

## WEATHERING OF MICACEOUS GNEISS IN ALBEMARLE COUNTY, VIRGINIA

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### INTRODUCTION.

In previous papers the writer has endeavored to show the changes taking place in the preliminary stages of rock-weathering as illustrated in the post-Cretaceous and post-Glacial disintegration of the granites of the District of Columbia and the diabase of Medford, Massachusetts.\* The purpose of the present paper is to discuss the results of similar processes, operating for longer periods, and incidentally to refer to other matters with which the subject is closely affiliated.

The material selected for investigation is a highly micaceous, feldspar-rich gneissoid rock and its residual clay, occurring at North Garden, in Albemarle county, Virginia. The region lies to the west of the Cretaceous submergence, the accumulated gravels of which enabled us to set an approximate time limit to the weathering manifested in the District of

\* Disintegration of the Granitic Rocks of the District of Columbia, Bull. Geol. Soc. Am., vol. 6, 1895, pp. 321-332, and Disintegration and Decomposition of Diabase at Medford, Massachusetts, *ibid.*, vol. 7, 1896, pp. 349-362.

Columbia rocks, and thus no criteria are afforded for estimating the relative rapidity of the process. The amount of material lost through leaching and erosion is obviously large, but at the locality from which the materials for study were selected, the fresh rock was still overlaid by several feet of residuary matter in the form of sand, gravel, and clay, which constitute the prevailing soil of the region. Although very plastic when wet, and inclined to cake during seasons of drought, this soil is nevertheless fairly fertile and easily cultivated.

#### PETROGRAPHIC FEATURES OF THE FRESH ROCK.

In its least changed condition—the best material obtainable from available outcrops—the rock is a highly feldspathic gneiss carrying abundant folia of black mica. Under the microscope it shows an extremely variable, sometimes cataclastic structure. Both orthoclase and soda-lime feldspars are present, the latter being often fairly clouded with enclosures of minute zircons. These last are so small as to have their optical properties quite obscured by those of their host, but can be washed from the residual sand in quantities and readily determined. The largest forms obtained thus measured some .12 by .4 millimeters, the average being perhaps .06 by .30 millimeters. Black mica is very abundant, as noted above, and quartz occurs in the usual granular forms. There is the usual sprinkling of iron ores and apatites, and in addition small garnets, and in considerable quantity a soda-potash bearing zeolite occurring in dense aggregates and radiating masses, almost wholly without action on light and with crystal outlines so poorly developed as to make their true mineralogical nature, except by microchemical tests, a matter of surmise. A bulk analysis of the rock and also one of the portion decomposed by boiling hydrochloric acid is given in columns 1 and 2 below.

#### PHYSICAL MANIFESTATIONS OF WEATHERING.

In weathering the rock becomes brownish and friable, passing into the condition of a loose agglomerate of angular gneissic fragments, so discolored by decomposition as to be scarcely recognizable, and imbedded in fine brown sand and dust. Finally, on the immediate surface the rock has weathered to a red, tenacious clay, which still retains a sufficient quantity of undecomposed silicates and of free quartz to have a distinct gritty feeling when rubbed between the hands. Under the microscope it shows sharply angular fragments of quartz and feldspar, numerous folia of black mica, and much opaque or amorphous matter so stained by iron oxides and decomposition products as to quite obscure its true mineral nature. The state of mechanical subdivision of the material is

made apparent by the following table, for which, as on previous occasions, I am indebted to Dr Milton Whitney, of the Department of Agriculture.

*Mechanical Analysis of residual Soil.*

Diameter (in millimeters).	Conventional names.	Per cent.
(1.) 2-1.....	Fine gravel.....	1.15
(2.) 1-.5.....	Coarse sand.....	2.92
(3.) .5-.25.....	Medium sand.....	6.29
(4.) .25-.1.....	Fine sand.....	17.42
(5.) .1-.05.....	Very fine sand.....	15.60
(6.) .05-.01.....	Silt.....	7.65
(7.) .01-.005.....	Fine silt.....	1.83
(8.) .005-.0001.....	Clay.....	35.73
Total mineral matter.....		88.59
(9.) Loss at 110° C.....		2.93
(10.) Loss on ignition.....		8.49
Total.....		100.01

CHEMICAL ANALYSES AND THEIR DISCUSSION.

Below is given the analyses of the fresh rock and residual soil, together with that of the portion decomposed by boiling hydrochloric acid, while in columns 6, 7, and 8 are given calculations from the analyses in columns 1 and 3 to show the total loss of material and also the percentage amounts of each of the original chemical constituents saved and lost. These calculations, as in previous papers, are made on the assumption that the alumina has remained essentially constant, and though nothing like absolute accuracy can be claimed for the results, they are by no means uninteresting and uninteresting.

The particular features to which attention need here be called are (1) that 30.51 per cent of the fresh rock and 69.18 per cent of the decomposed are soluble in hydrochloric acid and sodium carbonate solutions, and that more than half the potash and nearly the same proportion of the soda in the fresh rock is found in the acid extract; (2) that the insoluble portion of the residuary material is mainly in the form of free quartz; (3) that 44.67 per cent of the original matter has been leached away, and that (4) of the original silica, 52.45 per cent is lost, while 85.61 per cent of the iron and all the alumina\* remain. All the lime has disappeared; 83.52 per cent of the potash, 95.03 per cent of the soda, and 74.70 per cent of the magnesia. The total amount of water, as indi-

\* This is not absolutely correct, since all the alumina was assumed to have remained in order to give a basis for calculations.



cated by the ignition, has increased very greatly, as was to be expected. The small original amount of phosphoric acid prohibits our placing too much reliance upon an indicated gain of the fraction of one per cent in this constituent, since it may be due to errors in manipulation.

On the assumption that such calculations always yield results rather under than above the amount of material actually lost, I have assumed from this and other analyses available that a silicious crystalline rock of the granitic or more basic type in passing into the condition of a residual clay or soil, as the word is ordinarily used, loses about 50 per cent of its original constituents through solution and the leaching action of meteoric waters.\*

#### CAUSE OF RED COLOR OF THE SOIL.

The pronounced red color of this residuary material is worthy of consideration. It will be remembered that the cause of this striking difference in the color of superficial deposits in northern and southern latitudes has been the subject of much discussion, the names of Professors W. O. Crosby,† I. C. Russell,‡ and J. D. Dana§ being most conspicuous in existing literature. Professor Crosby argued that the intense color was purely superficial and due to a dehydration of the ferric salts with which the soils are impregnated, whereby the color was changed from yellow and brown to red, the cause of the hydration being the long continued higher temperatures to which the superficial portions were subjected in the lower latitudes. It is not necessary to go into a detailed discussion here of all the points involved in the controversy, but I wish to state that my own observations are entirely in accord with those of Professor Crosby, so far as the superficial character of the phenomenon is concerned. In some cases the brilliant color is found as a mere wash, or again it penetrates to the depth of a foot or more before giving way to more modest hues. In such instances the colors have penetrated most deeply along joint planes or other lines of weakness, leaving the intervening compact masses of more somber shade. The gradual transition from the surface downward, from bright red to brown, yellow, or gray, may be seen to have taken place, usually within the space of a few vertical feet, in any new road or railway cut, but becomes quickly obscured, even by the first rainfall, through the washing down of the ochreous coloring matter from above.

That the increased color in the superficial portions is due wholly to dehydration of the ferric salts, the writer is disposed to doubt. It must

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\* See *Rocks, Rockweathering, and Soils*. The Macmillan Company, New York, 1897.

† *Proc. Boston Soc. of Nat. Hist.*, vol. 23, 1875, and *Am. Geologist*, August, 1891.

‡ *Bull. U. S. Geol. Survey*, no. 52, 1889.

§ *Am. Jour. of Science*, vol. 39, 1890, pp. 317-319.

be remembered that the color imparted to a bed of sand or clay depends not merely upon the quality of the coloring constituent, but also upon its quantity. This is well shown in the fractional separations made by washing these residual clays and sands, whereby they are separated into proportional parts of varying degrees of fineness. Thus the disintegrated diabase of Medford, Massachusetts, described by the present writer at a previous meeting,\* is of but a dull brown-gray color, yet the finest silt separated out by washing, and which is but a ferruginous clay, is of a distinct brown-red color. A larger amount of this fine material would naturally impart a more decided brown-red color to the residual sand.

Now, rock-weathering in warm, moist climates in particular, is accompanied by a leaching process, as I have elsewhere pointed out, † whereby the more soluble constituents are gradually removed. But, of all those constituents occurring in essential quantities in ordinary rocks the ferric salts and the alumina are most refractory; hence the final product of decomposition is a highly ferruginous clay—a clay composed essentially of a mechanical admixture of hydrous aluminous silicates, free silica, and free sesquioxides of iron—and its color is due to the preponderance of this free oxide which has become segregated through the leaching out of the more soluble constituents. While not taking exception to the view advanced by Professor Crosby to the effect that the iron in these southern soils may exist in a state of partial dehydration, I would account in part for the brilliancy of color merely through the presence of this excess of coloring matter. Color is then indicative of advanced decomposition and, other things being equal, of geological antiquity. This view is rendered the more plausible when it is recalled that the post-Cretaceous decay of the granites of the District of Columbia, to which I have previously called attention, has in most cases given rise to residual sands and clays of but a gray-brown color, while rocks of a precisely similar nature, decaying under the same climatic conditions, but so situated that the products of decay have been allowed to accumulate for longer periods, give rise to colors of characteristic brilliancy.

#### ZEOLITES IN THE FRESH ROCK AND THEIR POSSIBLE ORIGIN.

The occurrence of zeolites in the still fresh rock and the proportionately large amount of soluble matter in both the rock and the residual soil brings up for consideration the probable form in which these soluble constituents exist. Those at all conversant with the literature of the subject will at once recall the work of Lemberg, Hilgard, and others and the conclusions reached regarding the formation of zeolites during the

\* Bull. Geol. Soc. Am., vol. 7, 1896.

† Rocks, Rockweathering, and Soils. The Macmillan Company, New York, 1897.

processes of rock-weathering and rock decomposition, and also the probable efficacy of these zeolites as conservators of potash in such form that it becomes available for plant food. It is unnecessary to here go into a discussion of the literature or even to more than briefly refer to the causes which have led to these conclusions. The fact that soda and potash can, in laboratory practice, be made to mutually replace each other in gelatinous precipitates of aluminum or magnesium, as well as in true zeolitic compounds, taken together with the ready decomposability of zeolites by weak acids and the presence in soils of easily decomposable compounds of these bases, are the main grounds for the assumption. So far as the writer is aware, no one has as yet actually proved either the formation of zeolites during the process of true weathering or of their existence in the weathered product in other than fragmental forms as detrital products from the breaking down of zeolite-bearing rocks.

As yet much is to be learned regarding the formation of zeolites. So far as can be judged from available information, they form most readily, if not invariably, in the presence of continual moisture and where protected from oxidizing influences. Synthetic experiments have shown that zeolites may be formed in sealed tubes during a comparatively brief period at temperatures of not above 150 to 200 degrees centigrade. The inference is fair that, given a longer time, they will form at lower temperatures, provided, of course, other conditions are favorable. In looking over the literature of the subject, in connection with my work on rock-weathering, I have, however, become impressed by the fact that a possibility has been too generally accepted as a probability, and, further, that the terms *weathering*, *decomposition*, and *zeolites* have been used so loosely that their exact significance is lost, and statements made are therefore frequently either misleading or incomprehensible.

#### USE OF THE TERM WEATHERING.

First as to the use of the term weathering. It is evident at once that this name should include only those physical and chemical changes in rock masses induced by atmospheric agencies, by temperature changes, and by the chemical action of water and absorbed gases and salts. It is a process which works from above downward, and which manifests itself mainly in a physical disaggregation of the rock and a hydration and oxidation, often accompanied by solution of its various constituents. Such action presumably can be carried on to a depth dependent upon the permanent water level, where it practically ceases. Below this level hydration and other chemical changes may be going on whereby new minerals are generated, but the final results are of a quite different nature. In

the upper zone, that above the water level and which may be called the zone of oxidation, the weathering is manifested by a physical breaking down of the rock mass as a geological body, whereby it is resolved into gravel, sand, silt, and clay; a more or less complete change in the character of the chemical compounds usually accompanies this disintegration.

In this latter process there is invariably a tendency toward simplification, complex silicates being broken up and their various elements recombined as simpler hydrous silicates, carbonates, oxides, sulphates, free silica, etcetera. It is to a certain extent comparable with the entire demolition of a building and the utilization of the old material in the construction of new ones of quite different architectural types. The deeper-seated process, on the other hand, is not destructive, but is to a certain extent comparable with that of here and there substituting new materials for old in a structure the general features of which are not otherwise changed. New minerals are formed to replace, wholly or in part, those that preexisted, but the rock retains its geological identity, and in many cases is rendered even more enduring when actually exposed to weathering influences than before. Among the minerals thus formed are zeolites, epidote, amphiboles, feldspars, free quartz, chalcidony, etcetera.

It is obvious that we have here two distinct processes which, while they may grade into each other, are widely separable in their extremes, both as to methods and results. Both unfortunately have been frequently grouped under the general name of weathering and still more frequently under the far more general name of decomposition.

It would seem to the present writer that the name weathering should be limited to those processes going on within the zone of oxidation and resulting as a rule in the destruction of a rock mass as a geological body, while the more deep-seated processes, which are really of mineralogical rather than geological moment, should be looked upon as metamorphic. Hydrometamorphism is sufficiently explicit, though the process in many instances is metasomatic. Roth\* makes some attempt at discrimination in calling the deep-seated process "complicirte verwitterung," in distinction from the ordinary superficial "verwitterung;" but this name can scarcely be considered as satisfactory, much less so in fact than our term alteration, as commonly used.

#### FORMATION OF ZEOLITES IN SOILS.

Second, as to the formation and existence of zeolites in the soil. From all that is known regarding the actual formation of zeolites, it appears that moisture and an absence of oxidizing agents is essential. They are

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\* *Allgemeine und Chemische Geologie*, vol. 1, p. 159.

products of hydrometamorphism and not those of weathering, as limited above. It is even questionable if the processes involved in weathering are not entirely opposed to zeolitic formation, and destructive rather than otherwise. The processes which result in the breaking up of such minerals as the feldspars, micas, amphiboles, and pyroxenes would certainly quickly destroy a compound of the zeolitic type, even if once existing. Again, the close juxtaposition of mineral particles, such as is favorable to the production of "reaction rims," is quite obliterated in the process of weathering and soil formation. In weathering, the amount of interstitial space is continually augmented, until it amounts to practically 50 per cent, by bulk, of that of the soil itself, as shown by Dr Whitney and by the present writer.\*

The fact, moreover, that zeolites are met with in the finest stages of development in cavities of basic eruptive rocks where there are no signs of such decomposition products as are incidental to weathering, and almost wholly lacking in secondary rocks, are facts which should not be overlooked in this connection.†

If formed in soils, why should they not be found in secondary rocks resulting from the reconsolidation of materials derived by the same processes and from similar rocks?

#### EFFICACY OF ZEOLITES AS CONSERVATORS OF POTASH.

Third, can zeolites, even if occurring in soils, be considered as of practical value as conservators of potash?

Among the twenty-three known species of zeolites (including apophyllite), in but five is potash considered an essential constituent. These five are enumerated below in tabular form:

Name.	Composition.					
	SiO <sub>2</sub> .	Al <sub>2</sub> O <sub>3</sub> .	CaO.	K <sub>2</sub> O.	Na <sub>2</sub> O.	H <sub>2</sub> O.
Apophyllite.....	53.7	.....	25.0	5.2	.....	16.1
Ptilolite.....	70.0	11.9	4.4	2.4	0.8	20.5
Mordenite.....	67.2	11.4	2.1	3.5	2.3	13.5
Phillipsite.....	48.8	20.7	7.6	6.4	.....	16.5
Harmotome.....	47.1	16.3	BaO. 20.6	2.1	.....	14.1

\* Bull. Geol. Soc. Am., vol. 6, p. 332.

† The formation of zeolitic compounds in amygdaloidal cavities of basic eruptives is commonly regarded as due to the action of waters heated by the hot lavas into which they were infiltrated or by water supplied from volcanic sources. See Geikie: Basalt Plateau of Northwestern Europe, Quar. Jour. Geol. Soc. of London, May, 1896, and authorities there quoted.

It will be noted at once that even in these five potash plays a comparatively insignificant part, being highest in phillipsite (6.4 per cent), and averaging for all a little less than 4 per cent. Assuming, then, that a soil contained as high as 10 per cent of zeolitic material all belonging to these five groups and none to the potash-free varieties, even then we would have this combined only some 0.4 per cent of  $K_2O$ . It appears to the writer that these figures are sufficient to throw considerable doubt on the subject of either the presence or the utility of zeolites in soils. It is possible that in nature the process of potash replacement as performed in the laboratory has gone on, and that there may exist in the soil zeolitic compounds richer in potash than are at present known to the mineralogist. Such a condition, however, can not be considered probable.

Reference should be made in this connection to the use of the term zeolite as found in the American literature bearing upon soil fertility.

It is apparent that the word is, in only too many instances, used almost wholly without regard to its mineralogical significance, and made to include a considerable variety of secondary hydrous minerals. One writer refers to the magnesia in soils as being in zeolitic combinations, and still another includes glauconite under this head. So comprehensive a usage is objectionable, since the word has a fairly well defined mineralogical significance. If the chemists so extend it as to include glauconite, it can be made also to include serpentine, talc, and even kaolin, and the word becomes of so little significance as to be useless.

#### PROPORTIONAL AMOUNTS OF SOLUBLE MATTER IN FRESH AND DECOMPOSED ROCKS.

There is an abundant opportunity for more work in the way of ascertaining the proportional amount of soluble matter in rocks and in soils which result from their breaking down. As the writer has pointed out,\* there may, particularly among basic rocks rich in magnesia, be actually a larger percentage of matter soluble in hydrochloric acid and sodium carbonate solutions in the undecomposed rock than in the soil. This, for the simple reason noted in the paper above referred to, namely, that the decomposition is accompanied by a leaching process, whereby soluble compounds are removed by atmospheric waters. Even in cases where the actual percentage of soluble matter is greatest in the soil, the apparent excess may be due to water of hydration and to the large amount of sesquioxide of iron in the latter, the last, while practically insoluble in meteoric waters so long as there is a free supply of oxygen, being readily soluble in hydrochloric acid. In order to emphasize this point I have tabulated below the analyses of the soluble and insoluble portions of

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\* Bull. Geol. Soc. Am., vol. 7, 1896, p. 353.

*Proportional Amounts of fresh and decomposed Rocks Soluble in boiling Hydrochloric Acid and Sodium Carbonate Solutions.*

	Phonolite.		Diabase.		Basalt (Absarokite).		Gneiss.		Granite.	
	Marienfelds, Bohemia.		Medford, Mass.		Fort Ellis, Mont.		Albemarle Co., Va.		District of Columbia.	
	Fresh.	Decomposed.	Fresh.	Decomposed.	Fresh.	Decomposed.	Fresh.	Decomposed.	Fresh.	Decomposed.
SiO <sub>2</sub> .....	21.64	17.98	10.85	9.50	20.90	19.90	10.09	17.69	9.49	
Al <sub>2</sub> O <sub>3</sub> .....	10.37	11.26	4.74	4.86	3.89	5.80	24.86	2.486		
Fe <sub>2</sub> O <sub>3</sub> .....	2.23	2.72	10.91	10.00	4.28	7.81	11.80	11.80	8.36	
CaO.....	1.07	1.01	3.09	1.50	1.01	1.59	0.06	0.06	0.60	25.37
MgO.....	0.40	0.44	2.20	1.84	16.42	6.88	0.37	0.37	0.71	
K <sub>2</sub> O.....	0.28	0.11	1.21	0.68	Not det.	0.08	2.40	0.75	1.68	
Na <sub>2</sub> O.....	5.45	0.06	0.50	0.17	Not det.	0.22	1.10	0.25	0.68	
H <sub>2</sub> O.....	4.10	8.78	2.73	3.07	5.42	12.34	13.40	13.40	1.23	
	45.54	42.36	36.23	31.62	54.13	54.62	30.28	69.18	22.75	25.37

fresh and decomposed rocks, so far as available material was at hand, the loss on ignition, minus the loss in the fresh rock, being tabulated as water and calculated as one of the soluble constituents.

The series given is not large enough to permit safe generalizations, but it is sufficiently large and varied to be more than merely suggestive, particularly when we compare these figures with those representing the "insoluble residues" of ordinary soil analyses, and which vary between 55 and 80 per cent in those rich in free lime carbonates and organic matter and between 65 and 90 per cent in others.

#### POSSIBLE FORM OF COMBINATION OF SOLUBLE CONSTITUENTS.

The possible form of combination of these soluble constituents is certainly an interesting question. Undoubtedly a large part of the iron exists as free hydrous oxides. The small amounts of lime and magnesia may exist partly as carbonates, and a part of the silica has been dissolved from the free quartz by the alkaline carbonate used for the extraction of the gelatinous silica after digesting in acids. Undoubtedly, too, a portion of all the constituents is derived from the partial decomposition by the acid of a variety of existing silicates—shreds of mica, hornblende, augite, flakes of feldspar, etcetera—shown by the microscope to be still existing. Eliminating from consideration in the analyses of the decomposed Bohemian phonolite and Virginia gneiss the  $\text{Fe}_2\text{O}_3$ , and noting only those other constituents found in sufficient quantities to be considered essential, we shall get, by calculating back to a basis of 100, formulæ approximating  $\text{Al}_2\text{Si}_3\text{O}_5 + 5 \text{H}_2\text{O}$ , and  $\text{Al}_2\text{SiO}_5 + 3 \text{H}_2\text{O}$ , respectively, suggestive of compounds allied to montmorillonite and allophane. The possible errors in these calculations are so obvious that it is unnecessary to enumerate them, but they are of interest, and sufficient to suggest a possible combination of these soluble constituents other than those of zeolites.

It would appear to the writer that the soluble potash in soils exists, not in zeolitic compounds, but in some of the numerous decomposition (?) products of feldspar, nepheline, scapolite, etcetera, to which the name *pinite* is commonly applied. Such at least is the case in the potash-rich soil of Maryland examined by R. L. Packard.\*

These remarks are made, not with a view of individual criticism, but to call attention to points which seem in danger of being overlooked.

The writer, assuming that his mental processes are similar to those of other workers, and that language used and statements made in such form as to convey to him erroneous or misleading impressions are likely to produce the same results on others, believes that the using of certain terms with a meaning more precise is a subject worthy of consideration.

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\* Bull. 21, Maryland Agricultural Experiment Station, 1895.