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THE

GEOLOGICAL HISTORY

OF

SERPENTINES

INCLUDING STUDIES OF

PRE-CAMBRIAN ROCKS,

BY

THOMAS STERRY HUNT, M.A., LL.D., F.R.S.

FROM THE

TRANSACTIONS OF THE ROYAL SOCIETY OF CANADA.

VOLUME I., SECTION IV., 1883.

MONTREAL:

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X.—*The Geological History of Serpentines, including Notes on pre-Cambrian Rocks.*

By THOMAS STERRY HUNT, M.A., LL.D. (Cantab.), F.R.S.

(Presented May 23, 1883.)

I.—*Historical Introduction.*—Discordant opinions as to the geognosy of serpentine; views of various European geologists; of American geologists; geological survey of Canada. Origin of crystalline rocks; plutonism; metasomatic hypothesis; neptunism; aqueous origin of magnesian silicates. A fundamental question in geogeny.

II.—*Serpentines in North America.*—Laurentian and Huronian serpentines; those with the younger gneisses and mica-schists. Serpentines of Chester Co., Pennsylvania; of Staten Island, Hoboken, Manhattan and New Rochelle; Taconian serpentines in Pennsylvania. Silurian serpentine of Syracuse, New York; its history. Sepiolite and other hydrous magnesian silicates.

III.—*Serpentines in Europe.*—The hypothesis of their igneous origin. Nomenclature of serpentines and related rocks. Views of some Italian geologists. Serpentines at the geological congress of Bologna.

IV.—*Rocks of the Alps and the Apennines.*—Early views. Studies of Gastaldi, von Hauer and others. Ancient gneiss; pietre verdi or greenstones; newer gneiss; youngest crystalline schists. Four pre-Cambrian groups in the Alps defined. Rocks of the Apennines and the adjacent islands.

V.—*Italian Serpentines.*—Their classification; plutonic and hydroplutonic theories of their origin. Serpentines of Tuscany, Liguria and the Alps. Antiquity of the so-called tertiary serpentines.

VI.—*The Genesis of Serpentines.*—Theories of plutonic and neptunian metasomatism; diagenesis. The derivation of serpentine from olivine, and the hydroplutonic hypothesis considered in relation to vulcanism. Theory of original deposition. History of olivine rocks.

VII.—*Stratigraphical Relations of Serpentines.*—Their supposed intrusive character considered. Stapff on the serpentines of the St. Gothard.

VIII.—*Conclusions;* followed by an analysis of the Contents of Sections and Note.

I.—HISTORICAL INTRODUCTION.

§ 1. Few questions in geology are involved in greater obscurity or more contradiction, than the history of serpentine-rocks. As a preliminary to a discussion of certain observations by myself and others thereon, it seems, therefore, desirable to recall some passages in this history which may serve to show the differences of opinion now existing and, it is hoped, prepare the way for their reconciliation. These differences may be considered under two heads: namely, the geognosy of serpentine, or its relation to the other rocks of the earth's crust, and the geogeny, or the origin and mode of formation of serpentine.

Setting aside for the moment the question of the occurrence of serpentine as an accidental mineral disseminated in calcareous rocks, and considering only its occurrence in rock-masses, either pure or mingled with other silicates, the first question which presents itself is whether such massive serpentines are contemporaneous with the enclosing rocks, or whether they have been subsequently intruded among these:—in other words, whether serpentines are indigenous or exotic rocks.

§ 2. We find at the beginning of our century, that the most competent observers were agreed in regarding serpentines as stratified contemporaneous deposits in the so-called primary rocks. Patrin described those of Mont Rose and of the Rothhorn as interstratified with calcareous and micaceous schists, while Saussure found those of Mont Cervin to present similar conditions, and described certain serpentines, found near Genoa, as alternating with bands of calcareous, quartzose, and micaceous schists or argillites. Humboldt, in like manner, noticed the stratified character of the serpentines near Beyruth, and Jameson found those of Rothsay, in Scotland, to be interstratified with micaceous and talcose schists, and with crystalline limestone, in repeated alternations, of which he gives a diagram, mentioning, however, as an opinion held by some, that the masses both of serpentine and of limestone "form great veins rather than vertical sheets." He elsewhere describes serpentine as a primitive stratified rock, contemporaneous, and alternating with crystalline schists.*

§ 3. A little later we find, in 1826, Macculloch, in his *Geological Classification of Rocks*, separating the primitive rocks into two groups, stratified and unstratified, the latter consisting of granite and serpentine. He assigned as a reason for placing serpentine in the latter class that it does not appear to be decidedly stratified, but, at the same time, remarks that, unlike other unstratified rocks, as granite or trap, he had not found serpentines to present ramifying veins. Subsequent studies in the Shetland Isles led him to make what he calls "an important correction" in its history, in the Appendix to the volume just named, where he announces his conclusion that the serpentines are stratified rocks, like gneiss or mica-schists, adding a revised tabular view, in which they are included with these in the stratified division of the primitive rocks, granite alone being retained in the unstratified division.†

§ 4. Boase, in his *Primary Geology*, in 1834, describes the serpentines of Cornwall as associated with talcose and chloritic and actinolite-schists, and what had been "called hornblende-slate," to which the serpentine seemed in some instances subordinated. He further compares these associations and modes of occurrences with those described by Macculloch.‡ De la Beche, in like manner, in his *Geology of Cornwall and Devon*, notes the seeming passage of the serpentine into the hornblende-slate in many places, but also its apparent "intrusion amid the latter with force;" a seeming contradiction which he recognizes, but endeavors to explain.§

§ 5. Unlike Macculloch and Boase, De la Beche regarded serpentine as an eruptive rock of posterior origin to the associated schists, agreeing in this with Brongniart, who had placed serpentine among plutonic rocks. A similar view was held by Elie de Beaumont ‖ and by Savi, and, without entering into further details, we may notice that they have been followed by Sismondi, Lory, and others, who maintain the plutonic origin of the Alpine serpentines, while, on the other hand, Scipion Gras, Gastaldi, Favre and Stapff regard them

* See for the text of the above references the quotations in Pinkerton's Petralogy, 1821, I. 334-343; II. 608:612.

† Macculloch, loc. cit., pp. 78, 243, 652-655.

‡ Boase, loc. cit., p. 46.

§ De la Beche, loc. cit., pp. 35, 99.

‖ After discussing the question with Elie de Beaumont in 1855, I asked his eminent colleague de Senarmont as to the eruptive origin of serpentines. He replied that his own extended studies of the serpentines of Europe had led him to reject, as wholly untenable, the theory of their plutonic origin.

as of aqueous and sedimentary origin. The views of the present school of Italian geologists, as well as Dieulefait and Lotti, will be noticed in part VI.

§ 6. In the United States, we find Edward Hitchcock, in 1841, reviewing the opinions of Macculloch, Brongniart, De la Beche and others, and deciding that the serpentines of Massachusetts are to be regarded as stratified rocks.* Emmons, in 1842, after noticing the conclusions of Hitchcock as to serpentine, regarded it, nevertheless, as an unstratified rock, but distinguish it from trappean rocks, inasmuch as, according to him, it is never found in injected veins or dykes.† Later, however, in 1855, he separated it from so-called pyroplastic rocks, like "basalt, trap and greenstone," and included it in both divisions of his pyrocrystalline class: that is to say, (1) as laminated serpentine with gneiss, micaceous, talcose and hornblendic slates and limestone, and (2) as massive serpentine, with granite, syenite, etc.‡

§ 7. J. D. Whitney, in 1851, included hornblende and serpentine rocks, together with magnetic and specular oxyds or iron, under the title of "Igneous," and the sub-title of "Trappean and Volcanic Rocks."§ Henry D. Rogers, in 1858, described the steatite belt on the Schuylkill River, in Pennsylvania, as formed from the mica-schists of the region through impregnation from "the dyke of serpentine which everywhere adjoins it," thus implying the posterior origin and eruptive character of the latter. Elsewhere he describes the crystalline rocks of the same region as including "true injected serpentines." He, however, looked on veins of quartz and epidote, and even of carbonate of lime, as also of eruptive origin.‖ Lieber, at the same time, in his report on the geology of South Carolina, regarded not only the serpentines of that region, but the associated steatite and actinolite-rocks as eruptive.

§ 8. In opposition to these plutonic views, the geological survey of Canada from an early date (1848,) insisted upon the stratified character of the serpentines found in the northern extension of the Green Mountain range in eastern Canada. They were shown to be accompanied by hornblendic, steatitic, dioritic and other schistose rocks, as well as by dolomites and magnesites. The writer, in discussing the relations of these in 1863, announced "the conclusion that the whole series of rocks . . . from diorites, diallages, and serpentines to talcs, chlorites and epidosites, have been formed under similar conditions," and were aqueous deposits.¶

§ 9. Here, it will be seen that we approach the second question mentioned in § 1, namely that of the origin and mode of formation of serpentines, which, in the view of those who maintain its indigenous character, is, of course, closely connected with the problem of the origin of its associated crystalline rocks. The notions of the earlier geologists with regard to this latter problem were, in most cases, very vague, some of them holding the view still taught in our own day by Hébert, that these rocks, including gneisses,

* Geology of Massachusets, II., 616.

† Geology of New York. Northern District, pp. 67-70.

‡ American Geology, I., 43.

§ Geology of Lake Superior, II., 2.

‖ Geology of Pennsylvania, vol. I. passim. See also the author, 2nd Geol. Survey of Penn., Azoic Rocks, pp. 15-19.

¶ Geology of Canada, p. 612. See also the author's Contributions to the History of Ophiolites, 1858. Amer. Jour. Sci. xxv. 217-226, and xxvi. 234-240.

micaceous, chloritic and hornblendic schists, were all formed by some unexplained process during the cooling of the globe, without the intervention of water.* With few exceptions however, they admitted, with Werner, the aqueous origin of these, whether holding with De la Beche, and with Daubrée, that they were deposited successively from the highly heated waters of a primeval sea,† or the more commonly received view, that the sediments were laid down under conditions of temperature not unlike those of the present time, and were afterwards the subject of internal change (*diagenesis*), or of indefinite replacement and substitution (*metasomatosis*).

§ 10. The latter doctrine, which, in the hands of some of its disciples, has found an extension limited only by their imaginations, was at once applied to explain the origin of serpentine. Silicated rocks, destitute of magnesia, and carbonated rocks destitute of silica could alike, it was maintained, be converted in serpentine, which was held to be the last term in the metasomatic changes of a vast number of mineral species. Hence it was no longer necessary to suppose the direct deposition of a magnesian sediment, or an irruption of an igneous magnesian rock to explain the presence of contemporaneous or of injected serpentines. The legitimate outcome of this hypothesis is found in the teaching of Delesse, in 1858, (when he yet held the eruptive nature of serpentine, which he classed with other "trappean rocks,") that "granitic and trappean rocks" may, in certain cases, be changed into a magnesian silicate, which may be serpentine, talc, chlorite or saponite.‡

§ 11. I have elsewhere shown how Delesse three years later abandoned alike the metasomatic hypothesis and the notion of the eruptive origin of the serpentines in favor of that view which I had put forth in 1859 and 1860, that the serpentines were "undoubtedly indigenous rocks, resulting from the alteration of silico-magnesian sediments." At the same time, as a concession to those who maintained the occurrence of eruptive serpentines, it was said that "the final result of heat aided by water on silicated rocks would be their softening, and, in certain cases, their extravasation as plutonic rocks," which were to be regarded as "in all cases altered and displaced sediments."§ It may still be an open question, however, whether certain eruptive rocks such as as basalts, may not be portions of an original igneous mass, which antedated the appearance of liquid water at the surface of the globe. Hence, in re-stating this point in 1880, I have said that, in my opinion, "the eruptive rocks (or, at least, a large portion of them) are softened and displaced portions of ancient neptunian rocks, of which they retain many of the mineralogical and lithological characters." ‖

§ 12. After careful studies, alike in the field and in the laboratory, I was led, in 1860, to maintain that the origin of serpentine and related magnesian rocks was to be found in deposits of hydrous silicates, like the magnesian marls of the Paris basin, and in 1861 we not only find Delesse teaching this doctrine of the origin of these rocks from the alteration, or so-called metamorphism of such magnesian precipitates, but declaring, in the spirit of

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* Bull. Soc. Geol. de Fr., 1882., xi. 39. See for farther illustrations of this view, the author's Chemical and Geological Essays, p. 294.

† Chemical and Geological Essays, p. 301.

‡ Ann. des Mines (5) xii. 509, and xiii. 393, 415.

§ Chem. and Geol. Essays, pp. 316-318.

‖ Amer. Jour. Sci., xix., 270.

my teaching, as above, that "*the plutonic rocks are formed from the metamorphic rocks, and represent the maximum of intensity or the extreme term of general metamorphism.*" * The history of the abandonment by Delesse of his former view of the plutonic for that of the neptunian origin of serpentines, and his acceptance at the same time of the hypothesis of an aqueous origin of plutonic rocks, is significant as a recognition of the new ideas for which I had contended, and which constitute a new departure in theoretical geogeny.

§ 13. In further explanation of this source of magnesian silicates, it was shown by the writer in a series of experiments, the results of which were published in 1865, that whenever the comparatively soluble silicates of alkalies or of lime (which are set free by the decay of crystalline silicates, and are found in many natural waters), are brought in contact with solutions like sea-water, holding magnesian sulphate or chlorid, double decomposition takes place with the separation of a very insoluble gelatinous silicate of magnesia; and further, that precipitated silicate of lime is decomposed by digestion with such magnesian solutions, its lime becoming partially or wholly replaced by magnesia.

This process, it was pointed out, is the reverse of that which happens when carbonates of alkalies or of magnesia come in contact with sea-water, in which case the comparative insolubility of carbonate of lime causes the decomposition of the soluble calcium-salts present. "In the one case, the lime is separated as carbonate, the magnesia remaining in solution; while in the other, by the action of silicate of soda (or of lime) the magnesia is removed, and the lime remains. Hence carbonate of lime and silicates of magnesia are found abundantly in nature, while carbonate of magnesia and silicates of lime are produced only under local and exceptional conditions. It is evident that the production from the waters of the early seas of beds of sepiolite, talc, serpentine, and other rocks, in which a magnesian silicate abounds, must, in closed basins, have given rise to waters in which chlorid of calcium would predominate." † The generation of magnesian silicates in aqueous sediments was thus shown to be the result of a natural process as simple as that giving rise to carbonate of lime.

§ 14. There are many questions connected with this theory of the source of serpentine and related rocks, such as the probable variations in the composition of the original silicates; their admixture with other silicates and carbonates; the changes wrought in these by subsequent chemical reactions, resulting in the genesis of talc, serpentine, enstatite and olivine, and, in certain cases, the subsequent changes of these anhydrous species; the presence in these magnesian minerals of ferrous silicate, which is so abundant in many serpentines, and its relations to the as yet obscure problem of the origin of glauconite, itself sometimes a more or less magnesian silicate; finally, the notable fact of the presence in most of these magnesian rocks of small portions of rarer metals, such as nickel and chromium, which is to be considered in connection with the similar metallic impregnation of certain mineral waters that may well have intervened in the production of these magnesian silicates. All of these are important points, which must be reserved for future discussion.

§ 15. One great object in geology is to discover by what natural processes the different

* Delesse, Etudes sur le Métamorphisme, 1861, p. 87.
† Amer. Jour. Sci. (2) xl., 49; also Chem. and Geol. Essays, p. 123.

hemical elements have been segregated and combined during successive ages in the forms in which we now find them in the earth's crust: in other words how, from a once homogeneous mass have been separated quartz, corundum, bauxite, carbonates of calcium and magnesium, as well as carbonates, oxyds and sulphids of manganese, iron, zinc, copper and other metals. Not less important is the problem of the genesis of the corresponding protoxyd-silicates, and especially of those of calcium, magnesium and iron, which form, often with little or no admixture, considerable masses in the earth's crust. Of these, it is unnecessary to say the magnesian rocks under consideration constitute an important part, and all analogies lead to the conclusion that their constituent elements have been brought together by aqueous processes, such as we have already indicated.

II.—Serpentines in North America.

§ 16. It is evident that if we once come to regard serpentine as a rock formed from aqueous sediments of chemical origin, there is no reason, *à priori*, why it may not be found, like limestone, dolomite or gypsum, intercalated in stratified deposits at different geological horizons, and with different lithological associations. Several such horizons of serpentine have been observed in North America, which will be noticed in ascending order.

Included in the ancient gneissic series to which the name of Laurentian has been given, serpentine is frequently met with associated alike with beds of crystalline limestone and with dolomite. In these beds, the serpentine is often disseminated in grains or small irregular masses, giving rise to varieties of so-called ophicalcite. These imbedded masses of serpentine are sometimes concretionary in aspect, and may have a nucleus of white granular pyroxene. They often recall in their arrangement, imbedded chert or flint, and, like this substance, sometimes attain large dimensions. These serpentines occasionally include the calcareous skeletons of *Eozoon Canadense*, the silicate replacing the soft parts of the organism, as described by Dawson and Carpenter. Occasionally, the serpentines of this horizon form beds of considerable size, either pure or mingled only with small portions of calcite or dolomite. Of these, many instances are seen with the limestones of the Laurentian in Canada, and a remarkable example occurs at New Rochelle, on Long Island Sound, near New York city, where massive bedded serpentine, highly inclined and interstratified with crystalline limestone, often itself mingled with serpentine, occupies a breadth of about 400 feet across the strike, the whole being conformably interstratified with massive gneisses and black hornblendic rocks with red garnet.* The general characters of the serpentines found with the Laurentian limestones have been elsewhere described by the present writer. Their lower specific gravity, and generally paler colors, together with a larger proportion of combined water † serve, in some cases at least, to distinguish the serpentines of this horizon from those to be mentioned as occurring in the Huronian series. To this may be added, a smaller amount of combined iron-oxyd, and, in most cases, the absence of compounds of nickel and chrome, which are almost invari-

* For an account of this locality see Mather, Geol. First District of New York (1842), p. 462; also J. D. Dana, Amer. Jour. Sci. (3) xx., 30-32.

† For descriptions and analyses, by the author, of Laurentian serpentines, see Geol. Canada 1863, pp. 471, 594; also Contributions to the History of Ophiolites (1858), Amer. Jour. Sci. (2) xxvi., pp. 234-236, 239.

ably present in the latter. This distinction is probably not absolute, since chromite is said to occur in the serpentine of New Rochelle, and chromiferous minerals have been found in the Laurentian rocks in Canada.

§ 17. The serpentines next to be noticed occur in very different lithological associations from the last, and in a group of rocks which has been described under the name of Huronian. These may be defined as in large part greenish hornblendic schistose rocks, passing in the one hand into massive greenstones, diorites or gabbros, and on the other hand into steatitic, chloritic and hydromicaceous, or so-called talcose or nacreous schists, some varieties of which resemble ordinary argillites, with quartzose layers, often with epidote, and with associated beds of ferriferous dolomite and magnesite. In this lithological group (already referred to in § 8) which is now known to mark a definite geological horizon, the serpentines are found interbedded, sometimes mingled with carbonate of lime or of magnesia, but seldom or never presenting varieties like the granular ophicalcite of the Laurentian. To this horizon belong the serpentines of eastern Canada, found in the continuation of the Green Mountain range (the altered Quebec group of Logan), as well as those of Newport, Rhode Island, and apparently those of Cornwall, Anglesea and Ayrshire in Great Britain. The serpentines of this series are darker coloured than the last, and generally contain small portions of chrome and nickel in combination. *

§ 18. Serpentines are also met with in eastern North America in somewhat different associations from the two foregoing groups, and apparently belonging to a third geological horizon. The determination of the precise stratigraphical relations of the serpentines in question presents, however, certain difficulties arising from considerations which will be made apparent in the sequel. Serpentine, though not exempt from subaërial decay, resists this process better than hornblendic, feldspathic and calcareous rocks. Hence it happens that in regions where these are decomposed and disintegrated to considerable depths, associated masses of serpentine may be found rising out of the soil, without any evidences of the precise nature of the rocks which once enclosed them. Illustrations of this condition of things are found in the vicinity of Westchester and of Media, in Chester county, Pennsylvania. The underlying rocks in this region are known to be chiefly gneisses, with hornblendic and mica-schists, and include what are believed to belong to two distinct series, both of which are well displayed in the section seen on the Schuylkill River, below Norristown. Here the older Laurentian gneiss, such as it appears in the South Mountain and the Welsh Mountain, comes up in Buck Ridge, while the newer gneiss and mica-schist series is seen succeeding it to the southward, at Manayunk and Chestnut Hill, at which latter locality it also appears on the north side of the narrow Laurentian belt. In this section, as it is exposed on the Schuylkill, a belt of serpentine, with steatitic and chloritic rocks, appears between the two series, but elsewhere it is wanting along the outcrop of the older gneiss. In the localities farther west in Chester county, already mentioned, at Westchester and Media, where the rocks adjacent to the serpentine are disintegrated, and have disappeared, from decay, it cannot be determined whether these serpentine-masses belong to the older or the newer series—which latter appears to be similar to that including the serpentine and chrysolite rocks of Mitchell county, North Carolina. (§ 123).

* For an account of these serpentines, see Geology of Canada, 1863, pp. 472, 608-612; also Contributions to the History of Ophiolites (1858), Amer. Jour. Sci. (2) xxv., 217-226.

§ 19. The serpentine of Brinton's quarry, near Westchester, Pennsylvania, is distinctly bedded, granular, and often finely laminated, with disseminated scales of a micaceous mineral, giving it a gneissoid structure and aspect. A black schistose hornblendic rock, with red garnet, is said to have been found in an excavation adjoining the serpentine, and fragments gathered in the vicinity showed thin interlaminations of black hornblende with greenish serpentine. The dip of the strata, of which several hundred feet are here exposed, is to the northwest at a high angle, approaching the vertical. They are traversed, nearly at right angles, by a vertical granitic vein, which has been traced for many hundred feet in a northwest course. This vein, which is generally from three to six feet in breadth, is white in color, and in parts may be described as a fine-grained binary granite, the feldspar of which is superficially kaolinized. In other parts, it becomes very coarse-grained, presenting large cleavage-forms of orthoclase. A banded or zoned structure, parallel to the well-defined walls, is observed in some parts, and in one case a lenticular mass of white vitreous quartz occupies the centre. This vein-stone, which carries black tourmaline, and is said to have afforded beryl, has all the characters of the ordinary endogenous granitic veins found in the gneissic rocks of the Appalachians, which veins I have elsewhere described in detail. *

§ 20. The rocks in the vicinity of the serpentine near Westchester are, as already said, deeply decayed, but wherever seen in the cuttings are found to be mica-schist and micaceous gneiss. Such rocks, with a northwest dip, appear to underlie, at no great distance, the mass of serpentine exposed at Stroud's mill. Similar rocks are also found on the railroad between Westchester and Media, where they are exposed in a cutting near the latter station, about a mile from which is found a great outcrop of distinctly stratified serpentine, resembling that of Brinton's quarry, and with a steep northwest dip. It includes an interstratified mass, about twenty feet thick, of a fine-grained reddish gneissoid rock, approaching leptynite or granulite in character, divided into distinct beds generally from four to eight inches in thickness, between which are sometimes found layers of a few inches, of a soft serpentine, and, in one case, of a broadly foliated green chloritic mineral. Considerable differences in texture and aspect were observed between the serpentine-beds below and those above this quartzo-feldspathic mass, which is indigenous, and not to be confounded with the endogenous transversal mass described at Brinton's quarry.

§ 21. Serpentine-rocks also occur on Manhattan Island, in the city of New York, where they are still exposed between Fifty-seventh and Sixtieth streets, west of Tenth avenue, and are directly interstratified in gneissic and micaceous rocks, which may either belong to the older gneiss series of the Highlands, or to a newer group. Associated with the massive serpentine of this locality are found small quantities of a granular ophicalcite, and near it is a mass of anthophyllite-rock. This locality was long since described by Dr. Gale, when the rocks were more fully exposed than at present. †

§ 22. Serpentine-masses are also found in the vicinity of the last, on Staten Island, and at Hoboken, in both of which localities the encasing gneisses, seen in New York city, are wanting, and the serpentine appears along the eastern margin of the triassic belt of the region. The serpentine of Staten Island is of much interest, as it presents many fea-

* Amer. Jour. Science (3) i. 182-187, and Chem. and Geol. Essays, pp. 192-200.
† Mather, Geology of the Southern District of New York, p. 461.

tures which would seem at first sight to lend support to the view of its igneous origin. The serpentine-rocks here occupy an area of a little over thirteen square miles, in the northern half of the island, and form a ridge, presenting a succession of rounded hills, from a mile and a half to two miles or more in width, extending in a northeast and southwest course, with an average height of 200 feet, but rising in one part to 420 feet above the sea. Along the western base of this ridge lie the red sandstones of the trias, but the contact of these with the serpentine is concealed beneath the soil. A long ridge of diabase-rock, similar to that which penetrates the trias on the west bank of the Hudson, runs through the sandstones for a length of nearly six miles, nearly parallel to the serpentine-belt, and at a distance of from half a mile to a mile. Along the southern and eastern borders of the serpentine are spread horizontal cretaceous clays, partially overlaid by drift, while on the north side of the island, where the serpentine hills rise abruptly at a little distance from the shore, are the only known outcrops of other rocks; one a ledge of anthophyllite-rock like that accompanying the serpentine in New York city, and another, a few hundred feet distant from the latter, and from the serpentine, consisting of a coarse pegmatite, having all the aspect of an ordinary concretionary granitic vein, and containing besides crystals of orthoclase, sometimes twelve inches in length, small portions of a white triclinic feldspar and rare crystals of red garnet. A second smaller outcrop of a similar kind is found near by. These granitic and anthophyllite-rocks appear from beneath the water and the sands of the beach.

§ 23. Such an occurrence of serpentine, rising from out of the nearly horizontal and low-lying mesozoic strata of the island, was well calculated to sustain the notion of the eruptive nature of this rock which was put forth by Mather in his description of this locality. He, in his report, above cited, included the serpentine in his "Trappean Division," in the same category with the adjacent diabase, regarding the serpentine "as due to the action of the same general causes, modified in a manner unknown to us." *

The history of this area of serpentine becomes intelligible when studied in the light of the facts already mentioned above. It was apparently, in triassic time, a range of hills left by the disintegration of the adjacent gneiss, the lower-lying surfaces of which are concealed beneath the newer sediments of the region. Since that time, as I have elsewhere pointed out, † the serpentine itself has undergone a process of subaërial change, as is evident by the layer of decayed matter, with included masses of limonite, which, in those portions that have escaped erosion, still covers the serpentine to the depth of ten or twelve feet. For many of the above details of this region I have availed myself of a description of its geology, with map and sections, published in 1880, by Dr. N. L. Britton, ‡ of the School of Mines, Columbia College, New York, with whom I have lately had the advantage of visiting this interesting locality, and to whom I desire to make my grateful acknowledgments for valuable information respecting it.

§ 24. The serpentine-rock which is seen at Castle Hill, Hoboken, on the west bank of the Hudson, opposite New York city, is believed by Dr. Britton to be a continuation of that of Staten Island, and, like it, lies on the eastern border of the trias; while the

* Loc. cit., p. 283.

† Amer. Jour. Science, (3) xxvi., 206.

‡ The Geology of Richmond Co. (Staten Island), N. Y., Ann. New York Academy of Sciences, Vol. II., No. 6.

serpentine-outcrop on the west side of New York city has a strike which would carry it to the east of Staten Island, and probably corresponds to a repetition of the same belt. Gneissic rocks are met with in a boring near the serpentine at Hoboken, and are found in the small islands between Manhattan and Staten Island, so that there can be no reasonable doubt that the serpentines of Staten Island and of Hoboken belong, like that of New York city, to the gneissic series of the region. The determination of the precise relations of these gnessic rocks to those accompanying the serpentines of eastern Pennsylvania, already described, remains for farther inquiry.

§ 25. We have next to notice the occurrence, in Pennsylvania, of serpentine in the Lower Taconic rocks of Emmons, the Primal slates of Rogers, which he supposed to belong to the horizon of the Potsdam of the New York series. In accordance with this view, we find that in a report by Genth on the mineralogy of Pennsylvania, in 1875, the occurrence of serpentine is mentioned, though without any details, in the "Potsdam sandstone" near Bethlehem, at the iron-mines of Cornwall, and also in the township of Warwick, Chester county. * This statement is, however, misleading, inasmuch as the serpentine is not found in the sandstone-rock which has been conjectured to be the equivalent of the New York Potsdam, but in certain schists and limestones, referred, rightly or wrongly, to the same geological horizon, the so-called Primal slates.

§ 26. I have had an opportunity of observing the occurrence of serpentine at Cornwall, where it forms small irregular masses disseminated in a bed of crystalline limestone, itself subordinate to the great mass of crystalline schists which include the magnetite largely mined at this locality. Serpentine, generally with limestone, is found at many other localities associated with iron-ores at the same geological horizon, as at Fritz's Island and elsewhere, near Reading, at Boyerstown, and at the Jones iron-mine, near to Warwick, where it is found in small lenticular masses imbedded directly in the crystalline schists which, as at Cornwall, include the cupriferous magnetites of the region. These schists include hydrous micaceous minerals, among which are chlorite, and the greenish foliated silicate of copper, magnesium and aluminum, to which I have given the name of venerite. The manner in which lenticular masses of pure serpentine, sometimes only a few ounces in weight, are found imbedded in these schists, not less than the mode of their occurrence in the limestones at this horizon, is such as to suggest very forcibly the notion that they have been formed under conditions not unlike those which have given rise to chert or to iron-stone nodules. No large masses of serpentine have, so far as known, been found at this horizon, yet they may be expected.

§ 27. We have next to notice the existence of a bed of serpentine at Syracuse, New York, which was, in 1839, examined and described by Prof. Vanuxem, then engaged in the geological survey of the State. The locality, "on the Fort-street road to the east of Syracuse" or, according to Dr. Lewis Beck, "on the hill a short distance east of the mansion of Major Burnet, at Syracuse," has long since been concealed by the growth of the city, and we have, so far as I am aware, no other description than those given by Prof. Vanuxem in 1839 and 1842, † of which, on account of the interest and significance of this curious

* Second Geological Survey of Penn., Report B, p. 115.

† Vanuxem, Third Annual Report on the Geology of the Third District of New York, pp. 260 and 283; also Final Report on the Geology of the Third District, pp. 108 and 110, and Beck's Mineralogy of New York, p. 275.

occurrence of serpentine, I make the following summary:—The rocks of the region, as is well known, belong to the Onondaga salt-group of the New York series, and occupy a position near the summit of the Silurian, being overlaid by the Lower Helderberg, and resting upon the Niagara division. The strata are, as elsewhere throughout this region, undisturbed and nearly horizontal, the inclination at Syracuse, as measured by Vanuxem, being less than thirty feet to the mile, in a southwest direction. The thickness of the Onondaga salt-group is subject to great variations, and at this point, not far from its eastern limit, it is thinner than farther west. It is described by our author as here consisting, in its lower portion, of a mass of red shales, varying from 100 to 500 feet in thickness, passing upward into a body of greenish shales including more or less gypsum, and followed by a third division, in which are found masses of gypsum of economic value.

§ 28. These occur on two horizons, one at the base and the other at the summit of the division, in the form of lenticular masses included in soft shales or marls, which are often marked by hopper-shaped cavities, doubtless formed through the removal, by solution, of imbedded crystals of sea-salt. Interposed in these marls is found a peculiar porous dolomite, generally drab or buff in color. The cavities in this are very irregular in form, and in most cases communicate with one another. They are sometimes spherical, and contain spherical crusts, besides some pulverulent carbonate of lime. They also vary greatly in size, in some portions attaining a diameter of half an inch, and giving the rock a vesicular aspect. Our author remarks, "the cavities of these porous rocks have no analogy whatever with those derived from organic remains." As seen in one locality, "the cells show that parts of the rock are disposed to separate into very thin layers which project into the cells, an effect wholly at variance with aëriform cavities, but evidently the result of the simultaneous forming of the rock, and of soluble minerals, whose removal caused the cells in question;" a condition of things which Vanuxem considers analogous to that shown by the hopper-shaped cavities in the associated marls.

§ 29. The distribution of this porous dolomite in the third division of the Onondaga group near Syracuse is somewhat irregular. Besides a well-defined stratum extending over a large part of the gypsum-bearing region, and from three to four feet in thickness, Vanxem noticed other "masses limited in extent, without fixed positions, appearing to have been deposited at irregular intervals in the marls;" while in some places, as at the serpentine-locality about to be described, there is a lower mass, with smaller pores than that above, sometimes attaining a thickness of twenty feet. The interval between the upper and lower gypsum-horizons, from various sections noticed by Vanuxem, would appear to be from forty to fifty feet. The marls found in this interval contain more or less disseminated gypsum, and in some cases small grains or crystalline masses of sulphur, and more rarely crystalline plates of specular iron in druses in the dolomite, as observed and shown me by Dr. Goessmann. The marls are described as yellowish or brownish in color, and generally soft and shaly, with harder masses included. Above this gypsiferous division, is a fourth, consisting of a compact magnesian limestone, marked by the presence of numerous small needle-shaped cavities, which forms the summit of the Onondaga group.

§ 30. It is, as already stated, between the two masses of porous dolomite, near Syracuse, that the bed of the serpentine was observed. Its thickness is not stated, but it was said to extend northward "for many rods." According to the original notes of Vanuxem, there was seen, in ascending the hill, after passing twenty feet of the lower porous dolomite, and an interval concealed by soil, "first, a marly shale, then mixtures with more carbonate of lime, some compact, some crystalline, some confusedly aggregated, presenting cavities lined with crystals of that mineral, and containing also sulphate of strontian in the mass, and in the cavities. With these, and above these, are other aggregates like serpentine, marble, etc., with purplish shale or slate, which are followed by a green and blackish trap-like rock, as to appearance, but too soft for that rock." After this, that is, above it, is a mass which resembles the material overlying the lower beds of gypsum, and this last is covered by the upper porous dolomite.

§ 31. In a supplement to the report of 1839, above quoted, it is added, "the green and trap-like rocks observed near the top of the hill to the east of Syracuse, have been examined, so far as time would admit. They are all serpentines, more or less impure, and of various shades of bottle-green, black, gray, etc. They all produce sulphate of magnesia with oil of vitriol. . . . Some have a peculiar appearance, like bronze, owing to small gold-like particles, with a lamellar structure, resembling bronzite or metalloidal diallage; also other particles highly translucent, like precious serpentine, with frequently small nuclei resembling devitrifications or porcellanites, colored white, yellow, blood-red, variegated, etc. The grain of this is like common serpentine. In other kinds, the mass seems to be made of small globuliforn concretions, varying in size, being centres of aggregation. Some are of dark vitreous serpentine, others of the compact kind, the enveloping part of a light color."

Vanuxem's farther notes, in his final report, add some important details to the above. He says: "The great mass of entirely altered rock is a well-characterized serpentine, especially when examined by the microscope." He mentions, moreover, the occurrence of mica, both white or light-colored and black, besides accretions which he compares to granite, and others in which a hornblende takes the place of mica, forming aggregates resembling syenite. He also describes granular carbonate of lime, like marble in texture, which "existed as accretions or nodules, enveloped in the serpentine."

§ 32. I endeavored many years since to obtain specimens of these rocks, and through the kindness of Prof. James Hall secured a single mass of the serpentine, which contained small plates of a copper-colored bastite or bronzite. Neither mica, hornblende, nor any other crystalline silicate was however present in the mass, which was a well-defined serpentine, with some admixture of carbonates. It agrees closely with the description given by Vanuxem, being an aggregate of grains and rounded masses of serpentine, with others of a fine-grained carbonate of lime, imbedded in a greenish-gray calcareous base. The colors of the serpentine vary from blackish-green to greenish-white; it is often translucent, and takes a high polish. An average portion of this rock gave to acetic acid, 34.43 parts of carbonate of lime, and 2.73 of carbonate of magnesia, with 0.34 of iron-oxyd and alumina, leaving a residue of 62.50 of insoluble silicate. This was a nearly pure serpentine, as shown by its analysis. It was completely decomposed by sulphuric acid, and gave silica, 40.67; magnesia, 32.61; ferrous oxyd, 8.12; alumina, 5.13; water, 12.77=99.30. No traces of either chrome or nickel could be detected. One of the small imbedded calcareous masses or concretions found in this serpentine was finely granular, greenish in color, and was nearly pure carbonate of lime. *

* For details of this serpentine and its analysis, see Amer. Jour. Science, (2) xxvi., 263, and Geology of Canada, 1863, p. 635.

§ 33. The associated shales and limestones of this gypseous division are, however, generally, if not always, highly magnesian. Beck found twenty per cent. of magnesia in the limestone overlying the lower range of gypsum-beds, and the precisely similar rocks associated with the gypsum at the same horizon in Ontario are dolomitic, the porous or vesicular beds being nearly pure dolomite, and other specimens of the limestones and shales consisting of dolomite with an argillaceous mixture, the latter sometimes predominating. *

§ 34. From a study of the facts before us, it is apparent that we have here evidences of the formation by aqueous deposition of a bed of concretionary silicate of magnesia, taking the form of serpentine, with a little associated bastite or bronzite, and probably some other crystalline silicates. The intimate association of silicate of magnesia with carbonate lime is significant, when it is considered that the magnesia which abounds in the accompanying strata is in the form of the double carbonate, dolomite, and serves to illustrate the views set forth in § 13, as to the relation between the carbonates and silicates of these two bases. It seems probable that we have in this deposit the results of some spring bringing to the surface, in this locality, waters holding solution in calcareous or alkaline silicates, which have given rise to a silicate of magnesia, in accordance with the reactions already explained in. It is to be hoped that further researches at this geological horizon may disclose other localities of magnesian silicates similar to that of Syracuse.

§ 35. We may recall in this connection some facts about the occurrence of magnesian silicates in other geological periods more recent than that of Syracuse. Deposits of sepiolite, a hydrous silicate approaching to steatite in composition, are well known in the tertiary strata of the Paris basin, in Spain, and elsewhere along the Mediterranean. I have long since described some of these deposits, and have discussed at length their chemical and geological relations. † Mention should here be made of the talc found with the anhydrous sulphate of lime, (karstenite) in the schists at the Mont Cenis tunnel, to be mentioned farther on (§ 62,) and also to the association of gypsum and serpentine in the crystalline schists of Fahlun, in Sweden. ‡

Freiesleben, and, after him, Frapolli, has described the occurrence of a magnesian silicate which occurs frequently in the mesozoic gypsums of Thuringia, in nodular imbedded masses resembling flints in their aspect and mode of occurrence, but composed essentially of a soft magnesian silicate, near to talc in composition, and coloured brown with bituminous matter. §

III.—Serpentines in Europe.

§ 36. Having thus passed in review some of the principal facts known with regard to the occurrence of serpentines in North America, we proceed to the consideration of the same rocks in different parts of Europe, where, as shown in the opening sections of this essay, they have long been objects of study, and have been alternately regarded as indigenous and as exotic in character.

* Géology of Canada, 1863, pp. 347, 625.
† Amer. Jour. Sci. [2] xxix., 284, and xxx., 286.
‡ See the author's Chem. and Geol. Essays, p. 336.
§ Bull. Soc. Géol. de France, 1847 [2], iv., 837.

The hypothesis of the igneous and eruptive origin of serpentine is well illustrated in the paper by Prof. Bonney on the serpentines of Cornwall, England, in the *Quarterly Geological Journal* for November, 1877, supplemented by his later observations on the geology of that region, communicated to the Geological Society of London in November, 1882, and published in abstract in the *Geological Magazine* for December, 1882; in which connection should also be consulted his paper on Ligurian and Tuscan serpentines in the same magazine for August, 1879.

§ 37. Bonney at first accepted the then generally received opinion that the crystalline schists in which the serpentines of Cornwall are included, are altered paleozoic, but in his latest studies of the region he announces the conclusion that they are not paleozoic, but eozoic (archæan) and consist of a great series, divided into three groups. The lower one, of greenish micaceous and hornblendic schists, he compares with those of Holyhead Anglesea, and the adjacent shores of the Menai strait, in Wales. The rocks of these localities, belonging to the Pebidian series of Hicks, have been examined by the present writer, and, by him compared with the Huronian of North America. *

§ 38. Above these greenish schists, in Cornwall, according to Bonney, is a black hornblendic group, and a still higher granulitic group with granitic bands; the characters of these two recalling portions of the Montalban or upper gnessic series of North America and of the Alps. It is in the lowest of these three divisions, consisting chiefly of micaceous and hornblendic schists, that the Cornish serpentines appear, accompanied by so-called gabbros or greenstones. Bonney finds, with Boase and with De la Beche, examples of apparent interstratification and passage between these rocks and the schists, but concludes nevertheless, that there is evidence that the serpentine was introduced after the crystallization of these, and that its eruption was followed by that of gabbros of two dates, and subsequently by that of granitic and dark-colored trappean rocks. He throws doubt upon the ancient hypothesis of the conversion of hornblendic and pyroxenic rocks into serpentine, and supposes this mineral species to have resulted from the hydration of an olivine-rock, such as lherzolite, which consists essentially of olivine with enstatite; grains of both of which species may be detected by the microscope in thin sections of some of the Cornish serpentines. According to John Arthur Phillips, some of so-called greenstones of Cornwall are eruptive, while others are undoubtedly indigenous, and graduate into the crystalline schists of the region. Respecting these, the writer said in 1878, "these bedded greenstones, with their associated crystalline schists, appear to have strong resemblances to the rocks of the Huronian series, to which farther study will probably show them to belong." †

§ 39. Bonney has also extended his observations to the serpentines and associated rocks in Italy, which he includes under the general title of ophiolites. This name, and the kindred one of ophites (Greek, *ophites*, a serpent), alluding to their greenish colour, resembling that of the skins of some serpents, has been extended so as to include both true serpentine, and the frequently associated rocks which present some analogies with it in color. In fact, we pass from pure serpentine, and admixtures of this with carbonates, to serpentinic rocks including more or less of diallage, bronzite or bastite, and thence to aggre-

* Amer. Jour. Science, 1880, vol. xix, pp. 276, 281.

† Harpers' Annual Record for 1878, page 308.

gates in which an admixture of these with a feldspathic element marks a transition to the great group of rocks essentially made up of an anorthic feldspar with a pyroxenic element, (hornblende, pyroxene, enstatite, etc.,) including the so-called greenstones—diorites, diabases and euphotides—which are the frequent associates of serpentines. All of these rocks were embraced by Savi under the convenient though not scientifically-defined name of ophiolites.

§ 40. The name of gabbro (from an Italian locality of these rocks, near Leghorn) was adopted and extended by Tozzetti, in the last century, in a similar sense. His numerous species of gabbro embraced serpentines, and the various diallagic, hornblendic and feldspathic rocks already noticed, of which the red gabbro, or *gabbro rosso*, seems but a locally discolored and partially decayed form. The name of gabbro has come, with many lithologists, to mean a diabase, but it is employed in such a very indefinite manner that it would be well if it were dropped altogether from use. * It is often made to include the *granitone* of the Tuscan stone-workers, the so-called euphotide, in which, as we are told. the feldspathic element is replaced by saussurite. Although this name is often given to a compact variety of triclinic feldspar, the true saussurite is, as I have elsewhere shown, a compact zoisite, distinguished from feldspar by its much greater density and hardness. The two minerals are, however, intimately associated in the euphotides alike of the Alps and the Apennines, as seen in specimens which I have examined both from Monte Rosa and from Monteferrato. †

§ 41. The results of Bonney's studies are given in a paper on Ligurian and Tuscan serpentines in the *Geological Magazine* for August, 1879. He therein records his observations in different localities in these regions, which, for reasons to be made apparent farther on, we arrange in three geographical groups. First, ophiolites on the sea-coast west of Genoa, where Bonney describes the serpentines as occurring with dark-colored schists and gabbros, instancing among the mineral species found with them, pyroxene, hornblende, glaucophane, chlorite and saussurite. He states that the ophiolites of this region are so like those of Cornwall that he feels justified in claiming for them a similar origin. In a second group, he notices the ophiolites of a region immediately eastward of the first, between Genoa and Spezzia, which he describes as very similar to these. Bonney rejects for all of these serpentines, as for those of Cornwall, the notion that they have been formed by metasomatosis from diorite, diabase or hornblendic rocks, a hypothesis which he conceives to have been founded on hasty and imperfect generalizations, and regards them as generated by the hydration of intruded olivine-rocks. In the third geographical group of the ophiolites described by Bonney, he places those of Monteferrato in Prato, near Florence. In each of these districts, he notices the close resemblances between the ophiolitic rocks and those met with in the similar areas in Great Britain, and supposes an intrusion of serpentine, or rather of olivine-rock, among crystalline schists, followed by a later intrusion of gabbro. He has no hesitation in assigning to the serpentines of these three districts similar conditions and origin to those in Cornwall, North Wales and Scotland, remarking that notwithstanding the fact that the Italian serpentines are, in part at

* See in this connection, Cocchi, Bull. Soc. Géol. de Fr. (1856), xiii., 261; also his valuable memoir on the Igneous and Sedimentary Rocks of Tuscany, ibid, 1861, pp. 227-300.

† Contributions to the History of Euphotide and Saussurite. Amer. Jour. Science, 1858, xxv., 437.

least, assigned to the cenozoic period, "they are practically identical" with the serpentines and gabbros of more ancient times.

§ 42. Bonney further calls attention to the breccias of serpentine with a calcite cement, found at various points with these Italian serpentines, and concludes that the serpentines have been brecciated *in situ*, so that it is possible to trace, in a short distance, the passage from unbroken or slightly fissured blocks to completely crushed and recemented fragments, and even to mixtures of finely broken serpentine cemented by carbonate of lime, in which he notes, here and there, filmy patches of a serpentinous material, as if it had been redissolved and again deposited. He believes that the crushing took place after the rock became a serpentine. The correctness of these views of Bonney as to the breccias, I can confirm from my own observations in the same regions, and also from my studies of similar breccias accompanying the ophiolites of eastern Canada. Gastaldi, in this connection, has made an important observation of a breccia in the valley of Trebbia, resting upon a diallagic serpentine, and consisting of cemented fragments of silicious and argillaceous slate with limestone (alberese), the paste being traversed in various directions by veins of chrysotile.*

§ 43. Bonney's observations thus bring us face to face with the views of those Italian geologists who regard certain of these serpentines as of tertiary age, and speak of them as having had an eruptive origin, although, as we shall see, their views of the genesis of these rocks differ as widely as possible from those of Prof. Bonney. In anticipation of the International Geological Congress at Bologna in September, 1881, the Italian geologists had, under the direction of the Royal Geological Commission (R. Comitato Geologico), made extraordinary preparations for the study the full discussion of the problems offered by the serpentines of Italy. A map, prepared for the occasion, was published, showing the localities of the ophiolitic masses for the whole kingdom on a scale of 1-1,111,111th; besides separate maps of particular regions on a scale of 1-10,000th, as that of Mazzuoli and Issel for the Riviera di Levante in Liguria, and that of Capacci for Monteferrato in Prato, in Tuscany; with especial memoirs on these districts, also published by the R. Comitato Geologico in 1881. Ophiolitic rocks are met with in greater or smaller outcrops in many localities from the Alps, throughout the Apennines, and as far as Calabria. To these, the studies of Taramelli, Lovisato, De Giorgi and De Stefani, among others, in addition to those previously named, have contributed a great body of information. A collection of ophiolitic rocks from various localities was also made and submitted to chemical and microscopical study by Cossa of Turin, aided by Mattirolo, the results of which occupy about 200 pages, illustrated with many plates, in the fine quarto volume recently published on Italian lithology. †

§ 44. During the International Geological Congress, a special meeting was held for the discussion of the question of serpentines, on September 30, 1881, in which took part, Taramelli, Capacci, Zacagna, Sella, Szabo, Daubrée, De Chancourtois and the writer, who presided on that occasion. A detailed report of the proceedings at this meeting is published in the first fasciculus of the Bulletin of the new Geological Society of Italy, pages 14-31, followed by an address on the general subject of serpentines by the present writer, pp. 32-38, by notes on the same subject by De Chancourtois, pp. 39-44, and finally by the extended

* Studii geologici sulle Alpi occidentali, parte II, p. 51.

† Ricerche Chimiche e Microscopiche sui Roccie e Minerali d'Italia, Torino, 1881.

studies of Taramelli on the Italian serpentines, pp. 80-128. It is impossible to speak too highly of the zeal, the industry and the scientific spirit exhibited by the Italian geologists in these researches undertaken for the solution of the great question of the ophiolites, which may well be held up as a brilliant example to be followed by other nations in similar circumstances.

§ 45. Mention should also be made of the brief memoir of thirteen pages, in the French language, by Pellati, prepared for the Geological Congress, entitled *Etudes sur les formations ophiolitiques de l'Italie*," in which are set forth, with great conciseness, the principal facts with regard to the geography and the geology of these ophiolitic masses, and the theoretical views entertained with regard to them by various Italian geologists. According to De Stefani, whose discussion is confined to the ophiolites of the Apennines, these rocks belong to three distinct horizons:—1. upper eocene; 2. upper trias; 3. paleozoic; none of them pertaining to a more ancient period. These ophiolitic rocks form zones and regular beds in the midst of the sedimentary rocks, and in no case plutonic dykes. The different varieties of serpentine, and of the non-sedimentary rocks which accompany it, are themselves found in regular alternating bands. * The conception of this observer as to the mode of eruption of these rocks appears to be essentially the same as that of Issel, Mattirolo and Capacci, to be explained further on. (§ 91-93 and 100.)

§ 46. The more recent studies of the R. Comitato Geologico, as announced in 1881, lead them to reject the views of De Stefani as to the age of the ophiolites, and to refer the whole of these rocks in Italy to two geological periods. They distinguish ancient serpentines, probably pre-paleozoic, and younger serpentines, referred to the tertiary. The older serpentines appear in large masses to the west of Genoa, between the valleys of the Polcevera and the Teiro, and from thence are traced to Monviso, from which point the ophiolitic group passes north-northeast to Monte Rosa, and thence, by the canton of Ticino, to the Valtelline. To the same ancient series are also referred the serpentines of the north of Corsica, those of Elba in part, and those of northern Calabria. These ancient serpentines, according to Pellati, follow the contour of the great zone of old gneissic and granitic rocks, which passes along the Alps, through Corsica and the Tuscan archipelago, and re-appears in Calabria. The older geologists, Collegno, Pareto and Sismondi, regarded the serpentines of the areas thus defined (in common with the others yet to be mentioned), as having been erupted, like granites, porphyries and basalts, at various geological ages. Gastaldi, however, as early as 1871, assigned the Alpine serpentines to a distinct pre-paleozoic horizon, which, from the association of the serpentines with various rocks known as greenstones or *pietre verdi*, he designated as the pietri-verde zone, and compared with the Huronian of North America, of which he supposed it to occupy the herizon.

§ 47. The conclusions of Gastaldi as to the Alpine serpentines have, according to Pellati, been confirmed by Baretti, and by Taramelli, the latter of whom clearly shows that the view held by many that the rocks of the pietre verdi are carboniferous or triassic, is inadmissable, and that they belong, as maintained by Gastaldi, to pre-paleozoic or eozoic time. All of the ophiolitic masses west of the meridian of Genoa, as well as those of northern Calabria, are, by Pellati, included in this class.

* Boll. Soc. Geologica Italiana, i., pp. 20-33.

To the east of this meridian, according to Pellati, we find the newer or tertiary serpentines, including, first, those of eastern Lignria, which have their greatest development along a line running north-northwest from Spezzia, and second, those of the Bolognese Apennines, consisting of a great number of small masses scattered between Florence and Reggio in Emilia. A third group includes the masses of serpentine found between Grosseto and San Miniato, in addition to which tertiary serpentines are indicated in Elba, and in the upper part of the valley of the Tiber. Further south, others are met with at Lagonegro in the Basilicate, from which point to Neopoli a remarkable development of serpentines is found along the upper part of the valley of the Sinni. The areas of serpentines, thus indicated by Pellati, are, according to him, generally found in the midst of the limestones, argillites, and sandstones of the eocene, except in the case of those between Grosseto and San Miniato, the outcrops of which are often seen rising out of pliocene clays and sands.

IV.—Rocks of the Alps and the Apennines.

§ 48. Before proceeding farther in the discussion of the Italian serpentines, it will be well to get a view of the present state of our knowledge of Alpine geology, and especially of the conclusions and generalizations of Gastaldi. These, so far as the Alpine serpentines are concerned, are, as we have seen, accepted by the Comitato Geologico, and this conceded, it is difficult to escape his wider generalization which brings the whole of the so-called tertiary serpentines of Italy into the same eozoic horizon with those of the Alps.

If we go backward to the early history of Alpine geology, we shall there find the origin of the well-known hypothesis that the crystalline stratified rocks are but portions of paleozoic or more recent sediments which, in certain parts of their distribution, have undergone a process of alteration or so-called metamorphism. The infra-position of the uncrystalline to the crystalline rocks in Mont Blanc, first noticed by de Saussure, was thus explained by Bertrand ; who suggested that these crystalline schists were altered rocks of a more recent date than the uncrystalline mesozoic strata of Chamonix. This notion was adopted without critical study by Keferstein, Murchison, Lyell, Studer, Sismondi and Elie de Beaumont, among others, till it was generally believed that the crystalline rocks of the Alps are wholly or in great part of mesozoic and cenozoic age. It is hardly necessary to say that this hypothesis in the Alps, as elsewhere, was based upon false stratigraphy. I have elsewhere discussed it in its relations to Alpine geology, in a review of the great work of Alphonse Favre, * whose life-long studies in the Alps of Savoy, have shown for all that region the fallacy of the metamorphic hypothesis. The farther studies of Gerlach, of Fr von Hauer, of Baretti, and especially of Gastaldi, have now fully established the great antiquity of the crystalline rocks in question, and have enabled us to compare them with the pre-Cambrian rocks of other regions. It is not here, however, the time nor the place to discuss this question, except so far as is necessary to the understanding of the geological relations of the Italian serpentines.

§ 49. The work of Gastaldi, interrupted by his death in 1878, was unfortunately left incomplete. We have, however, valuable records of it in a memoir in two parts, published

(*) Amer. Jour Science, 1872, vol iii., pp. 9-10, and Chemical and Geological Essays, pp. 337-339.

in 1871 and 1874, entitled *Studii geologici sulle Alpi occidentali*; in a letter to de Mortillet in 1872; in one to Zezi in 1876, and finally in one to Sella in 1877, with a postscript in 1878.* These various papers are illustrated with numerous maps, plans and diagrams. In attempting to gather from these sources a brief statement of Gastaldi's conclusions as to the geology of the Alps and the Italian peninsula, I feel that I am both rendering a veritable service to science and paying a tribute to the memory of my honored friend and correspondent of many years.

§ 50. The *Studii*, etc., contain, besides Gastaldi's own descriptions and sections, many important historical details and extracts from the literature of the subject. In the second part will also be found reproduced two engraved sections, the one by Gerlach, from Monte Rosa, by Varallo and the Lago di Orta to Arona on Lago Maggiore, and the other by Carlo Neri, from the same point, in a course more to the south-eastward, by Valsesia, to Monte Fenera, and beyond.† A comparison of these sections with those described by Gastaldi, will be found of much value for the elucidation of the questions before us. Starting from the granitic gneiss of Monte Rosa (the central gneiss of von Hauer, and the ancient gneiss of Gerlach and Gastaldi) we find in Neri's section a breadth of not less than seven kilometers included in the zone of the pietre verdi, and described as a stratified series of "serpentines, talc-schists, etc.," followed by seven kilometers additional, designated as diorites; the two being classed together as a "protozoic terrane." To this succeeds a breadth of not less than fourteen kilometers occupied by what is described as a more recent crystalline terrane, conjecturally referred to the paleozoic period, and consisting of calcareous schists and quartzites, with mica-schists, and a great mass of intruded granite. Succeeding this is a great breadth described as porphyry or porphyritic conglomerate, followed by limestones and dolomites, all of which are referred to the trias, and appear in Mount Fenera, succeeded by fossiliferous liassic and tertiary strata.

The section by Gerlach, from Monte Rosa to Arono, shows above the ancient central gneiss a great breadth described simply as diorite, having at its base a thin belt of micaceous schists, and above it, between Varallo and the lake of Orta, a wide extent of recent gneiss and granite, followed, to the east of the lake, by gneissic mica-schists, succeeded by porphyry, until we reach the dolomitic limestone at Arona.

§ 51. Coming now to Gastaldi's own sections, we have one from Turin passing westward to the French frontier, and crossing a broad mass of the central gneiss; to the west of which, in a distance of forty kilometers, we have, first, three and a half kilometers of euphotide and serpentine, followed by about the same breadth of mica-schists, calcareous schists and diorites, and finally, by a great extent of calcareous schists, with numerous intercalations of serpentine and, towards the summit, gypsum and dolomite. The less

* Studii geologici sulle Alpi occidentali; memorie del Regio Comitato Geologico, vols. I and II; Deux mots sur la géologie des Alpes cottiennes; lettre à M. de Mortillet, Comptes Rendus de l'Acad. des Sciences de Turin, vol. vii, 28 avril, 1872; Lettere del Prof. B. Gastaldi all'ingegnere P. Zezi, Boll. del R. Com. Geologico, 1876; Sui rilevamente geologici fatti nelle Alpi Piemontesi durante la campagna del 1877, lettere del Prof. Gastaldi al Presidente Quintino Sella; Reale Accademia dei Lincei, memorie della classe di scienze fisiche, ecc. anno CCLXXV., (1877-78.) See also the writer in his Report on Azoic Rocks, p. 245, and Chem. and Geol. Essays, pp. 336, 347.

† The section by Gerlach is probably from his Karte der Penninischen Alpen; Nouv. Mém. de la Soc. Helvét. de Sci. Nat., 1869. That by Neri is from the Boll. del Club Alpino, vol. viii, No. 22, Torino, 1874.

complete section, to the eastward of the central gneiss, shows also the serpentinic and dioritic rocks overlaid by mica-schists, and the same story is repeated in other sections.

Subsequently, in his letter to Zezi, Gastaldi describes and figures a section from Monte Bracco through Monviso and Monte Pelvo, along the upper part of the valley of the Po, and the valley of Varaita, to the frontier. His conclusions from the study of all these sections may be thus summed up: The crystalline rocks of the Western Alps are classed in two great groups, the lower of which (the central gneiss of von Hauer,) was described by Gastaldi as the ancient gneiss, and by him compared with the Laurentian of North America. It consists chiefly of a highly feldspathic granitic gneiss, sometimes porphyritic or glandular, and includes bands and lenticular masses of quartzite and crystalline limestone, with white steatite, and graphite. Reposing upon the ancient gneiss, is a great and complex group, designated by Gastaldi as the "newer crystalline series," which, from the frequent presence therein of serpentines, diorites, diabases, and related rocks of a greenish color, is also called by him the zone of the greenstones, or the *pietre verdi*.

§ 51. In a generalized diagrammatic section which accompanies Gastaldi's last published statement, (his letter to Sella in 1878,) the first division of the newer crystalline series is described as a great mass of serpentine, followed by a second division consisting of euphotide, succeeded, after an interval of crystalline schists, limestones and gneissic rocks, by a series made up of many alternations of epidotic, dioritic and variolitic schists, with green steatite. In some localities are found great beds of lherzolite and of amphibolite, with varieties of diorite, and rocks in which a triclinic feldspar prevails, together with schists more or less calcareous, and crystalline limestones. The serpentines and their associated ophiolitic rocks, which constitute the lower members of the newer crystalline series, are described by Gastaldi as resting in some cases in nearly horizontal stratification upon the ancient gneisses, and, elsewhere, as overlying the limestones of this older series, from which their uncomformable superposition may be inferred.

§ 52. The group of newer crystalline rocks, as given in Gastaldi's section of 1878, includes also what he designates as recent gneiss and granite, besides various undescribed schists, with crystalline limestones, followed by a second horizon of serpentines, to which succeed gypsum and dolomites. All of these, as is shown in the section from Turin to the frontier, are intercalated, with quartzites, in a vast series of schists, which are placed above the recent gneiss and granite. Finally, the whole series is overlaid by the uncrystalline sediments of the anthracitic group, of carboniferous age.

§ 53. The lithological characters of the lower part of this vast series of newer crystalline schists are sufficiently well defined in the various sections already noticed. As regards those which immediately succeed the serpentinic, chloritic and talc-schist zone, the group of "mica-schists" of Neri, the "recent gneiss and granite" of Gerlach and Gastaldi, we get additional light from various passages in the writings of the latter. They are spoken of, in one place, as gneissic mica-schists more or less rich in hornblende, in which, at Traversella, are also included serpentines. Elsewhere, the rocks of the same area are successively called mica-schist, recent gneiss and mica-schists, gneissic mica-schists, and also, a very micaceous gneiss, often passing into mica-schist and sometimes hornblendic. With these, or with the lower portions of the series, are associated granitic and syenitic rocks which, in the opinion of Gastaldi, are not eruptive, but the result of local modifications of the surrounding gneiss. From my own observations, I conclude that while these recent gneisses in the Alps, as in North America, assume a highly granitic aspect in certain beds, they are not to be confounded with veritable intrusive rocks which penetrate them.

§ 54. Gastaldi has described in detail and figured a section in the Biellese, a region carefully mapped by Quintino Sella and G. Berutti, and studied both by Gerlach and Gastaldi. * Here, in the section as given by the latter, the granite or granitic gneiss is bounded to the northwest by serpentine, diallagic rocks "and other greenstones," followed by a band of diorite. To this succeeds a great breadth of the newer gneisses, in which is included a large dyke of melaphyre, evidently of eruptive and posterior origin, and, farther to the westward, a mass of syenite, which is extensively quarried, and has been studied with great care and described by Cossa in his work already mentioned. I had the good fortune to visit this well-known region in 1881, in company with Signor Quintino Sella. The granitic rock of the eastern part of the section appeared to be a part of the ancient gneissic series so largely developed elsewhere near Biella, and consisting of reddish granitoid gneisses, sometimes hornblendic, but scarcely micaceous, often thinly banded, highly contorted, and indistinguishable from much of the gneiss of the Laurentides, or of the South Mountain in Pennsylvania, east of Schuylkill. Interstratified with it, near Biella, are beds of coarsely crystalline impure limestone, holding graphite, mica and hornblende, and resembling closely some Laurentian limestones. Elsewhere in the Alps, it may be noted, similar gneisses include serpentinic limestones, as for example the pale green ophicalcite found by Favre in the gneiss of Mattenbach near Lauterbrunnen, which is indistinguishable from that of the Laurentian of Canada, and like it contains *Eozoon Canadense.* † It is well-known that similar serpentinic aggregates are often found with the limestones in the ancient gneisses of Scandinavia and Finland, as well as in North America.

§ 55. This ancient gneissic series in the Biellese is directly overlaid by the ophiolitic and dioritic belt (pietre verdi), and this is followed to the west by the newer gneisses and mica-schists, which cannot be distinguished from those found in the vicinity of Philadelphia, or in the White Mountains of New Hampshire, which I have called Montalban. The intruded mass of syenite, made up of reddish orthoclase with some albite, hornblende, and a little sphene, presents, in the extensive quarries which I visited, the massive character and the comparative homogeneousness which belong to a pleutonic rock.* The usually great breadth of ophiolitic rocks met with in this part of the Alps is here, as pointed out to me by Signor Sella, rapidly reduced, to the southward, by the encroachment of the newer gneisses on the westward side, and where the crystalline rocks sink beneath the alluvial plain, does not excede a kilometer. These relations suggest a transverse superposition of the newer gneiss series alike upon the ophiolitic group and the older gneiss, of which we shall find evidence elsewhere.

§ 56. It has been seen that the designation of *pietre verdi* was by Neri restricted to the ophiolitic group beneath the newer gneisses, which he referred to a later and distinct geological period; Gastaldi, on the other hand, extended the term so as to include not only the newer gneisses and mica-schists, but the vast mass of crystalline strata between these and the anthracitic series, with their included gypsums and dolomites. The grounds of

* Gastaldi, Studii, etc., part I., pp. 3 and 26.

† Favre, Recherches géologiques dans la Savoie, etc., iii., 320, and also Chem. and Geol. Essays, p. 342.

this extension are these:—serpentines are not confined to the lower ophiolitic zone, but occur also alike among the newer gneisses and the succeeding crystalline schists. It is, says Gastaldi, "in contact with the gypsums and dolomites that we find the last limit of the serpentinous rocks which, for us, characterize the zone of the pietre verdi." This was in 1872, in his letter to de Mortillet, at which time Gastaldi was disposed to place in a separate group the crystalline schists above the horizon of the upper serpentines. He, however, subsequently included the whole of these schists in the zone of the pietre verdi,

§ 57. As will be made apparent, the schists for a great distance below this horizon. are not to be separated from those above. We have in them, in fact, a third great crystalline group, overlying the younger gneisses, but, by Gastaldi, included with these and the lower ophiolitic group under the common name of the pietre-verdi zone. At other times, Gastaldi used the term of pietre verdi in the more restricted sense in which it was employed by Neri. He speaks in 1874, of "the pietre verdi properly so-called," and in this sense he declares it to be comprised between "the ancient porphyroid and fundamental gneiss," and "the recent gneiss, which latter is finer grained and more quartzose than the older." He says farther: "I will not assert that when specimens of this newer gneiss are confusedly mixed with those of the more ancient, it would always be practicable to distinguish them petrographically; but I do not hesitate to affirm that, on the ground, the distinction is not difficult, on account of the frequent alternation of the younger gneiss with the other characteristic rocks of the upper series; while the older gneiss, however wide its extent, is generally unmixed with other rocks." *

§ 58. The newest crystalline group, mentioned as overlying the younger gneiss and mica-schist series, is that of the argillo-talcose schists of Favre, the grey lustrous schists of Lory (*glanzschiefer*), with their included serpentine, gypsum, karstenite, dolomite, micaceous limestone, banded and statuary marbles, and quartzites; a group very conspicuous in Alpine geology. These rocks are well seen in the section from Turin to the French frontier, and are traversed in the Mont Cenis tunnel. (See also § 62-66.)

§ 59. The vast thickness assigned by various observers to this entire series of newer crystalline schists, counting from the ancient gneiss below, is a remarkable fact in their history. We have seen the great breadth ascribed to the successive zones or groups in the sections already noticed. Gastaldi, in 1876, estimated the real thickness of the pietre-verdi zone, including the upper lustrous schists, at 24,000 meters, of which 8,000 meters, or one-third, was assigned to the lower ophiolitic group, or proper pietre verdi; apparently without including the younger gneisses and mica-schists, which make up the middle group. To the upper group, as seen in the Mont Cenis tunnel, Sismondi and Elie de Beaumont assigned a vertical thickness of not less than 7,000 meters, and Renevier finds for it elsewhere an apparent thickness of 6,000 meters.

§ 60. We have hitherto spoken of the Western Alps, and the sections as yet noticed do not extend to the eastward of Lago Maggiore. The map by von Hauer, of the Lombard and Venetian Alps, published in 1866-68, embraces the region from this meridian eastward, and shows the same order of succession as that laid down by Gerlach in the west. † The

* Studii, part ii., p. 31.

† Gastaldi, Studii, Part I., p. 18, and Fr. von Hauer, Geologische Uebersichtskarte der Osterreichisch-Ungarischen Monarchie, fol. v., West-Alpen u. fol. vi., Ost-Alpen; Wien, 1866-68.

various groups, as indicated by von Hauer, are as follows: 1. The ancient gneiss and granitic rocks, designated by him as the central gneiss; 2. Greenish schistose rocks, described as hornblendic, dioritic and euphotidic, with serpentines, chloritic and talc-schists; 3. Saccharoidal limestones, more or less micaceous, with talc-schists; 4. Serpentines, euphotide, diorite, and talcose and chloritic schists, as before; 5. A fine-grained gneiss, designated as recent gneiss; and 6. Mica-schist, with hornblendic and feldspathic varieties. We have evidently here the same great pietre-verdi zone as in the west, comprised between the older gneiss and the younger gneiss with its attendant mica-schists. There appears, however, a considerable development of crystalline limestones in the midst of the pietre verdi.

§ 61. Further light is thrown upon the question of these crystalline rocks of the Alps by the observations of Renevier, Heim and Lory, especially as embodied in an essay by the latter on the Western Alps, published in 1878, and in a study of the geology of the Simplon, by Renevier, in the same year. * According to Lory, the ancient crystalline rocks, designated by him as the *primitive schists*, as seen in the Simplon, and elsewhere in this region, include three groups, in ascending order: 1st. The stage of the *gneiss*, properly so-called, including varieties from the highly feldspathic and massive granitoid gneisses to others less feldspathic and more distinctly laminated. 2nd. The stage of the *mica-schists*, often garnetiferous, which embraces, however, alternating beds of gneiss, the two rocks passing insensibly the one into the other. These mica-schists, tender, and gray in color, are often more or less impregnated with carbonate of lime, and contain bands of limestone and marble. 3rd. The stage of the *talc-schists*, a term which, as Lory explains, he uses in a very general sense, to include not only steatites, but talcose, chloritic and hornblendic schists, the latter sometimes without visible feldspar, but often more or less feldspathic, and thus passing into varieties designated by him as talcose, chloritic or hornblendic gneiss. The so-called protogine of the Alps, according to Lory, is but a granitoid variety of talcose or chloritic gneiss, subordinate to the talc-schist stage, and passing insensibly into the talcose and chloritic schists, with which it alternates. It is not, therefore, as some have supposed, the fundamental rock of the Alps, but belongs to an upper portion of the primitive schists. The lower gneiss of the Simplon, described by Gerlach as the gneiss of Antigorio, to which this distinction apparently belongs, is further noticed by Renevier, who assigns to it it a great thickness, and regards it as the basal rock of the Alps, corresponding to the ancient gneiss of Gastaldi and the central gneiss of von Hauer. The succeeding mica-schists, often garnetiferous and calcareous, with alternating gneiss and limestone bands, have also a great volume. The hornblendic schists play a less important part in the series. Though these sometimes contain a little mica, or a little chlorite, chloritic schists are rare, and the stage of the talc-schists, indicated by Lory, is not mentioned by Renevier in his description of the Simplon.

§ 62. The term of primitive schists, as employed by Lory and by Renevier, is not extended to the grey lustrous schists, already noticed as forming the upper part of the great series included by Gastaldi in the pietre verdi. These upper schists are by Lory regarded

* Essai sur l'orographie des Alpes occidentales par Charles Lory, p. 76; Paris and Grenoble, 1878. Also, Structure géologique du massif du Simplon, etc., par E. Renevier, Bull. de la soc. vaudoise des sciences naturelles, vol. xv., No. 79.

as altered trias, a view in which Renevier acquiesces. They are, for the most part, soft, glistening, and talcose in aspect, and have been variously described as argillo-micaceous and argillo-talcose schists, being sometimes, according to Lory, true sericite-schists. * They closely resemble the crystalline schists with hydrous micas which abound in the Primal and Auroral divisions of Rogers, (Taconian) as seen in eastern Pennsylvania. These schists in the Alps are traversed by veins of calcite and of quartz, and include besides great beds of quartz-rock, often a detrital sandstone, beds of limestone, sometimes micaceous, of banded and of white granular marbles, of dolomite and of gypsum. This latter in the subteranean exposures made in the Mont Cenis tunnel, is represented by anhydrous sulphate of lime (karstenite), and is accompanied by rock-salt and sulphur. Magnesian silicates are also found in this group; nodules of talc are imbedded in the karstenite, chlorite occurs in veins and layers, and beds of serpentine (and of euphotide, according to Gastaldi) are interstratified with these shining argillo-talcose schists.

§ 63. The resemblances in mineral character between these upper argillo-talcose schists with chlorite and with interstratified serpentines, and the lower or true pietre-verdi zone, are obvious. Lory has moreover remarked the likeness between these upper schists with limestones and the mica-schists with limestones in the horizon of the newer gneiss series, included by him in the primitive schists, as leading to the confounding of the two. This resemblance, he suggests, "may have thown some obscurity" upon the relations of these various rocks, and the structure of the region It will not have escaped the notice of our readers that in the description of the section of the Simplon there is no recognition whatever of the great mass of serpentines, euphotides and other ophiolitic rocks belonging to the pietre verdi, which elsewhere are found at the base of the newer crystalline schists, occupying a horizon between the older and the younger gneisses.

§ 64. It will also be noted that Lory places a horizon of talc-schists, with chloritic rocks, etc., at the summit of the newer gneisses, and the view naturally suggests itself that Lory has himself confounded the lustrous schists of the upper series and their magnesian rocks, with the great lower ophiolitic zone. This latter would appear to be wanting in the section of the Simplon, where it is not noticed by Renevier. Lory thus places above the younger gneisses a talc-schist series to which he refers many of the types of rocks met with in the great ophiolitic and talc-schist zone, which elsewhere, underlies these younger gneisses, and in which the protogines are probably included. In this way the apparent discrepancy between Lory and all the observers hitherto mentioned is explained, as suggested by the present writer in 1881. The relations observed in the Biellese, as already noticed, suggest that the younger gneisses were deposited unconformably, alike upon the older gneisses and the great ophiolitic group, as is the case in many other regions.

§ 65. In like manner, according to Lory, the lustrous schists themselves, with included serpentines (which he regards as contemporaneous eruptions) rest directly upon the ancient gneisses in the Levanna, between Susa and Lanzo. Other evidences of a want of conformity between these various groups of ancient schists in the Alps are not wanting. At the Col de Mont Genevre, as described by Lory, there appears through the lustrous schists a

* Bull. soc. géol de France, x., 29.

great "mass of non-stratified rocks, comprising euphotides, serpentines, variolites, and various rocks of passage between these types." These ophiolitic rocks, which correspond to the lower part of the pietre-verdi zone of Gastaldi, are regarded by Lory as eruptive, and have not been recognized in his scheme of the divisions of the primitive schists. Their appearance among the lustrous schists is thus, according to him, an irruption in the midst of the trias, instead of being, as we should rather regard it, a protrusion of a portion of the pietre-verdi zone in the midst of the lustrous schists, which are here unconformably superimposed upon it, as elsewhere upon the ancient gneisses.

§ 66. The history of the upper or argillo-talcose schists of the section under consideration will be found discussed at some length by the present writer in a review of Favre on the geology of the Alps in 1872. It was there shown that these, though very distinct from and unlike the underlying micaceous, hornblendic schists and gneiss, are really crystalline schists, and very unlike the normal trias of the region, to the horizon of which they had been referred by most geologists. The section of them afforded by the Mont Cenis tunnel was then and there discussed, and many reasons were given for rejecting the notion of their triassic age, and for assigning them to the eozoic period. As was shown in a subsequent note to that review, Favre, after publishing his book in 1867, was led to adopt the view advanced by Gastaldi in 1871, that these schists were pre-carboniferous, though probably paleozoic, a conclusion which the latter subsequently exchanged for that of their eozoic age, as maintained by the present writer since 1872. *

§ 67. The section traversed by the St. Gothard tunnel furnishes important details for Alpine geology. This work, beginning at Goschenen, on the north, ends at Airolo on the south side of the mountain, the entire distance being 14,920 meters. The first 2,000 meters from the northern portal are in the massive rock of the Finsteraarhorn, called by various observers granite or granitic gneiss, and by Stapff regarded as an older gneiss than that of the remaining part of the section. Between this and the mountain of St. Gothard is included the closely-folded synclinal basin of Urseren, while the southern portal, at Airolo, is on the northern side of the similar basin of Ticino; the great intermediate mountain-mass of highly inclined and faulted strata, presenting a fan-shaped arrangement. The basin of Urseren holds, folded in gneiss and mica-schist, a group of strata consisting of argillites, sometimes calcareous and often graphitic, with grey lustrous, unctuous sericite-schists, together with quartzose layers, and others which, from a development of feldspars, pass into an imperfect gneiss. With these are interstratified granular crystalline limestones, white or banded with grey, with dolomite and karstenite. Some of the limestones included in this synclinal have afforded indistinct organic forms, and the series has been referred, like the similar rocks noticed in previous sections, to the mesozoic period. A repetition of these is met with in the Ticino basin, on the south side of the mountain. Apart from these, the great mass of strata along the line of the tunnel consists of micaceous gneisses and mica-schists with hornblendic bands, the whole having the characters of the younger gneissic series, and very distinct from the older gneiss of the northern portion. † If this latter be the central gneiss, the pietre-verdi zone is here absent.

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* Amer. Jour. Science, (3) iii. pp. 1-15, also Chem. and Geol. Essays, pp. 333, 336 and 347.

† For full details of this section see Profil géologique du St. Gothard, etc., par Dr. F. M. Stapff; Berne, 1881.

I have not seen the gneiss of the Finsteraarhorn, but having examined the gneisses and mica-schists of the St. Gothard and the Ticino, can affirm that they have the lithological characters of the Montalban series of North America and of the younger gneiss and mica-schists of Gastaldi and von Hauer, in which they were included by the Austro-Hungarian geological survey. (§ 60.) The serpentines of the younger gneiss, as seen in the St. Gothard section, will be described in part. VII.

§ 68. With regard to the presence of granites in these regions, Cordier, as cited by Lory, long ago asserted that true granites, occurring in veins or transversal inclusions, are rare in the Western Alps. He, however, excepted some masses, of which the granites of Baveno may be taken as a type, and others, which are rather veins of segregation (endogenous) than of injection. * For the rest, Cordier regarded the granites of the Alps as stratified rocks. Gastaldi, going still farther in his protest against plutonism, admits, in the regions examined by him, none but stratified rocks of aqueous origin, and has included in his sections masses that I regard as igneous and intrusive rocks, but which are by him confounded with true indigenous gneissic rocks under the title of "recent gneiss and granite."

As regards the porphyry mentioned in the sections of Neri as above the recent gneisses, and that placed by Gastaldi above the lustrous schists, it would appear that the latter employed this term in a very vague sense, since he speaks of the feldspathic and quartziferous porphyries of this region as presenting great varieties in structure and in composition, and as passing into other rocks, notably into granites, from which it is often difficult to separate them. † He seems, under the general term of porphyry, to have included both stratified rocks at different horizons, and intruded masses of various kinds.

§ 69. From the various descriptions and sections of the Alpine rocks, which we have here considered, it appears that they may be included in four distinct groups, which are as follows in ascending order :—

I. The central or ancient granitoid gneiss, with occasional quartzites and crystalline limestones, bearing graphite and many crystalline minerals. This group we refer, with Gastaldi, to the Laurentian.

II. The great group of the pietre verdi proper, in which, besides serpentines and ophiolitic rocks are included bands of limestone, and also apparently certain gneissoid rocks, the protogine or the talcose gneiss of Lory and Taramelli. (§ 61, 78.) It is worthy of remark that although Gastaldi, like Neri, Gerlach and Von Hauer, placed the great group of recent gneiss and mica-schists above the true pietre-verdi zone, which he declared to be confined between the older and the newer gneiss, he, in his last published sketch, indicated besides this, another horizon of "recent gneiss and granite" (not elsewhere noticed by him) intercalated in the pietre-verdi zone, as thus limited, and probably corresponding to these talcose gneisses. This second or pietre-verdi group, we refer with Gastaldi to the Huronian.

III. The younger gneiss and mica-schist series, with hornblendic varieties and intercalated crystalline limestones, and in some cases with serpentines and euphotides. This group, upon the lithological characters of which we have already insisted, (§ 53, 55, 67) we regard as the representative of the Montalban.

IV. The upper lustrous schists with gypsums and karstenite and talc, with inter-

* See the author in Chem. and Geol. Essays, page 331.

† Studii, etc., part II., p. 34.

stratified serpentines, quartzites, often sandstones, argillites, dolomites, micaceous limestones, and banded and statuary marbles. This group, as we have already indicated, presents many resemblances with the great Lower Taconic or Taconian series of North America. In it are included by Gastaldi, the crystalline limestones of the Apuan Alps, which yield the statuary marbles of Carrara and of Massa.

§ 70. In the Western Alps there is, so far as is known, no evidence of lower paleozoic rocks, the sandstones with anthracite, which succeed the crystalline schists, containing in many places a carboniferous flora. The same, according to Gastaldi, is true in the Maritime Alps and the Apennines, where, in many cases, he finds the crystalline schists overlaid by the anthracitic series. Thus in the valley of Macra, above the serpentines are found calcareous schists with crystalline limestones and quartzites, which are successively overlaid by the carboniferous sandstones, the limestones of the trias, with their characteristic fauna, the lias, the cretaceous and the nummulitic beds. At Torre Mondovi, the serpentines are overlaid by fossiliferous triassic limestones, while in the valley of Bormida they are directly succeeded by the marls, sandstones and conglomerates of the lower miocene, and in the valleys of Staffora and Polcevera by the alberese and the macigno of the eocene. The supposed pre-carboniferous fauna found by Michelotti in the limestones of Chaberton, has, on further examination by Prof. Meneghini, been shown to be of triassic age. *

§ 71. Passing now from the mainland of Italy, we come to Corsica and Elba. The serpentines of the former island have long been known to geologists, and have within the last few years been especially studied by Hollande, Coquand, Dieulefait and Lotti Coquand, who described the serpentines of Corsica in 1879, and who, like Hollande, regards them as eruptive, supposes them to be in part very ancient, and in part tertiary, since according to him, some of them overlie the nummulitic beds. † Pellati, whose essay we have already cited, refers however the whole of the serpentines of this island to a pre-paleozoic period, and Dieulefait, who described these rocks in 1880, ‡ declares that Coquand's reference of the serpentines found near Corte to the tertiary is based on an error of observation. He moreover asserts that the serpentines of Corsica are stratified sedimentary rocks belonging to a single geological horizon, at which they may be traced continuously for a length of more than 200 kilometres from Corso along the northeast coast of the island. The geological succession, according to him, is as follows:—1, stratified protogine; 2, gneiss; 3, lustrous schists; 4, saccharoidal limestones; 5, schists more or less talcose; 6, schists enclosing serpentines of many varieties; 7, clay-slates; 8, black limestones with carbonaceous matter; 9, beds often detrital; 10, infra-liasic limestones, with *Avicula contorta*.

§ 72. Lotti, who has since studied these rocks, § confirms fully the observations of Dieulefait. He describes the crystalline limestones, white or banded, with grayish, greenish or lead-colored talcose or silky schists, holding a mica, sometimes apparently damourite or sericite, in which are found layers of serpentine. The serpentine itself is generally scaly in texture and glassy, but granular varieties are met with including veins of epidote, others with altered crystals of olivine, and also ophicalcites. The gneisses beneath the serpentine-

* Gastaldi's letter to Zezi, in 1878, already cited.

† Coquand. Bull. Soc. Géol. de France, (3) vii.

‡ Dieulefait. Comptes Rendus de l'Acad. des Sciences, xci., p. 1000.

§ Lotti, Appunti Geologici sulla Corsica; Boll. del Comitato Geologico, anno 1883, No. 3-4.

zone pass into quartzose mica-schists, often including almond-shaped masses or segregations of quartz and feldspar, sometimes with large plates of mica. It would appear from the descriptions of Lotti, that these serpentines of Corsica belong to the upper horizon defined by Gastaldi, above the recent gneisses, and in what we have designated as the fourth group of Alpine crystalline rocks. (§ 69) The underlying protogine is, according to Lotti, a talcose gneiss.

§ 73. The resemblance of these rocks to those associated with similar serpentines on the neighboring island of Elba is declared by Lotti to be very close. There also the serpentinic horizon is underlaid by gneisses and mica-schists, as in Corsica. He concludes with Gastaldi that the great crystalline zone of the Alps is connected through the Maritime and Ligurian Alps with the similar rocks of Corsica and Elba. Resting upon the ophiolitic strata in Elba are found, according to Lotti, paleozoic carbonaceous slates containing *Orthoceras, Cardiola, Actinocrinus*, and probably also graptolites. Lotti, however, while he asserts the great antiquity of all of the serpentines of Corsica, and part of those of Elba, maintains the existence in the latter island of other serpentines which, like those of Tuscany, he refers to the eocene period.

A similar question is raised with regard to the granites of the two islands. Thus Pareto, who regarded as ancient, or at any rate pre-triassic, the granites of Corsica, admitted for the granites of Elba, Monte Cristo and Giglio a post-eocene age, a view which is also sustained by Lotti, while de Stefani, on the other hand, assigns the Elban granites to pre-triassic time. I can scarcely doubt that all of these granites, as well as the ophiolites both of the various islands and the mainland, will be found, as maintained by Gastaldi, of pre-paleozoic age.

§ 74. If we turn to the island of Sardinia we find a series of pre-Cambrian crystalline schists, said to consist, in their upper portions, of argillites, sometimes talcose, sandstones, crystalline limestones and dolomites. These, which are referred by Bornemann to the Huronian or pietre-verdi zone of the Alps, are overlaid, as was first shown by de la Marmora, by a series of uncrystalline limestones, shales and sandstones, containing an abundant lower paleozoic fauna. * Of this, the Upper Cambrian (Ordovician) † forms were long since described by Meneghini. The subsequent studies of Bornemann, in 1880, showed at the base of the series a zone marked by *Paradoxides, Conocephalites, Archeocyathus*, etc., which have also been examined by Meneghini, and establish the existence of a Lower Cambrian

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* Bornemann, sur les formations stratifiées anciennes de la Sardaigne. C. Rendus du Congrès Géol. Inter. de Bologne, pp. 221-232.

† The term Ordovician, sometimes contracted to Ordovian, was proposed by Lapworth in 1879, (*Geological Magazine*, vi., p. 13,) to designate the group of paleozoic rocks found in Wales between the base of the Lower Llandovery and the base of the Lower Arenig. These, corresponding essentially to the Upper Cambrian or Bala group of Sedgwick—the second fauna of Barrande—were, as is well-known, by a mistake in stratigraphy, joined by Murchison to his Silurian system, under the name of Lower Silurian, and have also since been called Siluro-Cambrian and Cambro-Silurian. By making of this debated ground a separate region, between the true Silurian above and the great Cambrian series below, (the Middle and Lower Cambrian of Sedgwick) Lapworth has sought to get rid of this confusion in nomenclature, and to restrain the attempts of some to extend the name of Silurian downwards even to the base of the Cambrian itself. This designation is convenient in American geology from the fact that it includes the group of strata between the base of the Silurian (Medina) sandstone and the base of the Chazy limestone; the latter, together with the Trenton, Utica and Loraine divisions, being equivalent to the Ordovician. The name was given in allusion to the Ordovices, an ancient British tribe inhabiting North Wales.

horizon. The writer had, in 1881, the pleasure of examining at Bologna, in company with with James Hall, a collection of these fossils. Above the Ordovician beds in Sardinia is found a great mass of limestone, of undetermined age, remarkable for its beds and included masses of lead, silver and zinc-ores.

§ 75. We have now shown that these crystalline rocks which, in parts of the mainland, are directly succeeded by tertiary sediments, are in different areas overlaid by various subdivisions of the mesozoic, and finally by carboniferous, Ordovician and Cambrian sediments, thus disproving the views of the older geologists who assigned to these same crystalline rocks a paleozoic or a mesozoic age. It is instructive to mark the steps by which this view, has, in the progress of investigation, been left behind. In Neri's section the older gneiss and the pietre verdi proper are called azoic or protozoic, but the recent gneiss is conjectured to be paleozoic. Lory, however, included the latter in the primitive series, but claimed the lustrous schists as altered trias, while later, Gastaldi, and with him Favre, placed even these in the paleozoic, until at last we find Gastaldi adopting the conclusion first put forward by the present writer in 1872, that the whole of these crystalline rocks are to be referred to pre-Cambrian time.

§ 76. The story of the crystalline marbles of Carrara, now included in this series, is not less instructive. They were regarded as eruptive by Savi, who taught that dolomites and limestones had been poured out in a fused state, alike in secondary and in tertiary times, * and even indicated what he supposed to be centres of eruption. The marbles of Carrara, with their associated schists, have since been called cretaceous, liassic, rhaetic, infra-carboniferous and pre-paleozoic. † They were in 1874, in the second part of Gastaldi's *Studii*, included in the rocks of the pietre-verdi zone, the term being then used in its larger sense, as embracing not only the true pietre verdi, but the whole crystalline series above the ancient gneiss.

§ 77. This was also clearly stated by Jervis, in his elaborate work on the mineral resources of Italy ‡ a veritable treasury of information, most carefully and systematically arranged. In his first volume, in a tabular view of the geology of the Alps, he had already adopted the views of Gastaldi, and placed the whole of the crystalline stratified rocks above the ancient gneisses in a pre-paleozoic group, which he regarded as synonymous with the pietre-verdi zone. In his second volume, in a similar tabular view of the geology of the Apennines and the adjacent islands he further insists upon the same view, and puts above the ancient gneiss, in what he calls the pre-paleozoic period, the great series of "stratified azoic rocks," including not only the ophiolites, and the recent gneisses and other crystalline schists, but the saccharoidal and compact marbles of the Apuan Alps (loc. cit. p. 9.) It is to be remarked, as shown both by Jervis and Gastaldi, that this great younger crystalline series is the metalliferous zone of Italy, containing much cupriferous and niccoliferous pyrites, in veins and interstratified beds, together with crystalline iron-ores, lead, zinc and gold.

§ 78. With the general succession of the Alpine rocks already given, we may compare

* Boué, Guide du géologue voyageur, II., 168. For the views of others as to the eruptive origin of crystalline limestones, see my Chemical and Geological Essays, p. 218.

† For a notice of some of the various views which have been put forward with regard to the age of these marbles, see Lebour in the *Geological Magazine* for 1876, pp. 287 and 385.

‡ I Tesori Sotteranei del'Italia, 3 vols. 8vo, Turin, 1878-1881.

the observations of Taramelli in the Valtelline, where he describes the ophiolites as lying below a great gneissic and granitic series, from which they are separated by a garnetiferous hornblendic rock and saccharoidal limestones. The lowest division in the series, as observed in the Valtelline is, according to Taramelli, a quartzose talc-schist, upon which reposes the serpentine in heavy continuous beds, having all the appearance of a stratified rock, followed by potstone, that is to say steatite or chlorite. To this succeed in ascending order, hornblendic and epidotic rocks, associated with crystalline limestones, often talciferous: then, schistose amphibolite, talcose gneiss, talc-schists and eclogite, and finally a coarsely crystalline glandular gneiss, itself overlaid by granitic and associated hornblendic rocks. This apparent reversal of the succession as defined by Gastaldi and others, suggests the probability that we may have in the Valtelline an overturn of the strata, such as is well-known in many parts of the Alps, and elsewhere, placing the more ancient rocks above the younger ones. *

§ 79. It is here the place to notice the mode of occurrence of the serpentines which, in Saxony, are found interstratified in the granulite series of the Mittelgebirge. The granulite proper may be described as a fine-grained gray laminated binary gneiss, consisting essentially or orthoclase and quartz, but often containing garnet and sometimes cyanite and andalusite. By an admixture of mica, it passes, through ordinary gneiss, into mica-schists, which are abundant in the series. In it are also interstratified dichroite-gneiss, sometimes in great beds, and a greenish hornblendic gneiss, as well as the so-called gabbros of the region (like that of Neurode.) These occur in larger or smaller lenticular interstratified masses, to which the distribution of the diallage in a granular labradorite base given a well-defined gneissoid structure. In this same series the serpentine is found in interstratified beds, occasionally garnetiferous, and sometimes associated with lherzolite.

§ 80. I have not seen these rocks on the ground, but have examined a large collection of them in Leipzig, with the assistance of my friend, Dr. Hermann Credner, and was struck with their close resemblances to the rocks with which I am familiar in the newer or Montalban series of gneisses and mica-schists throughout the Atlantic belt of North America. The muscovite-gneisses of the Erzgebirge, with their occasional layers of limestone and of hornblende-rock, and their intercalated and overlying mica-schists, I also refer to the same general horizon. It is in these, it will be remembered, that are found the abundant conglomerate beds described by Sauer, the pebbles in which consist chiefly of varieties of granitoid gneiss, resembling closely those of the ancient gneiss of the Alps (Biellese) and the Laurentian gneiss of North America. These are, however, as I have seen, accompanied by pebbles of crystalline limestone. †

Mention should also be made in this connection, of the existence of similar conglomerates in Sweden, at Soljoarne, where pebbles of ancient gneiss and granite are found at several points imbedded in fine-grained schistose gneiss, in calcareous mica-schist, and also in a red hälleflinta, the strata of all of which are shown to rest unconformably upon the older granitoid gneiss. ‡

* Boll. Soc. Geologica Italiana, I., p. 14.

† Zeitschrift f. d. ges. Naturwiss. Band lii.; also Geol. Mag. Jan. 1882, and Bull. Soc. Géol. de Fr., x. 26; also Amer. Jour. Science, (3) xxvi., p. 197.

‡ Hummel, Om Sveriges Lagrade Urberg., etc., Stockholm, 1875, p. 30.

§ 81. It will be remembered by students in geology that in 1870 the present writer announced his conclusion that there exists in North America, besides the Laurentian gneisses, "a great series of crystalline schists, including mica-schists, staurolite and chiastolite-schists, with quartzose and hornblendic rocks, and some limestones, the whole associated with great masses of fine-grained gneisses, the so called granites of many parts of New England." * These rocks were especially indicated as occurring in the White Mountains of New Hampshire, but were also said to be found to the northwest of Lake Superior, as well as in Ontario and in Newfoundland, in which last two regions they were believed to rest unconformably upon the Laurentian gneiss. In both of these latter localities, there were provisionally associated with this group some higher limestones, with crystalline schists, and for the whole series the name of Terranovan was suggested.

§ 82. In the following year, 1871, in an address before the American Association for the Advancement of Science, these rocks were farther noticed under the name of the White Mountain series. The higher limestones and schists, which were not found on the geological section then described, were however excluded. This great series of younger gneisses and mica-schists was then assigned to a horizon above the Huronian, and as a distinctive name was desirable for a series so conspicuous in American geology, that of Montalban (from the latinized name of the White Mountains) was proposed in the same year. † It was at the same time shown that the view held by most American geologists, that these rocks were altered paleozoic strata was untenable, and that they were to be regarded as pre-paleozoic. At a later period, the overlying limestones and schists, at first associated with these newer gneisses and mica-schists, were refered to the Lower Taconic of Emmons—the Taconian series. (†)

When, in 1870 and 1871, I thus attempted to subdivide the crystalline schists above the ancient gneiss of North America, and to define, above the Huronian, a younger series of gneisses with mica-schists, I was not aware that Von Hauer had already been led by his studies to similar conclusions for the Eastern Alps, and had discovered above the great pietre-verdi zone, a series of gneisses with micaceous schists, as indicated in divisions 5 and 6 of his section (§ 60). Gastaldi, in 1871, and for years after, included these, with all the crystalline schists found above the ancient or central gneiss, in one great group of newer schists, which he assimilated to the Huronian. In reviewing this subject, in 1878, ‡ I pointed out that the uppermost crystalline schists of the Western Alps should be separated from the Huronian, and compared them with the Taconian, while I noted the fact "that gneisses and mica-schists similar to those of the Montalban are found in many parts of the Alps." It was not, however, until after my studies among these rocks in 1881, that I referred the newer gneissic series of that region to the Montalban, for the two-fold reason that it occupies a similar stratigraphical horizon and is lithologically indistinguishable from it.

§ 83. Not less important in this connection is the succession of crystalline rocks in eastern Bavaria, which may be compared with those of Saxony. We have, in ascending

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* Amer. Jour. Science. (3) I, 85.

† Proc. Amer. Assoc. Adv. Science, 1871. p. 6; also Chem. and Geol. Essays. pp. 194, 244, 282; Das Ausland, Dec. 25, 1871, p. 1288, and Azoic Rocks, p. 181.

‡ Azoic Rocks, pp. 201-211, 215; ‡ Ibid, p. 245.

order, according to Gümbel, first, the red or variegated gneiss, called by him Bojian, which is followed immediately by the newer grey or Hercynian gneiss, his second division, and by a third, the Hercynian mica-schist series, occasionally hornblendic. To this succeeds, in the fourth place, the Hercynian primitive clay-slate series, which is immediately overlaid by Lower Cambrian fossiliferous rocks. This primitive clay-slate series contains interstratified beds of limestone, sometimes dolomitic, attaining in places a thickness of 350 feet, and associated with siderite, which gives rise by epigenesis to valuable deposits of limonite along its outcrop. With these limestones are found varieties of hornblende and serpentine, accompanying which is the *Eozoon Bavaricum* of Gümbel.

§ 84. The Hercynian gneiss is described by Gümbel as including much grey quartzose and micaceous gneiss, with frequent beds of dichroïte-gneiss, granulite, serpentine, hornblendic schists and crystalline limestones. With these are associated *Eozoon Canadense*, from which Gümbel supposed this upper gneissic series to represent the Laurentian, a view which was accepted by the present writer when, in 1866, he translated and edited Gümbel's paper * for the *Canadian Naturalist*, and has since been expressed by him elsewhere; coupled with the suggestion that the Bojian might correspond to the Ottawa gneiss which underlies the Grenville series, the typical Laurentian (Lower Laurentian) of the Canadian survey. We are not, however, as yet prepared to recognize a sub-division in the older gneisses of continental Europe, and meanwhile the analogies between the great Hercynian gneiss and mica-schist series combined, and the younger gneisses and mica-schists of Saxony and of the Alps, lead us to refer what Gümbel has described as the newer gneiss series of Bodenmais and the Danube, to the same horizon as the younger gneisses of Gastaldi and Von Hauer, the Montalban series; which in eastern Bavaria would seem, as in the Simplon, to rest directly upon the older gneiss, the Huronian being absent. The Hercynian clay-slate series, with its crystalline limestones, may correspond to the fourth group of the Alpine rocks, the argillo-talcose schists, which we have compared with the American Taconian.

IV.—The Serpentines of Italy.

§ 85. Returning to the Italian Alps, we have now to call attention to a very important conclusion reached by Gastaldi with regard to the geographical relations of the pietre-verdi zone; using the term in its larger sense as embracing all the newer crystalline rocks, or those above the ancient gneiss. In 1871, in the first part of his memoir on the Western Alps, he declared it as his opinion that "all the serpentinic masses of the Tuscan and Ligurian Apennines, and the serpentines, ophicalcites, saccharoidal limestones and granites of Calabria, are but a prolongation of this zone." In this were included, as we have already seen, the Apuan Alps, and, farther westward, a large part of the Maritime Alps. In support of these views he pointed out the mineralogical identity of the ophiolites and other crystalline rocks in the Alps and the Apennines. To the same horizon he also referred the so-called ophitic terrane of the Pyrenees.

§ 86. Gastaldi further called attention to the fact that ophiolitic rocks often appear in the form of isolated peaks or hills, for the reason that the accompanying crystalline schists

* Gümbel, Ueber der Vorkommen von Eozoon in dem Ostbayerischen Urgebirge, München Akad, Sitzungsb, 1866, (1.) pp. 25-70; also Can. Naturalist, iii., 1868, pp. 81-101.

and calcareous rocks, opposing less resistance, have been removed by decay and erosion, adducing many instances in support of this among the Alps. This being the case, he adds, we are not to be surprised when in the Apennines we find an isolated masses of ophiolite rising out of the midst of surrounding jurassic, cretaceous or tertiary strata, which conceal the rocks that accompany the ophiolite. Thus it is, he adds, that "the notion has arisen in the Apennines that the serpentines, diorites, etc., are always eruptive rocks." They are, in his view, to make use of the happy expression of Roland Irving in describing a similar occurrence, "protruding but not extruded." These views were reiterated by Gastaldi in his letter to Zezi in 1876, when he asserted that the skeleton of the Apennines is a continuation of that of the Alps, and that the crystalline rocks of the Apennines are Alpine rocks. From the summit of Mont Blanc, he declared, they may be followed, more or less concealed by overlying strata of more recent date, * to the Danube, to the plains of France, to the Mediterranean, and along the peninsula which separates this sea from the Adriatic; assertions which he supported in 1878 by many detailed observations to be noticed farther on.

§ 87. These bold generalizations of Gastaldi have met with but partial acceptance in Italy, as may be seen by the discussions in 1881, and the publications of the R. Comitato Geologico and the Società Geologica Italiana in 1881 and 1882, already referred to in § 43. Pellati, in his summary, declares that the views of Gastaldi as to the antiquity of the Alpine pietre verdi are confirmed by the work of Baretti and of Taramelli, the latter of whom clearly shows that the view entertained by so many that these rocks are carboniferous or triassic, is inadmissible. Hence these ancient serpentines are by Pellati designated as pre-paleozoic (eozoic.) This view he extends to all the ophiolitic masses situated in the Alps, to those of Calabria, and also to those of the Apennines west of the meridian of Genoa, those to the east of this meridian being included in the eocene. § 47.

§ 88. Regarding the so-called eocene serpentine, and its associated rocks, Pellati observes, "as to its composition, it differs but little from the older serpentine, the differences remarked being principally in a structure ordinarily less schistose, and in a greater frequency of subordinate ophiolitic rocks; euphotides, eurites, diorites, variolites, ophiocalcites, etc., more or less decomposed. The masses of proper serpentine are ordinarily more scattered and of smaller dimensions, having almost always gabbros and beds of phthanite and jasper around them." Cossa, it is true, has remarked in the specimens examined by him that the mineral species bastite is more common in the eocene or Apennine than in the eozoic or Alpine serpentines, but, with this possible exception, the mineralogical and lithological associations of the two are apparently identical. In fact, Pellati admits that it is in some cases difficult, if not impossible, to distinguish between them. Within the great basin lying to the east of the meridian of Genoa, and embracing, as we have seen, the so-called tertiary serpentines, we are informed by him that "the paleozoic and mesozoic rocks are generally very thin, and often are entirely absent, in which case the floor of *pietre verdi* or greenstones is directly overlaid by the tertiary, and in fact by the very eocene which includes the younger serpentines. This is the case in the vicinity of Genoa, upon the right bank of the Polcevera, where the greenstones come in direct contact with the shales and the limestones of the upper eocene, and it here becomes doubtful whether, along this line

* See the author on Azoic Rocks, p. 245.

of outcrop, portions of tertiary ophiolites are not mixed and confounded with others of the pre-paleozoic period." These supposed tertiary ophiolites "have a very great resemblance to those of the eocene of eastern Liguria, and present moreover a large development of of the rocks which Issel has designated as amphimorphic (§ 92.) Thus, near Pietra Lavezzara, for example, ophicalcites are exploited which are precisely like the green marbles of Levanto. In this same locality, moreover argillites, having the aspect of those of the eocene appear to dip beneath the ophiolites." In support of the belief that these seemingly tertiary ophiolites are really eozoic, however, we are told that their outcrops present lines of continuity, connecting these serpentines with those of which the eozoic origin is undoubted. We have seen (§ 41) that Prof. Bonney in his studies of the serpentines of Italy fails to remark any distinction between the serpentines thus separated by the Italian geologists, since he describes as similar both in mineralogical characters and in geognostical relations, the ophiolites lying to the west and those lying to the east of the meridian of Genoa. I shall further on have occasion to refer to my own observations of some of these localities.

§ 89. The older school of Italian geologists, as already noticed, supposed the serpentines to have been erupted, like basalts, at different geological periods, and applied this view not only those which are evidently included among eozoic rocks, but also to those which rise among the tertiary deposits. The study of the ophiolitic masses of eastern Liguria and of Tuscany, induced the earlier geologists, like Savi, Pilla and Pareto, to refer them to various ages between the cretaceous and the pliocene, but more recent observers have been led to include all of these ophiolites in the upper eocene. This view was first advanced for those of the mainland of Tuscany by De Stefani, in 1878, and has since been maintained by Lotti, Taramelli, Issel, Mazzuoli and Capacci, among others. The horizon in the upper eocene to which these observers refer the serpentines in question, consists of argillaceous and marly shales alternating with beds of limestone and sandstone, and is below the argillaceous limestones with fucoids and nemertilites, but above the sandstone known as macigno, which is found at the base of the eocene in Liguria.

§ 90. As regards the origin of serpentines, Pellati remarks that the recent studies of Italian geologists have led to hypotheses which differ widely from those formerly received, according to which serpentines were regarded "as plutonic or eruptive, having come to the surface after the manner of volcanic lavas, or at least, like certain massive trachytes, in a pasty state, or one of igneous semi-fluidity." Gastaldi, he adds, "from his studies of the ancient serpentines of the Alps, regarded them, however, as sedimentary rocks, modified by subsequent hydrothermal actions operating at great depths in the earth." He compared their formation to that of the accompanying gneisses, mica-schists, chlorite-schists, crystalline limestones, diorites, and even the granites, syenites and porphyries of the Alps, to all of which he ascribed an aqueous origin.

§ 91. This hypothesis has not, however, been favorably received as an explanation of the origin of the so-called tertiary ophiolites of the Tuscan and Ligurian Apennines. Taramelli, from his studies of the serpentines of the valley of the Trebbia, declared that neither the above mentioned view of their igneous eruptive origin, nor that maintained by Gastaldi could be conciliated with the facts of the stratiform and lenticular arrangement of the masses of serpentine, the want of evidences of alteration in the interstratified layers of limestones and argillites, and the absence of ophiolitic dykes in these same rocks. He was thus led to conclude that the ophiolites had been formed in the midst of the tertiary sediments by contemporaneous sub-marine eruptions of magnesian and feldspathic magmas, and that the euphotides and other associated ophiolitic rocks had probably resulted from subsequent crystallogenic concentrations, which took place in these erupted magmas. Capacci, from his investigation of the ophiolitic mass of Monteferrato, in Prato, advanced a similar view, supplemented by the hypothesis of thermal waters accompanying the eruption of the magnesian magma or succeeding it.

§ 92. Issel and Mazzuoli, from their joint studies in eastern Liguria, have formulated, more at length, an analogous hypothesis to explain alike the origin of the serpentines, and of the rocks there intimately associated with them, such as diorites, aphanites, variolites, and euphotides. To these, they give the general designation of amphimorphic rocks, suggested by the conception that they have had a two-fold origin, and have resulted from mixtures and combinations of slowly deposited argillaceous materials of mechanical origin with elements brought in by abundant thermal springs through a long period, both during and after the eruption of the serpentinous magma. This latter, they suppose, was a phenomenon of short duration, almost instantaneous, while the formation of the euphotides and other amphimorphic rocks was a slow process. Nor is this the only effect ascribed to the hypothetical thermal springs, which our authors suppose to have acted upon pre-existing contiguous calcareous and argillaceous strata, penetrating them with waters holding in solution silica and oxyds of iron and manganese, and converting them to jaspers, phthanites or silicious slates, or to certain ill-defined silico-argillaceous or calcareous rocks which Issel has called hypophthanites.

§ 93. The serpentines themselves having nothing in common with the argillites, sandstones and limestones among which they are found, these observers have imagined that after the deposition of the eocene sandstone, great eruptions of a hot impalpable mud, consisting principally of silicates of magnesia and iron, generated by some unexplained process, were poured out from submarine fissures in the earth's crust, were spread over the bottom of the sea, filling depressions therein, and were subsequently changed into serpentine. Thus, by this hypothesis, " the serpentines are considered as eruptive without being truly igneous, inasmuch as they do not contain in their composition any mineral which has been submitted to igneous fusion, and do not show, at their contact with the sediments adjoining, any metamorphic product due to a very elevated temperature. In order, however, to explain the slight traces of contact-metamorphism which are especially seen in enclosed masses of limestones, they admit that at the moment of its emission the magma may have had a temperature of several hundred degrees. As to the ophicalcites, which are often found at the contact of the serpentine with the sedimentary rocks, and sometimes even at a certain distance from these, their formation is attributed to the cementation of serpentine-breccias by calcareous waters discharged in the last phase of the eruptive period."

§ 94. Pellati sets forth, with wise caution, the preceding hypothesis as one suggested by the observers already named for the Apennine ophiolites, and adds that it might perhaps be also extended to the ophiolites of admitted eozoic age, which, he says, " so far as we know at present, consist essentially of rocks of the same nature and the same composition." He insists moreover upon farther researches, even in the case of the supposed eocene serpentines, and upon the importance of discovering the centres of eruption through the pre-existing strata, "or at least some positive evidences of such centres."

§ 95. I have thought it desirable to reproduce with some detail this ingenious hypothesis, with Pellati's comments thereon, for the reason that it shows clearly the difficulties which recent observers have found in accepting the older theory of the igneous eruption of ophiolites, and moreover brings clearly into view many points which are of importance for the solution of the problem before us, of the true relations of these ophiolites to the surrounding strata. In view of the fact that the resemblance between the supposed eocenic and the eozoic ophiolites is so strong that the two cannot be clearly distinguished or separated from one another, as we have seen alike from the comparisons of Bonney and the admissions of the recent Italian geologists themselves (§ 88), it is not surprising that some observers like Gastaldi should have been led to look upon the so-called eocene ophiolites as nothing more than portions of the underlying eozoic or pre-paleozoic series exposed through geological accidents. This explanation becomes more plausible when we reflect that within the great basin over which these ophiolites are met with, the paleozoic and mesozoic rocks have but a slight development, and are often entirely wanting, the tertiary rocks resting directly upon the eozoic *pietre verdi*.

§ 96. My own observations of the Italian ophiolites have been limited. I have had, however, an opportunity of examining two localities of these so-called eocene serpentines, in eastern Liguria and in Tuscany. It was my good fortune in October, 1881, to spend a day with Signor Capacci, (whose careful memoir on the region, with map and sections, I have already noticed,) in going over Monteferrato in Prato, near Florence, a locality for centuries famous for its quarries of serpentine, known as *verde-prato*. About three miles from Prato, a town on the railway between Florence and Pistoia, is the little village of Figline, which lies on the eastern slope of the ophiolitic mass in question, forming a hill which rises boldly from the plain of eocene limestones and shales (alberese and galestro.) The mass of ophiolitic rocks occupies an area somewhat oval in form, having, according to the determinations of Capacci, a length of about 2,600 meters from north to south and a maximum breadth of about 1,800 meters. In its highest points it attains elevations of 400 and 426 meters above the sea, the level of the surrounding plain being about 70 meters. Figline itself, where the serpentine appears from beneath the eocene strata lying to the east, is at a level of 103 meters, but the similar strata on the western side of the hill, where they apparently dip at high angles beneath the serpentine-mass, rise to heights of 295 and 322 meters above the sea level.

§ 97. Underlying the alberese, and resting upon the ophiolite along the eastern base of the hill, is seen in many places a fine-grained, laminated silicious rock, generally reddish, but sometimes greenish or grey in color, designated as phthanite by the Italian geologists, which abounds in microscopic forms referred by Bonney in part to polycystinae and in part to polyzoa. * This is succeeded, in apparent conformity, by the ordinary type

* Upon the organic forms found in these and similar silicious or jaspery beds, see a memoir by Prof. Dante ntanelli on the jaspers of Tuscany and their fossils, (I Diaspri della Toscana, ecc. Mem. R. Accad. dei Lincei, ser. 3. vol. viii., June, 1880; also Geol. Mag. for the same year, pp. 317,561.) These deposits are found alike at various horizons in the upper eocene, and in cretaceous and liassic strata, often in thin layers imbedded in argillaceous sediments. They consist in part of crystalline and in part of amorphous silica, with oxyds of iron and manganese, and contain large numbers of radiolarian forms, of many species, leading the author to conclude with de Stefani that they are deep-sea deposits.

of eocene limestones and shales, which, in some places, however, rest directly upon the ophiolite, or with the intervention only by a layer of comminuted serpentine-rock, described by Capacci as an ophiolitic sand (*arenaria ofiolitica*.) These overlying strata have a general dip away from the serpentine, that is to say to the easward, of from 20° to 70°, but in some sections, as to the east and northeast of Figline, are represented in Capacci's sections as nearly horizontal, with small undulations exposing, in valleys, the phthanite, and even the serpentine beneath the the alberese.

§ 98. On the western side of the hill where, as already said, these eocene strata appear nearly up to the summit, and plunge beneath the ophiolite, their dip, as seen along the southwest border, is from 54° to 64° to the northeast. Here is observed a significant fact, which is shown in the sections of Capacci; namely, that the previously-noted relations of the serpentine, phthanite and alberese are reversed. While on the eastern slope these three rocks appear in the ascending order just named, we find on the opposite flank of the hill, in the ascending section, alberese, phthanite and serpentine; the serpentine overlying the phthanite, and the latter the alberese. The natural and obvious interpretation of these facts is that we have here simply an inversion of the natural order, resulting from an overturn of the strata on the western side of the hill.

§ 99. The ophiolitic mass itself is not simple but, as described and figured by Capacci, is essentially composed of two layers of serpentine, with an intercalated lens of euphotide. Besides this rock, which has been the object of repeated studies, the last by Cossa, this lithologist has described associated masses of diabase, while Capacci has observed others of dioritic rocks, including a green variety distinguished as gabbro-verde, sometimes becoming variolitic, as well as the so-called gabbro-rosso, which, as there seen, is an iron-stained, somewhat calcareous dioritic rock, concretionary in structure, and apparently in a decomposing state.

§ 100. Capacci's view of the relations of these various rocks to one another, and to the accompanying eocene strata, is in accordance with the hypothesis already set forth (§ 93). He regards the ophiolite of Monteferrato as a great lenticular or almond-shaped mass (*un'amigdala ofiolitica*), "intercalated in perfect concordance of stratification, among the strata of alberese and galestro of the eocene formation," which have been subsequently tilted, so as to give to the whole series an eastward inclination. In accordance with this conception, he supposes that at a certain time during the accumulation of the eocene strata, there came, from a rupture in the earth's crust, a sudden effusion of an aqueous magnesian magma, which was spread out beneath the sea, and was subsequently overlaid by a continuation of the eocene beds, as before. The silicious sediment consituting the phthanite which on the west side, is seen to underlie the ophiolite is, in this view, a portion of previously deposited and altered shale, while the phthanite on the east side is another portion of a similar sediment, subsequently laid down upon the ophiolite.

§ 101. The ophiolitic mass is thus, like all the other serpentines of Tuscany, of eocene age. The various rocks which enter into its constitution appear in the form of "lenticular masses or almond-shaped concentrations," of which the euphotide and the gabbros are examples. The gabbro-rosso is found in masses at the contact of the ophiolite with the phthanite, and results from the alteration of a diabasic rock by the action of thermal waters. These have also changed the galestro into the phthanite found both above and below the ophiolites, and in perfect conformity with the adjacent eocene strata, "which have all their distinctive characters, and present no traces of alteration or of metamorphism." "the action which produced the phthanites being local, particular, and variable." Recomposed rocks, made up of grains and fragments of serpentine, in a cement generally calcareous, are found on the confines of the serpentine and at its contact with the phthanite. This is especially seen at Poggio, on the southeast side of the hill, where I found a veritable conglomerate of fragments of serpentine imbedded in a paste of silicious slate. These facts, as well remarked by Capacci, show that previous to the deposition of these eocene beds, the serpentine-mass along the shores of a shallow sea, was subjected to a process of disintegration; "and that, moreover, the formation of the serpentine corresponds to a kind of pause in the deposition of the eocene strata." The ophicalcites, in like manner, are found at the limits of the serpentine, and are breccias or conglomerates with a calcareous cement.

§ 102. I have thus given, in great measure in language translated from Capacci's memoir, the principal facts observed at Monteferrato, which I have, for the most part, verified. They, however, appear to me inconsistant with the hypothesis propounded by the modern school of Italian geologists, and with the eocene age of the ophiolitic mass in question. The effusion of a great mass of aqueous material from the earth's interior into the eocene sea, its subsequent arrangement and crystallization into mountain-masses of euphotide, diorite and serpentine, the elevation of these, and their subsequent disintegration to form the ophiolitic sands and conglomerates already described, marks a geological period, and a revolution which ought to have left some traces in the surrounding eocene deposits. These, however, we are to believe, in accordance with the proposed hypothesis, continued after this event to be laid down precisely as before, the alberese and the galestro previous and subsequent to the ophiolite making with this one conformable series. This process moreover, we are told, was here confined to an area whose greatest extent was less than three kilometers, and was repeated at a great number of localities in the Italian tertiary basin, in all cases giving rise, not as in ordinary eruptions, to a single kind of rock, but to a group of different rocks, indistinguishable in character from those which are known to be found in contiguous regions interstratified in crystalline schists of eozoic age

§ 103. The only explanation which seems to me admissable, and one which is in complete harmony with the facts, is that this area of serpentine, with its associated euphotides, etc., was an eroded and uncovered mass in the midst of the eocene sea; that around its base was deposited the disintegrated material which forms the ophiolitic sands and conglomerates, followed by the silicious sediments which make up the phthanite, and by the limestones and shales of the middle eocene. The subsequent movements of the earth's crust, which caused the folding of these strata together with the intruding mass of eozoic rock upon and around which they were deposited, has resulted in the production of an overturned synclinal on the western side of the hill.

§ 104. As I have elsewhere insisted, * in cases like the present, where newer strata are found in unconformable superposition to older ones, the effect of lateral movements of compression involving the two series, is frequently to cause the newer and more yielding

* Geological Magazine (Jan., 1882), ix., 39.

strata, along their border, to dip towards or beneath the older rock. These overlying strata, where they abut against their marginal limit, which was the ancient shore-line, will, in the conditions supposed, assume, according to local circumstances, either an anticlinal or a synclinal form. In the former case, the inclination of the strata towards the older mass, which forms a resisting barrier, follows necessarily, even though the elevation of the arch be slight. In the case of a synclinal fold or inverted arch, we have the strata dipping away from the older rock at a greater or less angle, as seen at the eastern base of Monteferrato; the strata appearing in their natural order of superposition. When, as is frequently the case, this inclination passes beyond the vertical, giving rise to an overturned synclinal, the same strata will appear to pass in reversed order beneath the overhanging mass of older rock, as along the western border of Monteferrato. It is hardly necessary to recall the fact that sharp or inverted folds, whether synclinal or anticlinal, are often attended with dislocations and vertical displacements.

It may seem superflous to insist upon these obvious principles of geological dynamics, but I have had occasion to notice that they are sometimes overlooked or misunderstood even by teachers of the science to-day.

§ 105. Prof. Bonney who, as we have seen, holds to the igneous origin of ophiolites, finds in the manner in which portions of the stratified silicious rock rest upon the serpentine near Figline what he regards as a "complete proof" of the eruptive nature of the serpentine, placing "the intrusive character of the latter beyond all doubt," while he is also satisfied that the great mass of euphotide (included by him under the name of gabbro) is "intrusive in the serpentine."* Whatever view may be held of the origin of these two rocks and their relations to one another, the occurrence of the layers of recomposed ophiolitic rock (*arenaria ofiolitica* and *conglomerato ofiolitico*) interposed, as already described, between the ophiolitic mass and the beds of phthanite, and even, as I observed in one section along the southeast base of the hill, the presence of fragments of serpentine in this latter, forces us to the conclusion that these sedimentary strata were deposited upon the ophiolite, so that the theory of the eruption of the latter since the deposition of the eocene beds is untenable.

§ 106. The examinations which I have been able to make of the ophiolitic rocks of Eastern Liguria, where I spent a little time near Sestri Levante, under the guidance of Prof. G. Uzielli of Turin, was such as to leave no doubt in my mind that we have here, as maintained by Gastaldi, portions of an ancient stratified series rising out of the overlying eocene. In addition to the varieties of serpentine, and of euphotides, diorites, diabases, (the amphimorphic rocks of Issel and Mazzuoli) we find eurites, jaspers, epidotic and steatitic rocks, with occasional limestones, and various types of argillites, including the hypophthanites of these authors. The whole series, including its masses of pyrites, more or less cupriferous and niccoliferous, presents a close resemblance to the group of strata accompanying the serpentine of the Huronian series in Eastern Canada, with which I have long been familiar. These rocks are well seen along the valley of the Acquafredda, near which I found in an eocene limestone grains of the underlying serpentine, as also evidences of a considerable dislocation since the deposition of the eocene strata. My

* Geol. Magazine, Aug., 1879, vol. vi., p. 362.

observations at this point served to strengthen my conviction that the ophiolite of Monteferrato is also but a small protruding mass of the same series.

I was enabled subsequently, as already noticed, (§ 54) to examine with Signor Quintino Sella a portion of the ophiolitic series of admited eozoic age, as seen in the Biellese, in the province of Novara, and to confirm the judgments of Gastaldi, Cossa, Bonney and others as to the apparent identity of these ancient ophiolites with those found in Eastern Liguria.

§ 107. We have already described, in a former part of this paper, the mass of eozoic serpentine which, in Staten Island, New York, rises from out of the horizontal or gently inclined cretaceous and triassic strata that have been deposited around its base. If now we conceive this region to be subjected to such movements as those which, along the eozoic belt a little further south, have compressed the Primal and Auroral strata against the northwest base of the South Mountain, and given them a southeast dip, we should have a phenomenon not unlike that presented by Monteferrato ; that is to say, a lenticular mass of ancient serpentine rising along the outcrop of southeastward-dipping mesozoic rocks, and differing only by the accidental circumstance that these, on the two sides, belong to different mesozoic horizons (22, 23.)

VI.—The Genesis of Serpentines.

§ 108. As regards the origin of the serpentine-rocks, we have already noticed briefly some of the hypotheses which have been proposed. Although those which suppose it to be derived by metasomatic changes from aluminous or calcareous rocks, either exotic or indigenous, such as granites, diabases, granulites or limestones, may be considered as now nearly obsolete, it may not be amiss to recall the fact that they represent two distinct and opposite schools, which agree only in admitting an unlimited alteration or change of substance in previously-formed rocks, through aqueous agencies.

The first view, which may be described as a general metasomatic hypothesis adapted to plutonism, is that which derives not only serpentine but limestone from ordinary types of feldspathic rocks, such as granites, granulites, gneisses, diabases, and diorites. The integral conversion of all of these into serpentine by the complete elimination of the alumina, alkalies and lime, and the replacement of these bases by magnesia, has been maintained by many writers of repute belonging to the school in question. *

§ 109. Others still have supposed that the same rocks might be changed into limestone, by a complete removal of the silica, also, and the substitution of carbonate of lime. This extreme view has found its boldest and most consistent advocates in Messrs. King and Rowney, who not only assert this origin for the limestone-masses found in the gneisses of Sweden and the Hebrides, but imagine that the bedded crystalline limestones, many

* Bonney, who maintains the origin of serpentines by the hydration of eruptive olivine-rocks, has, in his paper already cited, given many reasons for rejecting the notion of the formation of serpentines by metasomatosis from the basic feldspathic rocks so often associated therewith. The observed relations of the two are, in his opinion, wholly opposed to this view, and he insists upon the difficulty of conceiving that such a process of change should be limited to certain parts of a great mass, while leaving adjacent portions unaltered. From their distinctness, he is even led to the conclusion that the serpentines and their accompanying euphotides and diorites belong to successive periods of eruption.

hundred feet in thickness, which are interstratified in the Laurentian gneissic series of North America, and have been traced in continuous lines of outcrop for hundreds of miles, have resulted from such an entire transformation of corresponding portions of the granitic, gneissic and pyroxenic rocks of the series. * These very ingenious writers further imagine that serpentine also, to which they assign, in accordance with the received views of this school, an origin by metasomatosis (or, as they call it, methylosis), from dolerite, melaphyre, diorite, euphotide, and other supposed plutonic rocks—is itself subject to a similar change into limestone. The existence of ophicalcites, the presence of masses of serpentine, and of such serpentinic structures as *Eozoon Canadense*, in limestone, are but so many evidences to them of a still uncompleted conversion of serpentine into limestone.

§ 110. Opposed to this view of the genesis of serpentines and limestones by change of substance, from plutonic rocks, is that which may be described as a general metasomatic theory adapted to neptunism, and which, recognizing the aqueous and sedimentary origin of limestone, would derive from it, by alteration, not only serpentine, but the various other silicated rocks mentioned above. Illustrations of this are seen in the suppesed conversion of limestone into dolomite, and of this last into serpentine, both of which views have found many advocates. The probable change of limestone into granite and into gneiss, was suggested by Bischof, and Pumpelly subsequently, in 1873, proposed to explain the genesis of the bedded petrosilex-porphyries or halleflintas of Missouri by the transmutation of a stratified limestone, of which portions are found interlaminated with the petrosilex. † He, at the same time, suggested a similar origin for the hematitic iron-ore which accompanies these porphyries.

§ 111. With this second hypothesis of the origin of serpentines may be mentioned another, not, however, involving metasomatosis, which has sometimes been discussed, and which was suggested by the present writer in 1857, from the results of certain experiments on the artificial formation of silicates of lime and magnesia by the reaction between carbonates of these bases and free silica in presence of heated solutions of alkaline carbonates. Such a reaction is not without its significance, and, as I have elsewhere shown, has doubtless played a part in the local development of protoxyd-silicates in sediments in the vicinity of igneous rocks, and of thermal alkaline waters; but as an explanation of the genesis of great masses of comparatively pure silicates, such as olivine, serpentine and steatite, it is obviously inadequate, and was abandoned by the writer in 1860 for the view maintained below. ‡ Even if we could suppose the presence of sedimentary beds containing the requisite elements in proper proportions, it can be shown that the reactions required for the production of silicates were inoperative in the very regions where serpentine and steatite are found, since side by side with beds of these are to be met with in the Huronian series, in many places, beds of dolomite and of magnesite intimately mixed with quartz, sufficient in amount, if combined, to convert the accompanying carbonates into corresponding silicates.

§ 112. There remain then to explain the origin of serpentine, besides the three hypo-

* See for a discussion of the views of this school the author's Chem. and Geol. Essays, pp. 324-325; also, An Old Chapter of the Geological Record, by King and Rowney, 1881, chapters vii. and xii.

† Geological Survey of Missouri, Iron ores, etc., pp. 25-27; also the author on Azoic Rocks, pp. 194.

‡ Chemical and Geological Essays, pp. 25, 297, 300.

thesis just noticed, three others already mentioned, to which we must again refer. First of these, we have that which supposes the material of serpentine to have come from the earth's interior as an igneous fused mass consisting essentially of olivine, which by subsequent hydration has been changed into serpentine. This strictly plutonic hypothesis being, however, by many geologists held to be incompatible with observed facts in the geognosy of serpentine, one which has been called hydroplutonic, and has already been set forth at length in these pages, has found advocates. These, conceding that the geognostical relations of serpentine require us to admit that it was laid down from water, have conjectured that a material so unlike that of ordinary aqueous sediments was ejected from the earth's interior, not in a state of igneous fluidity, but as an aqueous magma or mud, consisting essentially of a hydrous silicate of magnesia, which subsequently consolidated into serpentine, and even into olivine and enstatite. This view, as we have seen, is maintained by a school of Italian geologists, and Daubrée, while holding to the origin of serpentine by the hydration of a plutonic olivine-rock, supposes this to have passed into a hydrous condition before its ejection. *

§ 113. There are, however, no facts in the history of vulcanism to justify this strange hypothesis of an erupted magnesian mud. The materials known to us as volcanic muds and ashes do not differ essentially, as regards their constituent chemical elements, from other detrital matters, and the origin of this conjecture may perhaps be traced to the unfounded assumption that olivine is peculiarly a plutonic mineral, and that rocks in which it and other magnesian silicates predominate are presumably plutonic in their origin. It is at best but a survival of the belief in a subterranean providence, which could send forth at pleasure from its reservoirs alike granite and basalt, olivine-rock and limestone, quartz-rock and magnetite. A rational science, however, seeks for the origin of these various and unlike mineral masses in the operation of natural causes, and endeavors to explain their production in accordance with known chemical and physical laws. Enlightened geologists are now agreed as to the aqueous origin of limestones, of dolomites, of iron-oxyds and of quartz, by processes which are intelligible to every chemist, and the formation in the humid way of the native silicates of magnesia is equally simple and intelligible.

§ 114. It was, as already set forth in these pages, after a careful study of natural mineral-waters and sediments, and of the chemistry of artificial magnesian silicates, that the present writer, in 1860, ventured to assert the aqueous origin of the masses of native magnesian silicates, and their formation by reactions between the soluble silicates of lime and alkalies from decaying rocks and the magnesian salts of natural waters. † This view, although adopted by Delesse, as we have shown in § 11, and also, soon after by Gümbel, by Credner, and by Favre, ‡ has not found general recognition. I have, however, to record the recent adhesion to it of Dieulefait, the eminent chemist and geologist of Marseilles, whose arduous and original studies have already placed him in the front rank of students in terrestrial chemistry; and also of Stapff, the learned and acute geologist of the St. Gothard tunnel.

* Géologie Experimentale, p. 542.

† Hunt, Chem. and Geol. Essays, pp. 122, 296, 317.

‡ Ibid. pp. 304, 305, 317.

§ 116. The conclusions of Dieulefait, as to the sedimentary character of the serpentines of Corsica, have already been mentioned (§ 71). He rejects the plutonic hypothesis of the origin of serpentines for the following reasons: The frequent alternation of very thin beds of serpentine with others of schists and of limestone equally thin; the changes in the constitution and composition of the serpentinic layers; these, being in one place pure serpentine, become gradually mingled with carbonate of lime, which at length constitutes a large proportion of the rock, and also forms lenticular masses in the midst of the calcareous serpentines. To all these, which are common to the serpentines of North America, we may add, as noted elsewhere, the frequent occurrence of grains, nodules, layers or lenticular masses of serpentine in beds of crystalline limestone. Dieulefait notes, moreover, the absence of any signs of igneous action at the contact between the serpentines and the underlying schists. He next adverts to the hydroplutonic hypothesis, and pertinently asks on what grounds we are authorized to suppose the ejection of muds of magnesian silicate from the earth's interior.

§ 116. His own conclusion is that while these serpentines are sedimentary rocks in the most complete acceptation of the term, the mud or sediment which gave rise to them was not ejected from below, but was formed in estuaries of the sea, by reactions between the silicious matters derived from the decay of pre-existing rocks and the magnesian salts of the sea-water; in which connection he insists upon the frequent metalliferous impregnations of the serpentines, as derived in like manner from the older rocks. This view of Dieulefait's, set forth in 1880,* is, as Lotti remarks, no other than "the hypothesis enunciated by Sterry Hunt," twenty years earlier. Lotti, for his part, while still reserving himself on the question of the supposed tertiary serpentines of Italy, adds, after his own studies of those of Corsica: "In any case, it is impossible, as Dieulefait has said, to regard the phenomena offered by these ancient serpentines as due to eruptions either of igneous or hydroplutonic magmas. The serpentine has either been deposited as such, as maintained by Sterry Hunt, and by Dieulefait, or is a sedimentary rock subsequently altered." † We shall notice later on the views of Stapff on this subject.

§ 117. The masses of rock known as serpentine are far from homogeneous in composition. Apart from the admixtures of carbonate of lime, dolomite and magnesian carbonate, which often enter into their composition, they occasionally include besides the hydrated silicate, serpentine, the anhydrous species, olivine and enstatite or bronzite, and more rarely the hydrous species, talc; silicates differing widely in density, in chemical stability, and in the oxygen-ratios between the silica and the fixed bases; that for olivine being 1 : 1, for enstatite 2 : 1, for talc approximately 3 : 1, and for serpentine 4 : 3. These differences, in the hypothesis of the aqueous origin of serpentine, may well depend upon variations in the composition of the generating soluble silicates, and upon the balance of affinities between silicic and carbonic acids in the watery menstruum, rather than upon the subsequent transformation of one magnesian silicate to another by addition or elimination of silica or magnesia. The association, in the same mass, of anhydrous olivine with serpentine is generally regarded as evidence of the change of olivine into serpentine; but, while admitting the conversion, under certain conditions, of both enstatite and olivine into

* Comptes Rendus de l'Acad. des Sciences, xci. 1000.

† Lotti, Appunti Geologici sulla Corsica; Boll. R. Comitato Geologico, anno 1883.

hydrous silicates, the view which supposes the olivine or the enstatite to be simply an instance of the crystallization of an anhydrous silicate in the midst of an amorphous hydrous silicate, is more consonant with the hypothesis of the aqueous origin of serpentine-rocks. It is well known that Scheerer, from his studies of the associated olivine and serpentine of Snarum, was led to reject the notion of the derivation of this serpentine from a previously-formed olivine, and to maintain a simultaneous formation of the anhydrous and the hydrous silicates.*

A somewh.t analogous case is presented in the occurrence of grains of anhydrous alumina or corundum found in the earthy and amorphous aluminous hydrate, bauxite, which forms beds in uncrystalline cenozoic rocks.† The notion which has been advanced that the bauxite has come from the hydration of previously-formed beds of corundum is obviously untenable, and we must regard this anhydrous alumina as formed by crystallization in the midst of the uncrystalline mass of hydrated alumina. De Senarmont, in the decomposition of aqueous solutions of chlorid of aluminum, at 250° C. observed a simultaneous production of anhydrous alumina in the form of corundum, and of hydrous alumina as diaspore, both crystallized.‡

§ 110. The late studies of Arno Behr throw further light on the association of hydrous and anhydrous species. He has found that solutions of dextrose, within very narrow limits of temperature and concentration, yield crystals either of hydrated or anhydrous dextrose, and that under certain conditions we can obtain an admixture of the two. as the result of simultaneous crystallization. §

A illustration of the influence of small variations in composition on the result of a chemical process under conditions otherwise similar, is afforded by the recent experiments, of Friedel and Sarrasin on the artificial production of albite in the wet way. When a solution of silicate of soda mixed with silicate of alumina in the proportions required to form the soda-feldspar, was heated in close vessels to from 400° to 500° C., no albite was formed, but crystals of the hydrated double silicate, analcime; silica, soda, and some alumina remaining in solution. When, however, an excess of the alkaline silicate was employed, the whole of the silicate of alumina was converted into a crystallized anhydrous compound, which was albite. ‖

§ 119. Much obscurity still surrounds the question of the conversion of olivine into serpentine. In the first place, it is to be remembered that the process is one which does not, under ordinary circumstances, take place at or near the surface of the earth, since olivine-rocks, whether exotic masses or indigenous crystalline schists, are often met with, presenting no evidence of such change. This is well seen near Montreal, where the hills of olivine-dolerite, demonstrably of pre-Silurian age, as well as fragments of the same rock imbedded in Silurian conglomerates, alike contain only unaltered anhydrous olivine. This mineral, on exposed surfaces, is subject to a subaërial decay, analogous to that

* Scheerer, Pogg. Annalen. lxviii., 319, and Amer, Jour. Science [2] v. 389, vi., 201, also xvi., 217.

† Deville, An. de Ch. et de Phys. [3] lxi., 309, and Hunt, Origin of Some Magnesian and Aluminous Rocks.

‡ Comptes Rendus de l'Acad. des Sciences, 1856, xxxii., 762.

Amer. Jour. Sci., 1861 [2] xxxii., 281, also, Chem. and Geol. Essays, p. 326.

§ For these facts I am indebted to a private communication from Dr. Behr. See also, his paper in Jour. Amer. Chem. Soc., in 1882., vol. iv., p. 11.

‖ Comptes Rendus de l'Acad. des Sciences, July 30, 1883.

suffered by pyroxene and hornblende, by which the magnesia, and a large proportion of the silica, are removed, leaving a residue of ferric oxyd, as long since observed by Ebelmen. The change of olivine into serpentine must then be distinct from that going on under the influence of atmospheric waters near the surface.

§ 120. One hundred parts by volume of olivine, with a specific gravity of 3.33, if converted into a serpentine of specific gravity 2.50, without change in its content of silica, must lose one-eighth of its weight of magnesia, and acquire the same amount of water instead, while, at the same time, its volume will be augmented by one-third, or to one hundred and thirty-three parts. I have long since discussed this matter in connection with Scheerer's views as to the relations of these two mineral species, noticed in § 117. A simple hydration of olivine would yield, not serpentine, but villarsite.

Serpentine, when subjected to dehydration and fusion, yields, as was shown by the experiments of Daubrée, an admixture of enstatite and olivine, of which the former should contain one-third and the latter two-thirds of the fixed bases of the serpentine; the oxygen-ratio of these in serpentine being 4 : 3, while that of olivine is 2 : 2, and that of enstatite, 2 : 1. Since, however, the natural olivine-rock, as is well known, often contains little or no enstatite, it could not have been formed directly from the simple dehydration of a silicate like serpentine.

§ 121. In considering the hypothesis of the derivation of serpentine from olivine-rocks, such as the so-called dunite and lherzolite, the question of the geognostical relations of these at once presents itself. The frequent presence of ferriferous olivine in igneous rocks, and its artificial production in the furnace, have given rise to a notion that it is generally of igneous origin, which is not justified by a more extended inquiry. It is true that eruptive rocks sometimes contain a large proportion of this mineral, and one of the most remarkable cases of the kind is that presented by the granitoid olivine-dolerite long since described by me, which forms the hills of Montarville and Rougemont, masses of paleozoic age in the valley of the Richelieu, near Montreal, which have broken through the Utica shales of the New York system and converted them, near the contact, to a flinty rock. A portion of this rock from Montarville, consisting chiefly of black aluminous augite, labradorite and olivine, contained forty-five per cent. of its weight of the latter mineral in amber-colored crystals, sometimes half an inch in diameter, which were completely anhydrous, and contained 39.6 of magnesia, and 22.5 of ferrous oxyd * (§ 119.)

§ 122. The nearly pure magnesian olivine, which has been distinguished by the names of forsterite and boltonite, occurs abundantly disseminated in magnesian limestone in eastern Massachusetts, and sometimes forms the greater part of the rock. Its relations are similar to the fluoriferous magnesian silicate, chondrodite, with which it is associated at Vesuvius, and which is also found in crystalline limestones in eastern Massachusetts, as well as in those of the Laurentian series elsewhere, and is itself associated with serpentine. The grains of both chondrodite and serpentine are sometimes so arranged as to mark the stratification of the limestone; and in one specimen from an unknown locality, formerly described by me, two adjacent layers in crystalline limestone contain, the one, chondrodite, and the other, serpentine. † The analogies between the limestones holding chondrodite and

* Geology of Canada, pp. 464, 666.

† Geology of Canada, page 465. See also Geological Report for 1866, page 205.

serpentine, and those containing the pure magnesian olivine, forsterite, are very close, and their relations indicate for all of them a common neptunian origin.

§ 123. We pass from the olivine-bearing limestones to those rocks composed chiefly of olivine, which have received the names of dunite and lherzolite, and appear to be indigenous interstratified masses. Such was my conclusion after examining them in North Carolina, in strata referred by me to the Montalban series, regarding which I wrote in 1879: "Noticeable among the basic members of the terrane is the granular olivine or chrysolite-rock which, often accompanied by enstatite and by serpentine, appears to be interstratified in the micaceous and hornblendic schists of the Montalban in North Carolina and in Georgia." * Olivine-rocks, similar to those of North Carolina, have been observed among the crystalline schists in the province of Quebec, on the south side of the Gulf of St. Lawrence, but have not yet been carefully examined.

§ 124. The typical lherzolite from the eastern Pyrennees, described by Zirkel, has since been studied by Bonney, who in 1877 † described the rock and its locality. It forms several masses of considerable size, near Vicdessos (Ariège), and is in contact with a saccharoidal limestone, in which occur broad tongue-like portions of the lherzolite. This rock consists of olivine with admixtures of enstatite, diopside and picotite (a chromiferous spinel), the constituent minerals showing in their arrangement on weathered surfaces a "linear structure," suggesting "an internal parallelism," which Bonney, who looks upon the rocks as "igneous," regards as due to movements of flow. The rock varies from coarsely to finely granular in texture, and includes in some cases a serpentinic mineral in its joints. The dunite of New Zealand, in specimens before me, presents in the arrangement of the contained chromite, a well-defined gneissic structure.

§ 125. Similar rocks are found in Norway, specimens of which from Tafiord, received by the writer in 1878 from Prof. Kjerulf, were micaceous, and showed an evidently gneissoid structure. These rocks, consisting essentially of olivine, holding enstatite, diopside, chromite and a greyish mica, are found interstratified in gneiss, with quartzites and mica-schists, sometimes garnetiferous. From their late studies of this rock in various Norwegian localities, Tornebohm, Reusch, and Brögger agree that it must be classed among the crystalline schists, a judgment in which Rosenbusch concurs. The reasons for this conclusion, as set forth by Brögger, are briefly as follows: First, the invariably laminated structure of the olivine-rock, which is conformable to that of the enclosing gneiss; and, second, the variations in the composition of the rock itself, as seen in adjacent layers. ‡ With these gneissoid olivine-rocks of Norway may be compared the olivine known as glinkite, found in nodules in a talcose schist in the Urals, and also the schists lately described from Mount Ida in Greece. § In these, the transition is seen from true talc-schists to talc-schists containing more or less olivine, with pyroxene, and finally to massive olivine-rock; the whole being associated with other crystalline schists and with limestones. The obvious conclusion from all the above facts is that no argument in favor of the igneous origin of serpentine can be drawn from its supposed derivation from olivine-rocks, since these are themselves, for the greater part, of neptunian origin.

* Macfarlane's Geological Hand-book, page 13.

† Geological Magazine, Feb. 1877.

‡ Neues Jahrbuch für Mineralogie, 1880, i., pp. 187, 195, 197.

§ Science, Aug. 31, 1883, p. 255.

In this connection may be noted the well-known fact of the aqueous deposition of serpentine in veins, in the forms of marmolite, picrolite and chrysotile, either alone or with calcite. Such veins, the result of a secondary process, are often found intersecting ophicalcites and serpentine rocks at various horizons, and are even met with in comparatively recent serpentine-breccias, as noticed by Gastaldi (§ 42.)

VII.—Stratigraphical Relations of Serpentines.

§ 126. The contradictory opinions expressed by different observers as to the geognostical relations of serpentine-rocks in a given area—one regarding them as indigenous and another as exotic masses—make it evident that certain appearances are differently interpreted according to the theoretical point of view of the observer. In greatly crushed and displaced strata the varying resistance of unlike rocks undoubtedly gives rise to accidents which are regarded by many as evidences of posterior intrusions.

The serpentines and related rocks of Carrick in Ayrshire, Scotland, may be cited as another instance of this conflict of opinion. As described by James Geikie in 1866,* the serpentine and its associated greenstones are both indigenous bedded rocks interstratified with greenish crystalline schists which he, following Murchison, called altered Lower Silurian. Geikie, however, found what he regarded as clear evidence that these strata had been greatly disturbed while in a softened condition. The remarkable resemblance between these crystalline schists of Carrick and those associated with the serpentines of Cornwall, is noticed by Warrington Smyth. Bonney, in 1878, † rejected the conclusions of Geikie, asserting that we have in Carrick, as elsewhere, truly eruptive serpentines, followed by eruptive gabbros of two ages, and like Geikie, adduceed evidence in support of his own views.

§ 127. In a critical notice, in 1878, of Prof. Bonney's description of the serpentines of Cornwall and of Ayrshire, the present writer said: "When it is considered that there is abundant evidence that the North-American serpentines are indigenous, though often, like deposits of gypsum and of iron-ores, in lenticular masses; and further, that the movements which the ancient strata have suffered, have produced great crushings and displacements, it is not difficult to understand the deceptive appearance of intrusion which these rocks often exhibit, and which are scarcely more remarkable than the accidents presented by coal-seams in some disturbed and contorted areas." ‡

The alternately thickened and attenuated condition of coal-seams in such districts, and the forcing of the coal into rifts and openings in the enclosing sandstone-strata, is familiar to those who have studied the contorted measures of the Appalachian coal-field. The latter phenomenon especially is well displayed in one of the elaborate sections made since 1878 by Mr. Charles A. Ashburner, and just published by the geological survey of Pennsylvania, in which the so-called Mammoth-vein is shown as it occurs in the Greenwood basin of the Panther-Creek district.§ The accidents in this great forty-foot seam of anthracite, here represented on a scale of one inch to 400 feet, are such as would, in a rock of conjectured igneous origin, be deemed strong evidence of its intrusive character.

* Geol. Journal, xx., 527. † Ibid, xxxiv., 789.

‡ Harper's Annual Record, 1878, p. 293.

§ Second Geol. Survey of Penn., vol. I., Southern Coal-Field; Cross-Section Sheet ii., Section 10.

§ 128. We have already referred to the conclusions of Stapff with regard to the indigenous character and sedimentary origin of serpentines. The observations of this eminent engineer and geologist, while superintending the work of the tunnel through Mont St. Gothard, from Goschenen to Airolo, in the years 1873-1880, are set forth at length in his recent memoir accompanying a geological section, * which we have noticed in § 67. Lenticular masses of serpentine appear to the east and west of the tunnel, along the line of which they are intersected between 4.870 and 5.310 meters from the northern terminus. Having described at length the rocks of the section, he adds: "We have in what precedes said nothing of the structure of the serpentine, not only because, from a petrographic point of view, it is to be separated from the other rocks of the St. Gothard, but also because it evidently cuts these last, so that it might be considered as a rock intruded among them." Having stated in detail its relations, he tells us that "the boundaries of the serpentine-mass sometimes follow the stratification of the neighboring rocks, but sometimes go across it." Yet, he hastens to add, "we nowhere find plausible proof of the penetration of the serpentine-mass into the encasing rocks. This serpentine had originally the form of a flattened lenticular mass, intercalated conformably in the stratification (like the layers of eulysite in the gneiss of Tunaberg, in Sweden), and now appears, as the result of numerous breaks and displacements, outcropping in a series of little lenses, the line joining which intersects at a sharp angle the schistose lamination of the beds. Near to the fissures which, with displacements, cut the mass, the rock adjoining the serpentine is stretched out and pushed back (*étirée et refoulée*) both at the surface and in the interior of the tunnel."

§ 129. This displacement in one case, on the surface, was found equal to 450 meters, and the adjacent strata were bent in the form of an inverted C. The maximum thickness of the serpentine at the outcrop was 100 meters, and the thickness of 440 meters, which it attains in the line of the tunnel, is believed by the author to be due to the accumulation, by the movements described, of successive portions of one and the same lenticular mass: a conclusion which is illustrated by a great number of minute observations. He adds, "the fissures along which this heaping-together must have taken place, present striations produced by the sliding of the rock; they are coated with a steatitic matter, and sometimes filled with a friction-breccia. Farther proofs of this crushing are found in the abrupt discontinuity of the schistose and compact portions of the serpentine, and in the indented outline presented by the upper surface of the serpentine-mass; a detail not represented in the profile." The author farther says:—"Although we would not consider the serpentine to be an intrusive rock, we must remark that it could not have had precisely the same [mechanical] sedimentary origin as that which we have supposed for the micaceous gneiss which encloses it. We may regard it as originally a deposit of hydrated silicate of magnesia, formed by springs, and enclosed between the sediments which gave rise to the mica-schists." The hydrated magnesian silicate is supposed by our author to have been subsequently converted into anhydrous olivine, etc., which by a later hydration has generated serpentine, portions of olivine still remaining in the mass. It may be questioned whether the phenomena require this hypothesis of a double change for their explana-

* Profil géologique du St. Gothard dans l'axe du Grand Tunnel, sur une 1: 25,000, avec text explicatif, par Dr. F. M. Stapff, 4°, pp. 65, Berne, 1881.

tion. The serpentine contains imbedded, in some portions, not only olivine, but hornblende, talc and garnet. Intercalated with the serpentine, which is often distinctly stratified, are layers of schistose talc, of compact chlorite, of actinolite-rock, of ferriferous dolomite, and of mica-schist. The serpentine itself is chromiferous, and also contains magnetite.

§ 130. Dr. Stapff farther adds :—"The curious modifications of form which the mass of serpentine has suffered from the effect of faults, etc., correspond to those of the adjacent micaceous gneiss, but in the case of the former they have been better studied, for the reason that it is more easy to define the limits of these forms. If we suppose, in the section, in place of the serpentine, a mass of ordinary micaceous gneiss subjected to all the movements of displacement and elevation which we have here displayed, we should perceive nothing more upon the profile than a uniform surface of micaceous gneiss, with some interlacings of beds. It cannot, however, be denied that movements arrested by the hard and tough mass of the serpentine have produced in the neighboring rocks perturbations much more intense than would have resulted from similar movements acting upon a more tender rock," (loc. cit., pp 43-44.) It would be difficult to illustrate more clearly than Dr. Stapff has done, the manner in which movements in the earth's crust may effect interstratified masses of unequal hardness and tenacity, giving rise to accidents which simulate to a certain extent those produced by the intrusion of foreign masses, and may thus lead different observors, as we have seen, to opposite conclusions with regard to the geognostical relations of rocks like serpentine and euphotide.

VIII.—Conclusions.

The following are the chief points regarding serpentine and ophiolitic rocks which we have sought to set forth in the preceding pages :—

1. To show historically the diversity of opinions as to the geognostical relations of serpentine and related rocks, which have been regarded by some writers as eruptive and of igneous origin, and by others as aqueous and sedimentary.

2. To show how, from the hypothesis of their eruptive origin, came the application of that of metasomatosis, and also to set forth the hypothesis of the aqueous origin of serpentine, explaining how silicates of magnesia may, on chemical grounds, be looked for at any geological horizon.

3. To indicate the various horizons at which serpentines are found in North America; and first, those of the Laurentian, of the Huronian, and of the younger or Montalban gneisses; in which connection we have noticed the serpentines of Chester county, Pennsylvania, and those of New Rochelle, Hoboken, and Manhattan and Staten Islands, all of which are regarded as indigenous stratified rocks; the apparently intrusive character of the serpentine of the latter locality being explained.

4. We have further described the occurrence of serpentine among the Taconian rocks in Pennsylvania, and also among the gypsiferous rocks of the Silurian series at Syracuse, New York.

5. Having noticed some points regarding the nomenclature of serpentine and related rocks, and Bonney's account of the serpentines of Cornwall, and of parts of Italy, we have considered the serpentine-bearing rocks of the Alps, in which we show four great groups, in ascending order, which are the older gneiss, the pietre-verdi or greenstone-series, the

newer gneisses and mica-schists, and the still younger lustrous schists, corresponding respectively to the Laurentian, Huronian, Montalban and Taconian of North America; the second and third of these being the Pebidian and the Grampian of Great Britain. * Serpentines, it was shown, occur in the Alps interstratified in the second, third and fourth of these groups, the youngest of which includes the marbles of Carrara.

6. The view that this youngest group is mesozoic, is discussed, and the relations of all these groups of crystalline schists to the fossiliferous rocks of the mainland, and of those of Elba and Sardinia, are set forth, showing their pre-Cambrian age; while it is maintained that the ophiolites and other crystalline rocks which have there been referred to the tertiary are but exposed portions of these pre-Cambrian rocks.

7. The crystalline rocks of the Simplon and the St. Gothard, and those of Saxony and Bavaria, are considered and are compared with the younger gneisses of North America.

8. The relations of the so-called tertiary serpentines to the surrounding strata are elucidated by a detailed discussion of the mass of Monteferrato, in Tuscany, which is regarded as of pre-Cambrian or eozoic age.

9. The various theories proposed to explain the genesis of serpentines are considered, and that of their aqueous origin is adopted.

10. The geognostical history of olivine is discussed, and the essentially neptunian origin of many olivine-rocks, is maintained.

11. The contradictory views as to the geognostical relations of serpentine are considered, and an attempt is made to show that the appearances of intrusion, upon which some have insisted, are explained by subsequent movements of the strata in which the serpentines are included.

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* It remains to be seen whether the Arvonian series, which is essentially composed of stratified halleflinta or petrosilex-rocks, passing into quartziferous porphyries, and is largely developed at the base of the Huronian in parts of North America, and of Great Britain, is not represented in the Alps. Since we have seen the serpentines, lherzolites, euphotides, diabases, and even the marbles of the Alps and other regions, removed from the category of eruptive mesozoic and cenozoic masses, and shown to be regularly interbedded members of pre-Cambrian stratified series, it is, I think, a legitimate subject for inquiry whether the quartziferous porphyries which are so largely developed at Botzen, and elsewhere in the Alps, and have been regarded as eruptive rocks of Permian age, may not prove to belong to a stratified series, the equivalent of the Arvonian, with which, to judge from descriptions, analyses and specimens, they bear a close resemblance. For an account of these rocks of Botzen by one who regards them as plutonic, see Judd in the *Geological Magazine* for 1876, vol. xiii., pp. 200-214, and for details with regard to the history of the Arvonian series, see the author in 1880, *American Jour. Science*, [3]. (xix. pp. 274,278, et seq.)

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Note.—In printing the above paper, in October, 1883, the author has referred to results made known to him since it was presented in May, 1883; namely, the recent studies of Lotti, (§ 72, 73) and the experiments noted in §110.—[T. S. H.]