specimens) nor vitreous variations being noted. I think if the present quarry opening had been available for Prof. Davis' observation not so much stress would have been laid on some points of his argument.

Neither does the rock resemble in the slightest degree such undoubted dykes as East and West rocks. The coarse ophitic structure of these dykes is not duplicated here, nor are the latter's variations in texture from centre to contact here present. Moreover, such structural evidence as we have available clearly prohibits such a mode of origin.

I conceive, then, Pond Rock to represent the remnants of an immense intrusive sheet. The intrusion antedated all important deformation. The rock cooled rather rapidly and under moderate pressure, producing the finely crystalline texture. The rather porous nature of the adjacent sandstone permitted the formation of a thin, vesicular layer. Accompanying the later folding, which raised the mass to its present oblique position, was extensive faulting. Two parallel faults with a general NW-SE trend separated the lower member of Pond Rock from the remainder of the ridge. The stresses induced in this faulted block resulting from the strain to which it was subjected, produced incipient fractures which later became channels for the deposition of soluble constituents resulting from the weathering of the rock by atmospheric influences.

Thus Nature's processes have served not only to bring this valuable mass of material to sea level, but to induce conditions which permit inexpensive quarrying, and without, at the same time, producing properties detrimental to the behavior of the rock as a road material. This last assertion is verified by a consideration of its physical properties as determined by laboratory test, to which we will now turn our attention.

LABORATORY TESTS.

There seems to be a difference of opinion in the minds of many engineers regarding the value of laboratory tests in the selection of road material. Local conditions play an important role, and experience alone must decide the material and method best adapted to a particular locality. Nevertheless, all will admit that the most accurate and rapid determination of the value of a material is effected when the physical properties have been carefully studied in the laboratory, and these results correlated with observations on actual wear.

All material to be used as road metal must possess certain characteristics. It must be hard, tough, and durable; if intended for use on macadam roads, its dust must possess binding properties; moreover, it is desirable that a smooth surface be maintained, yet one that is not too hard, or slippery, or noisy. It must, further, be free from dust and dirt. All laboratory tests aim to throw all possible light on the probability of the material at hand fulfilling these conditions.

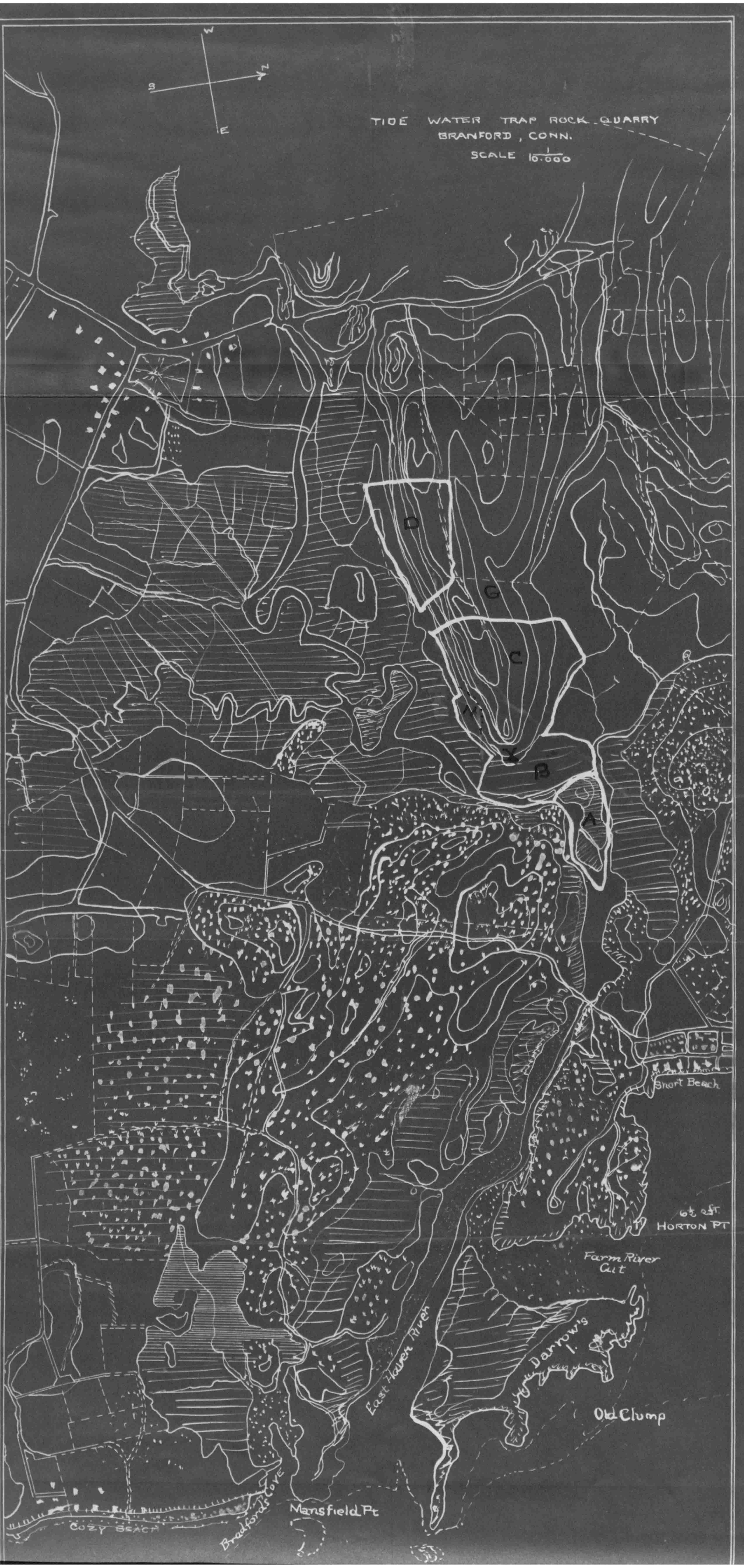
These tests may be conveniently grouped under the following heads:-

Specific Gravity.
Abrasive Resistanue.
Cementation Value.
Recementation Value.
Absorptive Power.
Weathering Tests.
Percussive "
Compressive Strength.
Chemical Analysis.
Mineralogical Analysis.

Specific Gravity.

From many points of view a determination of specific gravity is of considerable importance in the selection of road material. To a certain extent it influences durability, and is of great importance in estimating covering power. Moreover, a rock of high sp. gr. is less liable to have its finer detritus removed by the action of wind or rain. It depends primarily on mineralogic composition and compactness of the rock. In general the crushing strength increases with the sp. gr.

An average of four determination made with samples of the Branford trap yielded 2.82. A very normal result for a diabase



W
N
S
E
TIDE WATER TRAP ROCK QUARRY
BRANFORD, CONN.
SCALE 1/10.000
D
G
C
W
X
B
A
Short Beach
6½ ft.
HORTON PT
Farm River Cut
Darrow's I
Old Clump
East Haven River
Mansfield Pt
Branford Cove
COZY BEACH

Abrasive Resistance.

Aside from the mechanical disintegration of roadstone by the expansive force of frozen water, a much more important cause for the wear of roads is the abrasion by traffic, and the value of a roadstone largely depends on its resistance to this abrasion. Without going into detail, these various processes may be briefly summed up as follows:-

I. Wear and tear of travel.

(a) Action of horses' feet.

(b) " " wheels.

(c) Pressure due to weight of vehicle.

II. Wear produced by natural forces.

(a) Heavy rains.

(b) Winds.

(c) Chemical disintegration.

(d) Excessive temperature changes.

(e) Frost.

Various machines have been devised to imitate, as nearly as possible, the action of these forces, but all are, necessarily, imperfect. Toughness, cohesiveness, and chemical durability are the important factors controlling abrasive resistance. Hardness as a factor does not enter here. To attain a fair estimate of the influence of these several factors by a single test is obviously difficult. Further, the custom of employing freshly quarried samples for this test is to be decried since continual exposure to the action of solutions of decomposing organic matter on the road surface rapidly weakens the bonds of cohesiveness, making such tests unreliable.

The machines heretofore employed are quite alike in principle. A weighed quantity of rock is revolved a definite number of times in a rotating iron cylinder. The interior of the cylinder may be provided with iron ribs to aid the attrition; sometimes pieces of iron are enclosed for the same purpose. The tests are often performed both wet and dry.

The Deval machine with modifications has been largely used in French and American laboratories, and was the one employed in my experiments. In principle it consists of an iron cylinder 7.9" in diameter and 13.4" deep, the interior being perfectly smooth. It is so mounted on a shaft that the axis of rotation of the cylinder makes an angle of 30 with the axis of rotation of the shaft. The speed of revolution is so regulated that 10,000 turns occupy five hours in time. Eleven lbs. of rock broken so as to just pass through 2.4" ring are used as a sample, and the proportion of material less than 1/16" diameter ascertained.

Since it has been found that only the best varieties of rock yield less than .2 gram dust to 2.2 lbs. rock, or 2% of their weight, the number 20 has been adopted by the French as their co-efficient of wear. As the result of a large number of experiments, it has been proven that igneous rocks are much tougher than those of sedimentary origin. Their total loss ranges from 3-10%. Limestones range from 10-35%, flints 8-26%. In a series of tests with the Branford stone the following average result was obtained:-

Per cent. wear, 4.20; Fr. co-eff., 11.3.

Very few chips were obtained, the bulk of the detritus being the finest dust. These results are almost identical with those obtained by Mr. L. W. Page on the same rock in the Government laboratory at Washington, namely, 4.29 and 11.6. They indicate an excellent road material, although their values are somewhat higher than those obtained from most diabase traps. The discrepancy is due to the presence of a considerable quantity of vein material (about 1.4% the mass of the rock); but, since, as will be shown later, this dust has abnormally high binding powers, it enhances rather than deteriorates the value of the rock.

Cementation Value.

In the case of trap rocks in particular, this test is of the utmost value, for, in the construction of macadam roads, the binding power of the detrital material plays a very important role, and may serve to condemn an otherwise good rock. The cementation test, as now performed, yields a fairly accurate index of binding power. Before describing this test in detail, a few words on the influence of binding material in the construction of a road will not be out of place.

The conditions of wear to which a roadstone is subjected result in its gradual consolidation. An imperfectly consolidated road can never be maintained in a satisfactory condition. The consolidation is a result of the wear of the original stones by crushing and grinding in the road, so that on an average between 65-90% of the broken stone put upon a road wears down ultimately to a state of mud and detritus. The tougher the stone, the smaller the percentage of this detritus.

There has been a very spirited controversy among engineers in the past regarding the function and utility of binding material. Whether the road should be left to consolidate itself by the gradual wear and tear of traffic or whether the process should be aided and the sharp angles of the stone kept intact by the original filling of the interstices with binding material; and the quantity of this material to add, if any, have been much mooted questions.

The concensus of modern opinion seems to be that the true function of binding material is in forming a thin surface cover, which, being impervious, protects the broken stone beneath. In other words, a road should practically consolidate itself; hence, the paramount importance of selecting material possessing the requisite binding power.

The cementation tests, as conducted by me on the Branford material, were as follows: The dust obtained in the attrition test was passed through a 100 mesh sieve (to the inch). It was then made into briquettes of circular section, .98" in diameter, and the same height, by placing in a metal die with enough distilled water to moisten; a closely fitting plug was next inserted , and the mass subjected to a pressure of 1,422 lbs. to the square inch. The compressed briquettes were dried two weeks, and then treated as follows: A machine especially designed for this test and kept in the Harvard laboratories was used. Its mechanism is complicated, but its principle simple. A kilogram hammer, automatically arranged to fall through any desired height, strikes a flat end plunger, of weight one kilogram, which latter, by an arrangement of springs, presses on the briquette. The standard fall for the hammer is .39". The exact point of fracture is determined by means of a small drum carrying a paper on which a pointer marks the passages of the hammer. At the beginning a rebound of the hammer is indicated on the drum, but when once the elastic limit of the briquette is passed, this rebound no longer occurs. This is taken as the breaking point. The number of blows required to break the bond of cementation is taken as representing the binding power of the stone.

A series of tests made along these lines yielded results as follows:-

No. 1.	No. 2.	No. 3.	No. 4.
40	46	43	50

The result obtained by Mr. Page as given in the Company's Report was 49. All of these results are abnormally high, indicating an exceptionally desirable stone. In a series of tabulated results printed in the Massachusetts Highway Commission's Report for 1900, in which the cementation value for 116 samples of various road metals were determined, only eight exceeded these values, and of these only three were, in other respects, good road material. As a result of a large number of experiments in America, it has been determined that of all road metals only limestones and a few traps ever exceed more than 30-40 blows without breaking. The Highway Division of the Maryland Survey prints the following tables:

	Cementation Tests.
Trap rocks,	1-16
Serpentines,	10-300
Granites and quartz rocks,	1-13
Limestones,	1-73
Sandstones.	0-28.

It further states that:	Cementation.
Bad road metal may possess	1-4
Fair " " " "	5-10
Good " " " "	10-20
Excellent road metal may possess	20-

Recementation Value.

It is not only important to know the binding power of detrital material, but the capacity of the particles to reunite when again wetted and dried after being powdered. For, according to Prof. Shaler, "on this process of recementation largely depends the endurance of any macadamized way." To imitate, as far as possible, the effect of the action of the "fines" under the sharp blows of the horses' hoofs, the following test has been devised: The broken briquettes from which the cementation value has been determined are repowdered, mixed with definite quantities of water, and remoulded. The process is then repeated as above. Using consecutively 4^{cc}, 8^{cc}, 12^{cc}, 16^{cc} of distilled water, I obtained values of 46, 40, 22, 36 for the recementation power. Mr. Page obtained 44 as his result. All of these results are unusually high, and indicate a splendid road metal.

Absorptive Power.

This test does not indicate the porosity of the rock, but merely the pounds of water absorbed per cubic foot during an immersion of 96 hours. It is performed with a small specimen. A smoothly worn fragment left from the attrition test, and weighing from 20-60 grams, is weighed in air. It is then immersed in water, and immediately reweighed in water. After 96 hours' immersion it is again weighed in water. By a very simple calculation the amount absorbed per cubic foot is determined. As the result of a series of tests, the following values were obtained:

No. 1.	No. 2.	No. 3.	No. 4.
.42	.48	.54	.46

These results are considerably lower than the value submitted by Mr. Page (.83), but I feel great confidence in their accuracy. The results are still somewhat high for a normal diabase trap, owing, doubtless, to the extensive calcite veining affording planes of easy penetration.

Weathering Tests.

The liability of stone to disintegrate by the action of frost depends partly on its porosity and absorptive power, and partly on the presence of planes of weakness such as the lamination planes of flagstones. Tests have been devised to imitate the action of frost, as, for instance, Brard's Process--soaking a weighed sample in a saturated solution of Glauber's-salt and allowing to dry; and also by artificially freezing the sample while saturated with water. These tests are, however, of doubtful utility since a stone porous enough to disintegrate in this way would be valueless as a roadstone. Further, the weathering of minerals under atmospheric influences is, on the whole, an extraordinarily slow process.

Percussive and Compressive Strength.

Both these tests are restricted in scope and of very questionable value. The former is somewhat used abroad, but the result obtained by the attrition test gives a very fair estimate of the toughness of a rock and makes the percussive strength test superfluous.

The compressive strength is a factor of so many variables as to make it extremely misleading. Inherent flaws in the sample, small variations in mineralogic structure, and carelessness in the preparation of the cube introduce errors not readily detected. Neither tests were applied to the Branford rock.

Chemical Analysis.

A chemical analysis alone is of little value in indicating the quality of a roadstone; it is only when intended to supplement and corroborate a mineralogical analysis that it possesses interest. It is true that durability depends largely on resistance to abrasion, and this, in turn, is influenced by the chemical composition of the component minerals. Again, it is absolutely essential that the bottom layers of a road bed be of chemically durable material. But chemical analyses, as ordinarily calculated, do not yield all the information on these points. Such analyses do, however, serve to properly classify the rock. The following results were obtained by me on samples of the Branford rock:-

SiO_2	=	50.01	49.28
Al_2O_3	=	15.62	15.92
Fe_2O_3	=	1.91	1.91
FeO	=	10.30	10.20
MnO	=	.40	.37

MgO	=	5.60	5.99
CaO	=	7.22	7.44
K_2O	=	.65	.72
Na_2O	=	3.80	3.40
H_2O	=	3.10	3.90
CO_2	=	1.20	1.14
		99.81	100.27

The figures in the second column represent an analysis made in the Wesleyan laboratories for the Company, and checks my analysis in most respects quite accurately.

These analyses prove the rock to be a very normal diabase trap, as shown by a comparative study of several typical analyses tabulated in Rosenbusch.

Mineralogical Analysis.

This test is of extreme importance in the selection of a road metal. It serves to determine the composition of the sample, and hence to properly classify it. It reveals the minute structure of the rock, and thus throws much light on the question of durability, hardness and toughness.

Several slides of the Branford trap were cut xxxx and carefully studied. The microscope showed the rock to be composed principally of two minerals, very finely and evenly crystallized, closely interlocked, and, on the whole, fairly fresh, namely, a monoclinic pyroxene and a quite basic feldspar. Associated with these minerals were present in very subordinate amounts, apatite, iron ore, orthoclase, quartz, chlorite, and serpentine.

The pyroxene was almost entirely augite--the ordinary, brownish variety. It exhibited every gradation from perfectly fresh to entirely decayed crystals. On the whole, it was considerably altered. It occupied, in every case, the interstices between the feldspar crystals. Its usually well developed cleavages at right angles were often penetrated by films of iron oxide, one of the products of its decomposition, the black stains of which often imitate the appearance of a fir tree. In other cases the decomposition had proceeded so far as to obscure the original nature of the mineral--its identity being only surmisable from its position, and chloritic and serpentinic alteration products. Compared with the other minerals, the augite was the most subject to decomposition.

The feldspar was labradorite. It occurred as intergrown laths, sometimes long and slender, more rarely short and broad prisms. The crystals were clear and colorless, being, on the whole, remarkably fresh. Albite twining was frequently exhibited, more rarely Carlsbad. Zonal structure not noticeable.

Apatite was observed occasionally as thin, needle-like prisms, known by their high single,low double refraction, and opitcally negative extinction.

The iron ore was largely magnetite, with some ilmenite and limonite. Orthoclase was rarely noted. Some quartz, chalodonic in variety, was associated with the calcitic vein material. As before noted, the chlorite and serpentine were in every case secondary after augite. The latter predominated. The vein material was mostly calcite. Some small, almost isotropic areas confined invariably to the central portion of the vein, were undoubtedly quartz.

The rock may be ranked as a fairly fresh diabase. Decomposition has most affected the ferromagnesium constituent. Its decomposition products have remained "in situ", or passed into vein material. There is no evidence of a porphyritic structure, and nothing to indicate an extrusive mode of origin. From an economic standpoint, decomposition has not much affected the strength of the material. The firm, interlaced network of fresh feldspar guarantees the solidity of the rock for a long time to come.