ART. XXI.—*Contributions from the Sheffield Laboratory of Yale College.* No. XXXII.—*The Trap Rocks of the Connecticut Valley;* by GEORGE W. HAWES.

IT has been already stated in this Journal* that Mr. E. S. Dana and myself have been engaged in the study of the eruptive rocks of the Connecticut Valley. Some of the results obtained by me through chemical analysis are here presented.

The dikes which intersect the Mesozoic sandstone and the adjacent strata are very numerous and oftentimes very different both as to the physical appearance and composition of the rocks. The analyses of some of these traps show them to be nearly anhydrous and of the same composition as the rock which is called dolerite. They have, moreover, a bright and apparently unaltered appearance, and under the microscope a clear crystalline character. Others are hydrous and also contain carbonic acid; their luster is dull and they are more or less green, and possess the composition and the chloritic character of the rock called diabase. Every grade of variation between the extreme cases can be found; but the attempt will be made to show, by the following analyses, the

* See Abstract of a paper on the Trap Rocks of the Connecticut Valley, by E. S. Dana, this Journal, III, viii, 390. (Read before the American Association at the Hartford meeting, Aug., 1874.)

uniform character of the ejected material, and what were the changes which took place to alter it into its present varieties, and what were the causes of the same.

The specimens of which analyses are here given have in general been taken from railroad cuts or working quarries, in order to avoid material which had been altered by surface action.

1. Dolerite.

Lying to the west of New Haven there is a long ridge of trap, ending in a high bluff which is called West Rock. The trap is very firm, and analyses show it to be dolerite, the typical rock of this region.

West Rock. Sp. gr. = 3·03.

	I.	II.	Mean.
Silica	51·80	51·76	51·78
Alumina	14·21	14·19	14·20
Ferrous oxide	8·26	8·23	8·25
Ferric oxide	3·55	3·62	3·59
Manganous oxide	·42	·45	·44
Lime	10·68	10·73	10·70
Magnesia	7·63	7·64	7·63
Soda	2·15	2·13	2·14
Potash	·39	·38	·39
Phosphoric acid	·14	·14	·14
Ignition	·63	·64	·63
	99·86	99·91	99·89

West Rock is one of the southernmost dikes of the old Connecticut Valley. The red sandstone region extends northward through Connecticut to the northern boundary of Massachusetts, and in the latter State are Mount Tom and Mount Holyoke. A fresh specimen from the latter mountain had the following composition:

Mount Holyoke. Sp. gr. = 2·97.

	I.	II.	Mean.
Silica	52·70	52·65	52·68
Alumina	14·11	14·17	14·14
Ferrous oxide	9·78	9·80	9·79
Ferric oxide	1·87	2·03	1·95
Manganous oxide	·45	·44	·44
Lime	9·36	9·39	9·38
Magnesia	6·42	6·35	6·38
Soda	2·54	2·57	2·56
Potash	·89	·87	·87
Ignition	1·61	1·58	1·60
	99·73	99·85	99·79

These analyses show it to be dolerite, differing from the trap of West Rock in the proportion of its ingredients.

A specimen from the Mesozoic sandstone region of New Jersey, taken from a deep railroad cut in Jersey City, afforded the following results:

JERSEY CITY. Sp. gr. = 2·96.

	I.	II.	Mean.
Silica	53·16	53·09	53·13
Alumina	13·87	13·62	13·74
Ferrous oxide	9·09	9·10	9·10
Ferric oxide	1·01	1·14	1·08
Manganous oxide	·44	·43	·43
Lime	9·44	9·50	9·47
Magnesia	8·56	8·59	8·58
Soda	2·28	2·32	2·30
Potash	1·03	1·04	1·03
Ignition	·89	·91	·90
	99·77	99·74	99·76

Another specimen taken from a trap hill lying to the eastward of New Haven, called East Rock, was also analyzed. But enough has been given to show the uniform character of the unaltered rocks of this era; no two analyses differing from one another more than would those of samples which could be selected from the same dike.

The principal mineral ingredients are pyroxene and labradorite, with a small amount of magnetite, and often, as Mr. Dana has detected by his microscopic examinations, a little chrysolite and apatite. The *pyroxene* can be recognized by its cleavage. Spots are sometimes found in the rock where the crystals of pyroxene have considerable size, and often the prismatic angle as well as the basal cleavage can be distinctly seen. From one piece it was possible to extract a sufficient number of crystalline fragments of apparent purity for an analysis.

PYROXENE FROM WEST ROCK.

Silica	50·71
Alumina	3·55
Ferrous oxide	15·30
Manganous oxide	·81
Lime	13·35
Magnesia	13·63
Ignition	1·17
Alkalies and loss (by difference)	1·48
	100·00

On comparing this analysis with those of the dolerites, it leaves little doubt but that the feldspar is labradorite, as the low percentage of silica and the presence of so much lime proves. The presence in one case of a feldspar with even a lower percentage of silica (see beyond) renders it improbable that the chief feldspar constituent has a higher percentage than labradorite. Moreover, in the analyses, making due allowance for the magnetite, the oxygen ratio of the bases and silica is even less than one to two, which would not be the case if the feldspar were oligoclase.

The *magnetite*, which is always present, is quite variable in amount. There is much more in the trap of West Rock than in any of the other specimens analyzed. This is evident from the amount of sesquioxide of iron present, which, if it be all contained in magnetite, would represent five per cent of that ingredient. In the Mt. Holyoke and New Jersey specimens there is less magnetite, as is shown by the lower percentage of sesquioxide of iron, the higher percentage of silica and the inferior specific gravities. In some cases the amount is very large. In a part of one of the dikes, that form the "Hanging Hills" of Meriden, the rock is quite black and the amount of iron has been the cause of rapid disintegration, so that now the fine earthy debris reaches to the top of the ridge. A determination of the iron in this rock gave

	I.	II.
FeO	8·52	8·55
Fe_2O_3	5·30	5·35
	13·82	13·90

A few feet distant, however, the rock becomes as firm and undecomposed as usual, showing that the gathering of the magnetite was of no great extent. Often octahedral crystals of magnetite can be seen in the rock with the unaided eye.

The analysis of the pyroxene shows it to be ordinary augite containing equal amounts of lime and magnesia; and as magnesia does not enter into the composition of the feldspar, the evident excess of magnesia above that which would form such a mixture of labradorite and pyroxene belongs to the chrysolite. The minute crystals of apatite detected by Mr. Dana account for the presence of phosphoric acid.

The feldspar *anorthite* is sometimes a constituent of these dolerites. Passing up the West Rock ridge, at about a mile from its southern face, a smaller dike is seen with an eastern and western strike, while West Rock runs nearly north and south. This dike upon one side of West Rock forms the dam of Wintergreen Lake, then cuts directly through the main dike, and projecting out several yards upon the other side of West Rock ridge, forms what is called the buttress. Its position, intersecting the main dike, shows it to be of later origin. The direction of the columns of this buttress are horizontal, while the columns of the main ridge are nearly vertical, which shows that the main ridge must have cooled sufficiently to determine the position of the columns of the buttress, since the columns are always at right angles to the cooling surfaces. This dike is characterized by large grains ($\frac{1}{4}$ to $\frac{1}{3}$ inch across) of a clear whitish cleavable mineral, which render it sparsely porphyritic. Even at the extremity, where the dike becomes very small, and where in consequence the rock is very fine in texture owing to the more rapid cooling, this porphyritic character is retained. A sufficient quantity of the pure material was extracted for an analysis; its composition was

ANORTHITE.

		O.
Silica	45·95	24·50
Alumina	34·70	16·31
Ferrous oxide	·64	
Lime	15·82	5·06
Magnesia	*trace*	
Potash	·45	
Soda	1·80	
Ignition	·96	
	100·32	

It is therefore a lime feldspar; and the oxygen ratio for RO, R_2O_3 and SiO_2 is 1 : 3·2 : 4·8, which shows the feldspar to be anorthite. Mr. Dana informs me that under the microscope it has a different appearance from the other feldspar, and although triclinic it shows less tendency toward twinning. An analysis of a sample of the trap of the dike in which the anorthite occurs shows it to be a dolerite of the same composition as the others; which is proof of the uniformity of the ejections at different times in this period.

DOLERITE FROM WINTERGREEN LAKE. Sp. gr. = 3·00.

	I.	II.	Mean.
Silica	52·38	52·45	52·42
Alumina	14·59	14·50	14·54
Ferrous oxide	9·89	9·79	9·84
Ferric oxide	1·27	1·22	1·25
Manganous oxide	·50	·53	·51
Lime	10·63	10·54	10·59
Magnesia	7·36	7·31	7·33
Soda	2·20	2·27	2·23
Potash	·51	·48	·49
Ignition	·55	·55	·55
	99·88	99·64	99·75

The rock is therefore a mixture of pyroxene and labradorite, from which the anorthite crystallized out on account of its different composition; for a very slight change in the composition of the whole mass would account for the formation of the small amount of anorthite which the rock contains, and the difference in its fusibility, that of labradorite being 3, and that of anorthite 5, would favor the separation of the anorthite.

2. Diabase, or Chloritic Dolerite.

In the examination of the various dikes we find the rocks in all stages of alteration, from the almost anhydrous rocks, like the preceding, to those in which the original ingredients seem to have undergone an almost complete change. This difference we conclude to be connected with geographical location and not with geological age; and the following analysis, as well as the study of the positions of the different varieties, prove this.

The rocks which were selected for analysis were taken from the eastern side of the sandstone region and are typical specimens of very large and long dikes. The Lake Saltonstall ridge, which is hydrous through its whole extent, is cut through near its southern extremity by the Shore Line Railroad, and it was from this spot, at some distance from the surface and from any amygdaloidal cavities, that the sample was selected.

Lake Saltonstall. Sp. gr. = 2·86.

	I.	II.	Mean.
Silica	49·27	49·29	49·28
Alumina	15·87	15·97	15·92
Ferrous oxide	10·17	10·23	10·20
Ferric oxide	1·93	1·88	1·91
Manganous oxide	·35	·40	·37
Lime	7·46	7·42	7·44
Magnesia	5·90	6·07	5·99
Soda	3·45	3·36	3·40
Potash	·74	·69	·72
Water	3·92	3·88	3·90
Carbonic acid	1·12	1·17	1·14
	100·18	100·36	100·27

A specimen from the southern dike of a high ridge called the Durham Mountains exhibits still greater alteration, for the amount of water shows that the larger part of the pyroxene has been changed to chlorite.

It will be seen that the alteration of these rocks has not been attended by further oxidation of the iron, and therefore it could not have been accomplished by any surface action, since the oxidation of protoxide of iron is one of the chief causes of surface alteration; while in this case one mineral containing protoxide has been changed into another protoxide mineral. It would, therefore, seem certain that the alteration took place at

SOUTH DURHAM MOUNTAIN. Sp. gr. = 2·83.

	I.	II.	Mean.
Silica	46·56	46·51	46·54
Alumina	14·75	15·05	14·90
Ferrous oxide	9·89	9·78	9·83
Ferric oxide	3·58	3·50	3·54
Manganous oxide	·33	·35	·34
Lime	7·99	7·90	7·94
Magnesia	4·83	4·89	4·86
Soda	2·47	2·38	2·43
Potash	·59	·60	·60
Water	4·50	4·54	4·52
Carbonic acid	4·38	4·32	4·35
	99·87	99·82	99·85

the time of ejection, as has been urged by Prof. Dana.* If the trap-rocks of this eastern region, when coming up melted through the red sandstone strata, encountered subterranean waters, and if it would be impossible for the vapors produced by the heat to be pressed back, owing to the hydrostatic pressure above, then these vapors, together with other vaporizable material, as carbonic acid, set free from its combinations in the strata by the heat, would pass into the mass of molten matter. In this way we have a sufficient explanation of the change that made this diabase out of the material that formed the dolerite.

The pyroxene was the mineral that was most attacked, the result of the alteration being chlorite. As chlorite is a magnesian mineral, lime was set free by this change. Part or all of this lime united with carbonic acid; for on touching any of these hydrated rocks with a drop of dilute acid, effervescence takes place. In many of the amygdaloidal traps this carbonate of lime fills the cavities. The pyroxene, however, does not furnish sufficient alumina for chlorite; this was furnished by the feldspar, which also participated in the change, and which, under the microscope, appears more or less dimmed by decomposition. As a result, silica was liberated, which also fills many of the amygdaloid cavities; and often both silica and carbonate of lime are found in the same cavity. In other cases it has united with the lime and alkalies to form zeolites, which are common in the cavities. The exact chemical reactions that took place will be considered at another time, when more of the products of decomposition have been analyzed. That there was such a passage of vapors through the molten mass is evident; for the rock of some dikes contains long pipe-stem-like cavities, which were made by the ascending vapors, and which are generally filled with calcite.

* See this Jour., III, vi, 104. "J. D. Dana on Igneous Ejections and Volcanoes."

On excluding the water and carbonic acid from the two preceding analyses, (columns 3 and 4 below,) it will be seen how nearly the original unaltered material resembles that of the dolerites (columns 1 and 2) in composition. As usual, there is a small difference in the amount of magnetite and in the proportion between the pyroxene and feldspar.

	1. West Rock.	2. Mt. Holyoke.	3. L. Saltonstall.	4. Durham Mt.
Silica	52·11	53·54	51·90	51·06
Alumina	14·29	14·37	16·77	16·35
Ferrous oxide	8·30	9·95	10·74	10·79
Ferric oxide	3·61	1·98	2·00	3·88
Manganous oxide	·44	·45	·39	·39
Lime	10·77	9·53	7·83	8·72
Magnesia	7·67	6·49	6·31	5·33
Soda	2·15	2·60	3·59	2·66
Potash	·39	·88	·75	·66
	99·73	99·79	100·28	99·84

There is a remarkable uniformity at all points in the ejected material, which seems to prove that, whether now anhydrous or chloritic, it must have had a common source, and this a deep-seated one; for so great uniformity would be well nigh impossible if the source were nearer the surface among the metamorphic rocks of the crust, as has sometimes been supposed.