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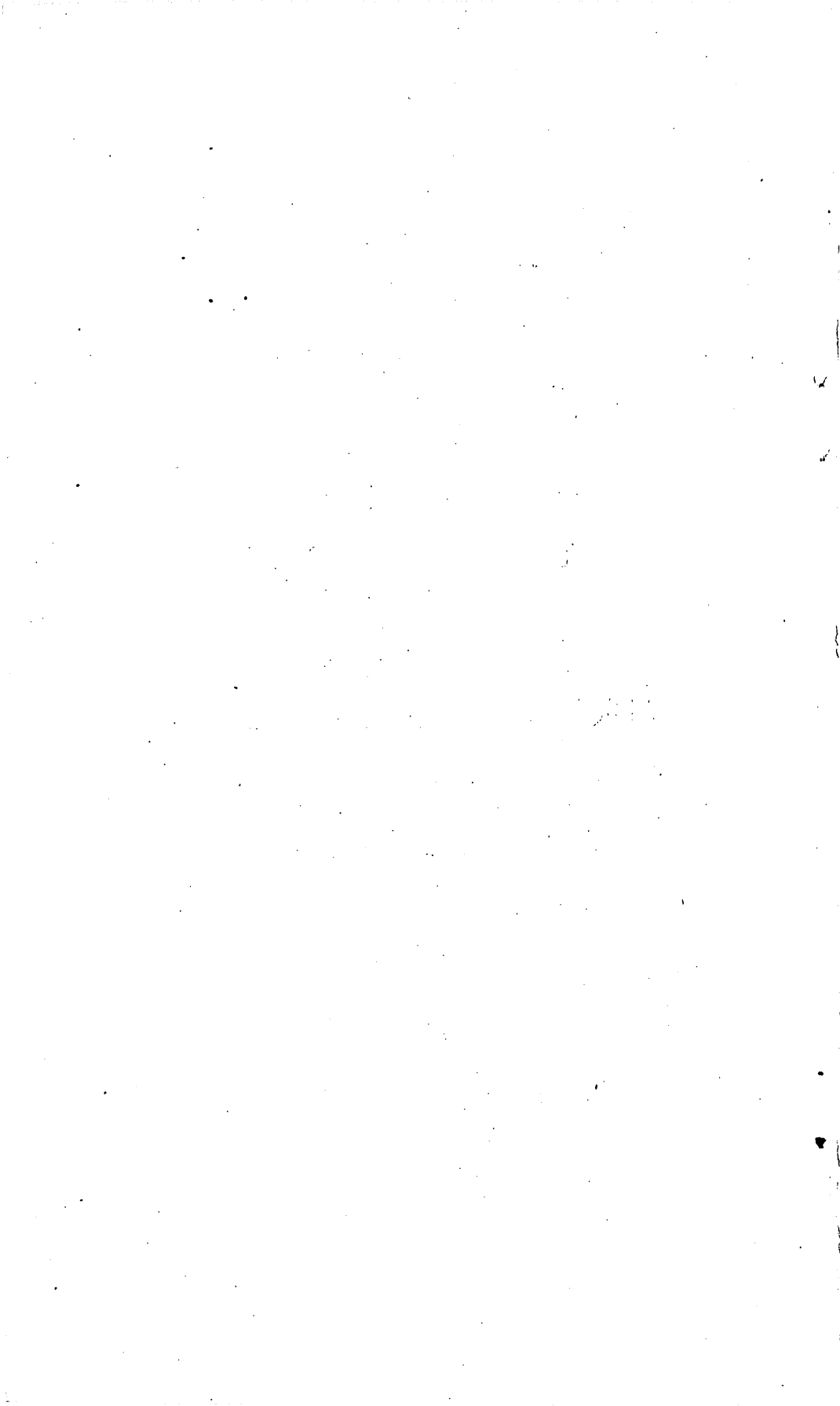
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UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

SUBAËRIAL DECAY OF ROCKS

AND

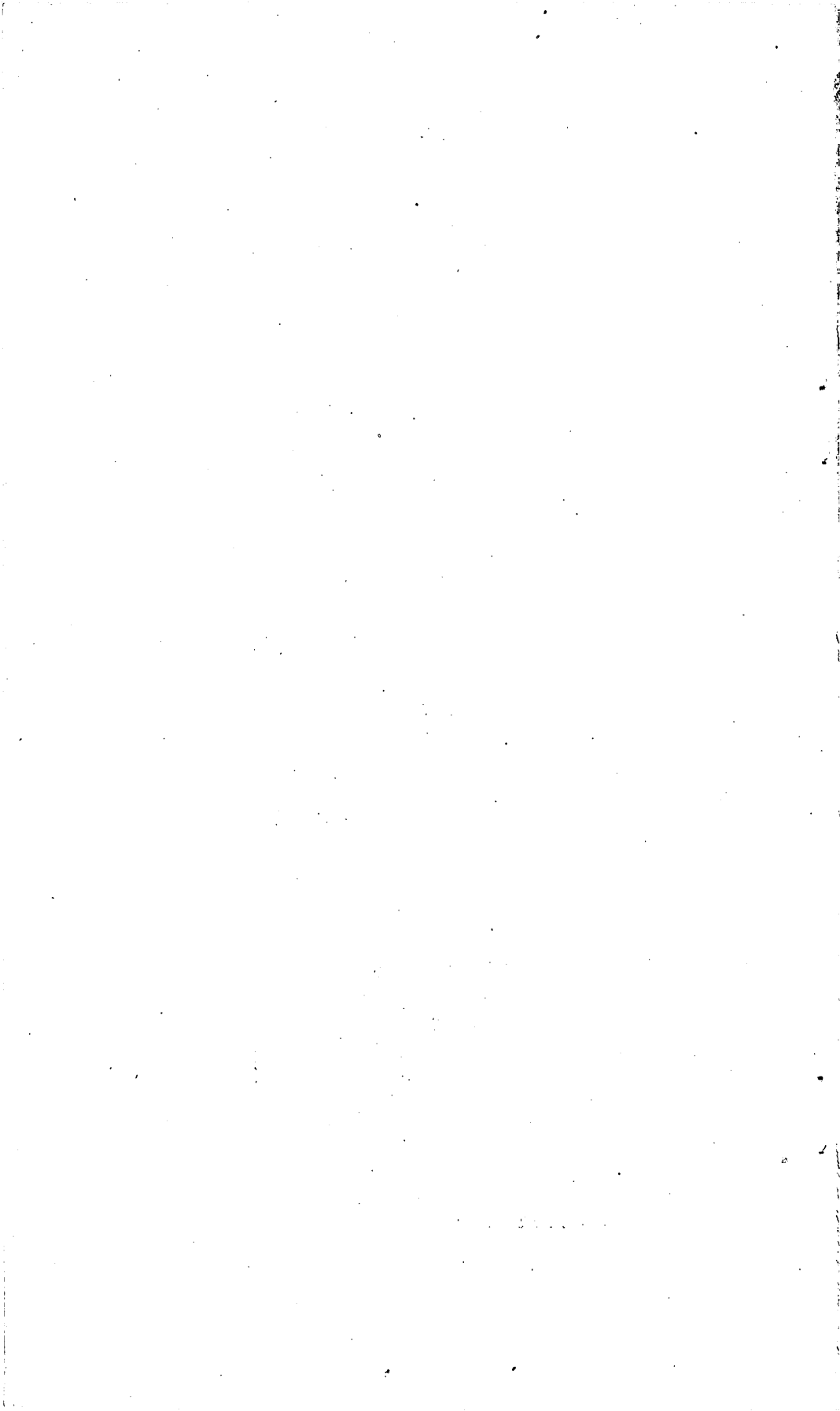
ORIGIN OF THE RED COLOR OF CERTAIN FORMATIONS

BY

ISRAEL COOK RUSSELL

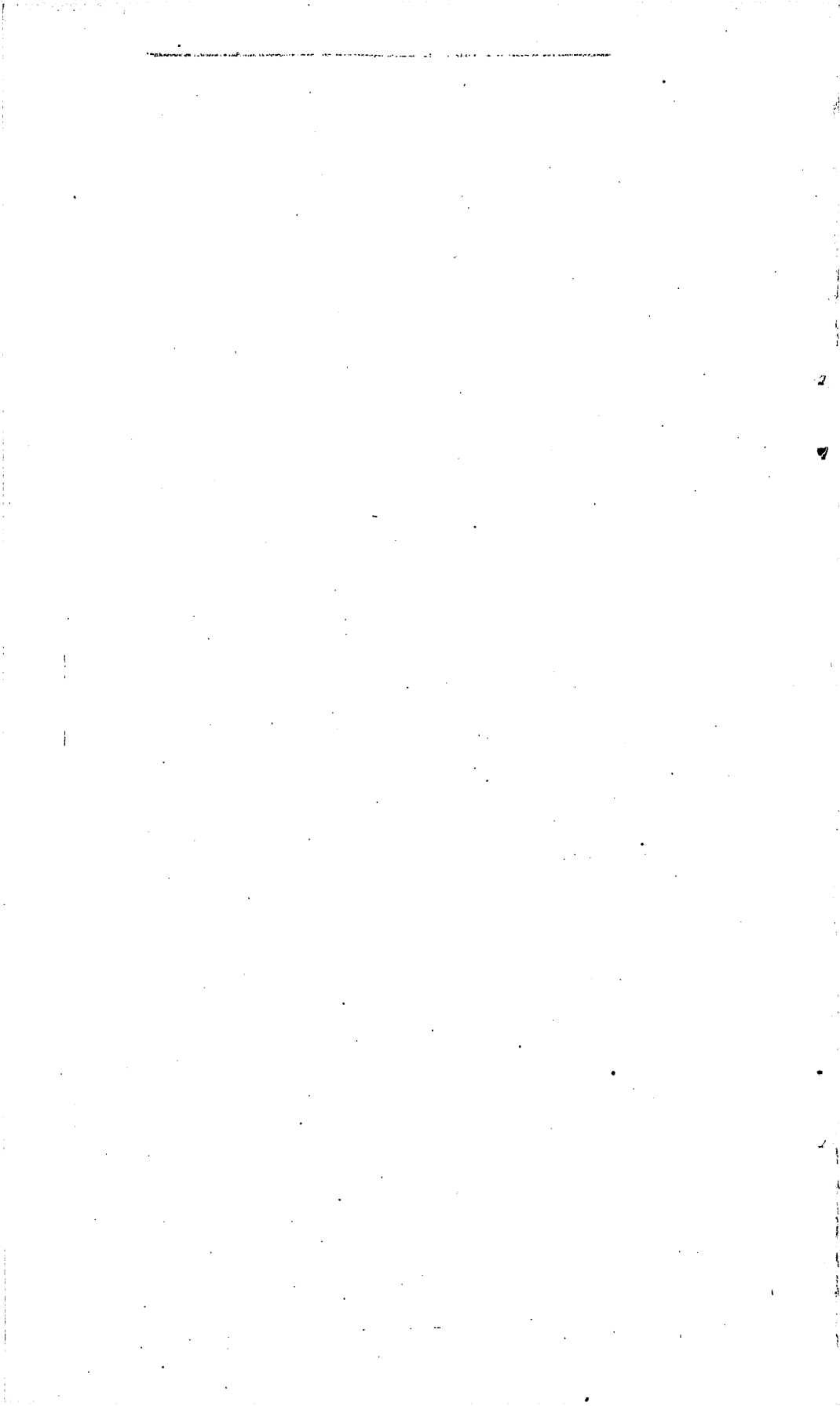


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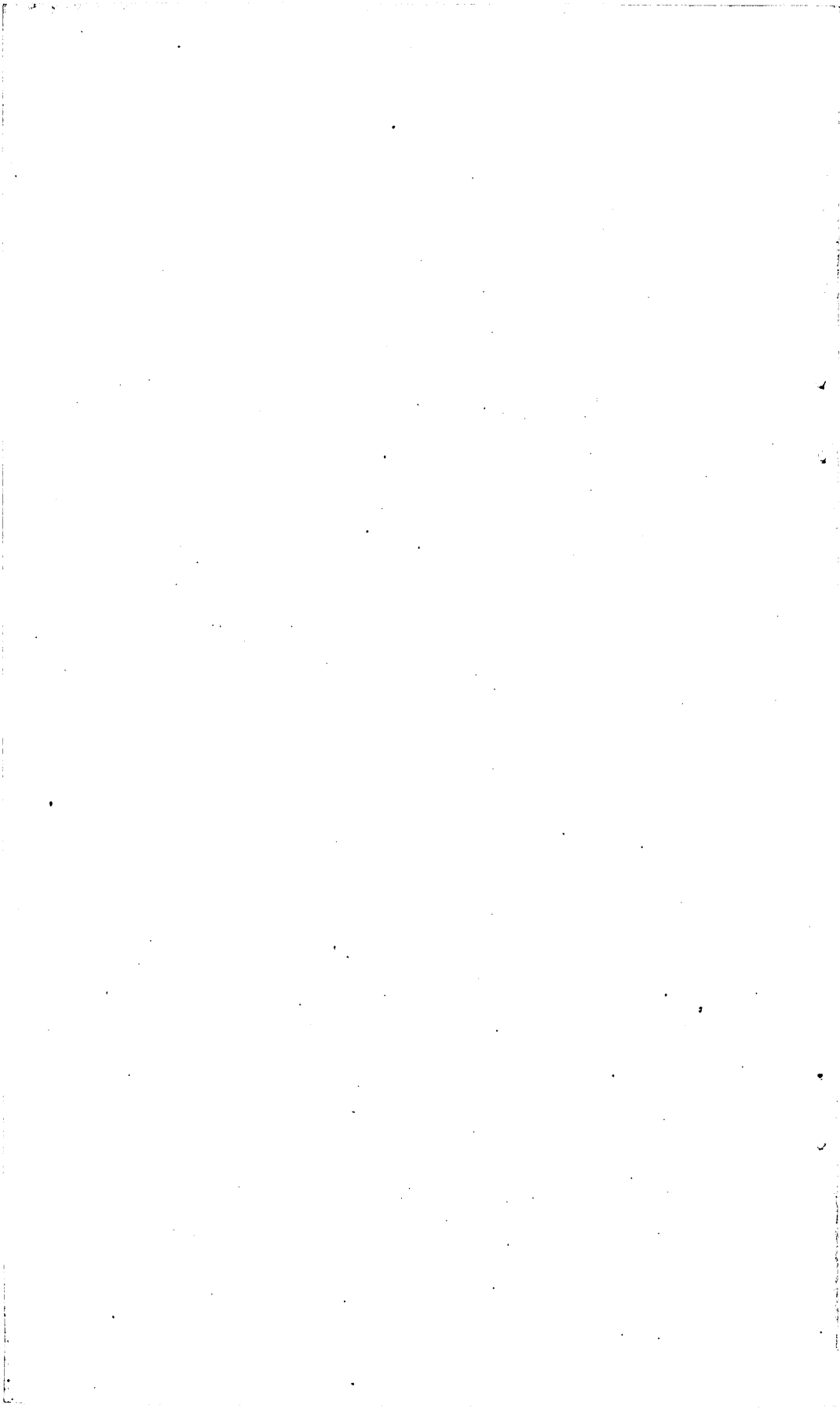
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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
U. S. GEOLOGICAL SURVEY,
Washington, D. C., October 12, 1888.

SIR: The observations on which the conclusions presented in the following pages are based were made principally during the summers of 1885, 1886, and 1887, in the Appalachian region south of Pennsylvania. This paper was presented for publication in the fall of 1887, but owing to a delay in printing I have been enabled to revise it during the present month and include certain observations made during the past summer.

In April, 1885, I began geological field work at Knoxville, Tenn., and traveled eastward across the Appalachians to Chester, S. C., whence my investigations led me northward through North Carolina and Virginia to the Potomac River. This field work lasted until late in October and enabled me to visit all of the areas occupied by rocks of the Newark system south of the Potomac, which were my special subject of study. In April, 1886, I resumed field work at Leesburg, Va., where I had disbanded my party the previous October, and carried examinations as far north as the Pennsylvania-Maryland boundary. As it was not deemed advisable to continue the study of the Newark system until satisfactory maps could be had of the regions it occupies, a field for geologic work was assigned me in Alabama and Georgia.

To reach this field I made a journey through the great valley which skirts the Appalachian Mountains on the west. As this valley is a marked feature, both topographically and geologically, all the way from New York to central Alabama, and is an important part of the Appalachian uplift, I shall speak of it in its entirety as the Great Appalachian Valley—a name applied to it by W. B. Rogers in discussing the physical structure of the Appalachians, and adopted by Arnold Guyot and others. In my journey south I traversed this valley, with various departures to points of geological interest, from Pennsylvania to central Alabama, having always in mind various problems relating to the subaërial decay of rocks. Finally, late in the season, my work led me into central and northern Georgia, where an opportunity was presented

for observing the decay of the crystalline rocks forming the extreme southern end of the Appalachians.

In the spring of 1887 I resumed field work in Alabama and Georgia, and spent five months in the completion of a geologic section 30 miles broad, extending from the undisturbed carboniferous rocks of north-western Alabama to the metamorphic schists of central Georgia. While traveling by rail to begin this work I stopped at Charlottesville, Va., Greenville, S. C., and Atlanta, Ga., for the purpose of examining the residual deposits at those localities.

The results of my observations during these various journeys, so far as they relate to the subaërial decay of rocks, are here presented. This subject was incidental to other geologic work, and was not the prime object of the journeys mentioned; yet it claimed a large share of attention for the reason that the records of decay are everywhere to be seen, not infrequently to the entire concealment of the general geology of the country. The journeys mentioned were made on horseback and on foot, with the aid of camping outfit, thus securing unusual advantages for observation. I record the manner of traveling and the routes followed in order to indicate to some extent the character of my observations, as well as the degree of confidence to be placed in the conclusions drawn from them.

The field season just closed necessitated a journey through portions of Colorado, New Mexico, Arizona, California, Nevada, Wyoming, and Dakota, during which the various questions relating to the disintegration and decay of rocks received as much attention as could be given them without detriment to other work.

I remain, very respectfully,

ISRAEL C. RUSSELL,
Geologist.

Hon. J. W. POWELL,
Director U. S. Geological Survey.

SUBAËRIAL DECAY OF ROCKS AND ORIGIN OF THE RED COLOR OF CERTAIN FORMATIONS.

BY ISRAEL C. RUSSELL.

INTRODUCTION.

In Part I of this paper attention is directed to the widespread decay of the surface rocks throughout the Appalachian region south of the southern limit of the glaciated area of northeastern America. It is shown also that rock decay is far more advanced in the southern than in the central and northern Atlantic States and increases gradually southward. This variation is thought to be due to climatic causes, combined with recent orographic movements which have accelerated denudation in the northern portion of the region under discussion. From a brief review of geographical distribution of residual deposits in various regions, together with other considerations, the conclusion is drawn that rocks decay most rapidly in warm, humid climates.

In Part II it is shown that iron-stained sands resulting from the subaërial decay of crystalline rocks agree in many ways with the similarly iron-stained sands forming certain geologic formations, of which the sandstones of the Newark system are an example. This, in connection with other facts, leads to the hypothesis that certain sandstones and shales, the grains of which are covered with ferruginous incrustations, received their red color during the subaërial decay of the rocks from which they were derived.

The name Newark system, proposed by W. C. Redfield in 1856, is adopted in this paper instead of Triassic, Jurassic, Jura-Trias, etc., to designate the formation composed mainly of red sandstones and shales, which occurs in detached areas along the Atlantic border from Nova Scotia to South Carolina.¹

The bibliography at the end of this paper contains a list of publications consulted relating to the decay of rocks.

¹Reasons for using this name are given in *The American Geologist*, vol. 3, 1889, pp. 178-182.

I. SUBAËRIAL DECAY OF ROCKS.

The formation of soils by the decomposition of rocks in place has already received a large share of attention, but recent observations suggest that changes of this nature have a wider geological bearing than has generally been assigned them, and that questions relating to the origin and distribution of soils and subsoils may still be discussed with profit.

DECAY OF THE CRYSTALLINE ROCKS OF THE PIEDMONT REGION.

In traveling south from the southern margin of the moraines left by the Pleistocene ice sheet of northeastern America, along the belt of crystalline rocks bordering the Appalachian Mountains on the east, the surface exposures exhibit greater and greater evidences of decay as one proceeds.¹ In Pennsylvania and Maryland the mica schists and allied rocks are frequently disintegrated to a depth of many feet, so that they may be removed with a pick and shovel. The strata, however, are for the most part simply broken down, so far as is apparent to the eye, although chemical alteration, especially of the feldspars, has unquestionably occurred. With the exception of a few feet at the surface, however, it is principally disintegration, not decomposition, that has taken place. In a handful of fragments the eye immediately determines the character of the rock from which they were derived; if chemical change was far advanced this would not be the case. It is difficult to ascertain the depth of this alteration, but in general it may be taken at from fifteen to thirty feet; localities are not uncommon, however, where well-marked disintegration has reached a depth of fully 50 feet below the surface. Typical examples of residual clay—the extreme result of subaërial decay—are not common in this portion of the Appalachian belt, but may occasionally be seen in railroad cuts and similar excavations.

As one travels south from the Potomac a great increase is seen in the extent and in the depth of the chemical changes that have affected the outcrops. Throughout nearly the entire area underlaid by crystalline rocks in Virginia and the Carolinas east of the Blue Ridge the soil is red clay, which is a residual deposit produced by the subaërial alteration of the rocks on which it rests. Over large areas this alteration reaches more than a hundred feet below the surface, but, owing to lack of exposures, its full extent is seldom seen.

¹The observations on the decay of rocks presented in this paper refer principally to changes that are obvious to the eye, and not to the alterations frequently detected when thin sections of apparently sound rocks are examined with a microscope.

The depth at which decayed rocks have been observed assures us that the downward limit of the changes produced in rocks by atmospheric agencies is not always determined by the level of stream erosion, or even by the horizon of the ocean surface. This may perhaps be due to recent subsidence, which has depressed the decayed rocks below the level at which the alteration took place, for it is evident that the changes due to atmospheric influences are of a different character from those produced by the circulation of water through rocks at great depth, although there is no sharp line of demarkation between the two processes.

In cuts along the line of the Carolina Central Railroad east of Wadesborough, on the Cape Fear and Yadkin Valley Railroad near Jonesborough, and along the North Carolina Railroad west of Raleigh, N. C., fine sections of decomposed crystalline rocks are exposed. These are but isolated examples, however, of what can be seen over thousands of square miles in the great area of crystalline rocks in which they are situated.¹ At the localities cited above the rocks retain little of their original character, but are now variously colored clays, which, when moist, can be molded in the fingers or cut with a pocket-knife. In many places the layers of granite, mica schist, hornblende schist, talcose schist, and similar rocks have been twisted and folded so that in their present eroded condition the bedding in the outcrops is nearly perpendicular. In such instances, when the rock is excavated, as in railroad cuts (the best example I observed is at Cary, eight miles west of Raleigh), the entire mass, to a depth exceeding fifty feet, is a soft, plastic clay, which reveals its original stratification and lamination by an almost infinite number of vertical bands and lines of various tints and shades. Bright red and brilliant yellow predominate, but these harlequin tints are many times blended with gray, purple, and white in such a way as to produce most remarkable examples of natural coloring. An analysis of a characteristic sample of this residual clay, apparently derived from chloritic schist, gave the following result:

Analysis of residual clay. By R. B. Riggs.

Silica (SiO_2)	54.54
Alumina (Al_2O_3)	26.43
Ferric oxide (Fe_2O_3).....	9.04
Water (H_2O).....	9.87
Total	99.88

¹ Other localities have been noted by L. S. Burbank, Proc. Boston Soc. Nat. Hist., vol. 16, pp. 150-155; and by W. C. Kerr, Am. Jour. Sci., 3d series, vol. 21, 1881, pp. 345-358. The formation of soils by the decomposition of crystalline rocks in Alabama has been well described by Eugene A. Smith in the Geol. Survey Alabama, Rept. for the years 1881 and 1882; and by William C. Stubbs in Berney's Handbook of Alabama, pp. 147 et seq.

About Greenville, S. C., the character of the residual deposits resulting from the subaërial decay of highly micaceous gneiss may be observed. The deep-red color of the plowed fields, merging at times into broad areas of yellow, to be seen in early spring, together with the exposures of decayed rock in railway cuts and along carriage roads, shows that this region has not escaped the decay and leveling effects of atmospheric erosion. The exposures of residual débris are not remarkable, however, as compared with typical localities in North Carolina and Virginia, for example, and seldom exceed forty or fifty feet in depth. The rock in the stream beds is quite compact, although presenting indications of considerable chemical change. This portion of South Carolina, in common with other areas in the southern Appalachians, forms an apparent exception to the rule that the residual deposits of the Atlantic States increase toward the south. As will be shown a few pages farther on, this exception is explained by the conditions of erosion which obtained in some portions of the Southern States.

In regard to the widespread decay of the crystalline rocks of South Carolina we have the testimony of M. Tuomey, whose conclusions in this connection of some forty years' standing can not be questioned, as is shown by the following quotation :

There is scarcely anything more striking in the face of the country in this [western] part of the State than the great extent and depth to which disintegration of the rocks has proceeded. Were it not for the occasional blocks of granite that lie scattered here and there, a person whose observations were confined to the surface would scarcely suppose himself traveling over the upturned edges of a series of rocks.¹

The quartz veins so common throughout the crystalline areas of Virginia, the Carolinas, etc., are more durable than the rocks inclosing them, and retain their integrity long after the associated schists have changed to plastic clays. Boulders and pebbles derived from the breaking up of quartz veins cover the surface with a continuous sheet of débris over large areas, forming a residual deposit, the origin of which is revealed at a glance. The quartz itself, although opposing great resistance to disintegration, is not indestructible, as is shown by the brown, iron-stained lines that traverse it in every direction, marking the course of incipient fractures. The continual breaking of the quartz into smaller and smaller fragments produces an angular sand which everywhere forms an ingredient of the red clay soil.

When average samples of residual deposits left by the decomposition of crystalline rocks are agitated in water more or less angular fragments of quartz and feldspar, with scales of mica and fragments of other minerals, are usually obtained. This material differs with variations in the character of the parent rocks and with variations in its degree of decomposition. On examining these residual sands with the microscope, especially in cases where the decomposition is well advanced, it has been found that each grain is coated with a thin shell

¹Report on the Geology of South Carolina, Columbia, S. C., 1848, p. 98.

having a brownish or red color. Prolonged washing fails to remove this superficial coating, a fact which is well illustrated by the color of the sands deposited by the streams of Virginia and the Carolinas in the regions underlaid by crystalline rocks. Hot hydrochloric acid dissolves the coloring matter, however, and leaves the grains of quartz, feldspar, etc., with their normal tints. It has been determined from chemical analyses of a number of samples of partially decomposed crystalline rocks that the incrustation which gives the grains their characteristic color is rich in both ferric oxide and alumina, and may perhaps be best described as a ferruginous clay. It is therefore evident that the predominant red color of residual deposits is due to a coating consisting largely of ferric oxide deposited during the disintegration and decomposition of the parent rocks, around the individual grains into which the rock becomes divided in weathering.

It may be remarked in passing that the residual deposits covering large portions of the crystalline areas of Virginia, the Carolinas, Georgia, and Alabama are sufficiently auriferous in many localities to be of economic importance.

The decay of the rocks in the southern Atlantic States has been observed by many travelers and has been the subject of a number of essays, as may be seen by turning to the bibliography at the end of this paper. Among the many contributions to the subject, one of the most definite and instructive is by T. Sterry Hunt,¹ who, in writing on the lithology of the southern Appalachian region, says :

The rocks are covered often to a depth of a hundred feet or more by the undisturbed products of their own decomposition, the protoxide bases having been removed by solution from the feldspars, the hornblende, and the whole rock, with the exception of the quartzose layers, reduced to a clayey mass, still, however, showing inclined planes of stratification.

Similar testimony is furnished by W. M. Fontaine,² who states that—

The depth to which decay has penetrated here [in the granites and gneisses near Richmond, Va.] is far less than in the southern and southwestern parts of the State. In the latter we find strata not specially prone to decay often decomposed and changed to a loose earth for fifty and even one hundred feet.

Descriptions of the surface decay of the rocks of the southern Appalachian region by other observers might be quoted, but enough has been presented for the purposes of this paper.

DECAY OF THE ROCKS OF THE NEWARK SYSTEM.

In the rocks of the Newark system in Virginia and North Carolina a widespread decomposition, similar to that affecting the older rocks of the same region, was observed at many localities.

The brecciated conglomerate which is found wherever the bottom of the Newark system is exposed is composed of both rolled and angular

¹ Chemical and Geological Essays, 1871-1873, pp. 187, 250.

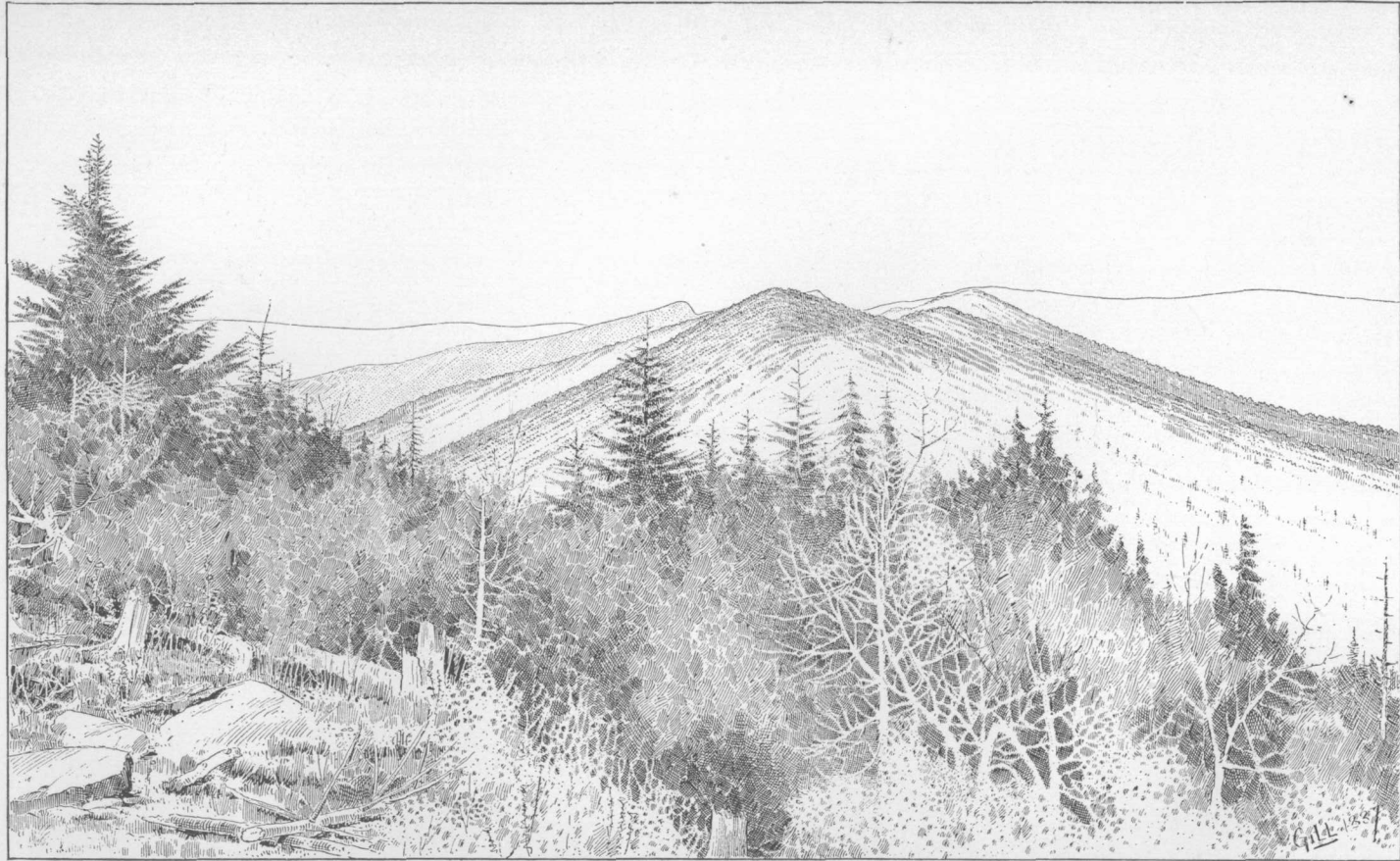
² Notes on the Mesozoic of Virginia, Am. Jour. Sci., 3d series, vol. 17, 1879, p. 30.

fragments of the adjacent crystalline rocks. These were compact and solid when deposited as pebbles and boulders, but they are now often as thoroughly disintegrated and decomposed as the neighboring rocks described above. In a cut on the line of the North Carolina Railroad, 10 miles west of Wadesborough, there is a fine exposure of the basal conglomerate of the Newark. The north side of the excavation still stands as a perpendicular wall about twenty feet high, in which the variously shaped fragments composing the brecciated conglomerate are clearly distinguishable. At a little distance the rock appears almost identical with the Potomac marble, with which it agrees in geological position. On examining more closely, however, one is surprised to find that it is completely decomposed, and that, when moist, it can be cut with a pocket knife, through pebbles and matrix alike, as easily as so much potter's clay. The full depth of the alteration in this instance is not revealed, but it extends more than thirty feet below the surface without change in character. Most of the pebbles observed were formed of talcose schist and the cementing material was apparently derived from rocks of the same composition.

In the ordinary brown sandstones and sandy shales of the Newark system throughout Virginia and North Carolina but little subaërial decay is apparent to the unassisted eye, except in the grains of feldspar which they contain. Some of the strata in this formation are composed of plastic red clay, but whether this was deposited in its present condition or is the product of subsequent decay it is not always possible to decide.

The most remarkable example which I observed of the change that rocks undergo when long exposed to the atmosphere occurs in the trap dikes traversing the Newark system of North Carolina. These are composed of dolerite of the same character as the "traps" so abundant in New Jersey and in the Connecticut Valley, and are exceedingly numerous throughout the various Newark areas south of the Potomac. In a single section, 13 miles in length, of the Newark area which crosses Anson County, N. C., over fifty trap dikes were observed, varying from a fraction of a foot to seventy-five feet in width. It is probable that many others exist which escaped notice.

These dikes trend approximately north and south and are nearly vertical in dip. They are usually undistinguishable in the topographic relief of the region, but their presence is occasionally indicated on the surface by long lines of weathered trap boulders. Sections of the dikes may frequently be observed in railroad cuts, and in such instances it is found that decomposition has reached to a great depth. In fresh sections forty or fifty feet deep the decomposition extends to the bottom of the exposures, without any indication of approaching its lower limit. Many dikes are completely decomposed throughout, and the originally hard, tough, bluish dolerite, which would ring under the hammer, has been transformed into a yellowish, clay like



VIEW OF MOUNT MITCHELL, NORTH CAROLINA, LOOKING NORTH ALONG THE CREST OF THE BLACK MOUNTAINS.

mass that can be molded in the fingers and cut like putty. In some cases, especially in the larger dikes, the decomposition is only partial, and the loose rotten mass contains rounded boulders in process of disintegration, in the center of which the rock still exhibits its original characteristics. These boulders usually occupy the center of a dike, as seen in vertical section, but at times there are two or more vertical bands of them distributed through the decomposing rock. The sides of the fissures through which the trap ascended are hardened or metamorphosed at some localities by the contact of the igneous rock, and thus rendered unusually durable. In such instances the trap is often completely decomposed, while the walls of hardened sandstone exhibit no sign of disintegration.

It is a noticeable fact that wells sunk in or near trap dikes in the Newark areas of North Carolina contain unusually "hard" water, which is frequently brackish. It may be that the saline matter in these wells was derived from salts impregnating the surrounding sedimentary rocks, but they must also receive mineral matter from the decomposing igneous rocks.

In speaking of the trap dikes in South Carolina, which belong to the same great system as those just considered, M. Tuomey remarks:¹

Both the trap and other rocks with which it is associated are so much disintegrated that it is impossible to observe the form presented by the dikes at the surface. I have not met with a single instance where this rock presented anything like an escarpment, although the manner in which it penetrates the rocks through which the dikes pass may be observed at many places, in ravines and such localities. On the surface the dikes are readily traced by the long lines of black or dark green and ferruginous spherical masses of trap scattered along in the direction of the dikes, often for miles in extent.

A chemical examination of decomposed trap from a dike near Wadesborough, N. C., shows that it is essentially a kaolin containing about seventeen per cent. of ferric oxide. An approximately complete analysis of this material by T. M. Chatard is given below, together with the average composition of eight samples of unaltered dolerite from New Jersey and the Connecticut Valley, as determined by G. W. Hawes.² The trap rocks are, in general, so nearly identical throughout the Newark system that we may consider this average as representing very closely the composition of the rock from which the residual clay described above was derived. It will be seen by the comparison that a large part of the silica, as well as of the more soluble portions of the original rock, has disappeared from the residual deposit, while the relatively insoluble alumina and ferric oxide have greatly increased their percentages.

¹ Report on the Geology of South Carolina, Columbia, S. C., 1848, pp. 65, 66.

² Am. Jour. Sci., 3d series, vol. 9, 1875, pp. 185-192 [the analyses used are on pp. 186, 187, 189].

Analyses of dolerite.

Constituents.	Average composition of unaltered dolerite.	Decomposed dolerite from Watauga, N. C.
Silica (SiO ₂).....	52.50	39.55
Alumina (Al ₂ O ₃).....	14.15	28.76
Ferrous oxide (FeO).....	9.24	.....
Ferric oxide (Fe ₂ O ₃).....	1.96	16.80
Manganous oxide (MnO).....	0.45	Trace.
Lime (CaO).....	10.03	0.37
Magnesia (MgO).....	7.48	0.59
Chromic oxide (Cr ₂ O ₃).....	.....	Trace.
Soda (Na ₂ O).....	2.30	Trace.
Potash (K ₂ O).....	0.69	Trace.
Phosphoric acid (P ₂ O ₅).....	0.14	0.10
Titanic acid (TiO ₂).....	.....	0.64
Water (by ignition) (H ₂ O).....	0.92	13.26
Total.....	99.86	100.07

In following the rocks of the Newark system south from Pennsylvania, through Maryland, Virginia, and the Carolinas, one finds the trap dikes exhibiting greater and greater evidences of decomposition. Thus, as in the case of the Archæan granites and schists and the Newark conglomerates, the decay of the eruptive rocks increases towards the south.

DECAY OF ROCKS IN THE SOUTHERN APPALACHIANS.

Subaërial decay is marked among the mountains of western North Carolina and eastern Tennessee, where the material filling the valleys, as in the lowlands to the eastward, is usually a red clay, in which angular fragments of quartz, feldspar, and mica are intermingled. All the stages in the formation of this material from the underlying schists and associated rocks may be observed at many localities. The same is also true of large portions of the mountainous region of Georgia and Alabama. In the area underlaid by Ocoee schists, however, which borders the more intensely metamorphosed rocks of the southern Appalachians on the west, transportation is being carried on so rapidly that comparatively little residual material remains. The reason of the more energetic action of the streams in this region is to be found in the fact that the limestone rocks bordering the Ocoee formation on the west are much more easily removed than the less soluble slates and schists of the metamorphic area; hence the latter stand in relief and impart a high grade to the stream channels which lead from them. The

streams are consequently rapid, and the surrounding slopes are in many places stripped of their residual deposits.

Throughout the southern Appalachians we find abundant illustration of the rounded summits and flowing outlines characteristic of a land that has been long subjected to decay, and in which decomposition and disintegration in general exceed transportation. Even in the most elevated portions of this range, however, the scenery is subdued and pleasingly picturesque, partaking rather of the beauty of hills overlooking pastoral valleys than of the rugged grandeur of mountains such as the Sierra Nevada and the Alps. To the geologist these differences appear to be wholly due to variations in the balance between disintegration and transportation. The mountains of the southern Atlantic States have a softness of outline and a delicacy of tint peculiarly their own, which depend largely on the luxuriance of the vegetation with which they are clothed, and on the vapory atmosphere with which they are surrounded. The charm of their beauty can not be shown in ordinary illustrations, but must be seen and felt to be understood. The flowing outlines of the hills and something of the atmospheric effects of the climate of the South may be gathered from the accompanying picture of the New Found Mountains, as seen from near Asheville, N. C.

Another convenient locality for studying the effects of atmospheric forces on crystalline rocks is furnished by the street excavations and suburban improvements of Atlanta, Ga. In every direction about that city the evidence of deep rock decay is to be seen, and the landscape presents the subdued outlines characteristic of "topographic old age."

In describing the formation of soils by the decay of the metamorphic rocks of eastern Alabama (and the observation would apply equally well to large areas in Georgia), E. A. Smith observes:¹

In some parts the strata have undergone complete disintegration in place, and have been converted into great masses of stratified clays, interlaminated with seams of quartz, which, gradually broken down, cover the ground with their angular fragments. The depth to which this decay reaches depends on the nature of the rock and its position, and in many instances even twenty or thirty feet below the surface the rock is still decomposed.

In the region mentioned in the last paragraph two varieties of soil, termed red and gray, are recognized by the author quoted:

The soil of the red lands is derived from the decomposed hornblendic gneisses and slates, which in many places, where exposed in washes or gullies, are seen to be mere stratified clays, containing fragments, more or less angular, of the quartz veins or seams which are nearly always interbedded with the other rocks of this region. The top stratum of this soil, from two to three inches in depth, has often a dark chocolate-brown color, but below it becomes a bright red, and at varying depths, from ten to fifteen feet, becomes a yellowish hard clay. Where the freshly decomposed rocks are seen the color is yellowish rather than red, the latter color being darker and more in-

¹Geol. Survey Alabama, Rept. for 1881 and 1882, p. 184.

tense apparently the further removed the soil is from its original position and the more it is affected by the decay of the vegetable matter.

The gray soils result from the disintegration of gneisses and mica slates, which contain comparatively little or no hornblende or other iron-bearing minerals. They are commonly somewhat sandy, usually light-colored, gray to dark gray, sometimes nearly black, with very often, however, a decidedly reddish color, similar to that of the hornblendic soils above described. Fragments of the partially decayed gneiss of a light-gray color often lie embedded in reddish and even red clays or clayey sands.¹

A number of analyses of the soils of the metamorphic region of Alabama, of interest to the student of rock decay, are given in the report^t just cited.

DECAY OF ROCKS IN THE GREAT APPALACHIAN VALLEY.

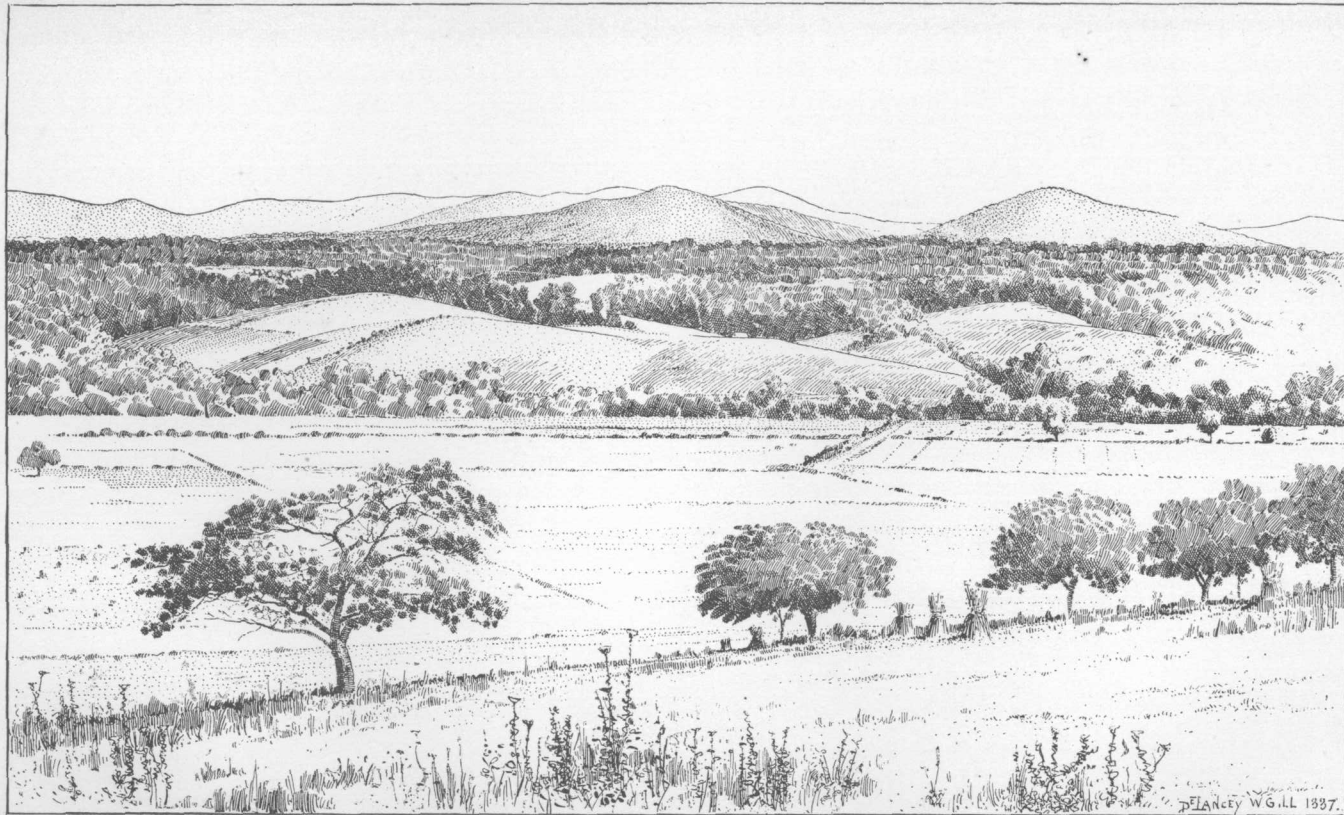
In traversing the Great Appalachian Valley² from Pennsylvania to Alabama, an increase in the extent and depth of the residual deposits toward the south was again observed.

This great valley owes its formation primarily to an upheaval, which brought the rocks within the reach of denuding agencies. The present topographic diversity, however, is not due to an elevation of the borders of the valley, but to the denudation of its bottom. The removal of rocks has been carried on, as usual, by the action of running water, but its work has been performed largely by chemical solution. That this process is still continuing is shown by the thousands of "sink holes" and by numerous valleys without surface drainage, to be seen in the limestone areas from Pennsylvania to Alabama. It is also indicated by hundreds of fine springs, and by numerous caverns, of which Luray is a type, which owe their existence to subterranean solution.

Throughout the entire extent of the valley thousands of feet of strata, principally of limestone, have been removed. In the Coosa Valley, Alabama, which is a portion of the Great Appalachian Valley, the minimum thickness of strata carried away since the Carboniferous period, as determined by careful measurements, is not less than eight or nine thousand feet. The maximum denudation, of which no accurate determination has been made, may largely exceed this.

¹ Geol. Survey Alabama, Report for 1881 and 1882, pp. 183-187.

² The valley referred to occupies for the most part a well-defined position between the Appalachian Mountains on the east and a great but somewhat indefinitely defined table-land—known as the Cumberland, Alleghany, and Catskill plateau—on the west. It crosses the prevailing corrugations of the Appalachians somewhat obliquely, its prevailing trend being nearly northeast and southwest, and in Pennsylvania is to the east of the Alleghanies. It has many local names; in Alabama it is occupied principally by the Coosa River, and is known as the Coosa Valley; farther north it is the valley of East Tennessee and the valley of Virginia; in Maryland and Pennsylvania it is the Cumberland Valley; in Pennsylvania it becomes the Lebanon and Kittatinny Valleys; in New Jersey and New York it is drained by the Walkill. The upper portion of the Hudson River Valley and the depression occupied by Lake Champlain are portions of the northern extension of the same topographic feature.



NEW FOUND MOUNTAINS LOOKING SOUTHWEST FROM ASHEVILLE NORTH CAROLINA.

The predominant rock of the Great Appalachian Valley is Paleozoic limestone. Throughout large areas, especially in Alabama and Georgia, this rock is highly charged with magnesia and silica and becomes a cherty dolomite. It is in regions underlaid by rocks of this character that the most abundant accumulations of residual deposits occur. The chert, being slow to decay, accumulates at the surface as the inclosing limestone dissolves away, and, together with the residual portion of the limestone, forms rounded hills and gentle ridges in which rock in place is seldom seen owing to the depth of the subaërial deposits. Over large areas in Wills and Coosa valleys, Alabama, residual deposits of this character have in general a minimum thickness of not less than a hundred feet. Their maximum thickness is probably two or three times as great. In regions where the limestone is less silicious the residual deposits are more homogeneous and usually consist throughout of red clay, frequently rich in concretionary iron ore.

The red earth, containing angular fragments of chert which have resulted from the decay of magnesian limestone (Knox dolomite) in the southern part of the Great Appalachian Valley, is very similar both in character and mode of origin to the red earth charged with flints which forms the surface over portions of the Chalk formation in the south of England, as described by W. Whitaker.¹

The chert, or "flint," which occurs in great quantities in the Silurian and Carboniferous rock of Tennessee and Alabama, although exceedingly hard and giving every indication of durability when fresh, crumbles to a fine white powder, bearing no resemblance to the original rock, when long exposed to the atmosphere. This change has been observed to extend to the depth of two or three feet from the surface of a bed of chert, which at a greater depth was compact and hard. The change from altered to unaltered chert is abrupt, and hand specimens may easily be collected in which one-half is a compact, bluish chert, fit for gun flints, and the other half a powdery, amorphous mass that crumbles between the fingers. The fact that the entire specimen in such an instance was originally homogeneous is shown by the concentric lines and bands of various tints that traverse both the solid and the friable portions without interruption.

The soil formed by the decay of the more calcareous portion of the magnesian limestone (Knox dolomite) of Alabama is thus described by Eugene A. Smith:²

A clayey loam of light yellowish to orange-red colors and of varying thickness, the average being perhaps 1½ feet. The subsoil is usually heavier, being a rather stiff clay or clayey loam of a red or yellow color. Both soil and subsoil are often filled with lumps of limonite or brown iron ore. Beneath the subsoil, at varying depths, lies the dolomite, or limestone. There is a great variety in the color of the top soil, between a

¹Mem. Geol. Survey Great Britain: The geology of Middlesex, Hertfordshire, etc. London, 1864, pp. 63-66.

²Geol. Survey Alabama, Rept. for 1881 and 1882, p. 200.

very light yellow, almost gray, and a deep red and brown; but the subsoil is commonly a yellow or red clay, and it is not unusual to find these soils and subsoils, especially those of a light color, filled with angular fragments of chert.

Portions of the Silurian rocks of Alabama, readily recognized as limestones when unweathered, are easily mistaken for sandstones and shales when only their weathered outcrops can be seen. The Clinton ore, or "fossil ore," interbedded with strata of shale and sandstone, forms one of the most characteristic beds in the Upper Silurian rocks of Tennessee and Alabama. In the mines of Gadsden and of Atalla, Ala., where Clinton ore is worked, the strata are highly inclined (a dip of 70° to 80° to the southeast prevailing) and well exposed for study. The outcrops of the beds are of soft, porous, highly fossiliferous ore, which has a deep brownish red color and is easily worked and easily smelted. The ore at Atalla retains this character to the depth of about two hundred and fifty feet, measured down the slope, and then changes to a hard, compact, ferruginous limestone, rich in fossils.¹ The marked difference in the character of the ore in the upper portions of the mines as compared with that from the lower portions is due entirely to weathering. This is shown by the general appearance of the ore at various horizons and by its chemical composition. Two typical samples of the ore, selected by me—one from near the surface, representing the ordinary character of the soft ore, and the other from a depth of two hundred and fifty feet, representing the hard ore, but not the most calcareous variety—gave on analysis the following percentages of iron, lime, and carbonic acid, after drying at 105° Centigrade:

Analyses of Clinton iron ore. By R. B. Riggs.

Constituents.	Surface sample.	Sample from 250 feet below surface.
Iron (Fe).....	57.52	7.75
Lime (CaO).....	1.38	47.64
Carbonic acid (CO ₂).....	0.30	34.90

The increase of lime in the Clinton ore of the Great Appalachian Valley when followed below the surface is well shown in the following table, compiled from analyses of ore mined near Birmingham, Ala., which I copy from a paper by John B. Porter:²

The ore is 13 feet thick and highly tilted, with an outcrop which has been located for many miles. At the time of the analysis the mine was 130 feet deep on the ore,

¹A similar change in fossil ore has been noted by T. H. Dewees, in Pennsylvania; Second Geol. Survey Pennsylvania, Report F, 1878, p. xlvi.

²"The iron ores and coals of Alabama, Georgia, and Tennessee." Trans. Am. Inst. Mining Engineers, vol. 15, p. 189.

and the following figures give the percentage of carbonate of lime for each 10 feet descent:

Percentage of lime in Clinton iron ore.

Surface	Trace.	70 feet below surface ...	25.61
10 feet below surface ...	Trace.	80 feet below surface ...	29.92
20 feet below surface ...	Trace.	90 feet below surface ...	29.89
30 feet below surface ...	Trace.	100 feet below surface ...	23.37
40 feet below surface ...	21.06	110 feet below surface ...	28.82
50 feet below surface ...	23.90	120 feet below surface ...	21.32
60 feet below surface ...	37.01	130 feet below surface ...	30.55

At Atalla the change from "soft ore" to ferruginous limestone, or "hard ore," takes place at about the present level of stream drainage. At this horizon the stratum increases from two feet and a half to three feet in thickness. This increase in thickness below the level of drainage indicates that the removal of the calcareous portion of the ferruginous strata has allowed the bed to be compressed. As the unweathered ore is of doubtful economic value, owing to its high percentage of lime and the difficulty of mining, exaggerated estimates of the importance of the Clinton ore deposits of the South are to be guarded against.

The Carboniferous rocks of eastern Alabama at some localities occur next above the Clinton, but are usually separated from it by a stratum of highly bituminous shale and sandstone, about thirty feet thick. In these Carboniferous rocks there are heavy layers of highly silicious limestone, abundantly charged with crinoidal remains. In its unweathered condition, which is seldom observed, this is a dark, heavy, siliceous rock, in which the fossils are quite obscure. On the surface, and usually to the depth of fifty or sixty feet, this rock appears as a porous chert, which is traversed in every direction by cavities left by the solution of fossils, principally the stems of crinoids. A greater contrast than is presented by the massive black limestone as it appears in its unweathered condition and the light-colored, slag-like chert of the weathered outcrops could scarcely be imagined. The débris of this peculiar siliceous limestone is found in most of the "red ore ridges" of Tennessee and Alabama, and when its geologic relations are known to the miner it furnishes an important aid in tracing the deposits of Clinton ore, with which its association is quite constant.

Many other illustrations of the character and of the extent of the weathering which has affected the rocks in the southern part of the Great Appalachian Valley, with reference especially to the genesis of limonite and manganese deposits, might be enumerated; but enough facts have probably been presented for the purpose in hand.

Residual clays of the same character and origin as those which impart their characteristic color to great areas in Alabama and Tennessee

also occur in that portion of the Great Appalachian Valley which lies in Virginia, Maryland, and Pennsylvania. In the northern portion of the valley, however, especially north of the James, the clays are not so continuous or of so great a thickness as farther south.

Throughout the valley of the Shenandoah and in the region drained by the James, New River, etc., in Virginia, the surface of the country is covered to a depth sometimes exceeding fifty feet with a red clay which has resulted almost entirely from the decay of limestone. This is a residual deposit that accumulated at the surface as the limestone in which it once formed an impurity was slowly dissolved away. It is evidently the product of a very long period of concentration, as the insoluble portion of the limestone in this region constitutes but a very small part of its weight.

In the following analysis the composition of a sample of light gray Trenton limestone from Lexington, Va., is given, together with the analysis of a characteristic sample of the superficial red clay of the same region, which was left after the removal of the more soluble portions of the limestone.

Analyses of Trenton limestone and of the residue left by its decay. By R. B. Riggs.

Constituents.	Unaltered limestone.	Residual clay.
Silica (SiO ₂)	0.44	43.07
Alumina (Al ₂ O ₃)	} 0.42	} 25.07
Ferric oxide (Fe ₂ O ₃) .....			15.16
Lime (CaO)	54.77	0.63
Magnesia (MgO)	Trace.	0.03
Potash (K ₂ O)	Not det'd.	2.50
Soda (Na ₂ O)	Not det'd.	1.20
Carbonic acid (CO ₂)	42.72	.....
Water (H ₂ O)	1.08	12.98
Total	99.43	100.64

An analysis of magnesian limestone (Knox dolomite) from Morrisville, Ala., and of the residual clay left by its decomposition, is here inserted, to illustrate still further the chemical changes which occur during the decay of calcareous rocks. The original rock in this instance was a grayish-white dolomite, typical of its class over a large area in the southern part of the Great Appalachian Valley, while the clay left by its decay is a fair sample of the red soil of the South.

*Analyses of dolomite and of residual clay left by its decay. By
W. F. Hillebrand.*

Constituents.	Unaltered dolomite.	Residual clay.
Silica (SiO ₂).....	3.24	55.42
Alumina (Al ₂ O ₃).....	0.17	* 22.17
Ferric oxide (Fe ₂ O ₃).....	0.17	8.30
Ferrous oxide (FeO).....	0.06	Trace.
Lime (CaO).....	29.58	0.15
Magnesia (MgO).....	20.84	1.45
Potash (KO).....		2.32
Soda (Na ₂ O).....		0.17
Carbonic acid (CO ₂).....	45.54	
Water (H ₂ O).....	0.30	† 9.56
Total.....	99.90	99.84

* With TiO₂ and P₂O₅.

† 2.10 at 100°C.

These investigations indicate that approximately from one to four per cent. of ordinary light-colored limestones, depending mainly on the amount of silica and alumina they contain, remains behind and contributes to the formation of residual clays when subaërial decay takes place. These analyses, however, are somewhat unsatisfactory in this connection, as only a small quantity was used in each instance, and no attempt was made to determine the minute portions of various elements which might reasonably be expected to be present.

The red earth of the southern portion of the Great Appalachian Valley is apparently identical, both in composition and in the method of its accumulation, with the "terra rossa" of southern Europe, the "laterite" of India, and the "red earth" of Bermuda, each of which will be noticed further on.

The red clay so frequently found in caves, especially in the limestone regions of the Southern States, and known as "cave earth," is another occurrence of the residual deposits resulting from the subaërial decay of rocks, and at times has considerable interest.

Although quantitative measurements of the extent and thickness of residual deposits of the Great Appalachian Valley have not been made, yet qualitative observations are sufficient to show that, like the similar deposits covering the crystalline and Newark areas east of the Blue Ridge, they are far more abundant in the South than in the North, as has already been stated, and increase gradually as one travels from north to south.

A comparison of the southern Appalachian region with the driftless area of the upper Mississippi Valley, as described by T. C. Chamberlin

and R. D. Salisbury,¹ shows that rock decay is far more advanced in the former region than in the latter. The average of one thousand eight hundred measurements of the depth of residual deposits over the driftless area of Wisconsin as given in the report referred to above, is 7.08 feet, the maximum, which was possibly in an enlarged fissure, being 70 feet. A general inspection of the southern Appalachian region is enough to assure one that residual deposits are there at least ten or fifteen times as thick as the estimated average thickness of the similar deposits in Wisconsin, etc. The driftless area described by Chamberlin and Salisbury is characterized by outstanding towers of castle-like masses of rock, frequently spoken of as "erosion columns," that have been left in bold relief by the removal of the surrounding strata. In the Southern States no such records of the former extent of particular formations are to be found. Their existence, except in immediate proximity to cliffs, is precluded by the fact that the rate of decay exceeds the rate of transportation.

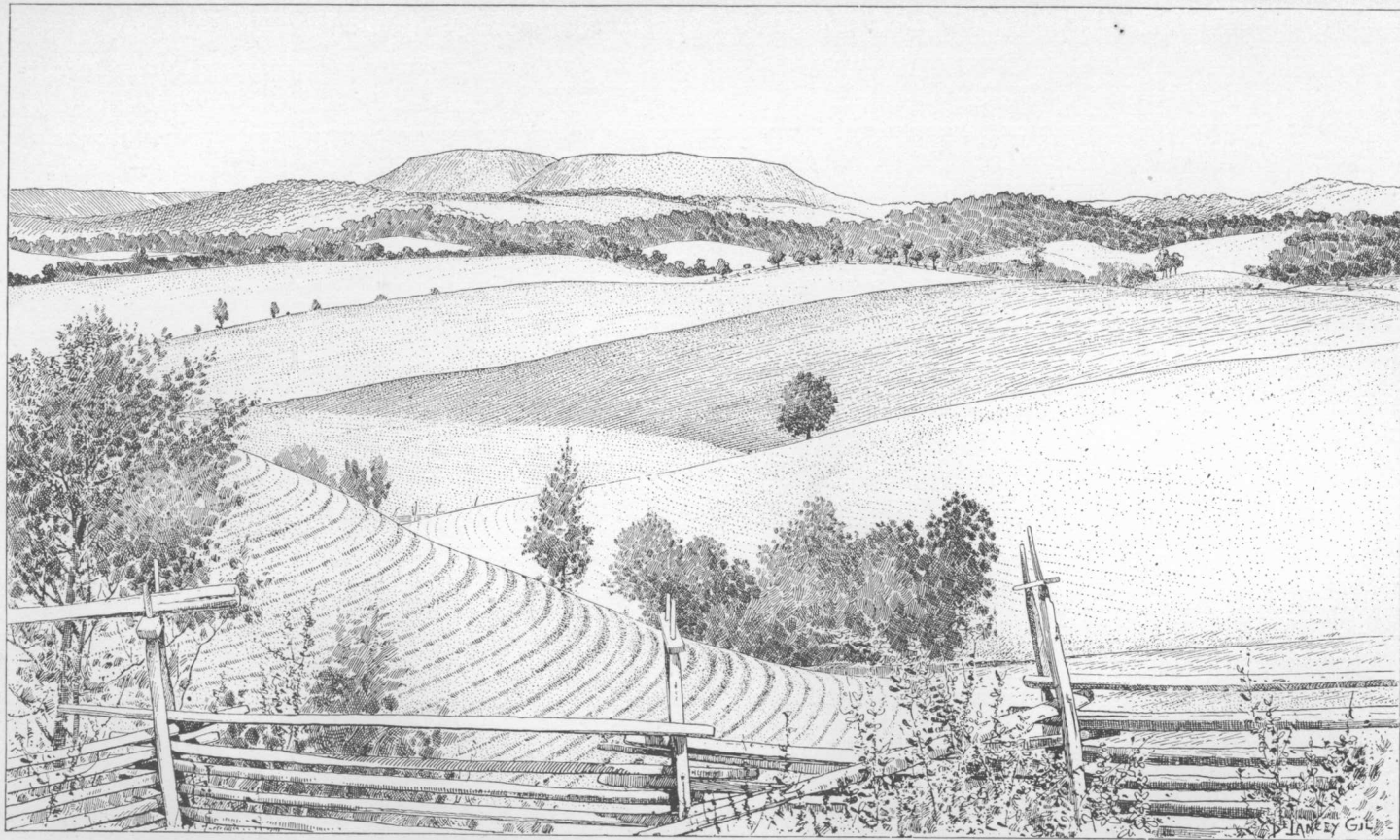
The general rounded character and soft, flowing outlines of a limestone country that has long been exposed to atmospheric decay is illustrated by Plate III, which represents the characteristic scenery between Lexington and Natural Bridge, Va. The elevated table-land in the background of the picture is House Mountain, which overlooks Lexington.

The increase of residual deposits toward the south in the Appalachian region is a geologic feature of interest, and one that demands explanation. A discussion of this question will be postponed for a few pages, however, in order to present something of the effects of subaërial decay in other regions, and to state the nature of the chemical changes which take place in rocks when exposed to atmospheric influences.

ABSENCE OF DECAYED ROCKS IN THE FAR WEST.

Nothing comparable with the extensive disintegration and decay of the rocks forming the southern portion of the Appalachian Mountains has been observed by me during somewhat extended journeys through other portions of the United States. In the Northeastern States the records of such decay are mostly obscured and obliterated by glacial deposits. West of the Mississippi, in New Mexico, Colorado, Idaho, Utah, Nevada, Oregon, and California, only secondary glaciers originating from local centers existed during the glacial epoch. The rocks in large portions of this region have presumably been subjected to subaërial influences fully as long as in the South Atlantic States, but no marked evidences of general decay are to be seen. In the mountains of the Far West, which, as nearly as I can judge, may be fairly compared with the more elevated portions

¹ U. S. Geol. Survey, Sixth Ann. Rept., p. 205.



VIEW OF FIELDS OF RESIDUAL CLAY NEAR NATURAL BRIDGE, VIRGINIA, LOOKING NORTH; HOUSE MOUNTAIN IN THE BACKGROUND.

of the southern Appalachians, so far as the conditions of transportation are concerned, the evidences of subaërial decay are not strongly pronounced, and, in fact, are usually absent. It is a matter of observation that the soil formed by the decay of a great variety of rocks is a red clay, which, in the more advanced stages of decomposition, is strikingly similar, both in appearance and in constituents, the world over. In the arid portion of the Far West soils of this character are wanting, and the prevailing tone of the landscape, so far as it is influenced by the color of the soil, or by the color of subaërial deposits generally, is subdued and unobtrusive, being usually gray, or light yellow brown. The brilliant coloring on the mountains and the gorgeous hues revealed in the cañons of this region are not due to products of decay, but to the inherent tints of the rocks. The marked contrast that exists in the colors of the superficial deposits in the South Atlantic and South Pacific borders of the United States can be illustrated in fancy by comparing the ashen tints of the Mojave desert with the brilliant reds and yellows that would be revealed could the vegetation be removed from Virginia and her sister States.

In considering the absence of red soils in the Far West the arid region alone is referred to. There are areas of considerable extent on the west slopes of the Sierra Nevada where deep rock decay has taken place and where the red color of the soil reminds one of the southern Appalachians. In this region the present rain-fall is about forty-five inches annually, and the country is clothed with vegetation. The climatic conditions thus approximate to those prevailing in the Middle Atlantic States, and the decay observed in the rocks, including schists, slates, and limestones, is what one would expect from the climatic environment. The west slope of the Sierra Nevada in central California is a plane inclined at a gentle angle, in which the streams have sunken their channels a thousand feet or more. The cañons are narrow, with precipitous sides, and are floored with rock that has suffered but little decay. These conditions indicate that the region referred to underwent a long period of disintegration before the plain was tilted so as to allow the streams to excavate their present channels. That the stream channels are of more recent origin than the principal part of the rock decay is shown by the occurrence of residual clays, sometimes fifty or seventy-five feet thick, on the hill-tops. These conditions are well illustrated in the hydraulic mines on Feather River, and may be studied to advantage at Colfax, Cal.

There are probably other areas in the Far West where rock decay is as marked as on the west slope of the Sierra Nevada, but they have not come under my notice. What the effects of the heavy rain-fall, and consequently dense forests, of the northern part of the Pacific Slope may be on the decay of rocks remains to be observed.

SUBAËRIAL DECAY IN OTHER COUNTRIES.

The studies of previous observers have shown that subaërial decay is a marked feature of the surface rocks in many other countries.

The extent to which rock decay has reached in portions of Central America is indicated by the following quotation descriptive of portions of Nicaragua, by Thomas Belt:¹

The decomposition of the dolerites is very great, and extends from the top of the hills to a depth (as proved in the mines) of at least two hundred feet. Next the surface they are often as soft as alluvial clay, and may be cut with a spade. This decomposition of the rocks near the surface prevails in many parts of tropical America, and is principally, if not always, confined to the forest regions. It has been ascribed, and probably with reason, to the percolation through the rocks of rain water charged with a little acid from the decomposing vegetation. If this be so, the great depth to which it has reached tells of the immense antiquity of the forests.

On the island of Curaçao, off the coast of Venezuela, as described by W. M. Gabb,² the rock is limestone and the soil is scanty. "There is no vegetable mold, and the earth is red, the same characteristic 'red earth' or clay as that found in Jamaica, Santo Domingo, the Bahamas, etc. The climate and vegetation are very similar to the rainless parts of Santo Domingo."

The observations of Agassiz, Liais, and Hartt indicate that the rocks over a large portion of Brazil have also been profoundly affected by the chemical action of the atmosphere and of atmospheric waters.³

In southeastern Europe a superficial deposit of red clay, or "terra rossa," resulting principally from the subaërial decay of limestone, occurs throughout the Istrian Peninsula, Dalmatia, Greece, etc. This deposit has been described and discussed to some extent by Stoppani, Fuchs, Neumayr, and others.

In the Spanish Peninsula the products of subaërial decay are to be seen on every hand; especially in the region southward of Madrid, where the landscape frequently calls to mind the characteristic features of central Virginia.

In southern Asia the deposit termed "laterite," formed by the subaërial decay of basalt, gneiss, granite, etc., is of wide geographic extent, and is one of the most interesting features in the surface geology of the country. Its thickness on the basaltic plateaus of western India sometimes reaches two hundred feet. Near Madras it imparts its characteristic color to the Red Hills. When not exposed directly to the action of the atmosphere, it is soft and may be easily cut into blocks with a knife; on exposure to the air these soon harden sufficiently to form a durable building stone. This formation is so widely spread and so characteristic that it has attracted the attention of nearly all who have

¹ The Naturalist in Nicaragua, London, 1888, 12mo., p. 86.

² Notes on the Island of Curaçao, Am. Jour. Sci., 3d series, vol. 5, 1873, p. 333.

³ For references consult bibliographic list at the end of this paper.

studied the geology of India. The observations concerning it have been summarized by Medlicott and Blanford in their *Manual of the Geology of India*.

The subaërial decomposition of basalt has been observed by J. D. Dana in Australia, Tahiti, and Tierra del Fuego; and similar alterations of other rocks have been noted in New Zealand and in China.

Perhaps the most instructive instance of the origin of a residuary deposit rich in iron from a formation that is not iron-stained is furnished by the "red earth" of Bermuda. The islands are composed, probably throughout, of coral limestone and are remote from any region that could contribute foreign material in any considerable quantity. The soil is a red clay which has been left as the more soluble portions of the limestone were dissolved away. In composition it closely resembles the similar red soils of Virginia and of many other regions, as is shown by the following analyses which we copy from C. Wyville Thomson's book, *The Atlantic*:¹

Analyses of red soil and of coral from Bermuda.

Constituents.	Red soil.	Coral from which the red soil was derived.
Hygroscopic water (H ₂ O)	18.265	0.328
Silica (sand) (SiO ₂)	45.156	0.052
Sesquioxide of iron (Fe ₂ O ₃)	13.898	} 0.540
Alumina (Al ₂ O ₃)	15.473	
Lime (CaO)	3.948	54.496
Carbonic acid (CO ₂)	2.533	44.521
Sulphuric acid (SO ₄)	Trace	0.214
Chlorine (Cl)	Trace	0.021
Magnesia (MgO)	0.539	1.751
Potash (K ₂ O)	0.133	0.066
Soda (Na ₂ O)	0.007	0.252
Phosphoric acid (estimated in nitric acid solution) (HPO ₄)	0.704	0.080
Total	100.656	102.321

An earth of similar character and origin occurs in the Bahamas, where the underlying rock is also coral limestone.

Superficial deposits resulting from secular decay have been described by various geologists in this country, as is indicated by the accompany-

¹ Vol. 1, pp. 325, 327. These analyses have been recalculated and organic matter left out. Other analyses of the soils of Bermuda may be found in J. H. Lefroy's essay on the botany of Bermuda, Bull. U. S. Nat. Mus. No. 25.

ing bibliographic list; but these observations are not inserted here at length, as they have already been assembled by T. Sterry Hunt in his essay on the decay of rocks.¹

CONDITIONS FAVORING THE DECAY OF ROCKS.

The extent below the surface to which rock decay extends indicates, in addition to the evidence of chemical changes, that such alterations have been produced by percolating waters and not by changes of temperature or any other cause with which we are familiar. The strain produced by changes of temperature and the freezing of water in the interstices of rocks, although of very great importance in assisting in their alteration, is confined to the superficial portions of outcrops.

The conditions, therefore, which facilitate the passage of percolating waters, especially of waters charged with organic acids through rocks, will favor decay. As is shown below, this process is regulated by climate.

In desert regions a hard, superficial crust is frequently formed on rock surfaces, probably by the deposition of mineral matter brought in solution from the inner portions of the rocks and precipitated as evaporation takes place. The "desert varnish," so common in arid regions, appears also to be of this nature. When the climate is sufficiently dry to admit of the formation of incrustations of this character, atmospheric influences are evidently conservative rather than destructive.

In high latitudes very little evidence of subaërial decay has been noted, but this may be due to lack of observation, to the recent existence of glaciers, or perhaps to the prevalence of abundant means of transportation.

I may remark from observation that in the Kerguelen and Crozet Islands, in the South Indian Ocean, where a cold, humid climate prevails, and where not only forests but arborescent growths of every description are wanting, there is but little soil, and nothing approaching terra rossa is to be seen. These islands are formed, probably throughout, of dark basaltic rocks, rich in iron, which under more favorable conditions would yield a deep layer of ferruginous soil. Contrast with the Kerguelen Islands others of similar origin in the tropics, as the Samoan Islands, for example. On Kerguelen the highest vegetation is a bitter cabbage which grows mostly in sheltered places along the coast, where it is surrounded with matted ferns and tussocks of moss. The landscape, even on the exceptional days of sunshine, is dark, silent, and gloomy. Among navigators this island is called, not unjustly, the "Land of Desolation." In the Samoan Islands the rank luxuriance of tropical vegetation imparts to the land when seen from the ocean the deep tint of malachite. Wherever the bare earth appears it gleams

¹Am. Jour. Sci., 3d series, vol. 26, 1883, pp. 190-213. Republished in Mineral Physiology and Physiography, Boston, 1886, pp. 246-278.

forth through the overshadowing boughs with a brilliancy that is enhanced by contrast and gives a dash of Pompeian red to the picture of tropical beauty. The soil is deep and rich, and, as in Bermuda, must have been derived entirely from the decay of the rocks forming the islands, which in this case, however, are basaltic, and agree in many ways with the rocks forming the Kerguelen Islands.

The contrast between the present condition of the Kerguelen Islands and that of the Samoan Islands has resulted from differences in climatic conditions. This conclusion would have to be modified, perhaps, should it be found that the former had recently been glaciated. There are abundant observations to show, however, that, in general, islands below latitude 50° south, where winter is almost continuous, are desolate, uninhabitable wilds, and that forty degrees nearer the equator, where perpetual summer reigns, lands formed of nearly identical rock have suffered deep decay and are covered with a rich ferruginous soil, which supports a varied and luxuriant tropical flora.

These observations concur with the conclusions of G. P. Wall and J. G. Sawkins concerning the formations of the soil of Trinidad, from which the following is copied: ¹

When the temperature is low, as in northern climates, the operation [of rock disintegration] (notwithstanding the action of frost) progresses very slowly. The soil is of the thinnest description, and even a bare surface of the original rock is frequently exposed; but, under this latitude [ten degrees north] and with the excessive moisture of this climate, it may be doubted whether any but the hardest quartz can entirely escape degradation, while in most cases the resulting soil will be of great depth.

On considering the geographical distribution of residual deposits, together with other facts bearing on the question, it seems safe to conclude that, in general, subaërial decay is more rapid in warm than in cold regions, and is far greater in humid than in arid climates. The most favorable conditions occur in warm, moist climates.

The intimate relation between climatic conditions and rock decay here stated might perhaps be considered as simply a coincidence, and not of the nature of cause and effect. The writer is not prepared to discuss in all their details the chemical processes which have transformed the superficial portions of the earth's crust and rendered it suitable for the formation of soil and the growth of vegetation, but the effects of climate in this connection may be designated in a general way.

Among the first conditions influencing rock decay is temperature. Its direct effects are felt in two ways: (1) The warm waters of temperate and tropical climates have greater solvent power than the colder waters of higher latitudes; (2) in warm regions the surface waters are enabled to exert their influence throughout the year, whereas in colder climates the ground is frozen during a portion of the year at least, the percolating of surface water is checked, and its chemical effects are decreased. More than this, precipitation is, in general, greater in low

¹ Rept. on the Geol. of Trinidad, London, 1860, p. 70.

than in high latitudes, and takes the form of warm rain which saturates the ground instead of falling in great part as snow. Genial temperatures and abundant rain-fall are accompanied by luxuriant vegetation, which not only retains rain-water at the surface and allows it to percolate slowly downward, but imparts to it various organic acids, thus increasing its solvent power. The tendency of all these conditions is to produce greater chemical alterations in the rocks of warm, moist regions than in those of cold countries. As the regions of abundant rain-fall and rank vegetation pass by insensible gradations into cold or arid, barren regions, so the products of rock decay change by insensible gradations from regions like the southern Appalachians, where they reach a maximum, to other areas where they are for the most part wanting.

The intimate connection between existing climatic conditions and rock decay has been clearly recognized by F. von Richthofen,¹ who states that—

Weathering, in fact, becomes in large measure a climatic phenomenon. In moist and hot regions it is accomplished easily and rapidly; in hot and dry regions it seems to play an unimportant part, and where high degrees of cold prevail even an abundance of water is unable to produce it in any but an insignificant amount. Beneath the ever moist moss cushions of Finland and the northern Ural, granite shows undecomposed surfaces.

The conclusions presented above are quite the reverse of those arrived at by certain writers who have previously considered the subaërial decay of rocks. Thus, Th. Fuchs, in his essay entitled, "Zur Bildung der Terra rossa," in which the origin of the terra rossa, or Karst earth, of southeastern Europe is considered, says:

One can hardly avoid the thought that the presence or absence of terra rossa is essentially dependent on climatic conditions; that it appears only where a dry climate prevails, and hence vegetable growth is scanty, whilst it can not appear where there is a moist climate, luxuriant vegetation, and consequently a greater accumulation of humus substances produced by both causes.

The greater extent of subaërial rock decay in the Southern than in the Northern States has been forcibly stated by W. C. Stubbs,² in reference to the formation of soils from the crystalline rocks of the southern Appalachian region, as shown in the following quotation:

* * * Decomposition of these rocks in southern latitudes has proceeded much farther than with same rocks in higher latitudes, and therefore has given us deeper soils. It is difficult to find in the North a soil over a few feet deep, while here it is not uncommon to find in railroad cuts, wells, etc., disintegrated strata to the depth of thirty, fifty, or even seventy-five feet. This can be accounted for to a large extent by climatic influences. The warm waters, charged with carbon dioxide, percolating throughout the year the easily permeable strata, act continuously as a chemical agent in the work of disintegration; while farther north not only the amount of water, the temperature, and the chemical activity are reduced, but for one-half of the year the soil is locked up by frost from all access of decomposing agencies.

¹ Führer für Forschungsreisende, Berlin, 1886, p. 100.

² The soils of Alabama, in Benney's Hand-book of Alabama, Mobile, 1878, p. 199.

The conclusions expressed in the above quotation have been cited with approval by F. H. Storer¹ in a note on rock disintegration in hot, moist climates. Very decided exception to these views has been taken by T. Sterry Hunt,² however, who insists that "present climatic differences have nothing to do with the fact that similar rocks are in one area covered with the products of decay and in another are wholly destitute of it." Hunt calls attention to instructive instances (some of which apparently admit of other interpretations) where ancient land surfaces have been protected beneath later formations, showing that subaërial decay took place during past geologic ages. He also points out that the rocks of the metamorphic portion of the Appalachian region have been exposed to atmospheric influences for a very great length of time.

The high antiquity of the residual clays of the Southern States is discussed in an earlier article by the same author,³ in which the opinion is expressed that the chemical decomposition of the rocks referred to was "effected at a time when a highly carbonated atmosphere and a climate very different from our own prevailed."

The assertion that the accumulation of the residual clays now forming the surface of our country over thousands of square miles took place when the climate and the composition of the atmosphere were very different from what they are at present, carries back the origin of these deposits to an age geologically so remote, that it antedates the very origin of the rocks from which the residual clays were derived. It may be asked what was the time "when a highly carbonated atmosphere and a climate very different from our own prevailed?" Certainly not in the Tertiary, for our country was then clothed with forests closely resembling those now growing, and inhabited by land animals in great numbers that could not have differed markedly in their habits of life from existing mammals. These same arguments apply, less positively, to the Cretaceous, Jurassic, and Triassic periods. It is believed by certain geologists that the luxuriant Carboniferous forests flourished in an atmosphere more highly charged with carbonic acid than at present. It seems, therefore, that the "great antiquity" of the residual clays claimed by Hunt must refer to the Carboniferous or to pre-Carboniferous ages; that is, to a time preceding the deposition of the rocks of the Newark system, and antedating the upheaval of the strata in which the Great Appalachian Valley has been eroded.

Still further evidence bearing on this question is furnished by the red earths of Bermuda, Santo Domingo, Trinidad, Jamaica, etc., which have resulted from the decay of Tertiary or post-Tertiary limestones.

¹ *Science*, vol. 1, 1883, p. 39.

² The decay of rocks geologically considered; in *Am. Jour. Sci.*, 3d series, vol. 25, 1883, pp. 190-213.

³ *Proc. Boston Soc. Nat. Hist.*, vol. 16, 1873-'74, pp. 115-117. See also "The disintegration of rocks and its geological significance," by the same author, *Proc. Am. Assoc. Adv. Sci.*, 23d (Hartford) meeting, 1875, pp. 39-41.

It must be admitted by every geologist that a chemical alteration of surface rocks has been in progress from the first appearance of land on the earth to the present day, and may have been more active in past ages than now. Denudation has accompanied decay, however, and the residual deposits now remaining represent the net excess of disintegration and decomposition over transportation. In no region of any considerable extent is denudation so limited that the residual deposits formed during past geological ages can be expected to have withstood denudation and to have remained intact to the present time, unless they have been protected by subsequent deposits, preserved in caves, or otherwise sheltered. We must conclude, therefore, that such deposits now found at the surface throughout the southern Appalachian region have been formed during comparatively recent geologic times and that their accumulation is still continuing. This conclusion is enforced by the fact that many thousands of feet of rock have been removed from large portions of the Appalachian belt since the elevation of the mountains, and that hundreds and probably thousands of feet of strata have been eroded from the Atlantic border since the upheaval of the rocks of the Newark system.

The observed increase in the decay of the rocks as one travels southward along the unglaciated portion of the Appalachian region, and the occurrence of characteristic residual clays on the west slope of the Sierra Nevada, where a comparatively moist climate prevails, certainly seem to indicate that rock disintegration and decay are intimately related to the humidity and the temperature of the present climate. Before this conclusion is accepted, however, another hypothesis should receive attention.

EFFECTS OF GEOLOGICALLY RECENT OROGRAPHIC MOVEMENTS ON THE DISTRIBUTION OF THE RESIDUAL DEPOSITS OF THE APPALACHIAN REGION.

Throughout the Appalachian region traversed by me in 1885, 1886, and 1887 the streams flow over rocky beds and are broken here and there by cascades, caused by layers of rocks harder or more insoluble than their neighbors, as illustrated by Plates IV and V. The fact that the streams flow over rocky beds has been observed throughout the Appalachians and the adjacent Piedmont region from Pennsylvania southward, and at many localities in the northern part of the same belt as well. It is apparently safe to say that the Appalachian streams at the present time are deepening their channels. In other words, the present drainage has not reached a base level of erosion, and has probably been affected by a comparatively recent change in the level of the land, which has caused a renewal or a continuation of corrasion. This change must have been comparatively recent, for the reason that if the land had been stable for a long time, geologically



MAYO RIVER, NORTH CAROLINA, ILLUSTRATING THE MANNER IN WHICH THE RIVERS OF THE
PIEDMONT REGION ARE ERODING THEIR BEDS.

The rocks producing the rapids are Newark sandstones.

speaking, the streams would have reached the limit to which they could deepen their channels and would be free from falls. This statement applies, however, only to that portion of the Appalachian belt where the drainage has not been affected by glaciers. Exception is also made of localities like Lookout Mountain, which have been left in relief by the more rapid denudations of surrounding areas. The fact that many of the Appalachian streams are flowing through narrow cañons, instead of broad valleys, likewise indicates that a base level of erosion has not been reached.

In reference to the rate at which the streams are now deepening their channels, there is apparently little if any difference in the various portions of the Appalachian belt. A critical examination might perhaps show, however, that the streams at the North are cutting more rapidly than those at the South, and that the change from north to south is gradual. As will be seen a little later, this would be in harmony with the evidence that a recent elevation of the northern part of the Appalachians has taken place.

When we consider the terraces bordering the present streams, which record former changes in the level of the land, a marked difference is at once apparent between the extreme portions of the Appalachian belt. The stream valleys at the north are terraced. In the central portion of the region the terraces are fewer and more obscure than at the north. Southward, below the James, for example, terraces are wanting, or if occasionally seen they are obscure and difficult to distinguish. The presence of stream terraces at the north and their absence at the south indicate that there has been a recent elevation of the northern portion of the Appalachian belt.

An increase in elevation of a large area would be followed by more rapid stream erosion, consequent on increased declivity, among the first effects of which would be the removal of residual deposits from all regions having free drainage. The comparatively recent elevation of the land indicated by the terraces along the streams north of the James may therefore account, at least in part, for the scarcity of residual clays in the central and northern portions of the Appalachian belt.

If we assume that a sheet of residual clays of uniform thickness covered the Atlantic States previous to the Glacial Epoch, the present unequal distribution, disregarding for the moment climatic influences, may be referred in part to each of two causes: First, the removal of the residual deposits from the region occupied by ice through glacial action. That this would be the result of the advance of a vast ice sheet is conceded by every one who has investigated the question, and need not claim further attention at this time. Second, the thickening of the sheet of residual clay toward the south from the southern margin of the glaciated area would be due to unequal erosion produced by unequal upheaval of the Appalachian region.

The effects of climate and of upheaval on residual deposits thus furnish two hypotheses to account for the observed increase in thickness of the products of decay as one travels southward along the unglaciated portion of the Appalachian belt. These may be called: (1) the hypothesis of climatic variation; (2) the hypothesis of orographic movement.

The correct explanation of the facts observed in reference to the present distribution of residual deposits in the region under discussion probably lies in part in each of these hypotheses.

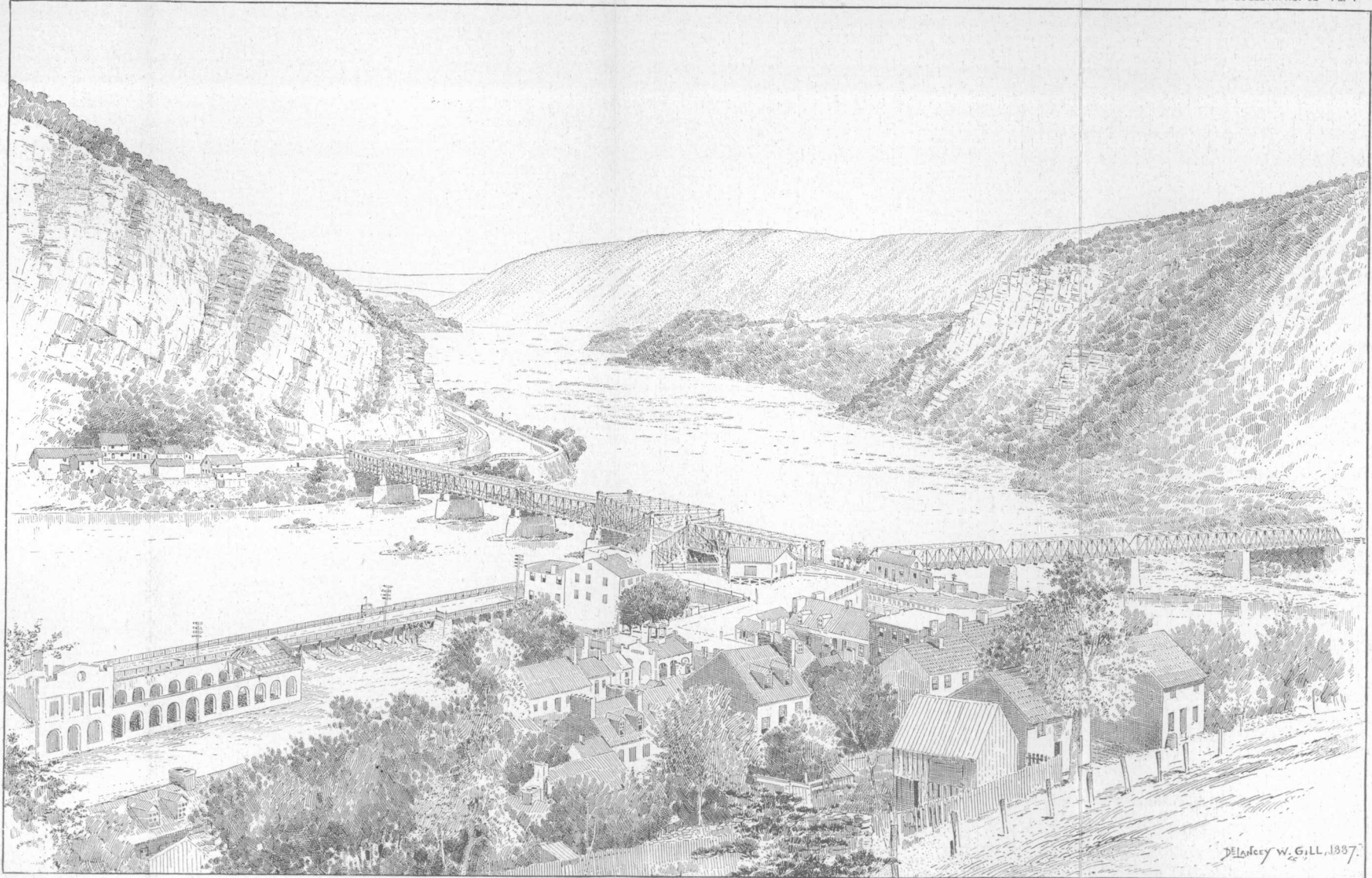
In a belt of country extending more than a thousand miles from north to south and composed from end to end of similar rocks, as in the case in the Appalachian belt, it is safe to assume, in view of the facts already presented, that weathering will be unequal, owing to variations of climate. In the case before us, however, the conditions have been varied by oscillations of the land at a late date in the period of decay, which have accelerated denudation over the northern portion of the belt.

My conclusion from the facts already presented, together with the impressions received in the field, but difficult to formulate, is that each of the causes mentioned above has had its share in producing the observed differences in the distribution of the residual deposits throughout the middle and southern portions of the Appalachian region, but that the controlling influences were temperature and humidity.

It is not to be inferred from what has been said in the preceding passages that no decay has taken place in the rocks of the Northern States. On the contrary, we have evidence, especially in the driftless area of the Upper Mississippi Valley, that the rocks at the North were disintegrated to a considerable depth before the advent of the great ice sheet; but, judging from the condition of the unglaciated area, this change was not nearly so pronounced as at the South. The ice erosion of the Glacial Epoch not only removed and commingled the previously formed residual deposits, but planed away the country over a vast area to a greater depth than had been reached by the previous decay. This is shown by the freshness of the rocks on glaciated surfaces and by the solidity of many of the boulders composing the moraines left by the ice.

The conclusion that subaërial decay is intimately related to existing climatic conditions does not appear to hold in Southeastern Europe and in portions of India, where, it is reported, extensive residual deposits occur in connection with comparatively dry climates. Very recent changes in the humidity of these regions may have occurred, however, which would remove the objections presented by their present condition.

The diversity of opinion indicated by the citations given above encourages a hope that the subject treated in this paper may receive greater attention from geologists, and that observations may be multi-



VIEW FROM HARPER'S FERRY, WEST VIRGINIA, LOOKING DOWN THE POTOMAC.

plied with reference especially to the geographic distribution of residual deposits and to the chemical changes that they have undergone. The mechanical condition of residual deposits is also worthy of attention, for the reason that the decay of rocks furnishes the raw material, so to speak, for the formation of sedimentary strata, and a knowledge of its characteristics will assist geologists in determining the nature of the parent rocks from which ancient elastic beds were derived.

THE SOLUBLE PORTIONS OF ROCKS.

I have approached the study of the chemical alteration of rocks by examining the deposits remaining after rocks have been exposed to a mild solvent, i. e., ordinary surface water, for a great length of time. The investigation might have been commenced by studying the soluble instead of the insoluble portions of rocks; in fact this is the usual method, as is shown by the many essays already written on the chemistry of natural waters. The problem is concerned mainly with solubility combined with oxidation. The mineral matter dissolved in river waters represents the soluble, and residual deposits represent the insoluble portions of rocks. It is evident that the average composition of the residual deposits of a given region should be the complement of the mineral matter contained in the streams flowing through it. Together these should represent the average composition of the rocks of the area in question.

It is not my aim to undertake the study of the chemistry of natural waters—this has already been done by able chemists; but it is of interest, in connection with an examination of residual deposits, to know what mineral substances are commonly contained in river waters. For this purpose the following analysis of the water of the James River,¹ Virginia, which drains a region covered throughout with residual deposits, is inserted. The sample analyzed was collected at Richmond, October 24, 1876, after a light rain.

¹Analysis reduced to parts per thousand. From Annual Report of the Richmond [Va.] Board of Health for 1876. See also Geological History of Lake Lahontan, Mon. U. S. Geol. Survey, No. 11, pp. 173, 174.

*Analysis of the water of James River, Virginia. By W.
H. Taylor.*

Constituents.	Parts per thousand.
Sodium (Na) .....	.00244
Potassium (K) .....	.00251
Calcium (Ca) .....	.01284
Magnesium (Mg) .....	.00377
Chlorine (Cl) .....	.00105
Carbonic acid (CO ₂) .....	.02954
Sulphuric acid (SO ₃) .....	.00363
Phosphoric acid (HPO ₃)	trace
Nitric acid (NO ₅) .....	.00231
Silica (SiO ₂) .....	.01024
Alumina (Al ₂ O ₃) .....	.00041
Sesquioxides of iron (Fe ₂ O ₃)	} .00072
Sesquioxides of manganese (Mn ₂ O ₃) ..	
Ammonia (NH ₄) .....	.00001
Organic matter .....	.00299
Total .....	.07246

From the analysis of the waters of twenty American rivers it has been ascertained that the average of solids in solution is 0.15044, and the average of calcium carbonate 0.056416 part per thousand.¹ The average of total solids in solution, as derived from a table of forty-eight analyses of European river waters given by Bischof,² is 0.2127, and the average of calcium carbonate 0.1139 part per thousand.

The analyses of thirty-six European river waters, published by Roth,³ including some of those tabulated by Bischof, give 0.2033 part per thousand as the average of total solids and 0.09598 part per thousand as the average of the calcium carbonate. In both American and European river waters, so far as can be ascertained from the data in hand, the average of total solids in solution is 0.1888 and the average of calcium carbonate 0.088765 part per thousand. In a general way, therefore, the amount of calcium carbonate dissolved by river waters may be taken as about one-half the amount of total solids in solution.

The amounts given above seem insignificant when considered by themselves, but when we remember the vast volume of water discharged by rivers every day, the quantity of solids in solution thus transferred from the land to the sea is seen to be so great, even in a single year,

¹Geol. Hist. Lake Lahontan, Mon. U. S. Geol. Survey, No. 11, pp. 173, 174.

²Chemical Geology, English edition, London, 1854, vol. 1, pp. 76, 77.

³Chemical Geology, vol. 1, Berlin, 1879, pp. 456, 457.

that we are unable to comprehend the meaning of the figures that indicate its magnitude.

For example, it has been estimated that the Thames, England, carries daily 1,682 tons of inorganic matter in solution, of which 1,121 tons are calcium carbonate. The Croton, New York, carries daily 183 tons of inorganic matter in solution, of which 47 tons are calcium carbonate; the Hudson, New York, 4,000 tons, of which 1,200 tons are calcium carbonate; the Mississippi 309,100 tons, of which 137,419 tons are calcium carbonate. The Mississippi alone carries annually nearly 113,000,000 tons of mineral matter in solution in addition to its visible load of silt carried in suspension, which is about four times as great.¹

From another analysis T. Millard Reade² has computed that the Mississippi discharges annually 150,000,000 tons of solids in solution. As this computation and the one presented above are each based on a single analysis, the discrepancy in the results reached is not remarkable.

Computations of this nature might be multiplied indefinitely, but the brief statements already given are sufficient to show what becomes of the vast quantity of soluble matter removed from the land in connection with the formation of the residual deposits which impart their characteristic color to large portions of the earth's surface.

CHARACTERISTICS OF RESIDUAL CLAYS.

A few chemical analyses of residual clays have been given in the preceding pages in connection with descriptions of the decay of rocks at various localities, but it is of interest to assemble these and other analyses of a similar character in a tabular form, in order to show especially the close similarity that exists in the composition of residual deposits of various countries, even when derived from rocks which differ widely in both chemical and physical properties.

In the following table, the analyses numbered 1, 2, 3, and 7 have been given in the preceding portion of this paper. No. 1 shows the composition of a red clay derived, as nearly as can be determined, from chloritic schist. No. 2 is an analysis of decomposed trap (dolerite) from the Newark rocks at Wadesborough, N. C. No. 3 gives the composition of dark red residual clay derived from Trenton limestone near Lexington, Va. No. 4 shows the average composition of four samples of residual clay formed by the decay of limestone in the driftless area of Wisconsin.³ No. 5 is the analysis of a kaolin, now used in the manufacture of pottery, from Chestnut Hill, Lancaster County, Pa. This is also a residual clay, and is considered by J. P. Lesley as having been

¹For references, see Geol. Hist. Lake Lahontan, Mon. U. S. Geol. Survey, No. 11, pp. 174, 175.

²Denudation of the two Americas. Presidential address; Proc. Liverpool Geol. Soc., vol. 5, 1884-'85, pp. 8-45.

³Published by Chamberlin and Salisbury, in the Sixth Ann. Rept. U. S. Geol. Survey, p. 250.

derived from "potash (orthoclase) feldspar rock." The analysis is by F. H. Genth.¹ No. 6 is the analysis of a typical kaolin or china clay,² the composition of which may be represented thus: ${}^2\text{SiO}_2$, Al_2O_3 , ${}^2\text{H}_2\text{O}$. No. 7 a red clay derived from the decay of Knox dolomite, Morrisville, Ala.

Analyses of residual clays.

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.
SiO_2	54.54	39.55	43.37	55.73	67.1	46.33	55.42
Al_2O_3	26.43	28.76	25.07	18.16	20.1	39.77	22.17
Fe_2O_3	9.04	16.90	15.16	10.57	3.9	.....	8.30
FeO} .....	.....	.....	.....	0.63	.....	.....	Trace.
H_2O	9.87	13.26	12.98	a9.40	5.9	13.96	9.86
MnO} .....	.....	Trace.	.....	0.03	.....	.....	.....
CaO} .....	.....	0.37	0.63	0.99	0.1	.....	0.15
MgO} .....	.....	0.59	0.03	1.12	0.7	.....	1.45
Cr_2O_3 .....	.....	Trace.	.....	.....	.....	.....	.....
Na_2O} .....	.....	Trace.	1.20	1.44	Trace.	.....	0.17
K_2O} .....	.....	Trace.	2.50	1.24	2.0	.....	2.32
P_2O_3 .....	.....	0.10	.....	0.03	.....	.....	Trace.
TiO_2 .....	.....	0.64	.....	0.26	.....	.....	Trace.
CO_2 .....	.....	.....	.....	0.35	.....	.....	.....
C} .....	.....	.....	.....	0.46	.....	.....	.....
Total	99.88	100.07	100.94	100.41	99.8	100.00	99.84

a Contains H of organic matter.

This table might be increased almost indefinitely, if so desired, by consulting reports on agricultural geology and other similar treatises. In Eugene A. Smith's report on the Agricultural Features of Alabama,³ especially, there are numerous analyses of soils formed of residual clays, which agree very closely in chemical composition and physical characters with the examples presented above.

In the analyses given in the table, it will be noticed that silica, alumina, ferric oxide, and water make up over 90 per cent. of the residual clays examined. As the samples analyzed are typical of their class and agree essentially with many other analyses of a similar character with which they have been compared, we may conclude that residual clays in general are ferruginous kaolins of varying degrees of purity. They differ from ordinary brick-clays since they have resulted from chemical decomposition and not from mechanical disintegration. They are hydrous and have a very low percentage of soluble salts; in both of these par-

¹Annual Rept. Geol. Survey Pennsylvania for 1885, p. 588.

²A. H. Green's Physical Geology, 3d ed., London, 1882, p. 174.

³In Geol. Survey Alabama, Rept. for the years 1881 and 1882.

ticalars they differ from clays produced by mechanical means. The fine sediment deposited by many glacial streams is remarkably clay-like in its physical properties, but chemically it has essentially the same composition as the rocks from which it was derived. The differences between glacial and residual clays have been clearly stated by Chamberlin and Salisbury in their description of the unglaciated areas of the Upper Mississippi Valley, previously referred to.

The close similarity between the analyses of residual clays from various localities and from diverse geologic formations, indicated in the table, is found only when the chemical decomposition, or decay, is far advanced; otherwise the residual material may contain fragments of undecomposed rock. Under the microscope a typical residual clay should show only amorphous matter, free from particles of crystals and rock fragments. In the examination of a large number of samples this complete disintegration was seldom seen, however, as the clays nearly always contain quartz fragments and not infrequently particles of other minerals.

In color, residual clays are usually red, owing to the oxidation of the iron contained in the minerals composing the original rock; but in some cases they are mottled red and yellow, or may have various shades of yellow, brown, purple, etc. It is the characteristic red color which gives the name *terra rossa* to the residual clays of Southern Europe. Unweathered elastic rocks, on the other hand, are usually gray, green, blue, etc., but are seldom red. All who traverse the Great Appalachian Valley or the Piedmont region of Virginia, the Carolinas, Georgia, and Alabama, must be impressed by the charming bits of color imparted to the landscapes by the red clays of the roads and fields. In dry weather this material is usually compact and hard, forming excellent roads, but during the rainy season the highways become soft and almost impassable. Among the many differences to be seen between a glaciated country, like New York and the New England States, and a region in which atmospheric decay has progressed uninterruptedly for geologic ages the colors of the soil and the prevailing tints of the landscape are not the least conspicuous. In glaciated regions the landscape is mostly sombre, usually gray, when not covered with vegetation, excepting where the rocks themselves are red, as in the Newark areas of New Jersey and the Connecticut Valley. But on an old land surface, where decomposition is far advanced, brilliant dyes are to be seen wherever the turf is broken. Although the rich color of *terra rossa* is especially pleasing to those who are sensitive to the play of tints in a landscape, yet at times it serves only to increase the ugliness of unsightly cuts and embankments. In such instances it seems as if the earth bled from the wounds inflicted by man.

The contrast in color between northern and southern landscapes in the Appalachian belt has recently been explained by W. O. Crosby, in

an essay on the colors of soils,¹ on the assumption that the observed difference of color has resulted directly from differences of temperature between the North and the South. In the essay referred to it is urged that the higher temperature at the South is capable of dehydrating the ferric oxides impregnating the soils, thus changing their color from yellow to red; and also that the red color of residual clays is a superficial phenomenon, confined to the immediate surface of the deposits.² My own observations do not confirm these conclusions. At many localities in the Appalachian region south of Pennsylvania where residual deposits were observed, the characteristic red color was seen to extend far below the surface, and as a rule to reach the bottom of fresh exposures. In many localities the color of the residual clays at a depth of 20 or even 50 feet is similar, so far as the eye can distinguish, to the color in the same sections only a foot or two below the surface. The great depth to which the red color extends renders it evident that it can not be directly dependent on solar heat. Again, over considerable areas in the South the surface clays are various shades of yellow, which would not be expected if the red color of adjacent fields is due to temperature.

Moreover, the dehydration of ferric oxide, as stated by Crosby, takes place at a certain temperature (about that of boiling water in laboratory experiment), but is not considered as resulting from a high mean annual temperature. Under this hypothesis we must consider, therefore, that the heating of the earth during the summer months is sufficiently high in the Southern States to dehydrate ferric oxide, and that at the North this is not the case. Certainly a very delicate adjustment of chemical conditions is here postulated. Having experienced the summer's heat both at the North and at the South, it seems to me to be doubtful whether the soil in northern Alabama, for example, is more highly heated during the summer than the soil in Pennsylvania and New Jersey. Exact observations on this point are not at hand.

The description of the colors of the residual clays in the metamorphic region of Alabama, quoted on pages 18-20, should be read in connection with the discussion here referred to.

¹ Proc. Boston Soc. Nat. Hist., vol. 23, 1875, pp. 219-222.

² This hypothesis has been applied by its author in an article on the "Geology of the Black Hills of Dakota" (Proc. Boston Soc. Nat. Hist., vol. 23, p. 509) in explaining the origin of the color of the Red Beds of the Rocky Mountain region which it is claimed "depend [for their color] largely upon an excessively hot and dry climate; and in the repeated exposures of the Red Bed sediments during their deposition to a hot and arid atmosphere." In opposition to this argument attention may be directed to the playa-lake deposits of Nevada and Arizona which are now forming under the atmospheric conditions named above, but which are always creamy white in color. The temperature to which these beds are exposed during the summer months very commonly ranges from 110° to 120° Fahr. in the shade—far exceeding any temperature reached in the southern Atlantic States.

ECONOMIC PRODUCTS OF RESIDUAL CLAYS.

The most important economic products of the residual clays in the southern Appalachian region is the iron ore they contain. This is often scattered irregularly through the terra rossa in concretionary masses varying from a small fraction of an inch up to a foot or more in diameter, which frequently have a glossy surface and bear a somewhat close resemblance superficially to certain meteorites. At other times the limonite is in irregular tubular masses of many tons weight. In both instances there is abundant evidence that the ore was deposited during the accumulation of the residual clays in which it occurs. Several of the iron furnaces of Alabama and Georgia are supplied from ore of the nature described. Manganese ores of varying degrees of purity are also an accompaniment of residual clays of the Southern Appalachian region.

In a few localities in the region underlaid by the Lower Silurian rocks of the Great Appalachian Valley the residual clays contain baryte in considerable quantities. In these instances the baryte is a residual deposit, having been left as the limestone in which it was originally formed was removed in solution. The red soil derived from the decay of this same limestone sometimes carries irregular fragments of galena, which formerly filled cavities of which they retain the form, and, like the baryte, they were left when the more soluble portion of their matrix was removed. The occurrence of gold in residual clays has already been referred to. At some localities terra rossa has been utilized in the manufacture of bricks.

II. ORIGIN OF THE RED COLOR OF CERTAIN FORMATIONS.

A HYPOTHESIS PROPOSED.

It follows as a corollary from what has been said in a preceding portion of this paper that the iron-stained sands resulting from the subaërial decay of crystalline rocks will furnish the material for red sandstones and shales when deposited in basins holding water. Exceptions may occur when the débris is subjected to sufficient attrition to remove the incrustations of ferric oxide or exposed to the action of chemical agents having the power to dissolve it.

It is well known that the red and brown colors of the Newark sandstone, and of many other similar sandstones and shales, are due to incrustations of ferric oxide which coat the surfaces of the grains of quartz and feldspar forming the strata and cement them together.¹

In order to verify the conclusions of previous observers in connection with this subject an examination was made of thirty thin sections of sandstone collected by the agents of the Tenth Census from quarries at various localities in the Newark areas from Massachusetts to North Carolina. All of the specimens examined were composed principally of angular quartz grains, with which were frequently mingled fragments of feldspar, hornblende, mica, etc. In several examples the rocks were gray, and derived their color from the inherent tints of the fragments composing them. In most instances, however, they had the brownish red color characteristic of the Newark system in general, and under the microscope revealed the fact that their color was not inherent in the particles composing them, but was due to a fine, amorphous, clay-like coating which enveloped the grains and filled the intervening spaces. The edges of the quartz grains, as seen in thin sections, are sharply defined by a red line, the outer border of which is less definite than that next the grains, and merges with the lighter red material filling the interspaces. The coloring matter which adheres to the grains is not composed of concentric layers, and does not show a crystalline structure—facts which indicate that it was not deposited from solution. The rifts and crevices in the quartz grains are filled with material of the same character as that which stains their surfaces, and was evidently introduced from the outside.

That the characteristic color of these sandstones is due to material

¹ The appearance of a thin section of these sandstones when examined with a microscope has been described and illustrated by G. W. Hawes, *Geol. New Hampshire*, vol. 3, 1878, part 10, p. 240, Plate XII, Fig. 6.

coating the grains of which they are composed, and filling the spaces between them, may also be shown by digesting the rocks in acids, when the color disappears and leaves the sands with their normal tints.

The coloring matter of the Newark sandstones thus agrees with the coloring matter of residual deposits resulting from the subaërial decay of crystalline rocks not only chemically, but also in the manner in which it incrusts the grains.

We know that the débris composing the stratified rocks of the Newark system was derived from the waste of the surrounding crystalline areas. It therefore seems safe to conclude, especially when we consider the nature of the subaërial deposits now being produced by the decay of the crystalline rocks of the southern Appalachians, that the material composing them acquired its red color during the disintegration of the rocks from which it was derived. The red cementing material is residual clay or terra rossa.

If the hypothesis here advanced in reference to the origin of the red color of the Newark sandstones is sustained by future investigations, it will follow that the débris composing these rocks was deposited in lakes or estuaries where it was not subjected to prolonged washing by waves or exposed to the action of natural reagents which have the power to dissolve it. Had the débris been deposited in the ocean and exposed to the action of waves and currents, the sands would have been more thoroughly assorted than we now find them. We should expect, also, that the attrition produced by the wash of the waves under such circumstances would have scoured off the incrustation of ferric oxide. A microscopical examination of a number of samples of the sand obtained by washing residual deposits failed to show that the iron-stained grains thus separated were more angular than the sand grains in an average sample of Newark sandstone. This indicates that the latter was deposited rapidly and not worn and rounded by prolonged wave action.

The chemical reaction of sea water on incrustations of this character has not been investigated.

The character of the deposits that result when débris is contributed to swamps or lakes rich in organic acids is illustrated by the middle or carbonaceous member of the Newark system exposed in the coal fields of Virginia and North Carolina. These beds are sometimes highly charged with iron, but it is combined with sulphuric and carbonic acids. The rocks are therefore not red and the grains of sand composing the strata in part are not incrustated in the manner observed in the red sandstone.

The assorting of residual deposits formed by the subaërial decay of crystalline rocks, like those composing the Appalachian crystalline belt, would afford material for the formation of stratified beds of diverse lithological character. When the rocks were much decomposed beds of iron-stained sand would predominate, interstratified with layers of red clay

formed by the accumulation of finer and more thoroughly decomposed material washed from the land. When the parent rock was disintegrated without suffering marked decomposition, light-colored and less homogeneous beds would be formed. The more thorough the subaërial decay, therefore, the more homogeneous and the more ferruginous would be the resulting sedimentary beds.

When the residual deposits of an ancient land surface contribute to the filling of lakes or estuaries the shore deposits should be coarse and contain fine red sediment in the interstices between the pebbles. Near the land such a formation would probably be a light-colored conglomerate or breccia, cemented with fine ferruginous clay; farther seaward the sediment should not only be finer but also more homogeneous and more completely iron-stained.

It has been remarked by several geologists that the sandstone forming the lower portion of the Newark system of the Southern States is more highly colored than the similar rocks in the upper portion of the same formation. This may be due to a removal of the more thoroughly decomposed residual deposits from the surrounding shores before the upper portion of the series was laid down.

F. von Richthofen's¹ view of the possible origin of red deposit agrees essentially with the hypothesis here proposed, as is indicated in the following citation, which follows a statement that great quantities of the residual soils of Brazil are now being carried to the sea and deposited as red sediments on the floor of the ocean. He says:

A far more prominent part would be played by the laterite if a wave of abrasion swept over Brazil scouring away the red soil formed in the course of centuries, in order to allow its redeposition in the overlaid sediments (*transgredirenden Sedimenten*). This has been the origin of many formations of by-gone time, and it is proper to note that the mightiest accumulations of red masses of sediments occur in the strata of the Rothliegende, which often appear in the manner of transgressions, and that these strata were preceded in time by the Carboniferous epoch, in which, to judge from analogy with the present time, there must have occurred the most intense deep decay of rock, involving the formation of laterite.

In Part I of this paper it has been shown that the residual deposits of warm, humid regions are red, and that the corresponding deposits of arid regions are light colored, usually gray or yellow-brown.

It seems to follow from this that the red rocks of the Newark system and of the Rocky Mountain Red Beds were formed from the débris of lands that had been long exposed to the action of a warm, moist atmosphere. This same suggestion has been made by Richthofen, as is shown by the citation just given.

The conclusions presented in the past few pages will perhaps appear more definite if we consider briefly the various hypotheses that have previously been advanced to account for the red color of certain formations.

¹ Führer für Forschungsreisende, Berlin, 1886, pp. 466, 467.

PREVIOUS HYPOTHESES.

A. C. Ramsay,¹ after studying the Old Red Sandstone and other formations in Europe which are largely composed of iron-stained rocks, advanced the hypothesis that lake deposits are usually red, and that their color is due to the presence of peroxide of iron, "the iron probably having found its way into the water as a carbonate, which, by contact with the air, afterwards became peroxidized, and incrustated the sedimentary grains as a thin pellicle."

A study of lacustral deposits at many points in the United States has shown that the generalization quoted above can not be accepted without important qualifications. The Quaternary and Tertiary lacustral beds of this country are light colored, almost without exception.² The grains of sand composing them in large part are not incrustated with ferric oxide. The sediments now forming in the saline and alkaline lakes of the arid region of the Far West are not iron-stained and do not differ in this respect from the sediments now being deposited in the Laurentian lakes.

In describing the Tertiary and post-Tertiary lake deposits of the western part of the United States, F. V. Hayden³ says:

The prevailing color is light brown-gray or nearly white, perhaps in some instances a cream color. There is a remarkable similarity in the color as well as the composition of these deposits all over the West, in Montana, Oregon, New Mexico and Texas.

F. von Richthofen⁴ describes the lake loess of China, which appears to be similar in every way with the playa deposits of the arid region of the United States, as being whitish yellow in color.

The observations indicate that the reverse of Ramsay's hypothesis is true, namely, that lacustral deposits in general are not characterized by a red color.

All the examples given above of lacustral deposits now forming, however, are located in regions that do not give evidence of having suffered marked subaërial decay. The existing lakes of this country do not receive the débris of lands that are deeply covered with residual deposits. In the South Atlantic States, where the greater portion of the country is buried beneath decomposed rocks rich in iron, the stream deposits are largely iron-stained sands, containing grains of feldspar and mica. Were there any lake basins in this region it is evident they

¹ On the physical relations of the New Red Marl, Rhenic Beds, and Lower Lias. *Quart. Jour. Geol. Soc. London*, vol. 27, pp. 189-206. Also, On the Red Rocks of England of older date than the Trias. *Ibid.*, 241-256.

² The only exception known to me is the red clay deposited during the Pleistocene expansion of Lakes Superior and Michigan. *Geological Survey of Wisconsin*, 1873-'79, vol. 1, p. 292.

³ Notes descriptive of some geological sections of the country about the headwaters of the Missouri and Yellowstone Rivers. *Bull. U. S. Geol. Geog. Survey Terr.*, Washington, 1876, vol. 2, p. 201.

⁴ China, vol. 1, p. 81.

would become filled with material of the same character as that now forming the stream beds and flood plains. Lacustral deposits accumulated under such conditions would comprise iron-stained sands interstratified with layers of red clay, etc., which, in general, would be practically identical with the rocks of the Newark system.

The hypothesis proposed by Ramsay necessitates that ferrous carbonate should be contributed in solution to lakes of great size in sufficient quantity to saturate their waters, and that its oxidation or change to ferric oxide should go on more or less continuously throughout the time the sediments were accumulating. This process, if I understand it aright, would be practically the same as that by which bog ores are formed. This complicated series of chemical reactions might furnish an explanation of the color of local deposits, but it does not seem applicable to such great formations as the Old Red Sandstone of Europe or the Mesozoic red sandstones of this country.

J. W. Dawson,¹ in an article "On the coloring matter of red sandstones, and of grayish and white beds associated with them," states that the coloring matter of the Carboniferous sandstones, red conglomerates, etc., of Nova Scotia "is the peroxide of iron in a very fine state of division, having indeed rather the aspect of a chemical precipitate than of a substance triturated mechanically. In the clays and shales it is usually very uniformly diffused through the mass; in the sandstones and conglomerates it is principally contained in the argillaceous matter which occupies the interstices of sand and pebbles, and it also stains the surfaces of these fragments." Dawson supposes that the ferric oxide was derived from the oxidation, through the action of igneous agencies, of iron pyrites disseminated through the rocks from which the Carboniferous sandstones were derived. This view has been discussed at some length by A. A. Julien in his essay *On the Geological Action of the Humus Acids*,² who shows that the coloring matter in the rocks described by Dawson must have been derived from the decomposition of the hornblende, chlorite, orthoclase, and the iron garnets as well as the pyrites of the parent rock.

The conditions under which the Carboniferous sandstones of Nova Scotia received their red color were repeated in the same region when the Newark sandstones were deposited. In describing the latter rocks A. W. McKay observes:³

The color of these beds seems to be derived from the iron contained in the neighboring metamorphic rocks. It occurs in these latter in three different forms: (1) There is

¹ *Quart. Jour. Geol. Soc. London*, vol. 5, 1848, pp. 25-30. See also *Acadian Geology*, by J. W. Dawson, 3d ed., 1878, pp. 622-623, and *On the parallelism of the rock formations of Nova Scotia with those of other parts of America*, by the same author, *Proc. Am. Assoc. Adv. Sci.*, 10th (Albany) meeting, part 2, p. 20.

² *Proc. Am. Assoc. Sci.*, 28th (Saratoga) meeting, 1879, pp. 405, 406.

³ *The Red Sandstones of Nova Scotia*. Rept. British Assoc. Adv. Sci., 35th (Hirmingham) meeting 1865, part 2, p. 67.

a quantity of it distributed generally throughout the slates and shales, of which these strata are composed; (2) there are veins and beds of specular iron ore, as in the Devonian rocks of Nictaux; and (3) it occurs in the shape of bisulphide of iron or iron pyrites. When these metamorphic rocks were worn away the iron set free was oxidized by contact with the atmosphere and mixed up with sediment as it was laid down.

J. D. Dana¹ attributes the red color of the Newark sandstones to the oxidation of the iron which they contain, through the agency of the intruded sheets and dikes of trap.² As the red color is not confined to the vicinity of the igneous intrusions, and is disseminated with remarkable uniformity through great thicknesses of sandstone,³ we are at a loss to see how the incrusting of the grains of sand with ferric oxide could have been brought about by the heat of the intruded rocks. This explanation fails entirely when applied to similar iron-stained sandstones which have not been disturbed by igneous injections. It also fails, in part at least, when applied to regions in which the trap is not intrusive, but was poured out as an overflow, and subsequently became buried beneath sedimentary deposits.

In another place Dana⁴ refers the red color of the sandstones of the Connecticut Valley to an alteration of the iron they contain by the action of heat resulting from orographic movements.

As stated by him, the change produced by the tilting of the rocks of the region referred to into their present inclined position "stopped short of metamorphism, the sandstones being only reddened and partially solidified." Applying this hypothesis to the Virginia and North Carolina coal fields, where the strata are as highly inclined as in the Connecticut Valley, one would expect that the rocks would have the characteristic color found in other portions of the same formation, providing that a change in color resulted from the tilting of sedimentary beds. The facts are, however, that the carbonaceous rocks in the coal fields referred to show no alteration in color, and the coal they contain is still highly bituminous, except in the immediate neighborhood of trap dikes. That reddening is a general result of metamorphism, as is assumed in the quotation given above, can scarcely be accepted in the presence of so many examples of metamorphosed rocks that are not red.

The view that the red color of the Newark sandstones is due to the heat of the intruded trap was advanced in substance many years since by E. Hitchcock⁵ and J. G. Percival.⁶ That the trap could have been

¹ Manual of Geology, 1875, p. 420.

² This hypothesis has also been controverted by Julien, loc. cit.

³ Among the many illustrations of the thickness of the iron-stained rocks of the Newark system that might be given are the records of a well over 1,400 feet deep at Durham, N. C., in which the rocks, with some exceptions, are reddish brown and remarkably similar in composition from top to bottom. Other wells of still greater depth in New Jersey and the Connecticut Valley have given similar results.

⁴ Am. Jour. Sci., 3d series, vol. 5, 1873, p. 431.

⁵ Rept. on the Geol., Min., Bot., and Zool. of Massachusetts, Amherst, 1833, p. 242.

⁶ Geol. Connecticut, New Haven, 1842, p. 430.

instrumental in producing the wonderful results assigned to it by the authors quoted above has been successfully refuted by W. M. Davis,¹ who has shown by observations made by himself and others, that as a general rule the baked strata near the trap are not so red as the unaltered layers farther away. Davis has also pointed out the fact that red sandstones occur in regions so far removed from igneous action that they could not be influenced by it.

B. K. Emerson² attributes the red color of a portion of the sandstone of the Connecticut Valley to iron derived from volcanic dust thrown out of certain small volcanoes, the remnants of which he has recently discovered in Hampshire County, Mass.

G. H. Cook³ has suggested in reference to the coloring matter contained in the Newark sandstones and shales of New Jersey, that the iron in the coloring matter with which the grains are incrustated was dissolved from the trap rocks of the region by percolating waters and redeposited in the sandstone. At least this is my interpretation of the following passage:

The deep red color of this formation shows its large percentage of oxide of iron, which in some of the shales amounts to 10 per cent., though it is usually much smaller. It is in the form of oxide, and forms the paste or cement of the mass. Where did this iron ore come from? Very little is found in the gneiss from which the sandstone has been formed, and there is not much in the lower and light-colored beds of the sandstone. The trap contains magnetic iron ore in little particles; so much that almost any specimen of it powdered will yield some to the magnet, and the rock itself is quite magnetic; irregularly so, however, as it produces local attraction and disturbance of the surveyor's compass. Did the iron ore come from the same source which supplied the trap? It might have come thus, and, dissolved in water, it could have made the coloring material and furnished the precipitated oxide of iron. It is very evident that the high-colored sands in the Cretaceous and Tertiary formations were white when deposited and have been discolored by water containing oxide of iron; for we often find little nests of perfectly white sand surrounded on all sides by red sand full of oxide of iron; and in some cases a perfect shell of sand, cemented by oxide of iron into stone, is filled with a mass of loose sand. The same kind of agency has, undoubtedly, supplied the coloring substance of the Triassic rocks, though it appears to have been done at the time of its deposition.

The fact that the sandstones are not more highly colored in the neighborhood of the trap ridges than at a distance of several miles from them, as has already been shown, is in direct opposition to the hypothesis presented in the above quotation.

It is well known also that with the exception of samples taken from near the outcrops of the trap ridges in New Jersey, the microscope fails to show that these rocks have suffered to a marked extent by the solution of their constituents, as is also proven by the discovery of metallic

¹ On the relation of the Triassic traps and sandstones of the eastern United States; in Bulletin of the Museum of Comp. Zoölogy at Harvard College, vol. 7 (Geological series, vol. 1), No. 9, 1883, p. 300.

² Gazetteer of Hampshire County, Mass., 1654-1887. By W. B. Gray, Syracuse, N. Y. (1888), p. 18.

³ Geol. New Jersey, 1868, p. 338.

iron in them.¹ Even if the whole of the iron contained in the trap rocks of New Jersey had been removed and redeposited uniformly throughout the accompanying elastic beds, it could scarcely have furnished sufficient ferric oxide to give them their characteristic colors. This statement is sustained, we believe, by the following considerations. An average of seventeen analyses of trap rock from New Jersey gives 12.9 per cent. of ferric oxide.² The per cent. of ferric oxide (Fe_2O_3) contained in five samples of Newark sandstone from New Jersey is as follows³:

(1) Brown sandstone from Whitehall	3.83
(2) Brown sandstone from Wortendyke.....	3.00
(3) Brown sandstone from Little Falls	1.34
(4) Shaly brown sandstone, Belleville quarries	5.74
(5) Light drab sandstone from near Plainfield, N. J.....	3.03
Average	3.39

These analyses show that the trap rock contains about 3.7 times as much ferric oxide as is contained in average samples of the brown sandstone of the associated sedimentary beds.⁴ It is impossible to compare the mass of the trap in New Jersey with the mass of the associated sedimentary beds, but we may assume with a fair degree of probability that the masses of the rocks mentioned are to each other as the areas of their outcrops. From the geological map accompanying the Annual Report on the Geology of New Jersey for 1881 I find that the outcrops of trap occupy 225 square miles, and the outcrops of the sedimentary beds 1,245 square miles.⁵ That is, the ratio of the area occupied by igneous rocks is to the area occupied by sedimentary rocks of the same system as 1:5.5. This rough computation seems sufficient to show that the Triassic igneous rocks do not contain as much ferric oxide in the aggregate as is contained in the sedimentary beds, which are supposed to have derived their color from them.

The facts presented above in reference to the uniformity of color of the Newark sandstones, the unaltered condition of the trap rocks, and the excess of iron in the sedimentary beds over that contained in the associated igneous rocks are true not only for New Jersey, but throughout all the Newark areas from Nova Scotia to South Carolina, and, I

¹ Ann. Rept. Geol. Survey New Jersey, 1884.

² Geology of New Jersey, 1868, pp. 215-218.

³ The analyses numbered 1 to 4 are by Charles Catlett, of the U. S. Geological Survey, and represent the per cent. of ferric oxide (Fe_2O_3) obtained by digesting samples of sandstone in acid, and therefore give the per cent. of ferric oxide in the cementing material of the samples. No. 5 is from the Geological Survey of New Jersey, 1868, p. 509. Other analyses are given on pages 515, 516 of the same report.

⁴ Persifor Frazer has computed that there are contained in every mile of strike one chain in dip and one yard in thickness of the Newark sandstone, 6,193.44 long tons of ferric oxide. Trans. Am. Inst. Min. Eng., vol. 5, 1876-77, p. 501.

⁵ The area given above for the outcrops of the trap rock is greater than would be obtained if the surface of the country were reduced to a plain, for the reason that the edges of the trap sheets stand in relief and form monoclinical hills.

believe, militate strongly against the hypothesis that the clastic beds of the Newark system derived their ferric oxide from the sheets and dikes of igneous rock which traverse them.

On pressing to the extreme the hypothesis proposed by Cook, it might be assumed that the sandstones and shales still existing in the Newark basins received their coloring matter from those portions of the intrusive rocks which have been eroded away; the iron having been leached out as decomposition progressed, and redeposited in the sandstones at a lower level. This extension of the hypothesis meets the objection that the proportion of trap to sedimentary beds in that portion of the formation which has been removed by erosion was probably about the same as in the terranes remaining, and that the iron derived from the trap would have been insufficient to color the clastic beds with which it was intimately associated. Again, it might be assumed that the sheets and dikes of trap now remaining led up to vast overflows of igneous rock which have been entirely removed, and that the disintegration of this supposed lava sheet supplied the ferric oxide of the clastic beds beneath. These extensions of the hypothesis, however, are so fanciful, that they need not be considered at the present time.

In the last line of the quotation given on page 50 the statement is made that the coloring substance of the Newark rocks appears to have been supplied at the time of their deposition. This manifestly could not have been the case had the coloring matter been derived from the leaching of the trap rocks, as suggested in previous parts of the same quotation, for the reason that the trap is largely intrusive, and was forced in among the sedimentary beds after their deposition and consolidation.

In discussing the origin of the characteristic color of the rocks of the Newark system in New Jersey, J. S. Newberry¹ states that—

The New Jersey highlands, as well as other portions of the Blue Ridge belt, are known to contain great quantities of iron ore, and the erosion of the gneiss which forms this belt must necessarily result in the distribution of a large amount of iron. Hence it is not surprising that the shales and sandstones all contain enough of this element to give them a red or reddish color whenever it is in the form of the anhydrous peroxide. The fact that it is generally in this condition, and therefore the rock is red, proves that it contained little or no organic matter when deposited, for whenever decaying organic matter is present in any considerable quantity it reduces the peroxide of iron to protoxide, and makes the color, so far as influenced by the salts of iron, gray, green, or blue. Where the organic matter is in very large quantity, it imparts the characteristic color of carbon, and makes the shale or limestone which contains it black.

The hypothesis that rocks are red because they do not contain organic matter has been stated with some minuteness by H. Newton,²

¹Mon. U. S. Geol. Survey No. 14, 1888, pp. 7, 8.

²Rept. on the Geol. and Resources of the Black Hills of Dakota, Washington, 1883, pp. 138, 139.

in explanation of the origin of the color of the Red Beds of the Rocky Mountain region. I quote his discussion in full:

The large percentage of peroxide of iron in the Red Beds, to which they owe their bright red color, bears an interesting relation to the absence of fossils. The material of which sediments are formed is derived by the various processes of denudation from rocks of older land surfaces. Whatever iron they contain is dissolved from the land and transported in the condition of protoxide or some protosalt, such as the carbonate, and the process is facilitated by the presence of carbonic acid in the water. Now iron occurs in these older rocks as peroxide and protoxide, the former of which is soluble and the latter insoluble in water. The peroxide, however, by the action of organic matter, such as is held in solution by boggy waters, may be deprived of a portion of its oxygen and converted into protoxide, and thus rendered soluble. If the iron-bearing water is confined, as in a shallow basin, and exposed long to the action of the atmosphere, the protoxide of iron absorbs oxygen, and is precipitated as the insoluble red peroxide of iron. If, however, plant or animal life be present in sufficient quantity, this oxidation is prevented. In case but little foreign material—clay or sand—has been brought by the waters, the deposit will be an iron ore; in the absence of organic matter, the peroxide or brown hematite; or in its presence, the protocarbonate, such as the iron-ore beds of the Coal Measures. But in case large quantities of foreign material are deposited from the waters at the same time, there will be produced, in the absence of life, a brown or red clay or sandstone, and in its presence a white or light-colored formation containing the iron as a protoxide. This question of the removal and deposition of iron has been ably elucidated by Dr. Newberry and others, and Dr. Hunt "can hardly conceive of an accumulation of iron, copper, lead, silver, or gold in the production of which animal or vegetable life has not either directly or indirectly been necessary." The point to be established by this seeming digression is this, that, reasoning from the condition in which the iron is found in the Red Beds, we must conclude that there could have been little or no life, animal or vegetable, in the waters from which they were deposited. The conclusion is strengthened by the fact of the presence of large quantities of gypsum, which has been derived from the evaporation of saline waters. The degree of saline concentration which the precipitation of gypsum indicates would be highly inimical to life.

That the chemical processes mentioned in this hypothesis are active in the segregation of ores there seems abundant evidence, but that the color of great terranes can thus be accounted for is not so definite.

This hypothesis implies that red rocks are the deposits of inclosed basins, which it is known is by no means the universal rule. It also suggests that red deposits should now be accumulating in the inclosed lakes of arid regions. This we know is not the case. Not a single instance of the deposition of iron-stained beds in the inclosed lakes of this country has been observed, although a number of cases are known where gypsum and other salts are being deposited. The lakes in which these precipitates are being thrown down are in a desert region and are free from notable quantities of organic matter.

There are striking exceptions, too, to the frequent statement that red rocks are destitute of fossils. Certain sandstones near Taylorsville, Plumas County, Cal., which are even brighter red than the normal sandstones of the Red Beds or of the Newark system, are rich in a great variety of marine invertebrates.

A. H. Green,¹ in a lecture on the geology of coal, remarks that the Middle and Lower Coal Measures and the Millstone Grit of England are blue and gray when protected from the action of the air, but of various shades of brown and yellow at or near the surface. On the other hand, the prevailing colors of the Upper Coal Measure are red, purple, and mottled red and green. The color of the red rocks "is caused by every grain being coated by a thin skin of ferric oxide." This coating of coloring matter is supposed to have been deposited on the grains of sand from the waters of the inclosed lakes in which it accumulated, which were "red as blood, owing to the presence in large quantity of finely divided ferric oxide." The source of the ferric oxide is thought by Green to have been of volcanic origin, and to have been derived from the decomposition of ferric chloride arising from neighboring volcanoes. In reference to this hypothesis A. A. Julien observes:²

Especially is there no need of ascribing to a volcanic sublimate the source of the ferric oxide. The western prolongation of the Archean rocks of the Scandinavian peninsula, referred to by this author, probably covered by heavy vegetation and swamps, must have afforded an ample area and volume of ferruginous materials for the solvent action of humus acids on a vast scale and through a long period, sufficient to have supplied the ochreous cement of the sandstones in the Carboniferous seas.

The hypothesis suggested by Green and supplemented by Julien falls in the same category as the hypotheses proposed by Ramsay, Newton, and Newberry, and is open to the same objections.

The red color frequently seen on the surface of many outcrops, which are light-colored when unweathered, is supposed by T. B. Comstock³ to have resulted from the action of ozone in the atmosphere on the iron contained in the rocks in small quantities.

The red coloring matter of the Newark and other similar rocks has undoubtedly been assumed by many to have resulted from the infiltration of ochreous matter after the fragmental grains of which they are composed were deposited. Microscopic examination of thin sections of the rocks in question, however, does not sustain this suggestion. As shown by the microscope, the sand grains are seldom in direct contact, but are separated by the incrustations surrounding them, which would not be the case had the red matter been brought in by infiltration. The spaces between the sand grains are usually completely filled with ochreous matter, and it is possible that a part of this at least is due to infiltration or to a re-arrangement of the finer material of the deposit; the same result would be expected, however, from the deposition of the

¹ Coal, its history and uses, by Professors Green, Miall, Thorpe, Rücker, and Marshall, London, 1878 pp. 62-66.

² On the geological action of the humus acid, Proc. Am. Assoc. Adv. Sci., 28th (Saratoga Springs) meeting, 1879, pp. 404. 405.

³ Geological report. In report upon the reconnaissance of northwestern Wyoming, by W. A. Jones, Washington, 1874; 8vo., p. 178.

finely divided ocherous material at the time the sand grains were accumulated.

The great thickness of the strata through which the coloring matter is sometimes uniformly disseminated can not be accounted for on the hypothesis of secondary infiltration. Besides, the iron-stained rocks are frequently interbedded with gray and often with white sandstones, showing that the coloring matter was deposited at the same time as the sand grains with which it is so intimately associated and not subsequently introduced. The interstratification of colored and uncolored layers is also opposed to the hypothesis that widely spread change in the color of rocks has been produced by igneous intrusion.

EXCEPTIONS.

The considerations presented in the present paper in explanation of the color of the iron-stained rocks manifestly do not apply to sandstones and allied rocks formed principally of feldspar and quartz in which the color is inherent in the composing minerals.

Again, it is well known from the explorations of the *Challenger* expedition and of the various surveys made by the U. S. Fish Commission, that red clay is found in the abyssal portions of the ocean. This clay, as shown by C. Wyville Thomson and others, is a subaqueous residual deposit, formed in part of the insoluble portions of the shells of mollusks and of microscopic organisms, which descend principally from the surface of the ocean and are partially dissolved during their subsidence. It is also composed in part of pumiceous particles, which have been drifted to great distances on the surface of the sea, together with volcanic, aerial, and cosmic dust. The material from all these sources has been long exposed to the solvent action of sea water, so that only the comparatively insoluble residue finally accumulates on the bottom in the deeper parts of the ocean. Owing to the extreme slowness with which ordinary sedimentation takes place in those portions of the ocean most remote from land, the residual deposits mentioned above are allowed to accumulate until they form homogeneous layers of broad extent and perhaps of great thickness. Although the red clay resulting from the solution of limestones, etc., under subaërial conditions, and the red clay resulting from the subaqueous decay of pelagic shells, dust, etc., are similar, yet, owing to their different associations, one is not likely to be confounded with the other. As the history of the formation of the oceanic clay is foreign to the purpose of the present paper, further notice of it is omitted.

Other exceptions might be cited, as when the colors of rocks are altered by volcanic heat or by the burning of carbonaceous strata. Fresh lavas and lapilli deposits are frequently brown and red, and would make sedimentary beds of the same colors if deposited in water. Such cases usually explain themselves, however, and need not be discussed at the present time.

III.—RÉSUMÉ.

The formation of red deposits from the débris of rocks that are not red, but contain iron in the hornblende, mica, chlorite, magnetite, garnets, pyrites, and other minerals of which they are composed, evidently necessitates that the minerals holding the iron should be decomposed and the iron oxidized. This process we now find in operation over large portions of the earth's surface in the formation of residual deposits, of which the terra rossa of Europe, the laterite of India, the red earth of Bermuda and the residual clays of the southern Appalachian region are the best known examples. The residual deposits resulting from the subaërial decay of crystalline rocks agree both in chemical composition and in the manner in which the grains of sand are incrustated with ferric oxide, with the sandstones of the Newark system, and with other formations of a similar lithological character. Moreover, the residual deposits of the Southern States are assorted and deposited by streams without losing the ferric oxide which incrusts the grains, thus showing that they are capable of forming iron-stained sandstones and shales.

The hypothesis advanced in view of these facts is, that the sands forming the sandstones of the Newark system and other similar formations received their incrustations of ferric oxide during the subaërial decay of the rock from which they were derived.

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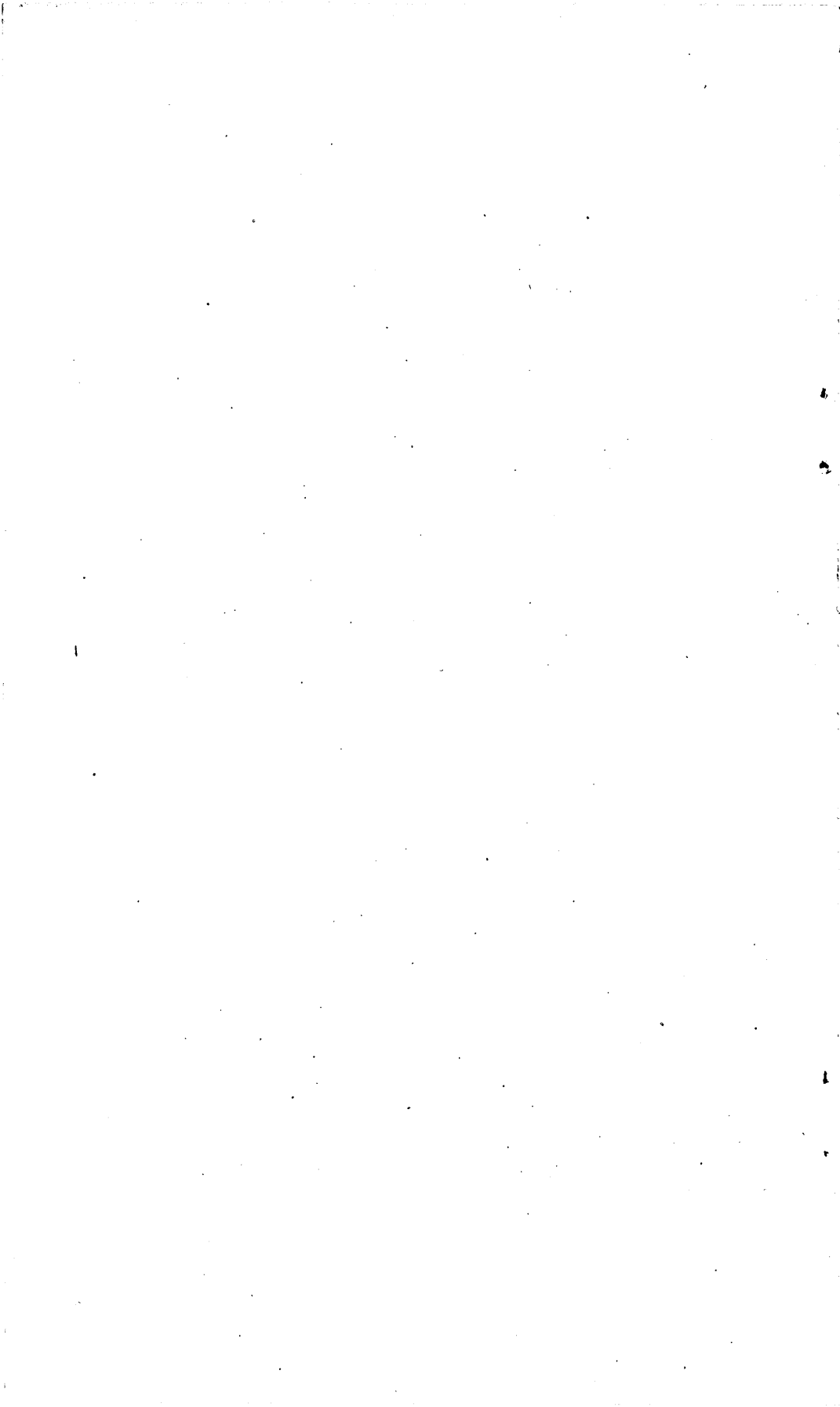
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