MEMOIRS

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ERRATA.

Page 6, 1st line, for "Wusiaceæ" read "Weissiaceæ."
" 6, 9th line, from top for "Weisia" read "Weissia."
" 7, 21st " " " " "Breverianum" read "Brewerianum."
" 15, 16th " " " " "heterostychum" read "heterostichum."
" 26, 9th " " " " "thyphylla" read "ithyphylla."
" 32, 10th, 18th, 19th " " " " "Breverianum" read "Brewerianum."
" 34, 3d " " bottom for "Eurynchum" read "Eurhynchum."
" 37, 5th " " top " "commulatum" read "commutatum."
" 37, 10th " " " " "Rhitidium" read "Rhytidium."

MEMOIRS

PRESENTED TO THE CALIFORNIA ACADEMY OF SCIENCES.

VOLUME I.

I. *A Catalogue of the Species of Mosses found, up to the present time, on the North-West Coast of the United States, and especially in California.*

By LEO LESQUEREUX.

[Presented Dec. 2d, 1867.]

PRELIMINARY NOTICE. This catalogue comprises all the species of Mosses found, up to the present time, so far as I know, on the western coast of North America, from the Mexican boundary to British Columbia. Most of the species are from California, gathered there by Dr. Bigelow, and Messrs. W. H. Brewer and H. N. Bolander of the State Geological Survey. It is to the last-named gentleman that the Bryology of the State of California is chiefly indebted. To render this list more complete, I have admitted into it the species collected by Dr. Lyall, in Oregon, on the Northwest Boundary Survey, along the 49th parallel, from the western base of the Rocky Mountains to Vancouver Island included.

I have not attempted, in this enumeration, to suggest any peculiar system of nomenclature or classification; but have merely followed what I considered the most natural grouping, copied from the "Bryologia Europaea," and from Schimper's Synopsis of European Mosses. New systems of classification are now originated in bryologic science, as it appears to me, for the mere satisfaction of their authors, and without the slightest advantage to science. Indeed, these new systems have had a most baneful influence on the study of this most interesting department of botanical science. A discussion of their merits—or rather, their demerits—will, especially in a catalogue like this, be useless.

Some species of mosses, considered as new and distinct by authors of high reputation, are included in this catalogue as mere varieties. The flora of California, in all its departments, is liable to great local varieties, according to the peculiar atmospheric and chemical conditions to which it is subjected. The more the phaenerogamic flora of that region is studied, the more the number of species is diminished. Having had access to a very large number of specimens—thanks to Mr. Bolander's zeal in collecting—I have been able to compare forms from different stations, and to see characters considered by others as indicating difference of species, blended together, sometimes even on the same specimen.

To prevent repetition of references, I will merely say that the species mentioned from Mr. Mitten, have been published in his Bryologia of the 49th Parallel of Latitude, in the *Proceedings of the Linn. Soc. of London, Bot., Vol. VIII,* — ; the species from Hampe in a pamphlet, *Musci Californici Novi*, 1860 ; those of Muller, not included in his synopsis, in the *Bot. Zeitung, No.* 40 ; those of Sullivant in *the Reports of Lieut. A. W. Whipple's and Chs. Wilkes' U. S. Expeditions ;* and those of myself in *the Transactions of the Amer Philos. Soc. of Philadelphia, Vol.* 13. A few species given with short diagnoses in the *Musci Exsiccati Americani, Ed. 2d.*, by *Sullivant and Lesquereux*, are here copied from this work, which has been published in a limited number of copies, and which is not therefore accessible to every bryologist.

As this enumeration is intended as a representation of our actual knowledge of the Bryology of the west coast of the United States, I have carefully mentioned the habitat of the species, and the names of the botanists who have gathered them.

COLUMBUS, O., 30th March, 1867.

CATALOGUE.

MUSCI.

SPHAGNEÆ.

SPHAGNUM, Dill.

1\. **S. acutifolium,** Ehrh.
Hab. Sierra Nevada; Upper Tuolumne Cañon; foot of Mt. Dana, 8,000 to 9,000 feet, *Bol.*

2\. **S. fimbriatum,** Wills.
Hab. by a brook, at about 11,000 feet on Mt. Brewer, *Brew.*

3\. **S. rigidum,** Schp.
Hab. Yosemite Valley, hillsides, in the spray of the Vernal Falls, *Bol.*

Var. *B. compactum,* Schp.
Hab. rivulets, foot of Mt. Dana, *Bol.*

4\. **S. squarrulosum,** Lsqx Ms.
S. squarrosum, var. B. Schp.
Hab. head of William Lake, near Lassen's Peak, about 5,000 ft., *Brew.*

The first Sphagnum found in California. On this species Prof. Brewer remarks: "It forms a large bog, and is the only Sphagnum I have yet seen in the State "in more than 13,000 miles of peregrinations."

The true value of this species is still uncertain. In his remarkable *Mémoire pour servir à l'histoire des Sphaignes,* (1857) W. P. Schimper mentions it as possibly a small marked form of *S. squarrosum,* Pers., and in his *Synopsis Muscorum Europæorum,* (1860) he joins it to this last species as *var. B.* The far different facies, long, slender branches, similar to those of some forms of *Sphagnum cuspidatum,* Ehrh.; the longer, narrower leaves, also indicate a specific difference. By details of analysis, *S. squarrulosum* shows indeed in the cross-sections of the leaves the same kind of reticulation as *S. squarrosum,* viz: large, round, primary cells with intermediate, elongated, narrow oval ones. But this is the only affinity; and even the cells are narrower in *S. squarrulosum,* and accordingly the leaves are proportionally thinner. The nearest relative to this still uncertain species is *S. rigidum,* Schp. One of its varieties, from the Racoon Mts. of Alabama, with branch leaves contracted above the middle and the point reflexed, is much like it, our species differing merely by more acute branch leaves and a broader reticulation of the stem leaves—differences of little importance. Therefore if *S. squarrulosum* should be united to any species as a variety, it would rather go with *S. rigidum*. But it is better to let the species stand as it is till its fruit is known, and it can be thus thoroughly studied. It is right to remark also that it was originally found in the bogs of the Jura Mountains, of Switzerland, where *S. squarrosum* has never been seen. For this species more generally inhabits the bogs and streams of primitive rocks, and not the limestone.

5. **S. subsecundum,** Nees & Hrnsch.
Hab. wet meadows, Mariposa Big Trees, *Bol.*
Var. B. *longifolium*, ramis attenuatis longioribus, foliis angustis lanceolatis, elongatis.
Hab. Mendocino City, swamps, *Bol.*

6. **S. auriculatum,** Schp.
Hab. in swamps, 8,000 to 9,000 ft., between forks of King's River, *Brew.* In pools, near Mendocino, *Bol.*

The form from Mendocino has a peculiar facies, which is not seen in any European specimens. The leaves are longer and narrower, the branches more slender and attenuated, similar to those of the floating large varieties of *S. cuspidatum*. But it has the lanceolate-pointed shape of the leaves, especially the loosely reticulated branch leaves, and the stem leaves with fibrillose stems filled with very numerous round small pores, a character ascribed by Schimper to this species only. The differences may be considered as mere local variations. In the California moss the auricles of the stem leaves are not more developed than they are generally in *S. subsecundum*.

7. **S. cymbifolium,** Ehrh.
Hab. swamps near Mendocino City, *Bol.*

PHASCACEÆ.

EPHEMERUM, Hampe.

8. **E. serratum,** Hampe.
Hab. on the ground in fields and meadows, Mission Dolores, *Bol.*

SPHÆRANGIUM, Schp.

9. **S. muticum,** Schp.
Hab. with the former, *Bol.*

This species has not yet been found, to my knowledge, in the Atlantic States, where it is represented by an intermediate form equally referable to both *S. muticum* and *S. triquetrum*, Schp. It is *S. triquetrum*, var. No. 31, of the Musci Exsicc. Amer., Ed. 2d.

PHASCUM, Schreb.

10. **P. cuspidatum,** Schreb.

Hab. with the former, *Bol.;* with var. *piliferum*, Fort Colville, *Lyall.*

11. **P. bryoides,** Dicks.

Var. B. *piliferum*, Schp. Synop.

Hab. south side of hills of Oakland, *Bol.*

A few specimens only were sent, mixed with *Anacalypta Starkeana* and *Weisia viridula.*

PLEURIDIUM, Brid.

12. **P. subulatum,** Brch. & Schp.

Hab. ditches and dry hills, San Rafael, *Bol.*

By the form of the capsule and of the leaves, the California moss is referable to *P. alternifolium*, Brch. and Schp. Even the two years' old plants bear slender innovating branches with short distant leaves, similar to the flagelliform branches of *P. alternifolium.* Yet. the inflorescence is that of *P. subulatum*, the anthers being free in the axils of the upper leaves.

BRUCHIA, Schwægr.

13. **B. Bolanderi,** spec. nov. Monoica, dense gregaria, cæspitulosa, pallide virescens. Caulis brevis, vix linearis, basi tantum radiculosus, simplex. Folia caulina remota, minuta, lanceolata; comantia erecto-aperta lanceolata, brevi subulata, costa plana sub apice obscure et obtuse serrulato desinens, reti basilari quadrato-elongato, apiciali angustiore distincto; folia perichætialia late ovata, amplectentia tubulosa, externa breviter acuminata, interna lanceolato-subulato erecta, caulinis duplo longiora, reti laxiore. Capsula in pedicello robusto, semipollicari subflexuoso erecta vel subobliqua, e collo elongato pallide viridi oblonga angusta, virescens, in rostrum rectum pallidumque producta; calyptra tertiam partem capsulæ obtegens, basi laciniata. Inflorescentia vere monoica sed primo intuitu dioica videtur, caule primario repente, radiculoso masculas, femineasque gemmas radiculosas gestante. Flores masculi crassiores, foliis perigonialibus internis brunneis, ovato lanceolatis acutis, obsolete nervosis.

Hab. near Big Tree Grove, Mariposa; Westfall's Meadow, 8,000 ft. *Bol.*

It is not easy to separate this species from *Vogesiaca*, Schw. The inflorescence is the same; at least, male and female buds bear in their position the same relation. The long pedicel, the form and color of the capsule, are also similar. The difference is essentially in the shorter stems, shorter leaves, the shorter beak, and especially the longer collum of the capsule. The pedicel is thicker than in the European species, slightly flexuous when dry, straight when moistened. The color of the plants is of a pleasant pale green.

WUSIACEÆ.

GYMNOSTOMUM, Brch. and Schp.

14. **G. calcareum,** Nees and Hrnsch.
Var. *perpusillum*, Sulliv. Whipple's Exped. p. 185.
Hab. on clayey soil, near San Francisco, *Big.*

15. **G. curvirostrum,** Hedw.
Hab. on wet rocks, Leroux Springs, base of San Francisco Mts.; Mogollon Ridge, *Big.*

WEISA, Hedw.

16. **W. viridula,** Brid.
Hab. on the ground, at and around San Francisco, *Bol.*, *Big.*
Var. capsulis longioribus, ovato-cilindricis, regulariter plicato-striatis, viridibus.
Hab. on the ground, San Francisco, *Bol.*

17. **W. cirrhata,** Hedw.
Hab. region of the Redwoods, common, especially on burnt and decayed wood; Big Trees, etc., *Bol.*, *Big.;* Vancouver Island, *Lyall;* N. W. America, *Douglas.*

18. **W. crispula,** Hedw.
Hab. Galton Mts., near Fort Colville, *Lyall.*

DICRANUM, Auct.

§ 1. CYNODONTIUM, Schp. Syn.

19. **D. polycarpum,** Ehrh.
Hab. Cascade Mts., Lyall.

20. **D. virens,** Hedw.
Var. G. *serratum*. Schp. syn.
Hab. Tuolumne Cañon and Mono Pass, 9,000 ft., borders of snow-water streams, *Bol.;* Galton Mts., *Lyall*, alt. 6,000 to 7,000 ft.

21. **D. crispum,** Hedw.
Hab. Galton Mts., *Lyall.*

§ 2. DICRANELLA, Schp.

22. **D. varium,** Hedw.
Hab. on perpendicular sandstone rocks, watered by springs, near the bay of San Francisco, *Bol.*

23. **D. subulatum,** Hedw.
Hab. foot of Mt. Dana, 8,000 to 10,000 ft., borders of ditches and streamlets, *Bol.;* Galton Mts., *Lyall.*

24. **D. heteromallum,** Hedw.
Hab. slopes of a ditch cut through a bog, edge of the redwoods near Big River City, *Bol.;* Cascade Mts., *Lyall.*

§ 3. DICRANUM, Schp.

25. **D. strictum,** Schl.
Hab. coniferous trees, Devil's Cañon, Forest Hill, *Bol.;* Fort Colville, *Lyall.*

26. **D. albicans,** Brch. and Schp.
Hab. N. W. America, *Douglas.*

27. **D. fuscescens,** Turn.
Hab. Redwoods, Bol.; Spokane River, Oregon, *Wilkes' U. S. Exp.;* Galton Mts., *Lyall.*

28. **D. scoparium,** Lin.
Hab. Oregon, *Wilkes' Exp.;* and a var. foliis vix denticulatis, in California? *Bol.*

29. **D. palustre,** Lapyl.
Hab. Pend' Oreille, *Lyall;* Vancouver Island, Wood. *Mr. Bolander* has sent it from Eureka, Humboldt County.
Var. foliis angustioribus, lævibus, falcato-secundis, areolatione longiori. *D. Brewerianum,* Lsqx. in litter.
Hab. Deep Cañon, Klamath River, *Brew.*

This variety is remarkable enough to be considered a proper species. Besides the characters indicated above, it differs from *D. palustre* by its shorter stems, its narrow, not at all, or scarcely undulate leaves, its more incurved, and more slender, and longer capsule, the great quantity of male plants intermixed in the cæspites. The male plants are slightly more slender than the fertile ones; the flowers large, terminal, or lateral by innovations; the perigonial leaves broadly ovate, narrowed into a pretty long point and nerved.

30. **D. majus,** Schwaegr.
Hab. Fort Discovery, Oregon, *Wilkes' U. S. Exped.*

FISSIDENS, Hedw.

31. **F. limbatus,** Sulliv.
Hab. on shaded ground, near Oakland; common around San Francisco, *Bol., Big.*

32. **F. ventricosus,** spec. nov. Monoicus, robustus, laxe lateque cæspitosus, cæspitibus nigricantibus, innovationibus junioribus apice tantum atro-viridibus. Caulis ultra pollicaris, e basi divisus, divisionibus simplicibus vel parce ramosis. Folia multijuga, conferta, erecto-aperta, cultriformia, duplicatura di-

latata ad mediam laminam verticalem procedente, margine crasso, gibboso, plerumque cum costa crassa in apiculum muticum confluente, raro sub apice cum costa evanido. Areolatio ovato-quadrata vel irregulariter polygona, minuta. Flores utriusque sexus terminales; folia perigonalia late ovata, sub lamina verticali apiculiformi irregulariter dissecta; folia perichætialia conformia. Capsula in pedicello brevissimo, vix exserta, erecta, obovata, in pedicello attenuata, obscure viridis. Peristomii dentes erecti latiores; sporæ ovales magnæ.

Hab. on submerged rocks, Mendocino City, *Bol.*

By the ventricose or enlarged duplicature of its leaves, this species resembles *F. rufulus*, Brch. & Schp. In our species the leaves are more obtuse, and generally entirely surrounded by a thick margin like those of *F. rivularis* of the same authors. It is only in the upper leaves of new branches that the leaves appear similar to those of *F. rufulus*. The division of the stems is generally from near the base and dichotomous, sometimes the primary divisions being divided again near the top in short branches. The axils of all the leaves bear tufts of radicles. The specimens sent to me had but one capsule, already deoperculate.

33. **F. adiantoides**, Hedw.
Hab. Fort Colville. *Lyall.*

33*a*. **F. grandifrons,** Brid.
Hab. sea-shore, Mattole District, Humboldt Co.; rocks over which spring water flows constantly, *Bol.*, June, 1867.

POTTIACEÆ.

POTTIA, Ehrh.

34. **P. subsessilis,** Brch. & Schp.
Hab. Los Angeles. *Big.*

35. **P. cavifolia,** Ehrh.
Hab. Fort Colville, *Lyall.*

36. **P. minutula,** Brch. & Schp.
Hab. Los Angeles, *Big.*

37. **P. Heimii,** Hedw.
Hab. ditches near the Soda Springs, alt. 9,000 ft., *Bol.*

ANACALYPTA, Roehl.

38. **A. Starkeana,** Nees & Hrnsch.
Hab. Mission Dolores, Oakland, etc., on clayey ground, *Bol.*

DIDYMODON, Hedw.

39. **D. rubellus,** Brch. & Schp.
Hab. Tuolumne Cañon, near Soda Springs, 9,000 ft.; foot of Mt. Dana, *Bol.*

DISTICHIUM, Brch. & Schp.

40. **D. capillaceum,** Brch. & Schp.
Hab. on shelving rocks, between Vernal and Nevada Falls, Yosemite Valley, *Bol.*, rare; Cascade Mts., *Lyall.*

41. **D. inclinatum,** Hedw.
Hab. Soda Springs, *Bol.*

CERATODON, Brid.

42. **C. purpureus,** Brid.
Hab. California, common, *Bol.*, *Brew.*, *Big.*; spray of Nevada Falls on rocks, *Bol.*; Vancouver Island, *Lyall.*
Var. *B. xanthopus,* Sulliv. & Lsqx.
Hab. on *Sequoia sempervirens,* extremely common; also, Big Trees, *Bol.*, *Big.*

LEPTOTRICHUM, Hampe.

43. **L. Schimperi,** Spec. nov. Monoicum, subcæspitosum, subsimplex, humile lutescente-viride. Folia patentia, flexuosa, vel falcato-secunda, e basi ovata, lanceolata, subulata, valde elongata, angusta, apice tantum subdenticulata, costa tenui vix totam subulam occupante percursa. Perichætii elongati folia late amplectentia, interna tubulosa, in subulam longiorem attenuata. Capsula in pedicello vix ultra pollicari lutescente, robusta, erecta, ovato-cylindrica brunnea, operculo elongato conico recto vel subobliquo. Peristomii dentes in membrana basilari lata fugaci pulcherrime aurantiaca vel rubella, gracillimi, pallide-lutei filiformes, læves, versus basim unocrure diviso tripartiti vel trabeculati. Annulus latior vix mediam partem membranæ attinens. Sporæ maximæ.
Hab. Coast Range, Mendocino, *Bol.*

This species much resembles *L. pallidum,* Hmp. But, besides the difference in the peristome, it is easily distinguished by its green color—the shorter, broader capsule borne on a shorter, thicker pedicel, having a longer, dark-red operculum. The leaves, also, of our species are much longer; their basilar reticulation larger, etc. The male flowers are gemmiform, axillary, and their leaves large, ovate, short, lanceolate, obtuse.

44. **L. flexicaule,** Schwægr.
Hab. Cascade Mts., *Lyall.*

TRICHOSTOMUM, Hedw.

45. **T. rigidulum,** Smith.

Hab. on rocks subject to overflow on Russian River, opposite Ukiah, *Bol.;* Vancouver Island, *Lyall.*

46. **T tophaceum,** Brid.

Hab. limestone rocks, constantly watered by a spring, Ukiah City; Fort Point, etc., *Bol.;* Cajon Pass, *Big.*

47. **T. anomalum,** Schp.

T. corniculatum, Wahl.

Hab. Oakland Cañon, *Bol.;* a few sterile stems mixed with *Hypnum leuconeurum;* Vancouver Island, *Lyall;* California, *Coulter.*

48. **T. flexipes,** Brch. & Schp.

T. crassinerve, Hmp. Musc. Calif.

Hab. in shaded grounds and decayed trunks, *Bol., Big., Bauer;* near San Rafael, and also in the mountains of the Coast Range, Mendocino, *Bol.*

DESMATODON, Brid.

49. **D. Californicus,** Spec. nov.

D. nervosus, var. B. *edentulus,* Sulliv. & Lsqx., Musc. Exsicc. Amer., 2d Ed., No. 121.

D. nervoso proximus, differt: caule breviore, foliis confertis, arctius imbricatis, brevi-acutis, vel nervo sub apice evanido obtusis, nervo medio inflato latiori, peristomii dentibus albidis, capsulo annulato.

Hab. on decayed ground and old walls of clay, (adobe) San Francisco, *Bol.*

Though the differences between both species are slight, the presence of an annulus, the broader, more inflated costa of the shorter generally obtuse leaves, appear the specific characters of the California moss.

50. **D. latifolius,** Hedw.

Hab. slopes of Tuolumne Cañon, *Bol.*

Var. *B. muticus,* Brch. & Schp.

Hab. Mt. Dana, 11,000 to 11,500 feet; Tuolumne Cañon, *Bol.;* Silver Valley, on exposed soil, 8,000 to 9,000 feet, *Brew.;* common in the mountains along water courses, Cascade Mountains, *Lyall.*

51. **D. systilius,** Brch. & Schp.

Hab. foot of Mt. Dana, *Bol.*

52. **D. Guepini,** Brch. & Schp.

Hab. on the ground, bank of a run, Oakland, *Bol.*

BARBULA, Hedw.

53. **B. membranifolia,** Hook.
Hab. dry ravines on William's Fork of the Great Colorado, *Big.*

54. **B. chloronotus,** Schultz.
Hab. same as the last, *Big.*

55. **B. fallax.** Hedw.
Hab. Cajon Pass, Sierra Nevada; also, near San Francisco, *Big.*

56. **B. subfallax,** Muller, Bot. Zeit. No. 40, p. 338.
Hab. San José Valley, *Bauer.*

57. **B. semitorta,** Sulliv., Whipple's Rep.
Hab. California, *Big.*

58. **B. brachyphylla,** Sulliv., ibid.
Hab. California, *Big.*

59. **B. artocarpa,** Lesqx.
Hab. Redwood Hills, Coast Range, Ukiah, etc., *Bol.*

60. **B. vinealis,** Brid.
Hab. near San Francisco, on the ground and stones, *Bol.*, *Big.*

61. **B. rubiginosa,** Mitt.
Hab. N. W. America, *Douglas.*

62. **B. insulana?** De Not.
Hab. California, *Beechy.*

A remarkable form, perhaps referable to this species, has been collected by Mr. Bolander, on gravelly soil, near the Big Trees. It is subcæspitose, with a robust stem branching by innovations generally in two, opposite, from one-half to one-inch long. Its color is brownish yellow; the leaves when dry are appressed or slightly tortuous, open-erect by humidity, loosely imbricated, ovate lanceolate, very entire, revolute on the borders, with a strong excurrent nerve-forming point; the basilar reticulation is equilateral, elongated, pellucid; in the upper part of the leaves, the areolæ are opaque, minute and minutely papillose. The capsule borne on a short, straight, reddish pedicel of half an inch long, is large, oblong, of a reddish color, with an erect pointed operculum half the length of the capsule. The teeth of the peristome are red, twice twisted on a short membrane; the annulus is double, pellucid or white; the male flowers terminal and thick. This form is more robust than any other of the section of the *Vineales*, and is easily distinguished by its appressed, scarcely twisted leaves, its thick, brown, reddish capsule on a proportionally short pedicel. The form and areolation of the leaves are like those of *B. vinealis*; but the peristome is twisted twice and dark red. The forms of this section of *Barbula* found in California are so numerous, that it will be necessary to reduce them to a few species, or to make a monograph of them, embracing more than one dozen species. I have only mentioned in this catalogue the most marked forms.

63. **B. flexifolia,** Hmp.
Hab. on sandy ground and boulders near the coast, San Francisco, *Bol.*, *Bauer.*

64. **B. virescens,** Lesqx.
Hab. same as the former, *Bol.*

65. **B. convoluta,** Hedw.
Hab. gardens in San Francisco; burnt logs, Ukiah, *Bol.:* Oakland, *Big.*

66. **B. cuneifolia,** Brid.
Hab. clay soil, Oakland, *Bol.*

67. **B. Wahliana,** Schultz.
Hab. Cajon Pass, Sierra Nevada, *Big.:* Mt. Diablo, *Bol.*

68. **B. Bolanderi,** Lesqx.
Hab. on rocks, near San Francisco, *Bol.*

69. **B. amplexa,** Lesqx.
Hab. on sandstone around springs, in water, *Bol.*

70. **B. marginata,** Bryol. Eur.
Hab. on rocks near San Francisco, mixed with *B. flexifolia*, *Bol.;* on dry rocks, *Big.*

71. **B. brevipes,** Spec. nov. Dioica, gregaria vel cæspitulosa. Caulis brevissimus, simplex. Folia in comam conferta, lingulata, vel oblongo-cuneiformia obtusa margine revoluta, superne concavo-carinata, costa in pilum sublæve excunte instructa, reticulatione basilari laxa, pellucida, quadrato-elongata, apicem versus compacta obscura irregulariter rotundata, chlorophillosa, papillosa. Capsula in pedicello longiori elongata, cylindrica, gracilis, subincurva, operculo longe conico obtusiusculo. Peristomii dentes arcte convoluti, sanguinei, in membrana longa quadrato-tessellata suffulti. Flos masculus in planta graciliori terminalis foliis perigonialibus brevibus-latioribusque.
Hab. on mud walls, Mission Dolores, in mats one inch in diameter or more; divide of the Russian River, *Bol.*

This species is similar in appearance to *Barbula marginata,* but widely different in its non-marginate leaves, and its capsule and peristome, which are syntrichial.

72. **B. subulata,** Lin.
Hab. Big Tree grove, *Bol.:* dry ravines on Big William's Fork of the Rio Colorado, *Big.*

73. **B. inermis,** Brch.
Hab. base of mountains west of the Rio Colorado, *Big.*. Sent also by Bolander without label.

74. **B. lævipila,** Brid.
Hab. railroad levees, Sacramento, *Bol.:* Vancouver Island, *Lyall.*

75. **B. latifolia,** Brid.
Hab. on *Alnus viridis,* borders of a creek near San Rafael, *Bol.*

76. **B. ruralis,** Hedw.

Hab. on rocks and trunks of trees from the plains to the mountains, very common, *Bol.*, *Big.*, *Brew.*, *Lyall.*

Var. *gigantea*, caule elongato, foliis e basi squarroso reflexis; areolatione papillosa, papillis elongatis, furcatis; costa dorso spinuloso-rugosa.

Hab. on moist rocks, Yosemite Valley, *Bol.*

77. **B. Muelleri,** Brch.

Hab. same as the former, especially common in the plain, *Big.*, *Bol.*, *Brew.*, *Lyall.*

GRIMMIACEÆ.

GRIMMIA, Ehrh.

78. **G. Scouleri,** C. Mull.

Scouleria aquatica, Hook.

Hab. on granite rocks in Merced River, at Clark's, near the Big Trees, sterile, *Bol.*; in Columbia River, near Fort Colville, *Lyall.*

79. **G. conferta,** Funk.

Hab. on metamorphic rocks, Mt. Diablo, *Bol.*; rocks in cañons near Green Valley, *Brew.*

80. **G. apocarpa,** Hedw.

Hab. on rocks, Yosemite Valley, *Bol.*; crossing of the Colorado, on rocks, *Big.*; N. W. America, *Lyall*, *Douglas.*

Var. *rivularis*, Brch. & Schp.

Hab. on wet rocks, Yosemite Valley, *Bol.*

81. **G. pulvinata,** Smith.

Hab. on metamorphic limestone-boulders, near Russian River, Ukiah; around Clear Lake, *Bol.*; rocks on Bill William's Fork, *Big.*; Fort Colville, *Lyall.*

82. **G. contorta,** Wahl.

G. uncinnata, Kaulf.

Hab. Big Tree grove, *Bol.*

I have received one specimen only with deoperculate capsule. The form of the leaves, their reticulation, the black color of the plants, and the small, slightly inclined capsule, mark the identity of this species.

83. **G. Muhlenbeckii,** Schp.

Hab. on a rock, specimen from Mt. Dana, 11,500 feet, *Bol.*

84. **G. trichophylla,** Grev.

Hab. on rocks, Redwood hills, common in California, *Bol.*, *Big.*; Vancouver Island, *Lyall.*

85. **G. ancistrodes,** Dur. & Mont.

Hab. on rocks, Dardanelles Cañon, *Bol.*

It agrees in every point with Muller's description of this species.

86. **G. Californica,** Sulliv.

Hab. on rocks, San Rafael, and around San Francisco, common, *Bol.*, *Big.*

Var. foliis caulinis obtusiusculis vel acutis, epiliferis, capsula subglobosa, operculo longiore.

Hab. same as the normal form, *Bol.*

87. **G. hamulosa,** Spec. nov. Dioica, irregulariter laxe pulvinata, nigricans. Caulis dichotome et innovante ramosus, subfasciculatim foliosus. Folia sicca homomallo-falcata, madefacta erecta hamuloso-incurvata, subhomomalla, laxe irregulariter imbricata, anguste lanceolato-subulata, apice plano obtusiuscula, carinato-concava, margine plana vel vix revoluta, nervo valido sub apice evanido intructa, reti basilari quadrato elongato, superiori irregulariter quadrato. Folia perichaetialia longiora, longius acuminato-subulata. Theca in pedicello laterali medio curvulo, emersa, ovalis, lævis, pachydermis, brunnea, operculo conico brevi; peristomii dentes breviores, lacerati vel perforato divisi, annulo nullo.

Hab. gravelly soil, Mt. Dana, 10.000 ft., *Bol.*

It resembles *G. contorta*, Wahl., but is very distinct indeed by the hamulose and homomallous leaves, with long, subulate, opaque points; by the large emerged capsule, the curved pedicel, the absence of an annulus, etc.

88. **G. leucophæa,** Grev.

Hab. metamorphic rocks, Dardanelles Cañon, *Bol.*; Fort Colville, *Lyall.*

89. **G. montana,** Brch. & Schp.

Hab. on rocks from the plain to the mountains; boulders near San Francisco, Mt. Diablo, Mono Pass, 7,000 to 8,000 ft., *Bol.*

90. **G. alpestris,** Schl.

Hab. Fort Colville, and Pend' Oreille, *Lyall.*

RACOMITRIUM, Brid.

91. **R. patens,** Dicks.

Hab. between Fort Colville and the Rocky Mts., *Lyall.*

92. **R. aciculare,** Brid.

Hab. on granite rocks above the Yosemite Valley, *Brew.*

93. **R. depressum,** Spec. nov. Longe, lateque cæspitosum, depressum, fusco lutescens. Caulis elongatus, 1–5 pollicaris, parce dichotome ramosus, laxe foliosus. Folia siccitate appresssa, humiditate erecta, aperta, homomalla, e basi late ovata, dilatato-semiauriculata decurrente, lanceolata, obtusa nervo lato planiusculo sub apice evanido instructa, concavo-carinata, margine medio revoluta, superne reflexa, apice denticulis remotis irregularibus instructa, quandoque integra, retis alaribus quadratis vel equilateralibus latis, plus

minus ve granulosis, fuscis, basilaribus subtuberculoso linearibus continuis, superioribus ovato rotundatis. Capsula in pedicello brevi innovationibus duplo longioribus immersa, e basi brevicolla subcylindrica: peristomii dentes irregulariter tripartiti, raro bifidi, cruribus inaequalibus vel liberis, vel cohaerentibus pertusis, laevibus.

Hab. falls of the Yosemite Valley, *Bol.*

This species, remarkable for its large size, is intermediate between *R. aciculare* and *R. protensum*, Brid. Its color is the same as that of var. *cataractarum* of the last, but the leaves turned to one side, even in the dry state, are larger, broader, and more obtuse, mostly denticulate, like those of *R. aciculare*, and nearly with the same areolation. The decurrent base of the leaves is slightly enlarged in a narrow auricle whose reticulation is particularly broad, resembling that of a *Dicranum*. The capsule, open at the mouth, is nearly exactly cylindrical, and sometimes slightly curved. The teeth of the peristome, generally tripartite near the base, are irregular, like those of *R. protensum*, but narrow, smooth, with well marked articulations.

94. **R. heterostychum,** Brid.
Hab. Fort Colville, *Lyall.*

95. **R. lanuginosum,** Brid.
Hab. Vancouver's Island, *Wood;* Mt. Rainier, Oregon, *U. S. Exp. Wilkes.*

96. **R. canescens,** Brid.
Hab. Vancouver's Island, *Lyall.*

Var. foliis pellucidis acuminatis, angustius reticulatis, vix papillosis.
Hab. on shaded rocks near the Paper Mill, Marin Co., *Bol.*

HEDWIGIA, Ehrh.

97. **H. ciliata,** Ehrh.
Hab. on stumps of *Sequoia sempervirens, Bol.;* on rocky cliffs of Bill Williams' Fork, *Big.;* British Columbia, *Lyall.*

BRAUNIA, Brch. & Schp.

98. **B. Californica,** Lesqx.
Hedwigia pilifera, Mitt.
Hab. on metamorphic rocks on low mountains; Mt. Diablo to 3,000 ft., very common and variable, *Bol.;* Vancouver's Island, *Lyall.*

In my description of this species, I have omitted to mention a few characters which, apparently important when one specimen only is considered, are, on the whole, local peculiarities or varieties only. This omission has led Mr. Mitten to suppose that his *Hedwigia pilifera* of Vancouver Island might be a different species, its capsule being plicate and the branches not inflated at the top. The capsule is indeed sometimes plicate, but generally smooth, at least when moistened. On rocks exposed to the sun, the branches of this species are longer and thickened at the top, and the perichaetial leaves are much shorter. When growing in the shade, the appearance of the plants is different, the leaves being longer and not appressed closely to the stem, etc. But the true specific characters of this species, as they are given in the description, are recognizable in every form.

PTYCHOMITRIUM, Brch. & Schp.

99. **P. Gardneri,** Spec. nov. Ramificatione, habitu, formaque foliorum, P. *polyphyllo*, Brch. & Schp., simillimum, differt: foliis brevioribus, latioribus, siccitate tortilibus vel cirrhatis, reflexis humiditate, margine argutius serratis, retis basilaribus longioribus, superioribus cellulis quadratis confertioribus; capsula in pedicello breviori, pallide ferruginea longiori, operculo longiori rubello persistente, margine minus crenulato; annulo angustiori revolubili; peristomii dentibus crassioribus, atro-sanguineis, ad basim plerumque trifidis; calyptra lævi.

Hab. on rocks, Dardanelles Cañon, Forest Hill, *Bol.*

The large size of this moss separates it at first sight from the European species. The male flowers are rarely axillary, generally two to four at the base of the vaginule within the perichætium. Its color is dark green.

ORTHOTRICHEÆ.

ZYGODON, Brch. & Schp.

100. **Z. Lapponicus,** Brch. & Schp.

Hab. spray of the Nevada Falls, Yosemite Valley, *Bol.;* Cascade Mts., *Lyall.*

101. **Z. Californicus,** Mull.

Hab. on shaded rocks, Marin Co.; Dardanelles Cañon, etc., *Bol.*

Z. cæspitosus, Mitt. A new species formed on sterile specimens collected on Vancouver Island by *Lyall*, appears, from the description, to belong to this species.

ULOTA, Mohr.

102. **U. phyllantha,** Brid.

Hab. Vancouver Island, *Wood.*

This division of the Orthotricheæ has not yet any representative from California.

ORTHOTRICHUM, Hedw.

103. **O. cupulatum,** Hoffn.

Hab. on metamorphic limestone rocks, near the Russian River, Ukiah, redwoods, deep gulches, *Bol.*

104. **O. Sturmii,** Hoppe & Hrnsch.
Hab. on shaded rocks, Yosemite Valley, *Bol.*

105. **O. Texanum,** Sulliv.
Hab. on rocks and trees, common in California, and extremely variable, *Bol.*

Var. *B. globosum*, Lesqx. Capsula breviori, subglobosa, pedicello longiori emersa, calyptra colore nitente brunnea, caule breviori, foliis humiditate erectis.

This form has a peculiar appearance, and seems, at first sight, a distinct species. But I do not find any good character to separate it. The peristome has either fugacious slender cilioli, or short incipient large ones, or none. A peculiar character of this species, and its varieties, which at once separates it from *O. anomalum*, is the black color of the spores.

106. **O. speciosum,** Nees.
Hab. on trees, *Bol.*; Fort Colville, *Lyall.*

Among the numerous varieties of this species, two forms, collected by Mr. Bolander, merit to be noted.

1st var. *polyanthum*, Lesqx. Læte viride; foliis caulinis laxe imbricatis, humiditate appressis, comalibus longioribus, floribus masculis pernumerosis.

It has long slender branches, and a male bud in the axils of nearly each leaf.
Hab. on rocks, Big Trees.

2d var. *brevicaule*, Lesqx. Pallide vel luteo viride; cæspitibus compactis, sicut pulvinatis; caule brevi, theca terminali, pedicello longiori exserta.
Hab. same as the former.

M. Mitten quotes still *O. elegans*, Schwægr., (from British Columbia, *Lyall*) a variety less distinct from the typical form than both the above described ones.

107. **O. rupestre,** Schl.
Hab. on rocks, Big Trees, *Bol.*

108. **O. rivulare,** Turn.
Hab. roots of elm trees and posts in water, Anderson Valley, etc., quite common, *Bol.*

109. **O. cylindrocarpum,** Lesqx. Pusillum, monoicum subpulvinatum. Caulis simplex vel parce ramosus, obscure viridis, inferne nigrescens. Folia in sicco appressa, madefacta erecto appressa, e basi latiori elongato-lanceolata acuta vel subobtusa nervo valido cum apice evanido carinata, margine e basi fere usque ad apicem revoluta, areolatione ovato-quadrata minuta papillosa versus basim polygono-elongata. Folia perichætialia vix longiora. Flos masculus in ramo proprio sub perichætio innovante, raro axillaris. Capsula in pedicello brevi, exserta, cylindrica, vel cylindrica-ovalis, pallide viridis vel luteola. Peristomii dentes 16 per paria approximati, albidi ciliis 8 robustis, basi dilatatis æquilongis, duplici serie cellularum formatis, separati. Operculum conicum, margine rubellum vaginula calyptraque anguste conica plicata, valde pilosæ.

Hab. on trees, Oakland, common, *Bol.*

This diagnosis completes the short comparative description given of this species in the Trans. Amer. Phil. Soc., vol. 13, p. 6. It is very small, not larger than the small forms of *O. strangulatum*, Beauv., with which it has some affinity by the peristome and form of the leaves.

110. **O. Kingianum,** Spec. nov. Monoicum, cæspitoso pulvinatum. Caulis erectus, pollicaris parce dichotome ramosus, inferne brunneus, superne obscure viridis. Folia humida erecto-patentia, breviora, ovato-lanceolata acutiuscula nervo carinata, e basi usque sub apice revoluta, reticulatione inferiori quadrato-elongata vel rectangulari, superiore quadrata, obscure granulosa et minute papillosa. Folia perichætialia conformia vix longiora. Capsula in pedicello 2–3 lineas longa, exserta, ovalis, brunnea lævis, collo brevi in pedicello attenuata, ore constricta, peristomii 16 dentes pallidi, breves, obtusi vel erosi geminati ciliis 8 interpositis e duplo serie cellularum compositis brevioribus. Calyptra elongata capsulam ad basim usque integens, sublævis.

Hab. rocks near the falls of the Yosemite Valley, *Bol.*

Distinguishable from *O. anomalum*, Hedw., which this species most resembles, by its peristome, and from *O. Hutchinsiæ*, Hook. and Tayl., by the areolation of its leaves and other indicated characters. Appears also nearly related to *O. consimile*, Mitt. But the author says of his species: *theca siccitate plicata, ciliis simplicibus æquilongis, calyptra ramentosa*, characters at variance with those of our species.

111. **O. consimile,** Mitt.

Hab. Vancouver Island, on trees, *Lyall.*

112. **O. Columbicum,** Mitt.

Hab. same as the former, *Lyall.*

113. **O. Coulteri,** Mitt.

Hab. California, *Coulter.*

114. **O. pulchellum,** Smith.

Hab. Clear Lake, *Bol.* Also communicated from Eureka and Vancouver Island by the same.

115. **O. Lyellii,** Hook.

Hab. on trees, very common in California, *Menzies, Bol., Big., Bauer, Lyall, Wilkes' U. S. Exp., etc.*

Var. foliis eorumque papillis longioribus, Sulliv. & Lesqx.

Musc. Exsicc. Amer., Ed. 2d, No. 185.

O. Menziesii, W. Hooker, Ms.

O. papillosum, Hampe.

Hab. same as the former.

All the authors who have examined this moss remark, that by its general appearance, it is indeed far different from the European species; but the analysis fails to show a specific difference. Among the great number of specimens collected by Mr. Bolander, all the transitional varieties may be followed from the European type to the largest forms with very long stems, leaves, capsules and papilla. One of the most marked varieties has short stems, longer, nearly cylindrical exserted capsules borne on a longer pedicel, with the calyptra covering the whole capsule and part of the pedicel, and spiniform or branching papillæ of the leaves.

TETRAPHIS, Hedw.

116. **T. pellucida,** Hedw.
Hab. redwoods, on logs near Big River City, very rare, *Bol.;* Fort Colville, *Lyall.*

ENCALYPTA, Schreb.

117. **E. vulgaris,** Hedw.
Hab. Monte del Diablo: Oakland hills, *Bol.;* Fort Colville, *Lyall.*

118. **E. rhabdocarpa,** Schw.
Hab. Cascade Mts., *Lyall.*

119. **E. ciliata,** Hedw.
Hab. spray of Nevada Falls, Yosemite Valley, in very large and fine specimens, *Bol.;* also banks of Russian River, near Ukiah.

SPLACHNACEÆ.

TAYLORIA, Hook.

120. **T. serrata,** Hedw.
Hab. Fort Colville. *Lyall.*

SPLACHNUM, Linn.

121. **S. melanocaulon,** Schw.
Hab. California, as indicated by Mitten.

FUNARIACEÆ.

PHYSCOMITRIUM, Brid.

122. **P. pyriforme,** Brid.
Hab. wet banks, Dardanelles, and swamps near San Rafael, *Bol.*

ENTHOSTODON, Schwægr.

123. **E. Bolanderi,** Lesqx.

Hab. on clayey ground, near San Francisco, *Bol.*

124. **E. Templetoni,** Schw.
Hab. swamp near Mendocino, Coast Range, very rare, *Bol.*

FUNARIA, Schreb.

125. **F. Californica,** Sulliv. & Lesqx., Musci Exsicc. Amer., Ed. 2d, No. 238. Pusilla; folia coronalia in gemmula congesta, vel erecta, oblonga, breviter acuta, integra, fere continuo-costata; capsula in pedicello brevi-recto, sicco sinistrorsum torto, sub pyriformi-oblonga, erecta, æqualis, vix asymetrica; operculum convexo-conicum, calyptra et peristomium generis, annulus nullus.
Hab. on clayey soil, Auburn, Ukiah, etc., *Bol.*

Is much like a small *Enthostodon,* the capsule being generally straight and symmetrical. The peristome is double, the internal being glued to the outer one to above the middle of the teeth. The reticulation of the leaves is remarkably close for a species of this genus.

126. **F. calcarea,** Wahl.
A var. *B. patula,* Schp.
Hab. on the ground, Mission Dolores; Mt. Diablo, *Bol.* *Funaria Muhlenbergii,* Schwægr. mentioned by Sullivant, as found by Dr. Bigelow near the crossing of the Colorado, is referable to this species.

127. **F. hibernica,** Hook.
Hab. Cajon Pass, Sierra Nevada, *Big.*

128. **F. hygrometrica,** Hedw.
Hab. California, *Bol., Big., Wilkes' U. S. Exp.;* Fort Colville and Vancouver, Island, *Lyall.*

Var. *C. calvescens,* Schp.
Hab. rocks in cañons of the American River, *Brew.*

129. **F. convoluta,** Hampe.
Hab. on the Sierra Nevada Mts., alt. 3,000 to 5,000 feet, *Bauer.*

130. **F. microstoma,** Brch. & Schp.
Hab. Soda Springs, Upper Tuolumne, 9,700 ft., *Bol.*

Appears to be abundant there; the specimens are very fine.

BRYACEÆ.

BRYUM, Dill.

§ 1 LEPTOBRYUM, Schp.

131. **B. pyriforme,** Hedw.

Hab. around Clear Lake and Mt. Dana, common from 8,000 to 11,000 ft., *Bol.*; moist banks of Sonora Pass, *Brew.*; banks of streams, Cajon Pass, *Big.*; Cascade Mts., *Lyall.*

§ 2. WEBERA, Hedw.

132. **B. polymorphum,** Hoppe & Hrnsch.
Hab. Mt. Dana, mixed with *B. nudicaule*, Lesqx., rare, *Bol.*

133. **B. longicollum,** Swartz.
Hab. Cascade Mts., *Lyall.*

134. **B. nutans,** Schreb.
Hab. foot of Mt. Dana, *Bol.*; Cascade and Galton Mts., *Lyall.*
Var. *C. bicolor*, Brch. & Schp.
Hab. Mt. Dana, *Bol.*; banks of King's River, 4,000 ft., *Brew.*

135. **B. nudicaule,** Spec. nov. Dioicum, cæspitosum; cæspites compacti, inferne brunnei, superne virentes. Caulis basi tantum radiculosus, subpollicaris, gracilis simplex vel raro ex apice innovans; plantæ antherigeræ graciliores fructiferæque e basi usque versus summitatem subnudæ, folia minima squamæformia, erecto-apressa, pellucida gerentes. Folia comantia dense conferta, erecta, ovato lanceolata brevia, nervo valido sub apice evanido carinato-concava, subintegra vel apice obsolete denticulata; floralia intima breviora denticulata; plantæ sterilis basi interrupte foliosæ folia breviora. Theca in pedicello vix semi-pollicari, valde flexuoso horizontalis vel pendula, ovata, subventricosa, ore haud vel vix constricta collo brevi fusca, pachydermis. Peristomii interni dentes liberi angusti, elongati, sæpius laciniis irregularibus summo conati, ciliis nullis interpositis; operculum conicum vel plano convexum annulatum; annulus pallidus compositus, revolubilis.
Hab. Mt. Dana, 11,000 ft., *Bol.*

The male plants of this species are mixed in an abundance in the cæspites, and their terminal buds are thick with numerous anthers without or with a few short paraphyses. The perigoñial leaves are broad, oval, short-pointed or obtuse, brown colored, and obscurely nerved. Some free anthers are also found, though rarely, in the axils of the perichætial leaves. The capsule is rarely symmetrical, but generally more or less inflated on the lower side. This moss agrees so well with the excellent description given by Muller (Bot. Zeit., N. 40. p. 328) of his *B. Drummondi* from the Rocky Mts., that I should have considered it identical, if it was not that Muller's moss has *cilia Weberæ duplicia brevia*, while ours has no trace of cilioli, and that also the former is *exannulata*, while the California moss has a pretty large white revolving annulus. Muller also does not mention the peculiar stem leaves of the flowers bearing plants, and the presence of anthers in the axils of the perichætial leaves. The areolation of the leaves is of a *Webera*, but short and broad.

136. **Bryum Bolanderi,** Spec. nov. Dioicum, laxe cæspitosum, depressum, pallide viride nitens. Caulis simplex, foliosus. Folia inferiora laxe imbricata, erecta, lanceolata; superiora comantia conferta, longiora, anguste lanceolata, nervo sub apice denticulato evanido. Planta mascula vix gracilior; folia perigonalia e basi late ovata concava in acumen longum flexuosum angustatum producta subintegra. Folia perichætialia conformia, vix longiora. Capsula in pedicello longiori rubello inclinata vel horizontalis, breviovata, in collum sat longum attenuata; peristomii dentes externi late brevesque, interni longiores ciliis vel nullis vel binis rudimentariis interjectis. Operculum conicum apiculatum; annulus compositus.
Hab. foot of Mt. Dana, *Bol.*

Distinct from the former by its longer capsule of a thinner texture, narrowed at the mouth, and borne on a longer pedicel; by its shining color, its long, narrow, strongly denticulate leaves, the form also of the perigonial leaves, etc. The perichætial leaves do not have any anthers in their axils. A fine species, rather related to *B. crudum*, Schreb.

137. **B. cucullatum,** Schwægr.
Hab. Mt. Dana; rare, *Bol.*

138. **B. crudum,** Schreb.
Hab. around Clear Lake and near the Big Trees, on shady rocks, *Bol.;* Fort Colville, *Lyall.*

139. **B. Ludwigii,** Schwægr.
Hab. foot of Mt. Dana, 9,000 to 10,000 ft., *Bol.;* Cascade Mts., *Lyall.*

The form collected by Mr. Bolander is robust, has thick branches and open leaves.

140. **Bryum Tozeri,** Grev.
Hab. on the ground, borders of ditches and roads around San Francisco, Oakland, etc., *Bol.*, *Big.*

141. **B. albicans,** Wahl.
Hab. wet banks, Dardanelles Cañon, *Bol.;* Galton Mts., *Lyall.*
Var. *gracilior*, capsulis brevioribus, etc.
Hab. on rocks watered by springs near San Francisco, *Bol.*

§ 3. BRYUM, Dill. emend

142. **B arcticum,** Brch. & Schp.
Hab. foot of Mt. Dana, *Bol.*
It slightly differs by the shorter capsule. Specimens few and deoperculate.

143. **B. cernuum,** Brch. & Schp.
Hab. foot of Mt. Dana, *Bol.*

144. **B. inclinatum,** Brch. & Schp.
Hab. on rocks at Clark's, Yosemite Valley, *Bol.*

145. **B. Warneum,** Brid.
Hab. foot of Mt. Dana, 9,000 to 10,000 ft., borders of ditches; abundant, *Bol.*

There is no difference whatever between this and the European moss. The flagelliform, twisted, nearly naked branches are extremely numerous.

146. **B. intermedium,** Brid.
Hab. on wet ground, Big Trees; on the ground near Crescent City; Mt. Dana, *Bol.*; Sonora Pass, mixed with *B. pyriforme*, *Brew.*; also found by Bigelow—no locality marked.

147. **B. cirrhatum,** Hoppe & Hrsch.
Hab. in a meadow near the Big Trees, 8,000 ft: Mono Pass, *Bol.*

148. **B. bimum,** Schreb.
Hab. Fort Colville and Galton Mountains, *Lyall.*

149. **B. torquescens,** Brch. & Schp.
Hab. Oakland, opposite San Francisco, *Big.*

150. **B. pallescens,** Schl.
Hab. Cascade Mountains, *Lyall.*

151. **B. subrotundum,** Brid.
Hab. on rocks, Yosemite Valley, *Bol.*

It differs from the European form only by the slightly longer capsule, rather horizontal than pendent.

152. **B. cæspiticium,** Linn.
Hab. on the ground, Yosemite Valley, *Bol.*; Silver Mts., and through the Sierra Nevada, from 7,000 to 8,000 ft.; *Brew.*: Cascade and Galton Mts., *Lyall.*

153. **B. argenteum,** Linn.
Hab. on the ground, San Francisco, *Bol.*; dry ravines, 50 miles west of the Colorado, *Big.*: rare.

154. **B. Californicum,** Sulliv.
Hab. near Benicia, *Big.*; common around San Francisco, on the ground, in grassy places, *Bol.*

155. **B. Bigelowii,** Sulliv.
Hab. trunks of trees above Sonora; base of the Sierra Nevada, *Big.*

156. **B. miniatum,** Spec. nov. Dioicum compacte cæspitosum. Caulis parce radiculosus simplex vel pluries sub capitulis inflatis innovante ramosus, gracilis, innovationibus quandoque gracillimis filiformibus. Folia sicca appressa, caulina laxe imbricata superiora in capitulum conferta concava, ovato-obtusa vel ovato-lanceolata obtusa, haud vel vix marginata, margine vix reflexa, nervo valido sub apice evanido instructa, e cellulis polygonis parietibus crassis reticulata. Folia perichætialia comalibus vix longiora, angustiora. Capsula

in pedicello longo rubello, inclinata, elongato-obconica, sub ore sub constricta, rufescens, operculo mamillari rubello, annulo latiori Peristomii interni dentes angusti, ciliis crassis articulatis interpositis.

Hab. on moist rocks, Yosemite Valley.

This fine species is somewhat related to *B. pseudo-triquetrum*, with which it grows, but easily separated by the enumerated characters. The ramification is the same as in *B. Bigelowii*, Sulliv., from which it differs by the long capsule and the form of the leaves. The top of the branches is purplish, abruptly crimsoned, as if it had been plunged in carmine.

157. **B. occidentale,** Sulliv.

Hab. on ground, rocks, old logs, very common in California, *Bol.*, *Big.*, *Brew.*

This species is most intimately related to *B. capillare*, Linn., presenting most of the forms which are marked as varieties in the European species. I owe to the kindness of Prof. Hooker, specimens of a *Bryum* named *B. capillare*, by Mr. Mitten, collected in Vancouver Island, by *Lyall*, and which is evidently a large form of *B. occidentale*, and at the same time undistinguishable from *B. capillare*. It would be too long to enumerate here all the varieties of the California moss. The most marked one is a small form with slender innovations emerging from under more distinct and thicker capsules having with generally longer pointed leaves, narrow, cylindrical proportionally longer, broad red capsules and a proportionally broader annulus. But even the largest forms, whose capsules are generally pale brown and the leaves short, pointed, bear in the same tufts capsules of various color, from pale buff to dark red, with leaves also elongated or rather contracted into a piliform point. Though, from its larger annulus —especially its shorter pointed leaves and peculiar ramification—this species may be separated with some right from *B. capillare*, it does not appear possible to subdivide its varieties into species. One of these divisions is *B. Baueri*, Hampe, which, according to the author, differs from *B. capillare: statura minori, foliis brevioribus immarginatis, nervo excedente flexipili.*

158. **B. Oreganum,** Sulliv. Wilkes' U. S. Expedition, p 10, tab. vii.

Hab. Oregon, *Wilkes' U. S. Exp.*

159. **B. obconicum,** Hrnsch.

Hab. flanks of Santa Cruz Mts., 2,000 feet, *Brew.*

160. **B. Canariense,** Brid.

B. Billarderii, Schwaegr.

Hab. cañons in Monte del Diablo, *Bol.*

161. **B. pseudotriquetrum,** Schwaegr.

Cum var *B. gracilescens*, Schp.

Hab. wet rocks, Big Trees, *Bol.*: Fort Colville, *Lyall.*

162. **B. Duvallii,** Voit.

Hab. Eureka, *Bol.*, in good though sterile specimens; Fort Colville, *Lyall.*

163. **B. turbinatum,** Hedw.

Hab. Galton Mts., *Lyall.*

Var. *C. latifolium*, Schp.

B. Schleicheri, Schwægr.

Hab. wet meadows, Big Trees, *Bol.*

MNIUM, Linn. emend.

164. **M. affine,** Bland.
Hab. near Clear Lake, sterile, *Bol.*

165. **M. insigne,** Mitt.
Hab. borders of creeks, Devil's Cañon, *Bol.;* Vancouver Island, *Lyall, Wood.*

166. **M. venustum,** Mitt.
Hab. shaded rocks, Ukiah, etc., *Bol.;* Vancouver Island, *Lyall;* Oregon, *Wilkes' U. S. Exp.*

167. **M. medium,** Brch. & Schp.
Hab. Fort Colville and Cascade Mts., *Lyall.*

168. **M. spinulosum,** Brch. & Schp.
Hab. Fort Colville, *Lyall.*

169. **M. punctatum,** Linn.
Hab. Eureka. Sent by Mr. Bolander in good fruiting specimens.

170. **M. Menziesii,** Müll.
Hab. shaded rocks, banks of creeks, *Bol.;* Coast Range, *Big.;* Oregon, Port Discovery, *Wilkes' U. S. Exp.* First discovered in N. W. America by *Menzies*, and gathered also by *Scouler.*

MEESIA, Hedw.

171. **M. uliginosa,** Hedw.
Hab. found again in swamps, 9,000 ft., *Bol.;* swamp, 8,500 ft., *Brew.;* Mooyie River, *Lyall.*

172. **M. tristicha,** Brch. & Schp.
Hab. Tack River, *Lyall.*

173. **M. longiseta,** Hedw.
Hab. Oregon, *Wilkes' U. S. Exp.*

AULACOMNIUM, Schwægr.

174. **A. androgynum,** Schwægr.
Hab. especially on burnt stumps of *Sequoia sempervirens*, from the plains to the mountains, very common, *Bol., Brew., Big.;* Vancouver Island and Fort Colville, *Lyall.*

175. **A. palustre,** Schwaegr.
Hab. swamps near Mendocino, *Bol.*; Cascade Mts., *Lyall.*

BARTRAMIA, Hedw.

176. **B. stricta,** Brid.
Hab. on rocks and ground near San Francisco, *Bol.*

It differs from the European form only by its pedicel, which is round and not square, obtuse under the capsule; agreeing, therefore, with Bridel's description, which does not mention this peculiarity.

177. **B. thyphylla,** Brid.
Hab. foot of Mt. Dana, ditches, abundant, *Bol.* It is the Alpine form, in compact tufts, with short stems and pedicels; also Cascade Mts., *Lyall.*

178. **B. fontana,** Brid.
Hab. Yosemite Valley, Big Trees; Clear Lake, on wet rocks, *Bol.*, *Brew.* Appears common in the Sierra Nevada Mts.; Fort Colville, *Lyall.*

179. **B. Menziesii,** Turn.
Hab. on shaded rocks; very common in California, and gathered by all the botanists who have explored that country, *Menzies*, *Big.*, *Brew.*, *Bol.*, *Bauer*, etc.

Var. foliis latioribus, brevius acuminatis, capsula longiore, ovato-elongata, ore la iori nudo, vel membrana integra circumdato.
Hab. on rocks, *Bol.*

With the normal form, whose capsule is oval, sometimes nearly round, Dr. Hampe has made a new species, under the name of *Glyphocarpa Baueri.* But the capsules of this normal form have generally a well developed peristome, though, indeed, this peristome is sometimes replaced by a pellucid membrane, lacerated in the form of irregular teeth, or even is totally wanting. The moss, which I consider as a variety as described above, has generally a naked mouth, though sometimes it shows traces of even a well formed peristome.

TIMMIA, Hedw.

180. **T. megapolitana,** Hedw.
Hab. Vancouver Island, *Lyall.*

POLYTRICHACEÆ.

ATRICHUM, Tal. Beauv.

181. **A. undulatum,** Tal. Beauv.
Hab. on rocks, Mission Dolores, *Bol.*; Oregon, *Wilkes' U. S. Exp.*; Fort Colville, *Lyall.*

182. **A. angustatum,** Bryol. Eur.

Hab. banks, Santa Cruz Mts., alt. 2,200 ft., *Brew.*

POGONATUM, Pal. Beauv.

183. **P. dentatum,** Menz.

Hab. pine woods of N. W. America, *Menzies;* clay banks in dense shade of the redwoods near Crescent City, *Brew.*

Prof. C. Muller says of this species: calyptra lævis; in my specimens it is rugose, like that of *P. urnigerum,* Brid., and, accordingly, the only difference which separates the Californian from the European species is the glaucous color of the more stronly dentate leaves.

184. **P. alpinum,** Roehl.

Var. *P. brevifolium,* Schp.

Hab. foot of Mt. Dana, borders of ditches, *Bol.*

185. **P. contortum,** Menz.

Hab. on shores of N. W. America, *Menzies.*

POLYTRICHADELPHUS, C. Mull.

186. **P. Lyallii,** Mitt.

Hab. foot of Mt. Dana, and around Clear Lake, *Bol.;* swamp, east side of the Cascade Mts., *Lyall.*

POLYTRICHUM, Dill.

187. **P. piliferum,** Schreb.

Hab. rocky places above Sonora, *Big.;* Vancouver Island, *Big., Lyall.*

Var. pilo brevi, serrato, foliis quandoque epiliferis.

Hab. Lassen's Peak, alt. 8,000 ft., *Brew.*

Var. *læripilum, P. læripilum,* Hampe.

Hab. Mt. Diablo and Coast range, *Bol., Bauer.*

188. **P. juniperinum,** Hedw.

Hab. California, from the plains around Mendocino, to the Yosemite Valley, common, *Bol.;* near Cajon Pass, *Big.;* abundant in woods, from 7,000 to 9,000 ft., Mt. Brewer, *Brew.;* Vancouver Island, *Lyall.;* Oregon, *U. S. Wilkes' Exped.*

BUXBAUMIA, Haller.

189. **B. aphylla,** Haller.

Hab. Cascade Mts., *Lyall.*

FONTINALACEÆ.

FONTINALIS, Dill.

190. **F. antipyretica,** Linn.

Hab. Swamps, in stagnant water and Coast Ranges in rivulets, *Bol. Big.*, Alpine Lake, near Silver Mts., *Brew.*

191. **F. Mercediana,** spec. nov. F. antipyretica habitu similis, differt: caule graciliori, distycho, raro trigono folioso; foliis acutius carinatis, plicatis, haud vel vix decurrentibus; areolis foliorum superne angustioribus, vacuis: alaribus brevioribus inflatis, paucis; peristomii interni, reti clathrato imperfecto; externi dentibus brevioribus, articulis distantibus, 18 to 20; operculo duplo breviori, capsulæ colore pallida.

Hab. on rocks, Merced river, *Bol.*

This species has the facies, color and peristome of *F. dalecarlica*, Brch. and Schp., differing essentially from it by the entire (not lacunose) teeth, the longer capsules, the flattened branches, etc.

DICHELYMA, Myr.

192. **D. uncinatum,** Mitt.

Hab. Fort Colville, *Lyall.*

193. **D. Swarzii,** Lndb.

Hab. upland swamps between King's and Kaweah rivers, *Brew.*; swamps near Mendocino city, and pools at the foot of Mt. Dana, *Bol.*; no fruit found.

This moss agrees in every point with Schimper's description of the species, and presents two forms far different in appearance. One, pale green colored, shining, with long, scarcely branching stems, and appressed, nearly straight leaves. It grows in prairie swamps, which are dry in summer. The other, black or brown colored, with stems much divided in horizontal short branches and falcate-uncinate leaves.

NECKERACEÆ.

NECKERA, Hedw.

194. **N. Menziesii,** Hook.

Hab. on rocks, in deep shaded gulches, *Bol.*; base of trees, near Crescent City, *Brew*; Fort Colville, *Lyall.*

From the Russian valley, Mr. Bolander has sent remarkable specimens, with leaves and branches covered with capillary filaments resembling tufts of confervæ, or of *Hypnum confervoides.* These filaments are generally simple, emerging from the axils of the branch leaves, and bear very small oval-pointed, entire or slightly denticulate leaves, without costa and with a loose reticulation. Other specimens also gathered by Mr. Bolander, and marked "shaded rocks, Yosemite Valley," are of a pale green color, with short stems, and without any trace of stolons.

195. **Neckera Douglasii,** Hook.

Hab. on trees, Marin Co., Mendocino City, etc., *Bol.:* Oregon, *Wilkes' U. S. Exp.:* Vancouver Island, *Wood.*

ALSIA, Sulliv.

196. **A. Californica,** Sulliv.

Neckera Californica, Hook. and Arn.

Hab. on trees and rocks; very common along the coast, *Bol., Big.:* Oregon, *Wilkes' U. S. Exp.*

197. **A. longipes,** Sulliv. and Lesqx., Musci Exsicc. Amer., Ed. 2d, No. 399: Dioica, pinnato ramulosa, subfrondiformis, compressiuscula foliosa. Folia oblongo-lanceolata, breviter acuta, superne grosse serrata, minute ovali-areolata, costa ultramedia apice dorsali denticulato; perichaetialia abrupte filiformi attenuata; capsula cylindracea, in pedicellum subuncialem perichaetio quadruplo longiorem defluente; peristomio 1–2 ciliolato, operculo calyptraque *A. abietina*.

Hab. on rocks in deep cañons, Oakland, *Bol.*

198. **A. abietina,** Sulliv.

Neckera abietina, Hook.

Hab. on trees, common in California, and gathered by all the botanists who have explored the country.

ANTITRICHIA, Brid.

199. **A. curtipendula,** Brid.

Hab. Mt. Diablo, sterile, *Bol.* It is a peculiar form, with closely appressed leaves and julaceous branches. Oregon, *Wilkes' U. S. Exp.:* Vancouver Island, *Wood.*

Var. *C. gigantea,* Sulliv. & Lesqx., Musci Exsicc. Amer., Ed. 2d, No. 356. Valde robusta, atro-viridis, foliis latioribus, homomallofalcatis, capsula cylindrica longiori.

Hab. on rocks and trunks of living trees, Redwoods, *Bol.*

200. **A. Californica,** Sulliv.

Hab. on shaded rocks, and sandstone boulders, Oakland, *Bol.*

HOOKERIACEÆ.

HOOKERIA, Tayl.

201. **H. acutifolia,** Hook.

Hab. in a deep cañon, *Bol.*

This moss is the same in every point as that described under that name from the Atlantic States. No fruit has been found as yet.

202. **H. anomala,** Mull.
Hab. N. W. America, *Menzies.*

LESKEACEÆ.

ANOMODON, Hook & Tayl.

203. **A. Californicum,** spec. nov. Cæspites laxi prostrati vel dependentes, fusco-lutei, inferne brunnei. Caulis parce ramosus, gracilis, sicco foliis appressis angulatus. Folia quadrifariam imbricata, humida aperta, basi semi amplectente auriculato-decurrentia, late ovata, acuta, margine replicata, nervo valido sub pallido cum apice evanido carinata, cellulis alaribus oblongis elongatis, inde superne ovato-quadratis utraque pagina papillosis, papillis ad auriculas longioribus, spinosis.
Hab. on rocks, Mt. Diablo, sterile, *Bol.*

A fine species, without near relation to any other described. The borders of the leaves are abruptly plicate backward to above the middle of the leaves, and only reflexed near the point.

FABRONIACEÆ.

FABRONIA, Raddi.

204. **F. pusilla,** Raddi.
Hab. bark of trees, Oakland, *Bol.*

HYPNACEÆ.

PTERIGYNANDRUM, Hedw. emend.

205. **P. filiforme,** Hedw.
Hab. on shaded boulders and trees, *Bol.*, *Big.*

Var. nervo validiore elongato, foliis apice cristato-serratis. *Leptohymenium cristatum*, Hampe.
Hab. on rocks, Sierra Nevada, *Bauer.*

PTEROGONIUM, Swartz.

206. **P. gracile,** Swartz.
Hab. on rocks near the bay of San Francisco, common, *Bol.*, *Big.* California, *Wilkes' U. S. Exp.*

Var. statura graciliori, ramis magis filiformibus, foliis duplicato-serratis.

Leptohymenium duplicato-serratum, Hampe.
Hab. on trees in California, *Bauer*.
This species is still more variable than the former.

HYPNUM, Dill.

§ 1. THUIDIUM, Schp. Bryol, Eur.

207. **H. Blandowii,** Web. & Mohr.
Hab. Fort Colville, *Lyall*.

208. **H. crispifolium,** Hook.
Hab. N. W. America, *Menz.*: on shaded ground and rocks, Oakland, etc., *Bol.*; Vancouver Island, *Wood*.

209. **H. (Leskea) laxifolium,** Hook.
Hab. coast of N. W. America, *Menz*.

Nothing like this species of Hooker has been found in California by recent collectors. It may be a variety of the former species, or appears, at least, to belong to this section.

210. **H. remotifolium,** Grev.
Hab. N. W. America.
An obscure species.

211. **H. Whippleanum,** Sulliv.
Hab. California, *Big*.

212. **H. leuconeurum,** Sulliv. et Lesqx., Musci Exsicc. Amer., Ed. 2d. Hypno Whippleano peraffine, cæspite densiore, operculo breviore. pedicello lævi etc, distinguendum.
Hab. on the trunks of *Quercus agrifolia*. Oakland; in woods, but more common on moist soil of shaded hillsides, Oakland.

213. **H. calyptratum,** Sulliv.
Hab. near Los Angeles, on the ground, *Big*.

§ 2. ISOTHECIUM, Brid.

214. **H. myosuroides,** Linn.
Hab. near San Francisco, dry woods, *Big*.
Perhaps a variety of the next.

215. **H. stoloniferum,** Hook.
Hab. on trees, in the Redwoods; very common in California, *Menzies, Bol., Big*. Oregon, as var. *B*. of *H. myosuroides*, in Sulliv., *Wilkes' U. S. Exp.*: Vancouver Island, *Wood*.

This species is particularly polymorphous. In order to elucidate the remarkable disposition of this moss to modify its form under peculiar circumstances, especially under the influence of wind and fog, Mr. Bolander sent me a large specimen, whose branches on one side are elongated in slender filiform stolons, from six inches to one foot long, while on the other side the stem and branches are thick, short, with large leaves. The filamentous part, according to Mr. Bolander's remarks, was hanging from a branch exposed to wind and fog, while the other part, presenting a normal development, was, by its extension to the other side of the trunk, preserved against this action. Specimens of *H. circinale* and *H. Nuttallii* are subjected to the same peculiar development. I can but therefore consider the multiplication of species from such polymorphous mosses as a hazardous task. I have admitted as a species the more distantly related form of *H. Breverianum,* which, growing in dense tufts on dry rocks, has a black color, short stems, short obtuse leaves, and in appearance is totally different from *H. stoloniferum.* But even on dry rocks, the part of the caespites which is not directly exposed to the sun's influence passes to a yellowish green color, and bears some more elongated attenuate branches, even stolons, showing more and more an approach to *H. stoloniferum* or *H. myosuroides*, for Professor Muller does not separate these species. Mr. Mitten has described a number of forms which are more or less intimately related to *H. stoloniferum,* and which, if the opinion of Muller is right, should be reunited as well as *H. Breverianum* as varieties of *H. myosuroides.*

216. **H. Breverianum,** Lesqx.
Hab. on metamorphic sandstone around San Francisco, *Bol.*

217. **H. aggregatum,** Mitt.
H. Breverianum var., Sulliv. and Lesqx. Musci Exsicc. Amer., Ed. 2d, No. 427,
Hab. in deep cañons; Oakland, on trunks, *Bol.*

218. **H. aplocladon,** Mitt.
Hab. N. W. coast of America, *Douglas.*

219. **H. lentum,** Mitt.
Hab. same as the former, *Douglas.*

§ 3. CAMPTOTHECIUM, Bryol. Eur.

220. **H. lutescens,** Huds.
Hab. Vancouver Island, *Lyall ;* California, *Coulter;* N. W. Coast, *Douglas.*
Received from Victoria, Oregon, through Mr. Bolander.

221. **H. Nuttallii,** Wils.
Hab. on trees, California, common, *Bol., Big. ;* Vancouver Island, *Lyall, Douglas.*

Var. stoloniferum. ramis elongatis, aggregatis filiformibus lutescentibus.

Hab. on trees. Sent by Mr. Bolander. A very remarkable variety. The stems are creeping, as in the normal form, and bear shorter and more slender capsules, and the crowded branches are elongated filiform, depending from the branches of trees.

222. **H. arenarium,** Lesqx.
Hab. on sand, around bushes near the shores, San Francisco, *Bol.*

223. **H. pinnatifidum,** Sulliv. and Lesqx., Musci Exsicc. Amer., Ed. 2d, No. 513. Ab Hypno aureo affinissimo distinguitur: capsula cernua annulo majori, foliis brevius filiformi acuminatis, reti multo laxiore denique inflorescentia revera dioica.

224. **H. Nevadense,** Spec. nov. Dioicum, laxe cæspitosum, robustum, lutescente viride. Caulis primarius repens pinnatim ramosus, ramis brevibus, horizontalibus vel longioribus, irregulariter divisis, arcuato curvatis. Folia lanceolata, sensim brevi-acuminata, homomallo-curvata, apice minute serrata, costa carinata, profunde biplicata, margine revoluta vel reflexa, cellulis alaribus perpaucis, irregulariter ovalibus. Capsula in pedicello rubello erecta vel sub cernua, ovato-cylindrica, longe rostrata, peristomii interni cilia vel rudimentaria, vel nulla; annulus compositus.

Hab. on rocks in the spray of Nevada and Bridal Veil Falls, *Bol.*

Is distinguished from *H. lutescens*, Huds., by its green color, larger thick stems and branches; the evidently pennate ramification, less marked, however, than in *H. aureum;* the alar reticulation scarcely marked by a few oval cells; by the large capsule, the peristome without cilia, etc. The leaves are more regularly and deeply plicate than in any other *Camplothecium.*

§ 4. BRACHYTHECIUM, Bryol. Eur.

225. **H. lætum,** Brid.

Hab. the Yosemite Valley. The plants are sterile, and the species not undoubtedly ascertained.

226. **H. salebrosum,** Hoffm.

Hab. Fort Colville and Pend' Oreille, *Lyall.*

227. **H. collinum,** Schl.

Hab. Cascade Mts., *Lyall;* Mr. Bolander sent it sterile from the Yosemite Valley.

228. **H. Hillebrandi,** Spec. nov. Monoicum, tenellum, cæspitibus intricatis condensatis sericeo-lutescentibus. Caulis erectus, plicatus, irregulariter subfasciculatim ramosus cum ramis undique divergentibus radiculosis. Folia laxe imbricata subsecunda, e basi ovata, sensim lanceolato-acuminata, concava, basim tantum plano reflexa, toto margine serrulata, costa medio vel paulo ultra evanida, areolatione angusta elongato-polygona, angulis dilatata, quadrato chlorophyllosa. Perichætialia pellucida, laxe areolata, plerumque enervia, e basi ovata, sensim in acumine longo, gracili erecto vel flexuoso subintegro attenuata. Capsula in pedicello breviusculo inferne rubello subrugoso, superne pallido lævi, brevis, turgide ovata, æqualis, erecto raro inclinata, sicca ore dilitata, operculo conico brevi obtuso truncato. Peristomii externi dentes longiores inferne pallide lutei, superne albidi, processus tenerrimi pellucidi dentibus perforatis ciliis duobus articulatis interpositis: annulus ?

Hab. on rocks, Merced River, *Bol.*

A fine species related to *H. collinum* and *H. salicinum.* The leaves have about the same form as in this last, but are broader, though not as broad as in *H. collinum*, with a shorter costa. The essential difference is in the small, generally erect capsule, with a pedicel rough from the middle downward. The operculum, though found in plenty among the tufts, is detached from all the capsules. No trace of an annulus is left.

229. **H. declivum,** Mitten.
Hab. Pend' Oreille River, *Lyall.*

230. **H. vallium,** Sulliv. and Lesqx., Musci Exsicc. Amer., Ed. 2d, No. 506.
Hypno læto inflorescentia, statura, foliatione et habitu accedens; distinctissimum autem caule rigidiore, pedicello scabro, foliorum cellulis quadratis ad basis angulos late decurrentes paucioribus, haud granulosis, etc.
Hab. on shaded metamorphic rocks, in deep cañons, *Bol.*

This species is apparently nearly related to the former, but the leaves are not denticulate from the base, and the costa is also not denticulate on the back.

231. **H. populeum,** Hedw.
Hab. Sierra Nevada, *Dr. Hillebrand.*

The specimens were communicated by Mr. Bolander; all the capsules are deoperculate.

232. **H. Bolanderi,** Lesqx.
Hab. on the ground, shaded by *Oreodaphne Californica*, rare, Oakland, *Bol.*

§ 5. SCLEROPODIUM, Bryol. Eur.

233. **H. illecebrum,** Schwægr.
Hab. rocks and ground, from the plain to the mountains, *Bol.* Extremely variable. In compact dark brown tufts, with densely imbricated, ovate-obtuse, nearly entire leaves and julaceous branches. Hab. in the water of the Yosemite Valley. In subdendroidal divisions, with acute and nearly entire leaves. Hab. deep cañons, etc. It is remarkable that no species of the genus *Scleropodium*, so widely distributed in California, has been found, except by Mr. Bolander.

234. **H. cæspitosum,** Wills.
Hab. on shaded rocks, and on the ground in the redwoods, Oakland, etc., *Bol.*

235. **H. Californicum,** Lesqx.
Hab. on shady, sandy ground, and sand around San Francisco, *Bol.*

§ 6. EURYNCHIUM, Bryol. Eur.

236. **H. strigosum,** Hoffm.
Hab. wet ground, Big Trees, *Bol.*; Fort Colville and Galton Mts., *Lyall.*

237. **H. Stokesii,** Turn.
Hab. on shaded ground and rocks, very common, *Bol.*, *Big.*; Vancouver Island, *Lyall*, *Wood.*

238. **H. Oreganum,** Sulliv.
Hab. in woods, on decaying logs or on the ground, *Bol.*, *Brew.*, *Big.*; Puget Sound, Oregon, *U. S. Wikes' Exp.*; Vancouver Island, *Wood.*

§ 7. RYNCHOSTEGIUM, Bryol. Eur.

239. **H. rusciforme,** Weis.
Hab. in a rivulet near Mt. Diablo, sterile, *Dr. Hillebrand*, *Bol.*

§ 8. THAMNIUM, Bryol. Eur.

240. **H. Bigelowii,** Sulliv.
Hab. on shaded rocks, in cañons, *Big.*, *Bol.*, *Brew.*

241. **H. Neckeroides,** Hook.
Hab. Vancouver Island, *Wood.*

According to Mitten, we have, in the United States, in this division of the Hypnaceæ, *H. Neckeroides*, Hook., found by Drummond in St. Louis; *H. alopecurum*, sent from Boston, and *H. Allegbaniense*, Mull. Though we have examined, with Mr. Sullivant, a great number of specimens, either collected by ourselves or sent from various points of the United States, we have never been able to find any species different from that of *H. Alleghaniense*, Mull., which differs from *H. alopecurum* by the inflorescence only. This *H. Alleghaniense* is the same moss as No. 119 of Drummond, *H. Neckeroides*, quoted by Mitten. And as the male flowers are rarely found on fruiting plants, incomplete specimens are often taken for *H. alopecurum*. I believe, therefore, that these three species, quoted by Mitten, are, for American specimens, referable to the same *H. Alleghaniense*, Mull. *H. alopecurum* from Europe, and *H. Neckeroides*, Hook., from New Zealand, are indeed different, but not yet found in our country.

§ 9. PLAGIOTHECIUM, Bryol. Eur.

242. **H. pulchellum,** Dicks.
Hab. Fort Colville, *Lyall.*

243. **H. turfaceum,** Lndb.
Hab. same as the former, *Lyall.*

244. **H. elegans,** Hook.
Hab. near Nootka, Vancouver Island, *Menzies.*

245. **H. denticulatum,** Lin.
Hab. Coast Range, Mendocino City; on a fork of redwood tree, Jackson Valley, *Bol.*; rare, Fort Colville, *Lyall.*

246. **H. undulatum,** Lin.

Hab. swamps near the coast, Mendocino, *Bol.;* Oregon, *U. S. Wilkes' Exp.;* Fort Colville, *Lyall:* indicated by Muller, as found at Cape Disappointment.

§ 10. AMBLYSTEGIUM, Bryol. Eur.

247. **H. compactum,** Mull.

H. serpens var. compactum, Hook.

Hab. on the ground around springs, Big Tree grove, *Bol.;* near Fort Colville, *Lyall.*

248. **H. serpens,** Lin.

Hab. on the roots of bushes, in swamps, *Bol.;* on the ground, near Crescent City, *Brew.;* common in California, *Big.*

249. **H. radicale,** Beauv.

Hab. Galton and Cascade Mts., *Lyall.*

According to Mr. Mitten, who mentions this species, which he calls a much misunderstood species, it differs from *H. serpens* in its narrower and longer leaf cells. If we admit the descriptions of Schimper and other authors, and rely for the nomenclature on our American specimens as types, the contrary should have been asserted. For, indeed, *H. radicale,* as it is generally understood, has the leaf cells shorter and proportionally broader, and a longer and stronger costa than *H. serpens,* Lin. About the understanding of this troublesome species, I readily admit what Mr. Sullivant says in his Icones, p. 200: "*H. orthocladon, H. contextum, H. tenax, H. inordinatum, H.* "*varium,* attributed to this country only, are (together with a few other supposed "species, included *H. radicale,* found both here and in Europe) so variable in their "characters, and pass so gradually into each other, that it appears quite impracticable "to define their specific limits, or to separate them from large forms of *H. serpens,* to "which they have been referred by Muller and others."

250. **H. orthocladum,** Beauv.

H. varium, Hook. and Wills., in Drummond.

Hab. borders of springs, and among willows, Little Lake Valley, *Bol.;* Pend' Oreille River, *Lyall.*

251. **H. riparium,** Lin.

Hab. Mill Falls, Oakland, and Big Tree grove; around springs, *Bol.;* near Crescent City, *Brew.;* wet places, *Big.*

§ 11. CAMPYLIUM, Sulliv.

252. **H. hispidulum,** Brid.

Hab. Mooyie River, *Lyall.*

§ 12. HARPIDIUM, Sulliv.

253. **H. aduncum,** Hedw.

Hab. a swamp in San Francisco, *Bol.*

254. **H. uncinatum,** Hedw.
Hab. Bridal Veil Falls, Mono Pass, near Merced River, Big Tree grove, and foot of Mt. Dana, *Bol.;* wet banks near King's River, *Brew.;* Cascade Mts., *Lyall.*

255. **H. commulatum,** Hedw.
Hab. east side of Mono Pass, sterile, *Bol.*

256. **H. filicinum,** Linn.
Var. Vallis-clusæ.
Hab. Fort Colville, *Lyall.*

§ 13. RHITIDIUM, Sulliv.

257. **H. robustum,** Hook.
Hab. Western Coast of North America, *Menzies;* Fort Colville, *Lyall.*

§ 14. DREPANIUM, Schp.

258. **H. fertile,** Sendt.
Hab. Big Trees, on humected rocks, *Bol.*

A small specimen only was received. It has the essential characters, the form of the leaves, the areolation, capsule, etc. But no male flower could be found on the plants. The species is therefore somewhat uncertain.

259. **H. subimponens,** Lesqx.
H. plumifer, (?) Mitten.
Hab. on shaded rocks in woods, from the plain, Oakland, to the mountains, Big Trees, Long Valley, *Bol.;* Vancouver Island, *Lyall.*

It is still doubtful if this species is the same as that described by Mr. Mitten as *H. plumifer* (among other characters) with *operculo brevi subulato rostrato,* and the general appearance of *H. Crista-Castrensis,* Linn. In our moss the lid is conical, sometimes obtuse, sometimes more elongated, pointed, but never rostrate; and its likeness to *H. imponens* is so remarkable that it is difficult to separate both species.

260. **H. circinale,** Hook.
Hab. base of trees, Siskiyou Mts., 4,000 to 5,000 ft., *Brew.;* on living redwoods exposed to winds and fogs, 2,000 to 2,500 ft., *Bol.;* Oregon, *Wilkes' U. S. Exp.;* Vancouver Island, *Lyall.*

§ 15. LIMNOBIUM, Bryol. Eur.

261. **H. arcticum,** Sommerf.
Hab. foot of Mt. Dana, entirely submerged, in streamlets, apparently very rare, and seen but once, *Bol.*

§ 16. HYPNUM, Schp. Synop.

262. **H. giganteum,** Schp.
Hab. Fort Colville, *Lyall.*

263. **H. cuspidatum,** Linn.
Hab. Pack River, *Lyall.*

§ 17. HYLOCOMIUM, Bryol. Eur.

264. **H. loreum,** Dill.
Hab. Oregon, *Wilkes' U. S. Exp.;* Vancouver Island, *Lyall, Wood.*

265. **H. splendens,** Dill.
Hab. Oregon, *Wilkes' U. S. Exp.;* Vancouver Island, *Lyall, Wood.*

MEMOIRS

PRESENTED TO THE CALIFORNIA ACADEMY OF SCIENCES.

VOLUME I.

II. *Principles of the Natural System of Volcanic Rocks.*

By F. Baron Richthofen, Dr. Phil.

[Presented, May 6th, 1867.]

INTRODUCTORY. Among the features peculiar to modern Geology may be noticed a revival of that speculative tendency which prevailed among the cultivators of this science at the close of the last century. But while in those early times imagination exerted a dominant influence in the framing of hypotheses, and discussions between the adherents of different doctrines were conducted with all the bitterness peculiar to such struggles, when neither party has a firm basis upon which to found its arguments, the constant ascendency of the spirit of the inductive method has imparted to those theories more recently propounded a more logical and scientific form, while, at the same time, the increasing amount of positive knowledge has given to the different doctrines a more varied and more definite character, and enlarged the scope of dissenting views.

This renewed tendency to systematize and theorize, which is especially conspicuous in the records of the last twenty years, must be ascribed, partly, to the vast amount of well-established facts gathered during the previous decades, and which have since been multiplied and intensified in a constantly increasing ratio, as regards depth and distinctness of observation as well as the geographical area over which they extend; partly, and in no less degree, to the rapid progress made by those sciences on which geology has to draw for the general laws which are alone capable of affording a philosophical guide to speculation on the basis of facts gained by observing and comparing. The advance of the chemical and physical sciences, especially, has had a powerful influence, by allowing an immediate application to geological problems of such general laws as are established beyond any doubt. Besides, the improvement of the practical methods applied in chemical and physical laboratories has given rise to the execution of numerous experiments, which were made with a view of imitating the processes applied in the great natural laboratories. They suggested frequently the causes of facts disclosed by the examination of a certain region, or obtained by comparing the observations made in different countries on one certain subject.

It appears to be mainly due to these causes that a number of theories have been proposed, in rapid succession, relating to the origin of rocks, to the mode and causes of metamorphism, to the agencies of vulcanism, to the structure and mode of formation of mountain ranges, to the structure of the entire globe, and other cognate subjects. It will be admitted, even by those who are most strongly opposed to theorizing, that geological science has in this way been promoted and enriched in various respects; since there is scarcely a theory which, even if insufficient to explain what it undertakes, has not some truth in it, or is applicable to some extent in certain cases, or has at least, even when proving to be erroneous itself, led to discussions on subjects of high interest, which is indeed a result of no little value. In reviewing the theories proposed on any particular subject, we find them, it is true, often in apparent contradiction with each other; yet almost every one is based upon arguments drawn from observed facts, and there are probably very few which will ultimately be entirely abandoned. The immense range of varied processes as applied by nature allows the applicability, in a limited way, of many a theory in certain instances, while in others it may be refuted on no less valid grounds; and the struggle between the defenders of different doctrines is often founded only in the difference of their standing-points. What appears to be true in one instance is frequently not applicable in others; it is the bold generalizations which render theories so often untenable in that form in which they are usually first expressed. An instructive example is presented by the different theories which have been proposed for explaining the mode of formation of mineral veins. Almost every one of them was based upon a limited range of observations, and was, from its first application to a few instances, extended to the generality of veins. Numerous exceptions to it were then found, leading to the rejection of the first, and the establishment of a different, theory, which, in its turn, shared a similar fate. Obscure as this subject still is, we are able to state this as certain, with our present state of knowledge, that every mineral vein is the product, not of one simple but of complex processes. Nearly every one of the theories proposed will, therefore, have its limited range of applicability, inasmuch as the agent it suggests may have been especially active in the formation of the veins of a certain order, while the same agent may have played a subordinate part in regard to the origin of other veins which were chiefly due to processes of another kind.

This instance points clearly towards the one principal cause of the divergence of opinions in regard to some of the most important geological questions. This cause is the want of latitude of the basis upon which arguments are founded. Conclusions which are obtained by reasoning on geological subjects solely on the strength of chemical analysis, are, when generalized, often found to be utterly in discordance with the facts revealed by geological observation; and how unsatisfactory general theories may be when based upon the latter alone, is sufficiently exemplified by the fantastical attempts made in all ages of geological science to interpret the geological structure of the world from that of a limited region. The basis for argumentation can therefore never be broad enough, and its enlargement should be, as it indeed is, one of the chief objects of geological science. But it is not sufficient to content ourselves with an accumulation of primary observations, which are in fact being infinitely increased by the conjoint labors of geologists in all countries: it should be a higher object of the student of geology, to compare the established results of observation, and to investigate their mutual relations. The study of the structure of one mountain range, or of several ranges comprised within a limited district, may lead to the establishment of an elaborate theory of the mode of their formation, which may apparently answer perfectly well in that one case, but may be found inadmissible when generalized, even in those cases where, by imperfect observation, one would expect to detect a great similarity to the structure first observed. But in determining those features which are common to a number of mountain ranges, or to certain orders of them which we may discern among their generality, we may aspire to form conclusions which are more generally applicable. It is particularly the auxiliary branches of geology to which these remarks apply. The value of observations made in limited regions, or from a limited point of view, on subjects such as the outlines of the morphological features of the continents, the occurrence of mineral springs, the structure of mineral veins, the age of those among them which carry a certain metal, the generality of volcanic phenomena, the mode of action of earthquakes, the nature of certain kinds of rocks, and their part in the structure of the surface of the globe—cannot be fully realized unless the comparative method is applied in as wide a scope as we may be able to do, and the mutual relations among the different modes of manifestation of force, or among the properties of the kinds of matter upon which it acts, or the bearing of all these relations to each other and to the evolution of the globe, are investigated from as many points of view as we may detect, and in as many combinations as possible. We may then be able to gain a foundation for argumentation on more involved problems, consisting not of imperfect premises, nor of a confused accumulation of facts, but of established truths of a higher order.

The mode of origin of the non-foliated crystalline rocks, made up of silicates,* is among those subjects which have at all times, but at no time more than of late, commanded a great deal of attention, and given rise to the establishment of numerous theories, each of which was applied in a general way, if not by its author, then by his followers. It is well known how conflicting they apparently are, and what weighty arguments have been brought in favor of as well as against each of them. The only method, promising success, of weighing the merits of these different theories, or of modifying them in accordance with the general advance of science, appears to be, to

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* I have for these applied the name "eruptive rocks" in the following pages, considering that, wherever we have occasion to observe them, they are not at their original seat, but ejected from it towards the surface. The reasons supporting this position will be more fully mentioned in the chapter on the origin of volcanic rocks.

ascend from the examination of the nature of these rocks to that of their mutual relations, to investigate these from as many points of view as we can discover, in regard to physical and chemical properties, mode of occurrence and age, as well as in regard to geographical distribution: that is, to try to establish the natural system of eruptive rocks. The results so obtained may then, in accordance with what we just remarked in a general way, be applicable to reasoning on remoter questions, of which we can only attempt to find the most probable solution. They regard chiefly the causes of those relations, the mode of origin of the eruptive rocks, and the processes connected with their ejection. The intricate nature of the subject, and the fact that the present changes on and below the face of the globe, as well as the events of the past, are often but dimly and imperfectly perceptible to our observation, demand that we should concentrate our endeavors in exploring first the laws of that which is definite and constant within the infinite range of phenomena, and await further experience to arrive at an explanation of those isolated facts which form apparent exceptions to the order of things.

It is with these views that the following pages were written. They extend chiefly over the comparatively limited, and yet very extensive class of "volcanic rocks," and are offered as a mere elementary attempt, which is necessarily very imperfect. The application to exact reasoning of the numerous observations which have been made on the subject of volcanic rocks in different countries, is nearly prevented by the extraordinary discrepancy existing in regard to the mode in which the names of rocks are used by different authors. The first condition of a uniform and harmonious mode of observation on volcanic rocks, and the phenomena connected with them, is the application of a uniform system of nomenclature.

In concluding these preliminary remarks, I dare express the hope that some indulgence may be had with the imperfections of this essay, if it is taken into consideration that it was written on the Pacific coast, where chemical laboratories are unknown, libraries scarce, and little opportunity is afforded of becoming acquainted with the current geological literature. I fulfill a deep-felt duty if I tender at this place my sincere thanks to Professor J. D. Whitney, not only for allowing me the use of his library and revising the manuscript of this essay, but also for the interest which he has constantly taken in my pursuits, and for what I owe to his personal intercourse, especially in a country where scientific communication is so extremely limited. The influence of this intercourse will, long after this, be kept in grateful memory by all those who are taking personally a part in the development of the California Academy, the members of which kindly allowed this paper to be published in their Memoirs.

THE NATURAL SYSTEM OF VOLCANIC ROCKS.

In reviewing the various attempts which have been made towards a classification of eruptive rocks—that is, those crystalline rocks made up of silicates, which, without showing themselves any traces either of stratified deposition or foliation, enter into the structure of the surface of the globe in such a way as to be unconformable with the stratification of the neighboring sedimentary rocks, and as a rule to abut against them without any gradual passage—we are struck by the observation that, if they are based on any principles at all, these are usually artificial, while none but unsatisfactory results have been obtained when the application of natural principles has been tried. This want of success is the more striking if we consider that it is peculiar to petrology, and that the efforts made in the same direction with other branches of descriptive natural sciences have been attended by extraordinary results. In zoölogy and botany, the natural system has long since been considered as the ultimate object of scientific research; and since the time when its first outlines were discovered, the progress of these sciences has been admirable. Since then only have the developments of their different branches coöperated harmoniously towards one common end: the profoundest investigations into the anatomy of animals and plants, the study of their geographical distribution in modern time, and of their gradual development in past ages, have in their final results but been subservient to the establishment of a foundation of the natural system, and the ingenious deductions made by Mr. Darwin on the origin of species are but its philosophical interpretation. As regards mineralogy, classification was for a long time a simple enumeration of minerals, governed by certain artificial principles. A new era was inaugurated for this science by the progress of chemistry, and its application to mineralogy, by Berzelius. It led to a more correct estimate of those principles which had been formerly applied, and to the discovery of the existence of an intimate connection between crystallographical form and chemical composition. The combination of these two principles gave rise to the natural system of minerals, which since their adoption has been constantly gaining in completeness.

These are results which surpass in a surprising degree those obtained in regard to the natural classification of eruptive rocks. Even the most recent and elaborate systematical arrangements, as those proposed by C. F. Naumann, F. Senfft, B. v. Cotta, and J. Roth, though marking a conspicuous progress, are based on almost purely artificial principles. In no other branch of the descriptive natural sciences, it is true, do difficulties arise so great as those which present themselves in petrology. Prominent among these is the entire absence of what we could call "genus," or "species," not to mention "individual." If we should succeed in discovering some natural group to which we might apply the term "family," (though even this can never be used in petrology in as definite a sense as it is in the organic kingdoms) we should find it made up of an infinite number of varieties; and if we should be able to establish several groups, the main types of which are conspicuously distinct in nature, we should find them linked together by gradual passage in chemical and mineral composition. It appears indeed utterly impossible to draw distinct boundaries between cognate groups. Certain names, such as those of granite, syenite, quartzose porphyry, trachyte, basalt and others, have been applied to designate distinct types of crystalline rocks, which can easily be recognized wherever met with. But, practically, they have to be used for larger groups of rocks, in which those distinct types appear like luminous centers, surrounded by clouds of varieties blending with each other in such a way as often to render it arbitrary whether to bring a certain rock within one or the other denomination. But there are other groups of rocks, of larger dimensions than the former, the nomenclature of which is far more indistinct, and which, in regard to classification, may indeed be said to be still in an entirely nebulous state. The vague and arbitrary mode in which different names are used for them shows plainly that difficulties in regard to them are greater than with other rocks. As will be seen in the sequel, this indistinctness of external character, as well as of designation, applies particularly (with the exception of basalt) to those rocks in the composition of which silica takes a less prominent part, while those which are richer in silica offer much more distinct characters. Most conspicuous among the names applied for the former are those of "trap," "greenstone," and "porphyry." The latter two may be conveniently used to designate groups of rocks having certain external characters in common, but as generic terms they should all be completely abolished.[1] They never convey a definite conception, as each of them is used for a great variety of rocks, and they have only too often been made to serve as a convenient cloak to cover ignorance.

The perception of these difficulties has caused the idea to be almost universally accepted, that only an artificial system of eruptive rocks can be established; that is, that classification should be made dependent on one certain principle previously as-

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[1] This applies chiefly to the term "Trap," (or trapp) which had originally a definite meaning, but has gradually been extended with wonderful elasticity. It was first introduced by Torbern Bergmann for a very ancient, dark colored, augitic rock of Uddevalla, in Sweden, which is arranged in superposed layers abutting against the slope of the hill in the shape of a stairway (trappar in Swedish). This rock would be called "diabase" in modern nomenclature. The name "trapp" was then applied to other, and gradually to all, dark colored eruptive rocks, particularly to such as were found occurring in dykes; afterwards the "greenstones" (which name, too, has shown itself capable of wonderful distension) were included in that denomination; and finally it has become still more comprehensive, though not quite to the same extent with every author. Its present meaning may best be seen from the following passage by Lyell, (*Elements of Geology*, 6th Ed., 1866, p. 601 of Am. Ed.): "This term (lava) belongs more properly to that (melted matter) which has flowed either in the open air or on the bed of a lake or sea. If the same fluid has not reached the surface, but has been merely injected into fissures below ground, it is called trap." Thus, the same name which was originally applied to a distinct rock of ancient origin has been generalized so as to express now a mode of occurrence, and, what is more remarkable, a mode of occurrence the very reverse of that exhibited by the original type, which must be supposed to have been flowing on the bed of the sea, and the position of which in relation to neighboring rocks can never be explained by assuming it to have been "injected into fissures below ground." Would it not be better to drop such a name altogether?

sumed as the point of issue. Taking crystalline texture, lack of stratification as well as of foliation, and the fact of their being made up of silicates to be the characteristic features of eruptive rocks in general, the most obvious external differences among them are caused by the variations of texture and color. During the early stages of petrographical science, rocks were therefore classified on these principles. The terms trap, porphyry, pearlstone, obsidian, lava, amygdaloid, wacke, as well as greenstone, black porphyry, green porphyry, and others, are the remnants, in our present nomenclature, of that epoch when the more minute differences of rocks arising from their mineral composition were but imperfectly investigated. This principle was necessarily next in order for serving as point of issue for classification, since, as far as regards external characters, it is only second to the former in value. The emergence of petrology from a chaotic state, by the scientific application of this principle, dates from the investigation of Gustav Rose on the feldspathic minerals entering into the composition of rocks, and it has since been more generally applied for establishing subdivisions than any other. The presence or absence of quartz, the predominance among the feldspathic minerals of orthoclase, oligoclase, or labrador, the presence of augite or hornblende, are the usual points of issue, even in the most recent attempts at classification. The high value of mineralogy as a basis of classification cannot be denied. But its exclusive application has caused the combination into certain groups, of such rocks as from a geological point of view are widely separated, while it has given rise to distinctions in cases where the results of geological observation would demand close connection, as we shall have occasion to illustrate in the following pages, with reference to those volcanic rocks which are composed of hornblende and oligoclase. Gradually, those differences based on chemical composition, not capable of being detected by the eye, and the knowledge of which could only be obtained after chemistry had made the necessary advances, have become an object of scientific research. But this principle has not yet been used to any great extent for classification. It can easily be demonstrated that, when exclusively applied, it leads to a systematical arrangement of rocks which is in even greater contradiction with the natural mode of occurrence than when the same is based upon mineral composition alone, notwithstanding the fact that its great value has been conclusively demonstrated, especially by the important results which Bunsen obtained from the chemical analysis of rocks, and which mark an era in petrology. To combine granite, quartzose porphyry, and rhyolite into one class, because they resemble each other in their chemical composition, and to place them at the head of the list because containing the highest amount of silica observed among eruptive rocks, would be to take no regard whatever of geological facts. Rhyolite is, mineralogically and geologically, far nearer related to trachyte than to either granite or quartzose porphyry; and these two are quite distinct from each other, while granite is closely allied, by gradual passage, to syenite, and quartzose porphyry to porphyrite.

It is by slow degrees only that we can hope to reach a more scientific, that is, a more natural system in this, the most intricate branch of descriptive natural sciences. The natural differs from the artificial system in this, that it starts from the application not of one only but of various principles, compares and weighs the results obtained by each of them, and accepts them as final only when perfectly harmonizing among each other. It is then that it tries to determine what principles are most available for establishing the higher orders, and which for the subdivisions. The singular complication which is peculiar to the classification of rocks, is, besides the reasons already mentioned, due in a great measure to the fact that geology combines the double functions of a historical and an inductive science, while in petrology we have besides the requirements of a descriptive natural science. The natural system of rocks should therefore be based, not only upon the entire range of their petrographical characters, such as mineral composition, chemical composition, texture, and specific gravity, but also upon their mode of origin and geological occurrence. Classification of objects and classification of relations are, with them, closely connected, and should be made to assist each other.

The question may be raised, whether a natural system of rocks based upon such principles can be established at all, and if it can, whether it would be of any use for the advancement of science. To the first question, the answer must be in the negative, as far as sedimentary rocks are concerned. They have been formed by a complexity of circumstances, and just so complex and infinite in variety are they, in respect to chemical and mineral composition and all external characters. To analyze in detail their mode of origin, and the sources from which their material has been derived, transcends the faculty of human intellect, and it would be a hopeless task to attempt to discover any laws regulating the boundless differences of their composition. They are thus debarred from natural classification, though its principles may be applied imperfectly to the establishment of some general groups. We arrive at similar conclusions in regard to those rocks, the sedimentary origin and subsequent metamorphism of which can be proved. Accidental and local circumstances have played as conspicuous a part in their first deposition as was the case in regard to those sedimentary rocks to which the term metamorphic has not been usually applied. But as metamorphic processes of a certain nature have ordinarily affected extensive tracts of these rocks, and similarly pervaded great thicknesses of them, the local differences of their action having been apparently more in degree than in mode, they have occasioned a certain similarity of effect which partly conceals the original differences in the composition of the rocks affected; and it appears that the differences in the kind and intensity of metamorphic action, though recognizable only in their final results, will, when better known, afford a convenient principle for a classification which may have some similarity with, but not the full requirements of, the natural system. It is different with those rocks which on the surface of the globe appear as intrusive or eruptive masses. Notwithstanding their infinite variety in character and composition, they are connected by definite relations which bring their elementary composition even within range of mathematical calculation. Their recurrence in the most widely separated countries, with similar external character, identical chemical composition, and in analogous relative order of succession, is another distinguishing feature of eruptive rocks. For these reasons, as well as in virtue of other peculiar characters which will be more fully mentioned in other pages, they appear to owe their present positions to the action of general planetary processes, and to reveal by their own nature that of the mineral matter participating in the original composition of the globe, and by their order of succession, the mode in which the same is arranged beneath the theater of those changes which since a remote period have been taking place on its surface. Only presumptive evidence can be adduced in favor of this common and yet much disputed theory. The probability of its approximating the truth could hardly be better established by any other evidence than by the proof that all eruptive rocks of the globe, taking their historical part into account, are capable of being brought into a natural system; or, to express it more correctly, that they form among themselves a natural system, the laws of which we may be capable of discovering. Considering this in its widest bearing, as embracing all the definite correlations of eruptive rocks, and being indeed their philosophical expression, we may expect that it will make us acquainted with the history of one great feature in the development of the globe. Bearing in their own character and system the imprint of their origin, the eruptive rocks will, by their nature itself, allow well-founded conjectures as to the interior structure and composition of the earth. This, then, together with a more perfect understanding of everything connected with the agencies working below the surface of the globe, would be the philosophical use of the natural system of eruptive rocks.

Only initiatory steps can be taken at the present time towards the establishment of this system. I have confined myself in this essay to an attempt at classifying, in a way as natural as experience will allow, the "*volcanic rocks*," that is, *the eruptive rocks of Tertiary and Post-Tertiary ages*. The term "volcanic rocks," has been chosen, because the rocky matter ejected by active volcanoes belongs altogether to this class, and because almost every kind of rock, generated by eruptive activity during the period indicated, has partially forced its way through volcanic vents. We must keep the two-fold mode of occurrence of volcanic rocks clearly separated in our minds. We see them at the present day flowing from craters in the shape of lava, or being thrown out as scoria and rapilli; and there is abundant evidence that their mode of origin was very frequently the same in past ages. But in other places, it is perfectly clear that volumes of matter of the same kind have been forced to the surface through extensive fissures and accumulated above them in elongated ranges, when the origin of the outbreaks cannot be ascribed to volcanic activity. These eruptions are evidently similar in nature to those by which the greater part of the granite, syenite, or quartzose porphyry ascended to the surface in ancient times. We shall distinguish the two modes of eruptions, for the use in this present paper, as "*volcanic eruptions*" and "*massive eruptions*," and shall dwell in the sequel more fully on the difference between both manifestations and their probable causes. Then, too, the reasons will be mentioned which justify the uniting of all recent eruptive rocks into one separate class.

No other class of eruptive rocks offers greater difficulties for a systematical arrangement, as none presents throughout so great a number of varieties, and so many accidental modifications of texture and mineral composition. On the other hand, their classification is of especial importance, as it furnishes the key for deciphering the natural system of the ancient eruptive rocks. Volcanic rocks issue from volcanic vents under our very eyes, and the record of the history of those which have originated in past ages, as preserved in their geological relations, is far more distinct than it is in regard to their ancient predecessors. No doubt exists in the mind of any observer in respect to the eruptive origin of all basalt; while in regard to granite, very different views are entertained by distinguished geologists, and supported by weighty arguments. In the former case, we have conclusive evidence, while in the second speculation has a wider scope. The knowledge of volcanic rocks will, for this reason, facilitate the correct interpretation of the nature of rocks generated in remote ages.

Volcanic rocks are widely spread over the face of the globe. It would be an object of great interest to lay down their geographical distribution on maps, and to explore the laws by which this distribution has been governed. This has been tried in regard to active volcanoes, and the importance and interest attaching to the results obtained are such as to have given rise at once to speculations as to the connection between volcanoes and other phenomena. The value of those results would be increased, if to the active craters were added the vastly greater number of those extinct volcanoes, the mode of preservation of which still allows us to recognize their former nature. Even then, however, the maps would convey but a remote idea of the general distribution of volcanic rocks; the areas comprised by which should be marked out with proper distinction of their main subdivisions. Besides an immediate bearing on more special geological questions, the knowledge of these subjects promises to be of high value for that entire department of geological science, by which the latter is most closely connected in scope with the science of physical geography. Many weighty problems, such as the causes of the present direction and extent of mountain ranges, of the outlines of continents, of the position and shape of groups of islands, of the secular oscillations of the surface of the globe, and many other questions, appear to be intimately connected with the geographical distribution of volcanic rocks and their mutual geological relations. The deduction from the latter of definite laws appears to be the initiatory step towards understanding the laws of eruptive activity of remote times, and, thereby, towards establishing a chapter in the history of the globe, which is among the obscurest and least understood.

The following classification, in which existing names are retained, as nearly as could be done with convenience, is chiefly founded on observations made in the Carpathians and in the States of California and Nevada. In respect to the variety and the distinctness of the mutual relations of the volcanic rocks, these two countries are hardly surpassed by any in which this subject has, up to this time, been scientifically investigated. Until recently, all volcanic rocks, at least those of more frequent occurrence, were comprehended in the terms: trachyte, phonolite, trachydolerite, dolerite, basalt; while, besides, separate names were used to distinguish modifications of texture, such as pumice-stone, obsidian, pearlite: or varieties somewhat more distinct in point of mineral composition, such as leucitophyre. The classification as given by Al. von Humboldt, in the fourth volume of the "Cosmos," may be considered as having represented the most advanced stage of the science a few years ago, because it was guided by a definite principle; though when compared with contemporaneous works on petrology, it gives, on the other hand, a remarkable illustration of the great difference in the way in which the same names have been applied. Since then, the name "rhyolite" (Richthofen, Studien aus den ungarisch-siebenbürgischen Trachytgebirgen, in *Jahrbuch der K. K. geologischen Reichsanstalt in Wien*, Vol. XI [1860], pp. 153–277) has been introduced for a very distinct class of volcanic rocks. Adding this to the previous list, there results a number of names which, in geological treatises, are either grouped completely at random,[2] or in an arbitrary order, or arranged by artificial principles, when the whole classification ordinarily comprises volcanic and ancient eruptive rocks promiscuously. In order to establish a more natural system, we have, not to *make* groups, but to *find* them. Dropping all of those *à priori* principles which may be conceived having an artificial basis, we must endeavor to discover whether any great divisions are established by nature herself, and if so, of what character they are. We may then apply, as second in the order of their importance, those results which are obtained in the laboratory or geological cabinet, for defining and subdividing those groups. Most of the natural divisions which may be derived from geological observation, coincide essentially with those based on artificial principles, but are more naturally limited as regards each other. Each of them has its own more or less independent part in the architecture of mountain ranges, and a distinct geological age in reference to the other groups. Each of them comprehends a series of rocks, which, besides, are closely connected by the relations of their petrographical characters, chemical composition, texture, specific gravity, and other properties. The test of the natural foundation and general validity of these groups will be their recurrence, with mutual relations unchanged, in different parts of the globe, of which test we are never to lose sight.

The following is the classification, the approach of which to a natural system of volcanic rocks, I will endeavor to set forth in the course of this paper:

ORDER FIRST: *Rhyolite.*
- Family 1. *Nevadite*, or granitic rhyolite.
- " 2. *Liparite*, or porphyritic rhyolite.
- " 3. *Rhyolite proper*, or lithoidic and hyaline rhyolite.

ORDER SECOND: *Trachyte.*
- Family 1. *Sanidin-trachyte.*
- " 2. *Oligoclase-trachyte.*

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[2] That this is even done in books of the highest standard, may be seen by reference to one so prominent as *Lyell's Elements of Geology*. The following is the order of names of which, under the head of "volcanic rocks," definitions are given (p. 592, pp. of 6th Am. ed., 1866): Basalt, augite rock, trachyte, trachytic porphyry (in connection with which the name "andesite" is mentioned), clinkstone, greenstone, porphyry, amygdaloid, lava, scoriæ or pumice, volcanic tuff or trap-tuff, agglomerate, laterite.

ORDER THIRD: *Propylite.*

Family 1. *Quartzose propylite.*
" 2. *Hornblendic propylite.*
" 3. *Augitic propylite.*

ORDER FOURTH: *Andesite.*

Family 1. *Hornblendic andesite.*
" 2. *Augitic andesite.*

ORDER FIFTH: *Basalt.*

Family 1. *Dolerite.*
" 2. *Basalt.*
" 3. *Leucitophyre.*

ORDER FIRST—RHYOLITE.

The name "rhyolite" was proposed, early in 1860,[3] for certain rocks frequently occurring on the southern slope of the Carpathians, and distinguished, in mineral character, from trachyte, which they otherwise resemble, by the presence of quartz as an essential ingredient, and an almost infinite variety of texture. Beudant[4] had, long before, described certain varieties of these rocks as *porphyre trachytique*, pumice-stone, pearlite, etc. In 1861, the name "liparite" was proposed by J. Roth[5] for rocks of similar nature occurring on the Lipari Islands. The term "rhyolite," however, being of prior date, has since been almost generally adopted, among others by F. v. Hochstetter, for rocks from New Zealand, by C. Peters, G. Stache, and others for those of Hungary and Transylvania, by Ferd. Zirkel for those of Iceland, by B. v. Cotta as a general term in his "*Gesteinslehre.*" The word "rhyolite" is designed to express one of the prominent features of these rocks. It is this: that their chief varieties have the appearance, as it were, of natural glasses, and bear evidence, more than any other rocks do, to the unpracticed eye, of having been flowing in a viscous state.

Mode of Geological Occurrence.—Rhyolite has had its distinct epoch of eruption in relation to other volcanic rocks. Wherever it occurs it may be easily proved to have been of more recent origin than either propylite, andesite, or trachyte, but to have preceded basalt in age. As to its geographical distribution, it is confined to the immediate neighborhood of one or all of those antecedent rocks, and occurs ordinarily within their very limits. Until lately, not much attention had been paid to it. But since the establishment of the name, rhyolite has been found to be widely distributed, though always occupying a subordinate position. In Hungary it usually skirts the lower part of the flanks of andesitic ranges, forming hillocks and ridges of little elevation, filling depressions, and issuing in currents from fractures, and, in general, giving evidence of its entire dependency on the places of previous eruptions. The greater portion of the rhyolite has, in that country, been evidently ejected by volcanic activity. It appears that the same may be said in regard to the

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[3] Loc. Cit.

[4] Voyage en Hongrie. Paris, 1820.

[5] J. Roth, die Gesteins-analysen. Berlin, 1861.

rhyolitic rocks of New Zealand, St. Paul, and Iceland. But it has not been so generally the case on the western coast of America. The volcano of Lassen's Peak, and the environs of Mount Helena, in California, present grand instances of a volcanic origin of rhyolite. But in the adjoining State of Nevada it appears to have been extensively brought to the surface by massive eruptions. It is of unusually frequent occurrence along the eastern slope of the Sierra Nevada, and farther east in the Great Basin. Ranges of hills are there completely built up of rhyolitic rocks, not always in as close proximity to such as are antecedent to them in age, as is the case in the Carpathians.

It is one of the characteristic features of rhyolite, that it presents, more than any other rock does, signs of having been in a state of what Daubrée has called "aqueous fusion," or the fusion of its mass by solution, under great pressure, in superheated water. Another peculiarity is the circumstance that the eruptions of rhyolite, whether massive or volcanic, bear evidence of having been generally accompanied by extremely violent solfataric action, which probably surpassed, on an average, that connected with the ejection of other volcanic rocks. This action appears to have been one of the chief agents in the formation of the rich silver-bearing veins of Hungary, as well as of some in Mexico, and to have also been peculiarly characterized by the occurrence of an unusually large amount of fluorine and chlorine among the escaping gases.

Mineral Composition.—Rhyolite may be concisely defined as trachyte with an addition of silica, not chemically combined, and which is either segregated into crystals of quartz, or dissolved in the rock, and then no longer recognizable to the eye. It is, owing to the high proportion of silica entering into its composition, the representative of granite among volcanic rocks. Chemically, it is its complete counterpart, as far as ascertained by analysis, and even in outward appearance certain varieties of rhyolite offer at first sight a striking similarity with granite, though closer observation will at once reveal well marked differences between both. Rhyolite outrivals any other rock in respect to the truly astonishing number of its varieties, which are chiefly occasioned by modifications of texture. It consists in general of a paste, with or without minerals enclosed.

The paste, chiefly, is liable to variation. Its colors are: white, gray, yellow, green, red, brown, which occur in all manner of shades; light ones prevail, while perfect black has not been met with. The texture is as varied as the color. First are to be noticed a number of hyaline varieties, which are represented by obsidian, pumice-stone, and pearlite, and the frequent occurrence of which is a peculiar feature of rhyolite. Though associated with volcanic rocks of every composition, these natural glasses, as they may be called, decrease in relative quantity and variety with the decrease of silica.[6] Obsidian when having the composition of rhyolite, offers little

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[6] There is no better example of the artificial principles on which the classification of rocks has usually been based than the fact, that accidental modifications of texture, which appear to result chiefly from the difference of the conditions attending either the fusion or the cooling of the mass, have been considered as of equal value with other differences of the greatest importance; and pumice-stone, trachyte, basalt and pearlite have been considered as coördinate subdivisions, even long after classification had been made dependent chiefly on mineralogical principles.

difference in character from that which is a modification of other volcanic rocks. In regard to pumice-stone, however, Abich has proved that when formed of the material of trachyte or andesite it has rounded pores, and ordinarily a green tint; while those varieties which have the composition of rhyolite, excel by the elongated and irregular shape of their cavities, which are enclosed in a fine tissue of fibres of silken appearance and white color. Between both kinds of pumice-stone there are gradations apparently dependent as to their character on the amount of silica entering into their composition. Pearlitic texture is peculiar to rhyolitic rocks. From these more or less perfectly glassy varieties there are gradations to the texture of enamel and porcelain, and to a certain cryptocrystalline texture very frequent among volcanic rocks in general, and for which we may apply the obsolete term "lithoid." This passes into the microcrystalline, and always more or less vesicular, texture of trachyte.

The paste constitutes occasionally alone the substance of the rock. But these instances are rare. More frequently it contains enclosed mineral substances differing from it in nature, and in a few instances these accumulate to such a degree as almost to exclude the paste. Quartz is of the most general occurrence among those which are crystallized. Sanidin is its almost unfailing companion. Oligoclase, usually of a vitreous variety, and black mica, are, too, among the usual ingredients, while hornblende is generally less conspicuous. Besides these minerals, there are two substances entering accidentally into the composition of rhyolite, which are, however, among the characteristic features of the rocks of this order. One of them consists in small globular grains, from the size of a pin-head to that of a rifle bullet, called "sphærolites" by Beudant. They have a radial structure, and contain ordinarily a small crystal of feldspar in the center. Certain hyaline, and, in a greater measure, lithoid varieties of rhyolite contain them in large quantity. They occur also, though less frequently, in other natural glasses not of rhyolitic composition, and may be produced artificially, by allowing molten glass to cool very slowly to what is known by the term "Réaumur's porcelain." The second formation frequently met with in rhyolitic rocks are the "lithophysæ," consisting in larger and smaller cavities filled by a substance strangely inflated by some gaseous evolution which apparently originated in the matter itself (Richthofen, l. c.). They constitute sometimes nearly the entire mass of the rock.

The endless varieties of rhyolite appear to be due to the susceptibility of the fluid mass to be influenced by accidental circumstances to which it may have been exposed, partly before being ejected, and partly during the process of solidifying. A considerable influence, which, however, has not yet been investigated, is probably exercised by the difference in the amount of water which entered into the composition of the molten mass, and partly expanded to steam in the instant of ejection. The vesicular inflation proper to trachytic texture, the spongy inflation of pumice-stone, and the concentric separation of infinitely fine laminæ, as is often shown in perfect pearlitic texture, are probably three different modes of manifestation of one slightly varied cause, which may most likely be found in the conversion of water into steam, which participated in the composition of the molten mass.

Difference of Rhyolite from other Rocks nearly related to it.—Several varieties of rhyolite bear so close a resemblance to other rocks, that some mention must be made of their distinguishing features. Rhyolite may be easily distinguished from granite. The varieties by which it mostly approaches the same are those which contain crystals of quartz, feldspar and mica in unusually large proportion and size. But in the case of rhyolite, the paste in which they are imbedded is never wanting. Moreover, the orthoclase and oligoclase are of the vitreous varieties, and quartz is present either in crystals or in rounded crystalline grains, while in granite it usually permeates the interstices between the other component minerals. Much closer is the affinity which certain other varieties of rhyolite bear to quartzose porphyry, especially those which have a paste of homogeneous appearance containing no crystals but those of quartz inclosed. Geological observation will never fail, in such instances, to establish the nature of the questionable rock, as it will show its association either with true rhyolite or with true porphyry. The same test has to be applied occasionally with respect to some other varieties which contain the silica equally diffused through the paste, and bear a close resemblance to trachyte. In this instance, however, even geological observations will sometimes fail to determine the exact position. There is a gradual passage in character between every two nearly related rocks, such as rhyolite and trachyte, or granite and syenite, and it frequently happens that either name may be used with equal right.

Subdivisions.—In establishing the subdivisions of most orders of eruptive rocks, mineral composition affords a principle, not only the most convenient for practical application, but one that answers well the requirements of the natural system, when made subordinate in value to those higher principles which determine the limits of classes and orders. In the case of rhyolitic rocks, however, it is not as applicable as in that of other orders. They should, from this point of view, be subdivided into those which contain quartz and those which are devoid of it, or into such as carry sanidin and such as contain both sanidin and oligoclase. But, since rhyolite of any certain chemical composition may contain its surplus of silica, either visibly segregated in crystals of quartz, or dissolved in the mass of the rock, and as the case may be similar in regard to the occurrence of either species of feldspar, the application of this principle would lead us to combine into one group quartzose rocks differing considerably among themselves as to the proportion of silica they contain, while another group might comprehend rocks of virtually the same nature as those of the first, and differing from them only accidentally in external character. More natural subdivisions of rhyolitic rocks are obtained by taking as a basis of classification their difference in texture, which either approaches, to a certain degree, that of granite or is porphyritic or hyaline. It is a singular fact, and one difficult of explanation, that rhyolite, at every place where it has been hitherto observed, presents, either solely or chiefly, one of those three modes of texture. Lassen's Peak, for instance, presents the granitic variety almost exclusively. Sonoma, in California, and the Tokay Mountains in Hungary, only the hyaline, and other places exclusively the porphyritic varieties. This circumstance, which is peculiar to none but rhyolite among eruptive rocks, indicates the dependency of the mode of texture upon deep-seated influences which acted at the very source of the eruptive matter, and produced a certain molecular condition of the latter, varying at each locality. Some light on this subject may be expected from minute geological observation, accompanied by exact chemical and microscopical researches.

The following are the subdivisions which may be distinguished in regard to the texture:

Fam. 1st. Nevadite or Granitic Rhyolite.—The name "Nevadite" is derived from that of the State of Nevada, where these rocks have been first met with in larger accumulations. The local derivation may answer in this instance, as granitic rhyolite is little known from other countries, excepting the neighboring California. In the Carpathians, it occurs isolated in Transylvania, but by no means as characteristic as in Nevada. The name "granitic rhyolite" is designed to indicate the general resemblance of these rocks to granite, which is conspicuous in boulders, or on large exposed faces, but disappears on closer examination. It is chiefly produced by the similarity in color, which is of light shades of gray and red in Nevadite, and by some affinity in mineral composition. Nevadite contains crystals of quartz in large proportion; the corners are usually rounded, and the quartz itself cracked, like glass when rapidly cooled. Sanidin occurs in crystals of larger size than oligoclase, sometimes of an inch in diameter. The crystals of both are often cracked throughout their mass, and rounded at the corners. Black mica and hornblende are ingredients of frequent occurrence. These minerals are, in more or less quantity, enclosed in a paste which is probably a partially microcrystalline, and partially amorphic aggregation of the same ingredients, and has a highly vesicular texture, rendering it rough to the touch, even more so than is the case with trachyte. Geologically, Nevadite appears to have been produced as frequently by volcanic activity as by massive eruptions. An interesting occurrence is that at Lassen's Peak, in California, where it was discovered by Prof. W. H. Brewer and Mr. Clarence King.

Fam. 2d. Liparite, or Porphyritic Rhyolite.—The name "Liparite," which was proposed by J. Roth for this whole class, may be conveniently retained for those varieties of rhyolite which approach quartzose porphyry in character, as they appear to occur on the Liparic Islands, either solely or at least in larger proportion than other varieties. They consist of a paste which has a similar texture to that of quartzose porphyry, and incloses crystals either of quartz only, or of quartz and sanidin, or of quartz, sanidin, oligoclase, and black mica, or of one or both kinds of feldspar, without quartz being present. The crystals have sharp corners and are seldom cracked; oligoclase is rarely of the vitreous variety. Typical varieties of the rocks of this family occur largely in the hills of Bereghszasz in Hungary.

Fam. 3d. Rhyolite proper, or Hyaline Rhyolite.—The extensive range of varieties afforded by all manner of modifications of hyaline texture are a peculiar feature of rhyolite, distinguishing it from any other eruptive rock. In outward appearance they remind one of artificial glasses cooled under the most varied conditions. *Obsidian, pumice-stone*, and *pearlite*, constitute but a small portion of the varieties occurring;

others resemble enamel and porcelain, or present appearances which are difficult to describe. The occurrence of sphaerolites and lithophysæ add to the variety of their aspect. Another feature peculiar to the rocks of this family consists in a foliated structure, the folia being often thinner than paper, and presenting an endless variety of color and modifications of texture. Pearlite alone does not participate in the peculiar form of foliated structure.

All these varieties again contain, enclosed, all the different minerals before mentioned, or only a few of them, or they enclose no foreign substances at all. The rocks of this family are chiefly of purely volcanic origin, but in some instances currents of them appear to have been ejected through crevices in the older volcanic rocks.

ORDER SECOND—TRACHYTE.

The name "trachyte" was first used by Hauy, in his academic lectures, to designate the well-known volcanic rocks composing the Drachenfels on the Rhine. But it did not come into general use, until Beudant, the pupil of the former, introduced the name into geological literature, by his justly celebrated work "Travels through Hungary," a book which abounds in sagacious observations on the subject of volcanic rocks. Beudant extended, however, the application of the name over a much wider range than his teacher had done. Several years later, in 1835, L. v. Buch introduced into literature the name "andesite," designating by it certain dark-colored rocks, which were then known, especially through the collections of Al. v. Humboldt and Boussingault, to enter largely into the composition of the volcanic portions of the South American Andes. These rocks, which form obviously a part of those which Beudant had comprised under the name "trachyte," were supposed to be particularly distinguished by containing a peculiar species of feldspar which Abich (in 1840) called "andesine." When, however, a few years later, this mineral was no longer considered to be a separate mineralogical species, and its name was dropped, that of "andesite" became obsolete with it, notwithstanding its prior origin. Thenceforth, the range of the varieties of volcanic rocks comprised in the term "trachyte" has been even more enlarged than Beudant had proposed in his dissertation. Eruptive rocks, widely differing in nature—in fact nearly all those of tertiary and post-tertiary age, with the exception of basalt—have been united in it. But by no author, probably, was the application of the name as much extended as by Al. von Humboldt.[7] On the other side, however, he was the first, by the establishing of numerous subdivisions, to draw attention upon the necessity of using separate names for more limited ranges of varieties. Recently, B. von Cotta, J. Roth, and others, have tried to demonstrate, how little reason there had been for dropping the term "andesite." They re-introduced it into petrology; but, in drawing the limits between andesite and cognate groups by principles of artificial classification, they used the name in a sense differing to some extent from that in which it has been applied in the following pages.

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[7] Cosmos, vol. iv. The first four orders of trachyte were proposed by G. Rose, the other two were added by Humboldt.

There is plainly indicated, from a geological point of view, the existence of two large groups within the limits of Beudant's "trachyte." The two existing names, "trachyte" and "andesite," may conveniently be used for their designation, since those rocks, for which either of the two names was first introduced, are indeed the types of the two natural groups.

Mode of Geological Occurrence.—The trachytic rocks have had their independent epoch of eruption in every volcanic country. They preceded rhyolite and basalt in age, and were posterior to the ejection of propylite and andesite. The trachytic epoch was usually of long duration. In many localities, its later part blended with the earlier of the rhyolitic epoch, which is manifest by the alternate emission of trachytic and rhyolitic matter, during that time which was intermediate between the epochs of the ejection of the principal bulk of either of them. As regards geographical distribution, trachyte is as much dependent upon, and as closely allied to, the preëxisting masses of propylite and andesite, as is the case with rhyolite. It towers up in peaks, cones, and ridges, which are distinguished by their rugged outlines, and rest, in the majority of cases, upon the summits or the flanks of the ranges composed of those older volcanic rocks. But there are also numerous instances when these may be seen to be accompanied, at some distance, by trachytic outbursts, when a cursory examination might make the latter appear to occupy an independent position. Trachyte does probably not compose, by itself, any extensive mountain ranges, and it remains, in general, greatly inferior in bulk to andesite. In Europe, its outbreaks were scattered and isolated, and, though they have been quite numerous, the aggregate quantity of trachytic rocks is not considerable. They occur in Hungary and Transylvania, on the Lower Rhine, in Central France, in the Grecian Archipelago, and in other parts of that continent, as well as in the adjacent portions of Asia. Specimens of trachyte, owing to their beauty and varied aspect, are usually much more numerous in geological cabinets than those of andesite—a fact which has frequently occasioned some misconception regarding the relative proportion and importance of trachyte and andesite among volcanic rocks.

In the structure of the North American Andes, trachyte takes a more important part than in Europe. A continuous range of it, at least ten miles in extent, and forming rugged crests, encircles the Washoe Mountains to the east, in the shape of a crescent. Trachyte rests there on propylite, and its ejection has probably had an intimate connection with the formation of the Comstock Lode. Other accumulations of similar extent may be noticed at Esmeralda, on the eastern slope of the Sierra Nevada, around Red Rock Cañon, south of Walker's Pass, in the surroundings of Lake Tahoe and Sierra Valley, and at other places east and west of the Sierra Nevada. In the northern provinces of Mexico, trachyte is known to occur quite extensively. At all the places mentioned, the greater part of its bulk bears evidence of having been brought into its present position by massive eruptions, while traces of extinct trachytic volcanoes are scarcely wanting at any of them. Trachyte is still being ejected by a number of active volcanoes. Among them may chiefly be mentioned those of Central America, the greater part of the modern lava of which has been proved to have the chemical and mineral composition of trachyte.

Mineral Composition.—Trachyte is only inferior to rhyolite in the number of its varieties. Yet its chemical composition is as simple as that of the latter, and ranges within as definite limits. The rock appears to contain, on an average, from 60 to 65 per cent. of silica, and is in this respect, as in others, next allied to rhyolite. The difference between the rocks belonging to both orders, having its fundamental cause in the chemical composition, manifests itself externally in certain differences of character, among which may be mentioned: the absence of quartz among the essential ingredients of trachytic rocks, which probably contain no free silica at all; the usual predominance in them of oligoclase over sanidin; the larger proportion in which hornblende participates in their mineral composition, and the fact of their specific gravity exceeding that of rhyolite. Like almost all volcanic rocks, trachyte consists of a paste in which are imbedded various crystallized minerals. This paste is of various colors, and has usually a more or less vesicular texture, which, by its property of imparting to the rock a certain roughness of touch, gave origin to the name. Chief in order among the enclosed minerals are sanidin, oligoclase, mica, and hornblende. They vary considerably as regards their relative proportion, and therefrom arises a number of varieties which have been partly distinguished by separate names. More numerous varieties, however, are occasioned by the differences of texture. Pumice-stone is of frequent occurrence among the latter, but it never exhibits that perfect long-fibrous and silken nature peculiar to it when being a variety of rhyolite. Obsidian, in different grades of perfection, is no unusual modification of the trachytic masses, and it is often filled with sphærolites, while no pearlite has yet been found having the chemical composition of trachyte. Foliated structure may frequently be met with; but the folia are not of that exquisite fineness which is peculiar to those of rhyolite. The modes of texture which alternate in the folia, are chiefly obsidian, pumice-stone, and microcrystalline varieties.

Subdivisions.—It appears that two natural groups of trachytic rocks may be distinguished, which differ at the same time, from a mineralogical and chemical point of view, and have therefore been arrived at similarly by the application of artificial principles.[8] We distinguish with B. v. Cotta:

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[8] I may here remark that I have endeavored to retain existing names, as much as possible, for designating the orders and families distinguished in this present classification. What I have tried to establish as natural groups, may therefore, on account of the similarity of nomenclature, coincide apparently, in many cases, with the groups established by artificial principles, and named in accordance with them. The former do indeed coincide in a few instances with the latter; but in the majority of cases, the limits of the application of the names differ widely when established from the two points of view mentioned. It would require too much space to go into detail on this point in regard to every name. I will, therefore, confine myself to an illustration regarding the order of trachytic rocks. B. v. Cotta, (with several other authors) unites under the name of oligoclase-trachyte all volcanic rocks consisting chiefly of hornblende and oligoclase, with the exclusion of certain dark-colored rocks, to which he applies the name andesite. The former name, if used in the meaning of that author, comprises, therefore, our order of propylite, together with all those rocks for which the term oligoclase-trachyte has been here applied. It is evident, from the different geological positions occupied by propylite and trachyte, as well as from the distinct petrographical character which either of them exhibits when occurring in large accumulations, how much their union would be opposed to a correct representation of natural relations. It is obvious, besides, that the union is unpractical. It would actually prevent the possibility of a clear and simple geological description of those countries in which propylite and trachyte occur together with other volcanic rocks. The distinction between both is so great that it has scarcely ever failed to be noticed by unbiased observers in those localities where both rocks occur. To unite them because

Fam. 1st. *Sanidin-trachyte.*—The color of the paste varies, but it usually presents light shades of gray, reddish, and reddish-brown; its texture exhibits all the varieties mentioned. There are imbedded in it: crystals of sanidin, or of both sanidin and oligoclase, besides mica and hornblende; the latter, however, is frequently wanting. To this family belong the rocks which compose the trachytic ranges of Washoe and Esmeralda, that of the Drachenfels, and many others.

Fam. 2d. *Oligoclase-trachyte.*—The paste is of the same color as in the rocks of the first family, though darker shades prevail, and presents a similar variety of texture. Imbedded are, chiefly, crystals of oligoclase and hornblende, the former being frequently of the vitreous variety; the latter having usually the shape of broad needles, with a black color and bright cleavage-planes. Besides those minerals, black mica is of frequent occurrence. The rocks of this family are ordinarily associated with those of the first subdivision, but in some localities are not accompanied by them. At Lassen's Peak there is but one limited space where rocks of both families intermingle; it is near the place where the lava has been ejected. Apart from it, the grand currents of lava, extending to from ten to twelve miles distance from the place of ejection, consist merely of oligoclase-trachyte. To this family belong those varieties of trachyte which were called "domite" by L. v. Buch.

The fact that the occurrence of the rocks of either one of these two families will frequently exclude those of the other, and that, even in those localities where they are associated together, they will occupy separate places in regard to geological superposition, appears to indicate that the distinction of these two subdivisions forms an approach to the requirements of the natural system.

ORDER THIRD—PROPYLITE.

The rocks of this order have hitherto occupied a very undecided position in the different classifications of rocks proposed, and just as various has been their nomenclature when they had to be mentioned in geological descriptions. The fact that they bear close resemblance in mineral character to ancient diorite, while, geologically, they are intimately allied to volcanic rocks, has been the principal cause of this uncertainty of their position. In Hungary and Transylvania, they occur quite extensively, and, being of practical importance as the bearers of rich metallic veins, have had to be noticed frequently in treatises on the mines of those countries. Beudant applied for them the name "porphyric greenstone," and classified them, along with syenite, among

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they are both chiefly composed of oligoclase and hornblende, would render it indeed, practically, a very difficult and complicated task to compare the geological relations of different volcanic countries on the strength of written descriptions. If we now follow the classification of J. Roth, we find the application of the name trachyte limited to those volcanic rocks which contain sanidin, but are devoid of quartz. All those numerous varieties which do not contain sanidin, but are intimately allied to sanidin-trachyte, by their mode of geological occurence as well as by their physical characters, are excluded from the denomination, and, together with all volcanic rocks composed chiefly of hornblende and oligoclase, are united into one subdivision of andesite. The reasons which justify the separation of the compounds of oligoclase and hornblende into three different groups, (oligoclase-trachyte, hornblendic propylite, and hornblendic andesite) will be detailed in the following pages. It may then be understood why the adoption of the different systems of the current nomenclature would render the concise geological description of volcanic countries extremely difficult, and would conceal the harmony really existing in the relations which they present in different countries.

the "transition rocks." Since then, the names greenstone, greenstone-porphyry, diorite, dioritic porphyry, and others, have frequently been applied for the same rocks of the Carpathians. Similar names have been used for them when they were mentioned as occurring in other countries, as for instance Mexico, where still oftener they have been simply styled "porphyry." In 1860, having had sufficient evidence of the Tertiary age of these rocks and their close connection with the volcanic rocks of that period, I separated them, in a treatise on some volcanic countries in Hungary, already referred to, by the name of "greenstone-trachyte," from the remainder of those rocks which then were usually comprehended by the name trachyte. That designation has since that time been frequently applied in geological descriptions. The attempts made to classify the rocks included in it have, however, been rather unsuccessful. J. Roth combines them into one group with amphibol-andesite, from which they are quite distinct as regards their petrographical as well as their geological properties; while others considered them as belonging to the dioritic rocks. The grounds upon which they have been united with the latter are purely artificial, since diorite is, from a geological point of view, widely separated from "greenstone-trachyte." Breithaupt established a new name, "Timacite," for a variety of our propylite, which is of very limited occurrence, and in which he discovered a new variety of hornblende, called by him "gamsigradite." Most valuable contributions for the knowledge of our "propylite," were recently given by Dr. Guido Stache, from observations made in Transylvania. (Hauer and Stache, Geologie Siebenbürgens, Vienna, 1863.) He discovered the occurrence, in that country, of quartz-bearing varieties in greater extent than they have been found hitherto at any other place. Stache retains the name "greenstone-trachyte," for those varieties which contain no quartz, and proposes the name "Dacite" (from the Roman province of Dacia to which Transylvania belonged) for those of which quartz is a common ingredient.

These statements will show the discrepancy of the views which have been entertained in regard to the systematic place and the nomenclature of the rocks under consideration. It is owing, partly to their twofold affinity with other rocks, (mineralogically to diorite, and geologically to volcanic rocks) and partly to the fact that they had, until lately, not been made the object of study. All observations made during the last few years concur in this, that those rocks, wherever they have been encountered, form a distinct link in the range of Tertiary and Post-tertiary eruptive rocks, being everywhere the first of them in age, while they are, in regard to their mineral character, no less distinct from any other eruptive rocks originated in those periods. They constitute, indeed, a more natural and more distinct group than any of the other volcanic rocks, and it has become desirable to unite them under a common designation. As no prominent property distinguishes them from diorite, and the derivation of the name from one certain locality did not appear proper for the designation of rocks of wide distribution, geological relations alone could be used as a basis for the nomenclature. The rocks under consideration, as we shall hereafter more fully develop, give evidence, in all localities where they have been met with, of having reopened the eruptive activity after ages of comparative repose. It is since then only, that this activity has continued with extreme violence over all parts of the globe, through the remaining part of the Tertiary and the Post-tertiary periods, growing, however, more and more faint during the latter. Propylite was, in fact, the precursor of all other volcanic rocks, and its appearance on the surface inaugurated a grand revolutionary activity on the globe. It is this position, at the entrance as it were to a new era in the history of the earth, which has given rise to the name "propylite."

Mode of Geological Occurrence.—The position of propylite at the bottom of all volcanic rocks is its most important geological feature. Its age has in no instance been ascertained with exactness. The nearest approach to its determination was made in Northern Transylvania, where I found, in several localities, nummulitic strata intersected by dykes and large intrusive masses of propylite, and covered by accumulations of it. As the greater part of the volcanic rocks in that country are of Miocene age, the ejection of propylite must have taken place either in the latter part of the Eocene or in the earlier part of the Miocene epoch. In view of the facts, that volcanic rocks have nowhere been observed to be anterior to the Eocene (probably even not prior to the Miocene) epoch, and that propylite is always allied to them as the first link in the order of succession, it may be inferred that propylite is, in general, of Tertiary age, until proofs to the contrary may be found.

The forms of propylitic mountains can be observed only in rare instances, since they are usually covered by other volcanic rocks, especially by andesite. This circumstance may also explain the fact of the comparatively rare occurrence of propylite as a surface-rock. In the environs of Bisztritz, in Northern Transylvania, it forms several high, isolated cones with steep slopes, resting on Eocene strata; their fine, dome-shaped appearance is scarcely surpassed in beauty by that of any other kind of rock. No estimate can be made in regard to the relative bulk of propylite which has been ejected, on account of its being overlaid by andesite and trachyte. It occurs, as far as exposed to view, in quite considerable accumulations, at Nagybanya and Kapnik, in Hungary, in Washoe, and at Silver Mountain, and covers large areas in Mexico, where it overlies the Cretaceous. It appears to have been profusely ejected through fissures, and its emission not to have been accompanied by volcanic action proper; no distinct traces, at least, have been found of propylitic volcanoes. Massive eruptions are known to have occurred, besides the places mentioned, in several other parts of the southern slope of the Carpathians, on the highlands of Armenia, and in Mexico, while the occurrence of propylite in Bolivia, the Altai Mountains, Northern China, and some other countries, may be inferred from the description of their geology.

Propylite has been repeatedly considered to be a sedimentary rock, metamorphosed *in situ*. The cause of this opinion was probably the fact that there are rocks which undoubtedly have had that mode of origin, and share with propylite the resemblance in mineral character to diorite. The eruptive origin of propylite is, however, evident, as it intersects stratified rocks in the shape of dykes. In Washoe and Silver Mountain, moreover, there are extensive accumulations of propylitic breccia and stratified tufa. The latter consists of alternate layers of coarse conglomerate, fine-grained propylitic detritus and massive propylite, and the entire system is intersected by dykes of the latter.

A particular interest, which has a practical bearing of some importance, attaches to propylite, inasmuch as, notwithstanding its limited occurrence, it yields probably a larger amount of silver than any other rock. Several of the principal silver-bearing veins, as the Comstock vein in Washoe, the celebrated veins in Hungary and Transylvania, as well as some of those in Mexico, and probably too in Bolivia, are enclosed in propylite.

Mineral Composition.—In propylite are united the petrographical properties of ancient dioritic rocks with those of andesite and oligoclase-trachyte. Varieties are numerous, but produced more frequently by the difference of the component minerals in size and relative proportion than by the texture, which remains porphyritic in every instance. The most common varieties consist of a fine-grained, microcrystalline paste of dark green or greenish brown, more rarely of reddish and dark gray colors, in which are imbedded crystals of oligoclase and hornblende; the former is of whitish or light green color, the latter ordinarily dark green and fibrous, seldom black with bright cleavage-planes (as is the case with gamsigradite). The paste appears to be a fine-grained aggregation of the same two minerals (the feldspathic ingredient prevailing), with the admixture of titanic iron, and to owe its ordinarily green color to the profuse dissemination of small particles of green, fibrous hornblende. Sporadic crystals of augite are occasionally met with in some of the common varieties, while others contain rounded grains of quartz sparsely enclosed. Recent observations have led to the discovery of two series of varieties deviating from the usual composition as explained. One of them is produced by the increasing proportion of the grains of quartz; the other by the more profuse occurrence of augite. The former was found by Stache, in Western Transylvania; the latter observed by me at Silver Mountain. Both appear to be of a limited geographical distribution, but are of great interest, as they extend the limits of the order of propylitic rocks, without rendering either their petrographical character, or their geological relations less distinct. In regard to the latter, it may be stated that the entire range of the quartzose to augitic varieties was anterior in age to andesite.

Difference of Propylite from other Volcanic Rocks nearly related to it.—The rocks of two other orders have an affinity to propylite, namely oligoclase-trachyte and andesite. The principal ingredients of either are hornblende and oligoclase, and either of them contains crystals of both these minerals imbedded in a paste. Yet there is a notable difference in character between these two, as well as between either of them and propylite. It is so conspicuous to the eye that the respective rocks have ordinarily been distinguished in geological descriptions, even in those of older time; and even the unprofessional eye would be able to distinguish the three groups in a collection of specimens belonging to them. Yet, it escapes description. It may, at this present time, safely be founded on what the botanist would call "habitus," a certain general character which it is as easy to recognize by the eye as it is difficult to describe it in words, and impossible to define its causes. It is probable that observations, such as Sorby has made in reference to those minute differences of texture, which can only be detected with the aid of the microscope, and H. Rose in regard to the modifications of silica and their causes, aided by exact chemical analysis and experiments made with the view of enquiring into the differences of origin of such eruptive rocks as differ from each other in texture, will, if further prosecuted, reveal the true nature and cause of the properties which distinguish the rocks of these three different orders.

A few of the more palpable differences may here be noticed. Propylite is essentially of greenish color, and some of its varieties resemble diorite in composition and texture; andesite is of blackish color and approaches basalt in aspect; trachyte is of various colors and shades, among which green and black are rarest of occurrence, and in regard to its external characters resembles rhyolite more than any other rock. Oligoclase, in trachyte, is frequently of the vitreous variety, scarcely ever so in propylite and andesite. Hornblende is an essential ingredient in these two, not so in the former; it is of fibrous texture and green color in most varieties of propylite, black in andesite and trachyte. Mica is seldom wanting in the latter, while it is not of common occurrence in propylite and andesite. Titanic iron enters largely into the composition of these, and is contained in smaller proportion in trachytic rocks. The latter excel by having the greatest variety of texture, while propylite has among the three the most perfect porphyritic texture, which has given rise to its frequent popular designation "porphyry;" this name has never been applied to andesite or trachyte.

The enumeration of all these trifling differences is, however, insufficient to express the marked distinction which exists in the external characters of propylite, trachyte and andesite. As a similar, and even more conspicuous, distinction manifests itself in their geological relations, we have to consider the existe ce of those three natural orders as a fact founded on observations, although we may be utterly unable to explain, and even to express it in words.

Subdivisions.—The remarks made in regard to the mineral composition of propylite have shown that the range of its varieties may conveniently, and in harmony with geological occurrence, be subdivided into three parts:

Fam. 1*st.* *Quartzose Propylite* or *Dacite.*—This embraces rocks which, though having in general a similar composition to those of the following family, contain besides, rounded grains of quartz, sometimes in considerable proportion. They occur in the western part of Transylvania, where their outbreaks succeeded those of rocks of the second family, and preceded those of andesite.[9] Similar rocks have been observed in Sinaloa (Mexico).

Fam. 2*d.* *Hornblendic Propylite.*—Rocks composed chiefly of hornblende and oligoclase, as described above. This family embraces vastly the majority of all propylitic rocks observed, among others those of Washoe. Breithaupt's "timacite" is one of its varieties.

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[9] Fully described by G. Stache, loc. cit.

Fam. 3d. Augitic Propylite.—Rocks distinguished by the accession of augite among the ingredients of the rocks of the foregoing family. It is present in greater or less quantity, sometimes predominating over the hornblende. To this family belongs the propylite of Silver Mountain, which contains augite in larger proportion than any other known variety.

ORDER FOURTH—ANDESITE.

The history of the name "andesite" has been noticed conjointly with that of "trachyte." At the time when the former name was first proposed for certain rocks of the Andes, a few specimens of which had been brought to Europe, it was intended as a designation of an accidental variety, proper to that mountain range. But those same specimens have proved since to be the type of one of the most important groups of volcanic rocks, which is distinct from others in character, and has a wide distribution.

Mode of Geological Occurrence.—Andesite vies with basalt in regard to the quantity of matter ejected to the surface, and probably excels the same in this respect. In most of those parts of the Andes, in regard to the geology of which we possess reliable information, it forms the chief bulk among volcanic rocks. The same is the case on the southern slopes of the Carpathians, at Nangasaki in Japan, and on the islands of Luzon and Java. Andesite succeeded the ejection of propylite, and prepared the way to that of trachyte. Preëminently the greater part of it has, to all appearance, been ejected through extensive fissures; that is, it has been produced by what we styled massive eruptions; though andesitic volcanoes, too, are not of rare occurrence, and, including those which are extinct, appear to have been particularly grand in their activity. It may be supposed that many of the former craters have been destroyed. Andesitic mountains are characterized by monotony in scenery. They form continuous ranges, which are often of considerable elevation and extent, but exhibit gentle outlines in their summits as well as in their slopes. Breccias only, which accompany the solid rock ordinarily in vast quantities, cause local interruptions of the monotony by their more rugged forms. They appear in castle-shaped rocks on the crests of andesitic mountains, and form high walls, naked and steep, along their slopes. Being more liable to destruction by the erosive action of water than solid andesite, they frequently compose the sides of steep ravines and cañons.

Mineral Composition.—Andesite is always of dark color, mostly blackish, though frequently reddish-brown on the weathered surface. Its mineral composition varies, though it is confined within more narrow limits than that of propylite. We may distinguish, in regard to it, two

Subdivisions, which are connected by gradual passage in composition and, in a greater measure, by geological relations.

Fam. 1. Hornblendic Andesite.—Paste of bluish-black to dark-gray color, and of microcrystalline texture, which passes by gradual steps into that of obsidian. In the former case it is frequently vesicular like trachyte. There are imbedded in it small but distinct tabular crystals of oligoclase, fine grains of titanic iron, small, elongated columns of hornblende, sometimes mica, and in most varieties a few isolated crystals or rounded grains of augite. Frequently these different crystals are so small as to be no longer recognizable, except by the aid of the microscope. The rock is then similar in character to certain varieties of melaphyr, but may be distinguished by its vesicular texture, which is scarcely ever wanting in the hornblendic varieties. This family comprises vastly the greater portion of all andesitic rocks.

Fam. 2. *Augitic Andesite.*—Two groups of varieties may be distinguished among the rocks of this family. Those of the first have a paste of an oil-brown color passing into black, a compact appearance, and ordinarily a microcrystalline texture which passes into that of porcelain. Vesicular inflation does ordinarily not occur. Crystals of a monoclinohedric feldspar (probably labrador) are almost invariably enclosed, and frequently accompanied by hornblende and augite. For the rocks of this group the name "*trachydolerite*" has particularly been applied. The other group comprises certain varieties for which the name "*anamesite*" has not rarely been used, and which are of dark-gray colors. Their texture is in most cases vesicular. The enclosed minerals are the same as with the other group; but, while for this the feldspathic ingredient is more characteristic, and frequently alone present in large crystals, the rocks of the second group are distinguished by the predominance of well formed crystals of augite and hornblende, while those of feldspar are often so small that they cannot be distinguished by the eye. The rocks of both these groups contain titanic iron in larger quantity than those of the first family, and are of greater specific gravity. Olivine enters occasionally into their composition, in very subordinate quantity. Geologically, the rocks of this family are closely allied to hornblendic andesite. They have succeeded it in age, and are limited in their geographical distribution to those places where hornblendic varieties had been ejected before, frequently intersecting and overlying them. Notwithstanding the resemblance which they bear to certain varieties of basaltic rocks, they appear to be never associated with them geologically.

ORDER FIFTH—BASALT.

No one of the names applied to volcanic rocks is of equal antiquity with that of "basalt," and with none there has ever been less change of opinion, and uncertainty in respect to its application. It may be inferred from this fact that the rocks comprised by that name are very distinct in character and little liable to variation, which is indeed true for the typical rocks of the order. But there have to be associated in the same order with them certain other rocks, which, though nearly related to basalt in regard to their chemical and mineral composition, differ from it in the more conspicuous external characters.

Mode of Geological Occurrence.—Basaltic rocks are more independent than those of any of the foregoing orders (perhaps with the exception of propylite), in respect to their epoch of ejection as well as to their geographical distribution. In the order of time they succeeded next to rhyolite, but locally, both are usually separated. Basalt occurs always in the neighborhood of more ancient volcanic rocks, but the cases are rare when it intersects them and expands over them. Almost invariably it is found accompanying their ranges at some distance, forming itself extensive ranges; more frequently, however, it occurs in groups or lines of isolated outliers. It may sometimes appear to have no connection with the distribution of older volcanic rocks. But closer investigation will always show it to be within or in the neighborhood of the limits of former eruptive activity. The belts along which this had taken place may be locally interrupted for quite a distance, and the gap be filled by some isolated outbreaks of basalt, or the latter may extend the limits of those belts, in length as well as in width. It is a strange phenomenon that these isolated outbreaks of basalt occur particularly in connection with granite. It intersects this rock very frequently in small dykes, and expands over it in thin sheets. This connection of granite and basalt is very conspicuous on the eastern slope of the Sierra Nevada, and along the belt of basaltic eruptions which traverses the middle part of Germany. Such places are often the seat of basaltic volcanoes, which, though now mostly extinct, are also otherwise of very frequent occurrence.

Mineral Composition.—Basalt is the representative of what Bunsen has called the "normal pyroxenic type," and is thereby, as well as by its specific gravity, mineral composition, and little variety of texture, the reverse of rhyolite, which represents the "normal trachytic type." All the essential ingredients of basalt, and most of the minerals which enter accidentally into its composition, are different from those which are characteristic of rhyolite. Augite, labrador and titanic iron, imbedded in a paste consisting essentially of the same minerals, constitute generally the rocks of this order; or labrador may be replaced by leucite, nepheline or a zeolitic substance; or other minerals may enter into the composition, such as olivine, basaltic hornblende, hauyne, apatite and black mica; and in many instances basaltic rocks consist merely of a fine-grained aggregation of the different minerals mentioned. Ordinarily, the paste has a microcrystalline texture, and may either contain crystallized minerals imbedded, or may be devoid of them. This mode of texture passes by gradual steps into that of obsidian, which is the only hyaline variety occurring. Among the peculiarities of these rocks, and which may also in some measure be observed with augitic andesite, is the occurrence of rounded cavities filling the rock and giving it a cellular, sometimes spongy appearance. It is different in nature from pumice-stone, which is a modification of hyaline texture, while those cavities occur in microcrystalline rocks.

Subdivisions.—Fam. 1st. Dolerite (including nepheline-dolerite and the greater part of anamesite).—A crystalline aggregation of augite and labrador with titanic iron. Labrador is usually replaced by nepheline, either in part or totally. Accessory minerals are: olivine, hornblende, apatite, black mica.

Fam. 2d. Basalt.—Paste of dark-gray or black color, and of the varieties of texture mentioned; it constitutes either the mass of the rock by itself, or encloses olivine, augite and labrador, in crystals or crystalline grains. Besides these are frequently enclosed: titanic iron, black mica, rubellan, zircon, apatite and other minerals. This family comprises nearly the whole bulk of the rocks which constitute the basaltic order, the two other families being of rare occurrence.

Fam. 3d. Leucitophyre.—Rocks of porphyritic texture, crystals of augite and leucite being imbedded in the paste.

It will be noticed that no place has been assigned in this classification to phonolite. As regards those rocks for which this name was first proposed, our knowledge is still quite limited. It appears that, notwithstanding their comparatively rare occurrence, they form a distinct natural group closely allied to basalt; but they are so different from true basalt as regards lithological characters, that they should not be classified with it before further observations will have determined their real position in reference to the natural families of volcanic rocks. The name phonolite has, however, been so much extended in its application, that this task is not so easy to accomplish. Some external properties, easy of recognition to superficial observation, such as a certain tabular structure, lithoid texture of the paste, with small, bright crystals of feldspar enclosed, and the peculiarity of ringing by a blow of the hammer, which have been often considered as the characteristic features of phonolite, are just as common with certain varieties of trachyte and rhyolite, and even with some of propylite. It must be ascribed to this reason, that the name phonolite has been used for the designation of rocks which bear an accidental resemblance to true phonolite, but are distinct from it in nature. It has probably been oftener applied to rocks belonging to the trachytic order than to such as have the distinguishing features of those varieties for which the name has been first used.

Correlation of the Five Orders of Volcanic Rocks.

In the foregoing pages I have attempted to lay down the outlines of a classification of the volcanic rocks by natural principles, and to apply a nomenclature which should be appropriate to these, and embrace, at the same time, the most current of existing names. It is the next object of this paper to prove that these rocks are mutually connected by definite relations, and that their totality, in virtue of this property, forms actually what may be called a system in nature, and that the form into which we have tried to bring it, imperfect though it must be, is an approach towards its expression. In order, therefore, to fully realize the philosophy of the natural system, we have to contemplate the relations which, firstly, the rocks of the different orders offer mutually among themselves, and by which, secondly, they are connected as an entire class with ancient eruptive rocks; while we will have, thirdly, to examine into the mode of origin of volcanic, and of eruptive rocks in general, in order to establish the nature of their fundamental difference from sedimentary and metamorphic rocks. Our task is thus three-fold. The present chapter will be devoted to the first order of relations. They may be considered from several points of view, the more important of which are: chemical and mineral composition, geographical distribution, and all those complex relations which may be comprehended in the term "mode of geological occurrence." We will confine ourselves to the last point of view. But even with this restriction, we can only trace general outlines.

Laws relative to the Age of Massive Eruptions.

The succession of *massive* eruptions during the Tertiary and Post-tertiary ages has taken place in the following order :

1st. Propylite.
2d. Andesite.
3d. Trachyte.
4th. Rhyolite.
5th. Basalt.

This singular mode of succession, in which no regularity (as to increase or decrease of silica or specific gravity, or as to a gradual change of mineral composition) can be discovered at first sight, and which might indeed appear to be devoid of order, and to bear the character of such a succession as might have been occasioned by the coöperation of accidental circumstances in one single country, can nevertheless be proved to exist in widely separated parts of the globe. It may justly be objected to this assertion, that observations in regard to the relative age of different volcanic rocks are scarce, and hardly sufficient to establish definitely such a law. But hitherto no deviation from it has been discovered,[10] and it appears to be true for all volcanic regions on the globe, though with this restriction, that the epochs marked in each country by the ejection of rocks of any certain orders have not been contemporaneous in different countries. The commencement of eruptive activity in the Tertiary epoch has been earlier at one place than at another ; it is its further mode of development in regard to the nature of the matter ejected which has everywhere been regulated by the same definite relations, though it has been independent, in some measure, at each place, or, to use a more correct expression, over the area of each belt of eruptive activity. We have to mention another restriction. Abrupt passage may be said to be an almost unknown conception in geological matters, where the order in time is concerned ; nor has it to be applied to the order of succession of volcanic rocks. The eruptions of propylite appear not to have been interrupted by the ejection of any other rocks. This may too be said, though less strictly, of the andesitic epoch. But some, as it were, retarded eruptions of andesite, which, however, have always been insignificant, may occasionally be traced during the first part of the trachytic epoch, and similar relations exist between trachyte and rhyolite. Basalt, however, appears to have had everywhere its own epoch of ejection, uninterrupted by the massive eruptions of any other rock of the orders just mentioned.

We proceed to a short review of some salient facts observed in those countries where the mutual relations of volcanic rocks in regard to their age have been made an object of study.

In Hungary and Transylvania, propylite, as we have had occasion to mention, was ejected first of all volcanic rocks, and may be said to have inaugurated all sub-

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[10] It must be borne in mind that we are speaking of massive eruptions. Apparent exceptions are known to occur with rocks ejected from volcanoes, of which mention will be made hereafter.

sequent eruptions of those belonging to other orders. At several places it has been observed to intersect Eocene strata, and to expand above them. The country of Nagybánya, Felsöbánya and Kapnik, the celebrated silver-bearing veins of which are enclosed in propylite, offers especially conspicuous illustrations; not less, from the descriptions given by G. Stache, the "Erzgebirge" of Transylvania, where the same kind of rock is rich in mineral veins. In this country, hornblendic propylite forms an older series, followed by eruptions of highly quartziferous varieties. In both countries, but chiefly in that first named, and at several other places along the southern slope of the Carpathians, andesite may be seen intersecting propylite in large massive dykes, and towering up above it in mountain ranges. Andesite composes entirely the Hargitta-range, which extends over one hundred miles in length, and twenty-five in width; the Vihorlat-Gutin-range, which is of still larger dimensions, and the Eperies-Kaschau-range; all of which are densely wooded, and of a gloomy, monotonous aspect. The only change observable on their summit ranges is a more or less dark color of the rock, occasioned by the predominance of augite or hornblende in its composition, (the augitic varieties being invariably of more recent age than the hornblendic), while their slopes, and particularly their ends, present a much greater variety in rocks as well as in scenery. It is here that the more silicious volcanic rocks are encountered. Trachyte is of rare occurrence; but it forms several isolated cones, some of which, on account of their prominent position, were crowned by castles in the middle ages. Rhyolite is much more frequently met with, bursting forth on the flanks, and skirting the foot of the andesitic ranges, particularly where they verge towards the Hungarian plains, which in the rhyolitic epoch were still covered by a shallow and slowly retiring sea. It projects against this in promontories, which are now covered by the most celebrated of the Hungarian vineyards, those of Tokay among others. The boundaries of these vineyards towards the adjoining beech forests mark the dividing line between rhyolite and andesite. An interesting mode of occurrence of the former may be witnessed in large circular or amphitheatrical basins which are surrounded by andesite. Such places are the theater, especially, of the volcanic activity connected with the outbreak of rhyolite, and abound in endless hyaline varieties of the same. Telkibanya is the most interesting among the localities of this description. There is no lack of evidence to prove that trachyte and rhyolite are both of more recent age than andesite, while the assertion that trachyte preceded rhyolite in age, rests only on a few though conclusive observations. Basalt occupies a singular position in the geology of Hungary. It keeps altogether aloof from the places occupied by the other four orders of volcanic rocks, and forms extensive, though isolated, hills at some distance from them, scattered over a wide range of country. It would be difficult to determine its relative age, but for the volcanic sediments which were of formation contemporaneous with the ejection of the different volcanic rocks, and have been spread over wide areas at the bottom of the then existing sea, with fossils occasionally imbedded. In several localities, especially in the neighborhood of Kaschau, basaltic sediments may be seen, covering those composed of rhyolitic matter, while at Gleichenberg in Styria, Mr. Franz von Hauer has observed fragments of rhyolite enclosed in basalt.

The observation of these relations in Hungary and Transylvania has first given rise to the establishment of the above mentioned law of the periodical succession of volcanic rocks.[11] It has since been corroborated by observations made in other countries far remote from the Carpathians. Near Nangasaki, in Japan, andesite preceded trachyte in age, and of the former there are two varieties represented, one augitic and one hornblendic, of which the former is of more recent origin than the latter: thus, even the more minute relations observed in the Carpathians are repeated in other countries. The islands of Java and Luzon are too intensely volcanic and covered with lava to aid in establishing the laws in respect to massive eruptions without very close observation. But another region offering copious evidence is that of the Sierra Nevada, together with the adjoining parts of the Great Basin. Observations in these countries are still limited as regards our present subject. The great part, however, which volcanic rocks take in their composition, as well as in that of the highlands of Mexico, and of the entire range of the Andes, promises to make the Western Coast of America the most prolific source of observations necessary for the definite establishment of geological laws of which, at the present day, we can only trace the first foundation.

In Washoe, a country adjoining the Sierra Nevada immediately to the east, propylite forms extensively the foundation for all other volcanic rocks, which fact proves clearly its priority in age. It composes the plateau of Virginia City and Gold Hill, and derives a practical interest from the fact that the Comstock vein is enclosed between propylite and syenite, though in some parts of it both walls consist of the former rock. Andesite is insignificant in bulk in that region. It composes a few small hillocks on the propylitic plateau, and in some cuts and tunnels andesitic dykes may be seen, which appear to have been the feeding channels of the surface accumulations. Trachyte, on the contrary, is among the prominent rocks of Washoe. It forms a high and rugged crest, encircling the plateau of Virginia and Gold Hill to the east, and extending for miles to the north, while to the south it reappears across the Carson River. No evidence is afforded, in Washoe, for the establishment of the mutual relations of andesite and trachyte, while it is conspicuous that the latter was of later origin than propylite. Besides the evidence offered by intersection and superposition, another fact may be noticed which is suggestive for the length of the period that elapsed between the eruptions of both rocks. It is this, that propylitic sediments occur, at least, at one thousand feet more elevation than those consisting of trachytic matter, which fact appears to indicate that the former have been deposited at a much earlier part of the period marked by the gradual subsidence of the inland seas of the Great Basin than has been the case with trachytic sediments.

At Silver Mountain, propylite, of the augitic variety, fills the bottom of a deep basin encircled to the west by granitic walls several thousand feet in height. Its massive accumulations are intersected by andesitic and trachytic rocks, which latter appear to compose the summit of the high peak of Silver Mountain itself, while rhyolite occurs in such a position as to make it probable that it has arrived at the surface last of all eruptive rocks. Basalt appears to occur only to a limited extent at Silver

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[11] Richthofen, loc. cit.

Mountain. But this rock is largely distributed in the regions adjoining the Sierra Nevada to the east, and bears evidence of its recent origin. It is the only volcanic rock which covers in places the sand of the deserts, and the belts distinguished by its eruptions are still marked by the occurrence of hot springs and other post-volcanic phenomena. Most of these are contiguous to those places where basalt and granite are in close contact, as is very conspicuously the case at Steamboat Springs, near Washoe, and in the Coso Mountains. No phenomena of similar nature appear to be connected at the present time with any other volcanic rock east of the Sierra Nevada. There are not a few instances where basalt may be seen covering propylite or andesite; but I met with only one case where it comes in contact with rhyolite, close enough to establish their mutual relations. This is in Esmeralda, on the eastern slope of the Sierra Nevada, a country of unusual interest for the study of volcanic rocks in general. Propylite encloses the silver-bearing veins of that place. It is overlain by trachyte and rhyolite, both of which occur in very great variety. To the east of the place, basalt has not only flowed over rhyolite, but contains numerous fragments of it enclosed, which fact confirms also for this country the more recent origin of basalt.

Many other examples might be added to this short list, partly of positive observations made in the countries already mentioned, and partly of facts described in treatises on the geology of other countries, such as Armenia, the Caucasus, Central France, the Eifel, Bolivia, Mexico. As these descriptions, however, have not directly in view the illustration of our subject, great care should be used in drawing from them conclusions in regard to it. Let it suffice to remark, that every observation on record which bears on our subject, appears to confirm the proposed law, while none can be found giving evidence against it. This may justify the assumption that the periodical succession of volcanic rocks, in the order above mentioned, is a general law, true for all parts of our planet.

Laws regarding the Mutual Relations of Massive Eruptions and Volcanic Activity.

It has been mentioned in this chapter, that the law of the periodical succession of volcanic rocks regards those outpourings of large volumes of matter not resulting from volcanic activity proper, and which we called massive eruptions. For convenience' sake, we make use of the following expressions: *propylitic epoch; andesitic epoch; trachytic epoch; rhyolitic epoch; basaltic epoch* — designating thereby those epochs in which the *massive* eruptions of rocks belonging to each of these orders, have taken place in every different country. If we now direct our attention to the other mode of manifestation of subterranean energy, the *volcanic* eruptions, a cursory review of active volcanoes in regard to the nature of the rocks which they eject, shows that the same law is no longer true for them, as their lavas belong to several different orders of volcanic rocks. It is, however, known that each volcano ejects lava or scoria belonging petrographically only to one distinct order, and the examination of the material accumulated by former activity will show that with most volcanoes the nature of the rocks ejected has never materially varied, while with some of the grander vents it has undergone a periodical change. Volcanoes, whether active or extinct, may be classified from this point of view. We shall distinguish: *andesitic, trachytic, rhyolitic* and *basaltic volcanoes*, according to the nature of the mineral matter which each volcano has ejected *in the first epoch* of its activity, regardless of any later changes. Two noteworthy relations may be traced between these different orders of volcanoes and the massive eruptions of the synonymous orders of volcanic rocks. The first of them is the alliance of both in regard to geographical distribution, the volcanoes of each order being limited, in this respect, to the immediate neighborhood of massive accumulations of rocks similar in nature to their first lavas. From this may partly be inferred ,the second relation, that the massive eruptions of each order have been succeeded by volcanic activity, which occasioned the ejection of lava corresponding in nature to their own rocks, and continued for long after-time, in many instances to the present day. This dependence of volcanoes upon massive eruptions explains why the number of active volcanoes is so small when compared with those which are extinct, and why the present activity even of those which are still in operation, appears to be only a faint remnant of that which the same vents exhibited in former time. It will further explain why no vestige can be found of a rhyolitic volcano having been active before the rhyolitic epoch, or of a basaltic volcano having originated before the basaltic epoch, while geological observation goes to show that during, and immediately after those epochs, the volcanoes of either order have been most intense, numerous and extensive, and their activity has, from that epoch of culmination, gradually relaxed, in most cases to perfect extinction.

An instructive instance of one of those grander volcanoes which have undergone a periodical change in regard to the nature of the matter ejected from them, is afforded by the extinct volcano Lassen's Peak, in Northern California, which Professor J. D. Whitney and I visited in 1866. We found it to have been originally an andesitic volcano, and it has to be ranked as such in our proposed classification. The enormous bulk of the ancient volcano is totally built up of stratified layers of andesitic tufa and rapilli, which, in the steep gorge issuing from its lower crater, are exposed in a thickness of nearly four thousand feet, notwithstanding the total destruction which the upper part of the former cone has undergone, and the fact of its lower parts extending down far beneath the present surface, and being therefore concealed to view. Besides these stupendous accumulations of loose matter, currents of andesitic lava appear to have been emitted from the crater, extending at least twenty miles from the place of ejection. At a later epoch, the activity of the same volcano has been distinguished by the emission of trachytic lava from the northeastern part of the wall of the crater; its currents have expanded to elongated and sloping tables, bounded by abrupt descents. A third epoch is marked by the outbreak of rhyolite at the same place whence the trachytic rocks had issued. Rhyolite composes the present summit of Lassen's Peak, on which it is accumulated in a thickness of more than fifteen hundred feet, also some other summits of less altitude, and at least one prominent current of lava of great volume.[12] The noteworthy fact illustrated by these observations on Lassen's Peak, and corroborated in numerous other instances, is this:

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[12] Mr. Clarence King has observed the occurrence of basalt of apparently very recent origin immediately north of

that the same law of periodical succession which has been established in regard to massive eruptions, is true for volcanic action, particularly when this happened to assume such unusual intensity and dimensions, and has been of as long duration as was the case at that volcano.[13]

Summing up these considerations on the correlation of the different orders of volcanic rocks in respect to the age of their emission through volcanic vents, we arrive at the following conclusion: The commencement of the activity of the volcanoes of each separate order has been nearly coincident with, though in every instance successive to, the main phase of the corresponding massive eruptions. Thence it has, by each separate vent, either continued emitting similar material to that first ejected, until its extinction, or it continued in the same way to the present day, or it has been subjected to a periodical change in regard to the nature of its lavas, and this change is analogous to that exhibited by the succession of massive eruptions. In this case, as in the former, the volcano has either become extinct when in a certain phase, or it is still active. We are thus furnished with a natural cause of the fact, that most active volcanoes are emitting basaltic, a smaller number of them rhyolitic or trachytic rocks, while andesitic lava is peculiar only to a few of them, especially to some of the prominent volcanoes of South America (Chimborazo, Cotopaxi, Antisana, Tunguráhua, also Popocatepetl, Colima, and Teneriffe) which appear never to have changed in mineral character. It will, too, be self-evident, why generally no material change in the nature of their lava should have been observed in regard to those volcanoes which have originally emitted basalt and constitute our order of basaltic volcanoes.

A few more instances may here be mentioned in support of our propositions. The interest attaching to volcanoes has furnished us with a much greater number of facts in regard to volcanic rocks when occurring as lavas, than we possess in regard to the grander and more frequent instances when similar rocks have been produced by the comparatively neglected action of massive eruptions. Among those observations, none will be better evidence than such as prove the abrupt succession, by ejection from the same volcano, of two rocks so dissimilar in composition as rhyolite and basalt. On the other hand, the nature of volcanic action will explain why we should meet among lavas, more frequently than among massive eruptions, with the fact of two successive epochs blending into each other by the alternation of the two kinds of rock peculiar to them separately, and it cannot be surprising if instances are occasionally observed exhibiting, at least partly, a reversed order of succession.

Lassen's Peak. It is probable that it indicates the existence of a fourth epoch in the activity of that volcano. The ejection of basalt has been so frequently connected with the opening of vents in the neighborhood of, but not coinciding with, channels through which its predecessors had ascended, that its local separation cannot be an argument against its belonging, in our case, to the system of Lassen's Peak.

[13] The fact that trachytic lavas are frequently followed by such of basaltic character has been known since long time, and was till now the only law of succession observed. Mr. Scrope has suggested the hypothesis indorsed by Mr. Darwin, Sir Charles Lyell, and other distinguished geologists, that in the subterranean reservoirs of volcanic matter, the heavier particles will occupy the lower part, and the lighter ones be nearer the earth's crust. It will easily be seen how totally inadmissible this theory is in the case of Lassen's Peak. It is not less so in those cases where rhyolite was succeeded by basalt, since the process of liquation can certainly not be supposed to have produced an abrupt passage under ground from one mass to the other, and it would be much more natural to suppose a gradual transition to take place, there as well as in the succession of the rocks emitted to the surface, if liquation had really taken place.

An instance, which is instructive on account of its simplicity, is furnished by the island of St. Paul, in the Indian Ocean. F. von Hochstetter found its foundation to consist of rhyolitic rocks. These are intersected by basaltic dykes. Rhyolite overlays the first basaltic formation, and is itself superposed, first by dolerite and then again by basalt. These two rocks of the basaltic order constitute the main body of the island, and encircle its crater. Similar relations, though on a much grander scale, have been observed by the same eminent geologist on New Zealand. More frequently than this order of succession between rhyolitic and basaltic lava, has been observed the sequence of basalt to trachyte, with the omission of rhyolite, or immediately to andesite, when both those rocks are absent. Vesuvius is built up of rocks of the basaltic order, and still emits lava corresponding in mineral character to its predecessors, while the rocks of its surroundings (Campi Phlegræi), on the prior origin of which geologists agree, are trachytic. The industrious explorer of Mount Etna, Sartorius von Waltershausen, has described its foundation as being composed of white and reddish colored trachytic rocks, which contain hornblende as a characteristic ingredient, while among those rocks which build up the summit, as also in all modern lava of the volcano, no hornblende but, in its place, augite is visible. This mineral and labrador compose the recent lava, which belongs to the basaltic order. The much more extensive recurrence of a similar order of succession in the Eifel and in Auvergne, is too well known from the accurate descriptions of the geology of those regions, to require to be here more fully mentioned. It contributes especially to confirm our proposition, that the volcanoes of the different orders, as regards their origin, have been nearly contemporaneous with the correlated massive eruptions. The classical descriptions of the Eifel, by Mr. von Dechen, give conclusive evidence thereof.

Among those volcanoes the lava of which has never undergone a material change and is, at the same time, similar in nature over the area of larger volcanic districts, may be mentioned, besides numerous basaltic volcanoes, those of the trachytic order in Central, and those of the andesitic order in South America, as far as may be seen from the descriptions given of them.

We might greatly enlarge this enumeration of observations confirming our propositions; but, as by most authors only a "trachytic" or a "basaltic" character of lava have been mentioned in a general way, they would only furnish evidence in favor of the general tenor of the law, but would fail to give it in regard to any of its details.

Relation of Volcanic Rocks to Ancient Eruptive Rocks.

All rocks which, bearing evidence of an intrusive or eruptive origin, preceded in age the Tertiary period, may, by principles similar to those which we applied in tracing the natural system of volcanic rocks, be divided into two great classes, for which we may use the terms "granitic rocks" and "porphyritic rocks," derived from the mode of texture predominating in either class. Granitic rocks are, besides, geologically associated with granite, which is their principal type, while quartzose porphyry occupies a similar position among porphyritic rocks. The annexed table

FIRST CLASS: GRANITIC ROCKS.	SECOND CLASS: PORPHYRITIC ROCKS.	THIRD CLASS: VOLCANIC ROCKS.		ESSENTIAL INGREDIENTS.
Order First—Granite.	*Order First—Felsitic Porphyry.*	*Order First—Rhyolite.*		
Fam. 1st. Granite.				
Fam. 2d. Granitite.	Fam. 1st. Quartzose Porphyry.	(Quartziferous Varieties.)	Fam. 1st. Nevadite.	Quartz, Orthoclase, Oligoclase, Biotite, (Hornblende.)
Fam. 3d. Syenitic Granite.			Fam. 2d. Liparite.	
	Fam. 2d. Varieties without Quartz.	(Varieties without Quartz.)	Fam. 3d. Rhyolite proper.	
Order Second—Syenite.	*Order Second—Porphyrite.*	*Order Second—Trachyte.*	*Order Third—Propylite.*	Oligoclase, Orthoclase, Hornblende, (Biotite), (Quartz.)
		Fam. 1st. Sanidin-Trachyte.	Fam. 1st. Quartzose-Propylite.	
Only Family: Syenite.	Only Family: Porphyrite.	Fam. 2d. Oligoclase-Trachyte.		Oligoclase, Hornblende, (Titaniferous Magnetic Iron-ore.)
Order Third—Diorite.	*Order Third—Melaphyr.*	*Order Fourth—Andesite.*	Fam. 2d. Hornblendic Propylite.	Oligoclase, Hornblende, Titaniferous Magnetic Iron-ore.
Fam. 1st. Diorite.	Fam. 1st. Melaphyr.	Fam. 1st. Hornblendic Andesite.		
Fam. 2d. Rocks intermediate between Diorite and Diabase.	Fam. 2d. Rocks intermediate between Melaphyr and Augitic Porphyry.	Fam. 2d. Augitic Andesite.	Fam. 3d. Augitic Propylite.	Oligoclase, Labrador, Augite, Hornblende, Titaniferous Magnetic Iron-ore.
Order Fourth—Diabase.	*Order Fourth—Augitic Porphyry.*	*Order Fifth—Basalt.*		
Fam. 1st. Gabbro and Hypersthenite.		Fam. 1st. Dolerite.		Labrador, Augite, Titaniferous Magnetic Iron-ore.
	Only Family: Augitic Porphyry.			
Fam. 2d. Diabase.		Fam. 2d. Basalt.		

will show the mutual relation of these two classes and their subdivisions, and of either of them to volcanic rocks.[14]

It appears that this general classification is based upon as natural principles as are within reach of our still limited knowledge of eruptive rocks, and therefore may at least approach the natural system. The following are the systematical principles chiefly involved :

1st. *Chemical Composition.*—Each class contains all possible compounds intermediate between those which Bunsen styled the normal trachytic and normal pyroxenic types, and may, therefore, be represented by a numerical series of infinite gradations within two certain limits, and progressing according to a definite arithmetical law. If this law applied to the composition of rocks with mathematical precision, it would be sufficient to know the relative quantity in which any one single ingredient enters into the same, in order to find by calculation the relative proportion in which every other ingredient should be present. It is, however, well known, that analysis shows ordinarily a slight deviation from the composition as required by theory ; and, considering the various influences to which the rocky masses must have been exposed before and after their consolidation, we should naturally presuppose that such deviations would be the rule, and may indeed be astonished to see how slight they generally are. Silica has been found to be not only the most convenient, but also, on account of its predominance over other ingredients, the safest element by which to determine the place any rock occupies in the series. In the classification as proposed in the preceding page, each class of eruptive rocks commences with those varieties of granite, quartzose porphyry and rhyolite, which contain the highest amount of silica as found by analysis, and descends to the most basic varieties of diabase, augitic porphyry and basalt. In a chemical respect, therefore, the three classes are identical.[15]

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[14] This table is only designed to show the mutual relations of the subdivisions of the three great classes of eruptive rocks in their most general outlines. I have purposely avoided to detail them any more, since it appears that great progress in regard to their knowledge will be made in the next years, and considerable changes in the details of classification may have to be looked for. The composition of eruptive rocks is just at the present time being made an object of more careful study than it ever was before. Contributions of high value in regard to the chemical and mineral composition of volcanic rocks are being furnished by the members of the Geological Institute of Vienna ; while H. Abich continues with untiring energy his fruitful researches on the same rocks of Armenia, the Caucasus, and the borders of the Caspian Sea. The examination of the granitic rocks by G. vom Rath, A. Streng, Th. Scheerer and many others ; the more general labors of G. Rose., Robert Bunsen, A. Delesse, G. Bishoff, F. Zirkel ; the microscopic investigations which have been commenced with so much success by A. Sorby, and are being extended by his numerous followers—all these labors pursued zealously by those named and a great many other workers in the same branch of geological science, whom it would be too lengthy to mention, promise a rapid advance of our knowledge of the properties of eruptive rocks. In respect to their mineral composition, the discovery of some new species of feldspar (such as the plagioclase of Rath and the microtine of G. Tschermak) which appear to be of wide distribution among the components of eruptive rocks, promises alone to enlarge quite considerably the basis of classification, as it appears to give a clue to the causes of the differences in outward appearance (frequently referred to in this paper) of rocks which are alike in regard to their chemical composition, and among the mineral ingredients of which no difference could be recognized heretofore.

[15] Objections have been raised against the validity of the law of Bunsen, partly on the ground of the frequent discrepancy of the figures obtained by chemical analysis from those which would be required by the theory, and partly on account of the highest and lowest amounts of silica occurring in eruptive rocks having as yet by no means been fully ascertained. We referred above to the first objection. As regards the second, it is evidently very trifling in importance. The limits of the series may, and probably will, be somewhat extended, and the figures representing the compounds which form those limits may have to be slightly changed, yet the series itself will remain essentially the same. The law of Bunsen will have to be revised and corrected when increased experience shall have established a broader basis for it ; but no change of its principles may ever be expected, as an overwhelming amount of evidence has accumulated in support of its essential tenor.

2d. *Mineral composition*, in respect to which each class represents a series of gradations essentially dependent on the chemical composition, and therefore chiefly coincident with the chemical series, but differing from it inasmuch as it is more articulate. Certain types, corresponding to certain steps in the chemical scale, and consisting in distinct aggregations of a few minerals, are the centers for which the petrographical names have been applied in the first place; around them other members are grouped which connect every two types by gradual passages, and are ordinarily composed of an aggregation of all the minerals peculiar to either of them. Expansion of the series, as it were, in a lateral sense, occasioned by the accession of minerals inferior in importance, are not unfrequent, but do not affect in a great measure the definite character of mineralogical gradation, as they are of local occurrence, and probably less dependent upon any material differences in chemical composition, than upon certain influences which acted upon the mass of the rock, either before its ejection, and then by the admixture of matter differing from it in nature, or after its solidification, and then by chemical metamorphism.

3d. *Specific gravity*, which increases in the reverse proportion of silica. In this respect, too, each class represents a series of infinite gradations from the lowest to the highest value.

Taking the three foregoing principles exclusively as the basis for classification, all eruptive rocks would have to be united into one class. This union, made regardless of any other relations, may be traced as the leading feature of nearly all systematical arrangements proposed. There are, however, other points of view which must be considered if a more perfect classification is aspired. They lead to the establishment of further separations, by principles similar to those which we had to apply above in defining the different orders of the compounds of hornblende and oligoclase among volcanic rocks. These points of view are the following:

4th. *Mode of Texture.*—Eruptive rocks exhibit, in regard to their modes of texture, very peculiar differences, which are little capable of explanation with our present state of knowledge. They are especially conspicuous with the most silicious rocks. Free silica, in granite, has probably been solidified cotemporaneously with the other component minerals; but its solidification appears often to have been completed last of all, as the quartz does envelop the aggregation of the other crystals. In quartzose porphyry and rhyolite, on the other hand, free silica, at least the greater part of it, has been solidified first, which is obvious from the fact that its perfect crystals are imbedded in an ordinarily microcrystalline aggregation of the other ingredients, which however contains, in most cases, some surplus of free silica that had not entered into the composition of the crystals. This fundamental difference from granite points to some difference in the mode of origin. Quartzose porphyry and rhyolite differ in regard to the texture of their paste, which has a compact aspect in the first, while it is more or less vesicular throughout the mass in most varieties of the latter. This difference, like the former, appears to indicate, that the molecular condition of the liquid mass, at the time when it was ejected, was different in either case. The variety of texture diminishes with the decrease of silica, and the more basic rocks of the three classes bear a much closer resemblance to each other than the silicious rocks. The cause must be, either that the conditions of the mass before cooling were less varied with basic than with silicious rocks, or that the differences were alike, but manifested themselves less conspicuously in the character of the solidified rocks; the latter cause is the most probable of the two, since even our cotemporaneous basaltic and andesitic lavas offer but a small number of varieties comparing with those of rhyolite or trachyte, although it is not likely that there is any more variety among the circumstances modifying the latter than among those which are acting upon the former. It is chiefly the similarity in texture which has occasioned the general application of such names as "trap," "greenstone," "aphanite," and others, for basic rocks of all ages, while those containing a large amount of silica have scarcely ever been similarly confounded. We may, however, note this difference among the former, that granitic texture—that is, a crystalline aggregation of the component minerals—is peculiar to those basic rocks associated with granite, while the vesicular or trachytic texture is only proper to volcanic rocks. Occasionally, though very rarely, rocks of granitic texture are geologically associated with porphyritic rocks, as is the case near Predazzo, in southern Tyrol.

5th. *Geological age:* granitic rocks being generally the most ancient in origin, volcanic rocks the most recent, while those of porphyritic structure are intermediate in age between both.

6th. Other geological conditions resulting from the correlation of the different foregoing principles, the outlines of which I will attempt to trace in the following pages.

Correlation of Age and Texture.

It is scarcely possible to treat of one of the foregoing principles in its application to eruptive rocks singly, without constantly encountering points of intimate connection with others, so thoroughly are they intertwined and mutually dependent. It is the object of petrology to develop these correlations. We contemplate them here only in their purely geological bearings, in order to try to establish the true relation of volcanic rocks to their ancient predecessors. We have, while occupied with these considerations, constantly to keep in view how few are the observations upon the strength of which we have to base conclusions. The area on the globe whose special geology has been made the object of investigation, though extending every year, is still very limited; and even in the best explored countries, little attention has, in most instances, been paid to the distinction of eruptive rocks. Observations in regard to them are abundant in some parts of Europe, fortunately in such countries as are especially capable of giving a clue to their general knowledge. Distinct conclusions may be arrived at in regard to portions of that continent, but little scope is afforded for giving them latitude by comparison with the relations presented in other countries. We have, therefore, to keep well separate in general petrology, those positive conclusions which are founded upon sufficient observations, and are applicable to the relations in those countries where the latter were made, and the realm of theories, which are arrived at, partly by the generalization of those conclusions, and partly by making deductions from hypothetical suppositions: because, the premises being founded on local occurrences, and their general validity not being proved, the theories must necessarily have a great deal of uncertainty, which will only gradually be dispelled by the advancing knowledge of the geology of the globe.

The correlation of age and texture, as resulting from observations made in Europe, will occupy us first. Granitic rocks are widely distributed on that continent. Their great eruptive masses are of Azoic and Palæozoic age. The rocks have almost throughout granitic texture, though the distinguishing features of porphyritic rocks are proper to some subordinate varieties of diorite and diabase. The eruptive activity exhibited in the granitic era gradually relaxed. It appears to have been insignificant, though it was by no means extinct, in the latter part of the Devonian and the first part of the Carboniferous periods. But it recommenced about the time of the deposition of the coal measures, thence increased in intensity, and was most violent in the Permian age, though it was, during all that time, much more limited in extent than it had been during the granitic era. The middle portions of Germany were then its principal theater, until it changed, in the commencement of the Triassic age, to the southern slope of the Alps and Carpathians. The rocks produced during this era possess, almost exclusively, porphyritic texture. The Jurassic, Cretaceous, and the first part of the Tertiary ages, were distinguished by an almost complete repose of eruptive action, in Europe. It was only after the commencement of the Tertiary period when that violent resumption of eruptive activity took place to which we have repeatedly called attention in the foregoing pages, and which thereafter continued, gradually relaxing, down to our present era, the manifestations of volcanic action in which are its last faint remnant. Vesicular inflation, which is the characteristic feature of trachytic texture, is peculiar to the rocks of this class; all of them possess it more or less, though there are varieties resembling porphyritic rocks closely in aspect. A combination of the trachytic and porphyritic modes of texture is of more common occurrence than either of them singly, and is indeed the distinguishing feature of volcanic rocks.

These relations of age and texture have been conclusively proved to exist in Europe, and appeared to justify the conclusion, that the three classes of eruptive rocks are geologically separated, and represent three successive and distinct phases of the manifestation of subterranean agencies. Considering in their generality the facts observed in other countries, they appeared to confirm these views, since granitic rocks are known to be generally very ancient; volcanic rocks to have been generated during the Tertiary and Post-tertiary periods; while, in regard to porphyritic rocks, observations have been scarce, and descriptions lack distinctness, yet no relations have been recorded in reference to them which would be contradictory to those observed in Europe. On the western coast of North America, however, eruptive rocks exhibit some peculiar relations—differing to some extent from those which they offer in Europe. Positive facts are known sparsely outside of California, but conditions similar to those observed in that country appear to be repeated through large portions of the range of the Andes. Prof. J. D. Whitney's admirable researches on the age of the metamorphic rocks of the Sierra Nevada have clearly demonstrated that the granitic rocks, which partake to great extent in the structure of that mountain range, cannot possibly have been ejected prior to the Jurassic epoch. The texture of these rocks is, notwithstanding this comparatively recent origin, that of all true granite, and the prominent varieties cannot be distinguished from some European kinds of granite, as for instance those of the Adamello and the Cima d'Asta in the Southern Alps, which are among the most recent in age on that continent. Volcanic rocks are widely distributed in the Sierra Nevada, and are of the same or similar age as in Europe. Quartzose porphyry occurs to some extent in Washoe, under circumstances which make the exact determination of its age difficult, but render it certain that it is intermediate in this respect between granitic and volcanic rocks. These relations would appear to be an exact counterpart of those observed in Europe, with the one prominent difference, that the commencement of the eruptive action was much later in America. Very recently, however, additional observations have been made, which give a somewhat different aspect to these relations. Mr. Clarence King observed granite, covered by Palæozoic rocks and antecedent to them in age, near the Colorado River; while Prof. Whitney and myself discovered true quartzose porphyry in the county of Plumas, in northern California, associated with rocks proved by the former to be of Triassic and Liassic age, in such way as to leave little doubt about its cotemporaneous origin. Farther east, in the Great Basin, Palæozoic granite is of no rare occurrence, and it is among the prominent features in the geology of the Rocky Mountains; while the discovery of porphyritic rocks may have to await further examination, they having been in most countries the last eruptive rocks to be detected.

However these facts may affect the theoretical conclusions in regard to the origin and mutual relations of granitic and porphyritic rocks, which had been made on the strength of former observations, they appear to confirm the separation, from a geological point of view, of both classes of rocks. There has been in the Sierra Nevada and adjacent countries, it appears, an ancient granitic era corresponding to that of Europe, followed by a porphyritic era which was nearly or quite coincident with the European. But, while the manifestations of subterranean agencies almost ceased in Europe during the following ages, they recommenced with great intensity on the western coast of North America, and gave rise to a second granitic, followed by a second porphyritic era. The volcanic era commenced in both countries in the Tertiary epoch, but it appears to have been in an advanced stage in Europe while it was still in its birth-throes in America.

Correlation of Age and Composition.

This point of view is not inferior in interest to the foregoing. The most noteworthy fact is this, that quartzose, and in general highly silicious rocks prevail among those of ancient origin, basic compounds among those of later ages. Granite and syenite are overwhelmingly predominant among ancient eruptive rocks. Diorite and diabase are generally associated with them, but remain always quite subordinate in bulk. The relative proportion is different with porphyritic rocks. So little attention has been paid to these, outside of Europe, that general conclusions in regard to them should be drawn with care. In the middle part of Germany, and in southern Tyrol, where they have been repeatedly studied, subjected to chemical analysis, and described in numberless treatises, quartzose porphyry is rather predominant. But porphyrite, melaphyr, and augitic porphyry, are, in the aggregate, little subordinate in bulk. The volcanic offers the complete reverse of the granitic era, respecting the proportionate quantity in which the different compounds have come to the surface. Andesite and basalt compose as large a proportion of the aggregate bulk of volcanic rocks, as granite and syenite do of those of the granitic era.

Some minor differences in age may be noticed among the different orders composing the three classes of eruptive rocks. Extrusions of granite and syenite appear to have been almost the exclusive feature of the eruptive activity during granitic eras, and to have been succeeded only towards their close by the emission of diorite and diabase, or of other rocks of limited occurrence, such as gabbro and hypersthenite. Such at least has been observed to be the case in several countries, in regard to the chief outbreaks; but if we enter into the details of the mode of succession of the rocks belonging to the different orders, we perceive that it has not been so definite as with volcanic rocks—granite and syenite bearing evidence, in many localities, of a more recent age than some neighboring masses of basic rocks. Yet, in keeping only the main features in view, we may easily see, that the general order of succession of granitic rocks has been conformable to a gradual decrease in silica. Syenite is usually more recent in origin than granite; and even among the different varieties of the latter, true granite, containing the highest ratio of silica, has generally been anterior in age to G. Rose's granitite. There may be some connection between these relations as they are exhibited in any single granitic district, and the fact that the granitic rocks of the Sierra Nevada, belonging altogether to a more recent era, contain no true granite—their chief bulk consisting of rocks intermediate in composition between granitite and syenite. The porphyritic era, in Germany and on the southern slope of the Alps, was inaugurated by eruptions of quartzose porphyry, and has terminated in the Alps by those of augitic porphyry. The intermediate epoch has been distinguished by rocks intermediate in composition. The mode of succession of the different orders is more distinct than with granitic, but less so than with volcanic rocks. Melaphyr and porphyrite interchange frequently; but, at many places, the former appears to have preceded the latter in age, in a similar way as andesite preceded trachyte. They form together one epoch, which, in the commencement, was occasionally interrupted by an outbreak of quartzose porphyry.—The laws of the periodical succession of the five orders of volcanic rocks have been developed in the foregoing pages. Their epochs are much more distinctly separated than those of the ancient rocks, but the mode of their succession is more complicated. With granitic rocks, silica as a component part decreases with the age; with porphyritic rocks the same is true in a broad sense—the precedence in age of melaphyr and porphyrite forming the only conspicuous deviation; while in reference to the volcanic era, no rule at all may be discovered at first sight. Considering, however, the predominant rocks of that era, which are propylite, andesite, and basalt, we perceive that the former two were the precursors of the latter, containing at the same time silica in a proportion superior to basalt. The singular phenomenon of trachyte and rhyolite being ejected at a time intermediate between the epochs of those rocks, is a notable deviation from the mode of succession peculiar to granitic and porphyritic rocks. We will try to consider its probable causes in another chapter.

Correlation of Eruptive Rocks in regard to their Geographical Distribution.

Another point of view offering in the contemplation of eruptive rocks, and which has a close bearing to their natural system, is the correlation among them in regard to their geographical distribution. This is, however, a vast subject, and volumes might be written in collecting evidence for final argument of general value. At this place we can give it only a cursory notice. We will consider, first, what is the mode of distribution peculiar to each class of rocks, and then trace the correlations perceptible among them in regard to their different modes of distribution.

Granitic rocks are scattered widely over the globe. Wherever its surface is composed of ancient sedimentary rocks, and these give evidence of disturbances of some intensity, by the plication of their strata, we may be almost certain to find granite entering into the geological composition to some extent. In the diversified structure of the European continent, geological maps show the existence of granite in nearly every prominent mountain-range. Considering among them the range of the Alps and Carpathians, we find granite scattered over its whole extent, from Savoy to Transylvania, particularly on the southern slope. It forms some prominent summits, but occurs also in subordinate positions. The geological relations of several of these places have been examined, and careful investigations made of the mineral and chemical composition of the rocks. They have resulted in proving an individuality of granite such as is peculiar to no other kind of eruptive rocks; different granitic masses are of different age, and exhibit a corresponding diversity in regard to the composition of the predominating rocks. Sometimes, it is true, several neighboring masses are similar in respect to their petrographical character, and bear evidence of being nearly of the same age (for instance those of the Adamello, the Cima d' Asta, and Brixen), but others, next adjoining, will be found differing from them in nature and in age. The length of geological time during which they have been ejected, has never been established; but the period appears to have been one of immense duration. A similar individuality as to age and mineral character may be noticed in respect to the granite of other mountain ranges on the European continent. Altogether, the mode of distribution of the ancient granitic rocks, as far as they enter into the structure of the surface, may be said to be in numerous small districts, which are independent of each other in regard to their epoch of ejection and petrographical character. With reference to the latter, each separate district shows a great preponderance of rocks belonging to one of the families of the granitic order, which are usually accompanied by syenite in smaller proportion, and by some subordinate eruptions of diorite and diabase. These districts are principally scattered along the present lines of elevation. But this may be due in part to their concealment, in the spaces between those lines, by sedimentary rocks. More signs of the separation of distinct "regions of eruptive action," as they may be called, are exhibited in the porphyritic era. Eruptive activity has been intense within them, but appears not to have spread beyond certain boundaries. Each of these regions embraces a number of the former granitic districts, while it leaves others excluded. Some resemblance with the peculiar features of the granitic era is afforded, inasmuch as each porphyritic region has been independent from others in regard to the epoch of its eruptive activity. We mentioned before that one of the porphyritic regions comprises the middle part of Germany, while another stretches along the southern slope of the Alps and Carpathians.—If we proceed to the volcanic era, it presents to us the reverse of the individuality peculiar to granitic districts, in the wonderful unity exhibited in regard to time and space over the whole area of extensive belts. In reference to unity of time alone, we might call the greater part of the continent of Europe, and even the entire surface of the globe, one great region of eruptive action, during the volcanic era, since the first emission of rocky matter has been nearly cotemporaneous in widely separated countries, while its culminating epochs have probably varied but little in them separately, and the rocks have been ejected everywhere in a similar order of succession. In regard to local distribution, however, we have to distinguish certain belts, far exceeding in area the porphyritic regions. Each of them extends over a number of preëxisting mountain ranges, and the eruptions in each have followed, in their distribution, chiefly the lines of former elevation and ancient seacoasts. But there is unmistakably to be recognized a tendency of the agencies which caused the eruptions, to connect these separated ancient belts of elevation; either longitudinally, when ranges superior in extent to the preceding ones would be formed, as appears to have been the case in the Andes; or, as it were, in a lateral sense, when the connection of neighboring mountain ranges into table lands would be either initiated or promoted. One of these belts, consisting of parts which had previously been disconnected, may be traced from Armenia to the Rhine, though I will try to show in the sequel that it is only a part of another belt which is of far greater extent.

We mentioned before, that porphyritic rocks are encountered chiefly in those places where granitic rocks had preceded them. As regards the volcanic belts, eruptive activity has been particularly violent in certain portions of them. It is worthy of note that, wherever this has been the case, either granite or both granitic and porphyritic rocks had been ejected before. This fact leads us to consider the correlation of the three classes of eruptive rocks in reference to their peculiar modes of distribution. Little information exists in regard to this subject. Only one instance[16] shall be related, which is highly suggestive for the existence of such a correlation, though it is of slight value as long as it is not corroborated by corresponding facts observed in other countries. A survey, on a geological map of the Alps and Carpathians, of the southern boundary-line of those highly metamorphosed formations which preceded the Trias in

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[16] Referred to in Richthofen, Geognostische Bechreibung der Umgegend von Predazzo, Sanct Cassian und der Seisser Alp in Süd-Tyrol: Gotha, 1860.

age, and chiefly compose the central portion of the Alps, shows that it is directed from west to east in Lombardy, but in the vicinity of Lugano bends suddenly to the northeast, then turns as abruptly back to its former direction from west to east. After having passed the granitic mass of the Adamello, the same change is repeated on a grander scale. The boundary is turned again in a perfectly straight line to the northeast, and then resumes its former course, which it follows in an equally direct manner, and in which it continues, exceedingly distinct at first—less distinct, by the encroachment on it of more recent formations, farther east—until it turns a third time to the northeast at the sudden termination of the Alps near Vienna, and continues in this direction for a long distance. Finally it re-assumes, in the Carpathians, a similar course to that which it had on the southern slope of the Alps. Three very distinct reëntering angles are thereby formed. The first of them encloses the country of Lugano; the second comprises the vicinity of Predazzo and Fassa in southeastern Tyrol, and of Belluno and Vicenza in Venetia; while the third, which is by far the most extensive, comprehends all northwestern Hungary. Each of them has been a center of eruptive activity, commencing with the granitic, and continuing through the porphyritic down to the volcanic eras, and all three are among the most classical countries for the study of eruptive rocks. There is, however, a conspicuous difference in the mode of manifestation of the eruptive activity in each of the three eras. Little connection exists apparently between the granitic masses of the three countries. They are portions of the generally scattered granitic outbreaks, and differ among themselves probably as much in age as they do in regard to the nature of their rocks. In the porphyritic era, eruptive activity was contemporaneous in the three localities, but scarcely extended beyond them. In the volcanic era, when the southern slope of the Alps and Carpathians formed only a portion of a much more extensive belt, the countries adjoining those three places were chiefly distinguished by the intensity of eruptive activity.

Great as have been the interruptions between the different eras, the continuance of the selection of those three nooks at the foot of a prominent mountain range for the manifestation of subterranean energy, from Palæozoic down to modern time, is evident. Similar instances, though less striking, might be mentioned from other parts of Europe, such as the porphyritic region of middle Germany. Reverting to other parts of the globe, it appears to be a general experience, though it is far from being absolutely proved, that all the principal accumulations of volcanic rocks are encountered in the neighborhood or immediate vicinity of granitic masses. These are scattered over areas where no volcanic rocks occur; but the distribution of the latter within any of the volcanic belts appears to have been dependent, in a great measure, upon the vicinity of the channels which had in preceding time afforded vent to granite.

The general law deduceable from these relations is this: that, with the growing thickness of the earth's crust, the systems of fractures which were formed in it at certain epochs, and partly gave vent to the emission of rocky matter, increased in depth as well as in length, and were more and more concentrated to definite portions of the crust, which are recognizable upon the earth's surface by the partly coincident areas of eruption; that further, simultaneously with the increase in extent, each area manifested a growing complexity in regard to the distribution of eruptive activity within it, and that this distribution depended in a great measure upon that of the outlets of more ancient eruptive matter. The first recognizable stage of this development, which, however, was probably a far advanced one, is the individualization of those numerous districts of fractures, the narrow limits of which are made manifest by the mode of occurrence of Azoic and Palæozoic granite. A growing development from that stage, in the different directions mentioned, is conspicuous in the porphyritic era in Europe; when, besides the greater extent of the regions in which subterranean agencies manifested themselves by the fracturing of the crust, every such area had become more definite concerning its boundaries towards those which were not fractured during the same era. On the other hand, however, each porphyritic region was more complex than the granitic districts had been, inasmuch as the former were composed of certain areas of greatest activity, which, as we had occasion to remark, appear to have been chiefly dependent upon the distribution of the granitic districts enclosed within each porphyritic region, while intermediate portions were contemporaneously affected by disturbances merely, but not by any eruptions. A more advanced stage in this gradual development seems to be exhibited by the Jurassic granite of the Andes. The belt distinguished by its eruption appears to have been distinctly bounded, and the area over which contemporaneous manifestations of like character took place, to have been even more extensive than the porphyritic regions of Europe. All these features, however, are conspicuous on a much grander scale in the volcanic era. The growing definiteness of the boundaries of the volcanic belts towards large areas which were entirely free of eruptive activity, the increasing complexity of their interior arrangement, and its dependency upon preëxisting lines of elevation, and particularly on the distribution of granitic and porphyritic rocks, are evident from what has been said before. We may even trace a development from the andesitic to the basaltic epoch. It is known how far superior in extent is the range of basaltic outbreaks to the area occupied by other volcanic rocks. If considered with attention, it will be found that there is a tendency in the former to connect within each belt the subordinate ranges of the latter, longitudinally as well as laterally. The only connection, for instance, between the volcanic districts of Hungary and those on the lower Rhine, is occasioned by the chain of isolated basaltic hills which extends through the central part of Germany.

ON THE ORIGIN OF VOLCANIC ROCKS.

The facts established in the foregoing chapters, and the inferences drawn therefrom, may assist us in considering some questions of wider bearing. We have seen that the volcanic rocks of several, and probably of all parts of the globe, are connected by simple and definite relations, which together comprehend the main features of their natural system; and we found that correlations of a similar nature ally the volcanic with all the ancient eruptive rocks, justifying, to some extent, the supposition that the eruptive rocks of all ages and places form one harmonious whole, and that we may be able to discover the laws of the natural system embracing their totality. In order to arrive at a more perfect understanding of this system, we must now attempt to examine into the causes of those mutual relations. It would naturally occur to us that they would be implied in the circumstances which attended the generation of the eruptive rocks, and in the conditions in which they have been before arriving at the places they occupy at present. We have, therefore, to investigate the following questions: What was the nature of volcanic rocks before they arrived at the places which we now see them occupying? Where did they originate? By what agencies did rocks connected in widely separated places by simple and definite relations come to their positions among others which bear no such relations either to them or among each other? The importance of these questions for our subject, the attention which they have attracted through the whole history of geological science, and the great diversity of opinion prevailing in regard to them, will make it necessary to treat them more fully than might otherwise appear consistent with the objects of this paper.

Volcanic action and massive eruptions, notwithstanding the similarity of the material produced by both, would appear, from the most cursory review of the phenomena connected with either of them, to differ to some extent, not only in regard to the causes to which they owe their origin, but also in regard to the position the matter occupied before its ejection. We have for this reason to keep again distinctly separated these two modes of manifestation of subterranean energy. In regard to massive eruptions, which will first occupy our attention, we can scarcely draw up any argumentation without enlarging on the entire range of eruptive rocks, and extending, at least partially, our views to them.[17]

1. *On the Origin of Massive Eruptions.*

In order to establish some positive premises available for drawing conclusions in regard to the origin of the massive eruptions of volcanic rocks, we reiterate the following facts, of which mention has partly been made in the foregoing pages: 1st. The eruptive (including the volcanic) rocks offer a great diversity of chemical composition; but all the compounds represented by them are mutually connected by simple and definite arithmetical relations as regards the figures which

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[17] The following considerations are given notwithout some hesitation, partly on account of the uncertain ground on which they have to move, and partly because some of their main features are, of necessity, only well known theories reproduced, though, perhaps, under a somewhat different form. Yet, the establishment of the relations detailed in the preceding chapters, and other observations made of late years, may allow us to arrive at more satisfactory conclusions in regard to some weighty problems than could be done before, or, at least, to determine more precisely the only direction in which we have to look for their solution. It should be borne in mind that among the theories recently proposed upon the subjects specified above, there is not one which has not already had its prototype in the phantasmagorias of the time of the dawn of geological science, and that it is these which have been constantly reproduced, enlarged, diversified, remodeled according to the advance of science, and supported by continuous accumulation of evidence. Propositions which had been accepted as being beyond the necessity of proof, and which are still occasionally reproduced as axioms in popular works on geology, have been weakened, and not unfrequently overthrown, when facts newly revealed would withdraw their chief supports, but have, after some time, revived under new forms. In treating on a topic where the degree in which the results of our speculation appear satisfactory to us depends upon the degree of probability which we think we see in the theories arrived at, and of their faculty of explaining observed facts, and where we are in constant danger of making incorrect deductions from imperfect premises, not enough can be done in the way of weighing the evidence by which different doctrines are supported; and this is particularly necessary in reference to those theories which we are too much accustomed to consider as matters of fact, upon which further conclusions may be safely built.

express the value of the different ingredients entering into their composition. The law of Bunsen, in which are embodied these relations, though true for all eruptive rocks, has never been applicable to those of sedimentary origin, nor to the metamorphic sedimentary rocks. 2d. The order in which massive eruptions of volcanic rocks have taken place in different countries, is by no means conformable to a regular succession of gradations in chemical or mineral composition, but shows the existence of several distinct groups, each of which comprises, chemically, a certain portion of the entire range of compounds intermediate between the two extreme types, and has, besides, its own peculiarities of texture and mineral composition. It is for the latter reason that rocks, belonging geologically to two different groups, may be identical as chemical compounds, and yet differ petrographically. We may repeat here that these groups, wherever their mutual relations have been made an object of study, occur in the same order of time, and that the rocks belonging to each of them present generally a great similarity in character wherever they are encountered. 3d. The massive eruptions of volcanic rocks are distributed over the globe in certain belts, differing in extent and width as well as in direction.

There are, among those of a general bearing, two manifest conclusions at which we may arrive by the aid of these facts. The first relates to the origin of the matter ejected. It may be said that equality of physical and chemical properties, and of the mode of occurrence, will commonly involve equality of origin. We have, therefore, to infer, that the source from which volcanic rocks have derived their origin has been similar in nature in every locality, that the definite numerical relations existing in the chemical composition of the matter ejected must exist similarly at that source, and that they must there pervade matter equally in different parts of the globe; and we may further add, that at the same source the different kinds of matter which correspond to the different passages in composition among volcanic rocks, must be arranged, at every locality alike, in a definite order of position in reference to the distance from the center of the earth, since such relation in space can alone explain the definite order of succession in time in which those rocks have been ejected. If we consider the relations existing between volcanic and ancient eruptive rocks, there can be no doubt that all of these have derived their origin from that same source, and that it is of general distribution under the surface of the globe. The second general conclusion relates to the cause and mode of ejection. As like effects imply like causes, and the similarity of the phenomena connected with the massive eruptions of volcanic rocks is conspicuous, we may infer that the agencies to which they have been due, were, in the main, similar in all cases. However accidental and local circumstances may have caused minor differences, the prominent features in the mode of geological occurrence and geographical distribution cannot be due to them. In how far we may be justified to ascribe the ejection of the granitic and porphyritic rocks to similar agencies, will depend upon the degree of similarity of their part in the structure of the surface of the globe with that of the volcanic rocks. The conclusion must be drawn from those correlations which have already been mentioned, that the fundamental causes of all eruptive activity are alike, and implied in general planetary processes which are closely connected with the evolution of the globe. These general conclusions appear to be the only ones which are fully justified. If we venture to inquire into the nature of the agencies which caused eruptive activity, and to explore their fundamental causes, we have to transgress the limits of legitimate speculation and enter the realm of hypothesis, the only way of proceeding in which consists in weighing probabilities. Further experience, it may be hoped, will extend the limits of induction, in the same measure as it will furnish increased evidence.

I will attempt, in the first place, to consider, what must be the nature, and what the position of the source at which the volcanic and all eruptive rocks have originated, in order that their physical and chemical properties and their mutual relations may be explained, and then to examine what have been the agencies that have had, in all probability, the most immediate influence upon the facts connected with the mode of distribution and succession of eruptive rocks in general. We have to start in these considerations by a well-known argument.

If no changes had ever taken place on the surface of the globe, and no sediments had ever been deposited on it, but that state was still preserved which the globe must have exhibited when the substance of the rocks was liquid on its surface, then the matter nearest to this would probably be of a nearly uniform chemical composition, and, consequently, of a uniform specific gravity. If we imagine the globe to consist of concentric layers, it is exceedingly probable, from physical laws, that then the substance of each successive layer would be, too, of a nearly uniform composition throughout its extent. Proceeding, however, from those layers nearest to the surface to those at greater distance from it, the specific gravity of the matter composing them severally would necessarily increase gradually towards the interior. This would be effected by the tendency of the heavier elements to predominate as the depth became greater, while the lighter would increase in as gradual a ratio towards the surface. If the layers were infinite in number, then the passage, in chemical composition as well as in specific gravity, from the surface towards the center of the earth would be one of infinite gradations. This condition is eminently the most probable, if physical laws are taken into consideration. If the crust was then allowed to solidify, to any depth required, the same interior arrangements would continue to exist unaltered, regardless of any changes on the surface That a condition similar to this actually exists at the present time, is rendered evident by the well-known fact, that the specific gravity of the mass of the globe greatly exceeds that of the average of the matter which composes its exterior crust. Eruptive rocks have been carried to the surface from places beneath it. The depth from which their material has been derived, the way in which it was rendered liquid, and the cause and mode of its ejection, these are the principal points of conjecture in regard to them. The most probable place of its derivation are those imaginary layers which are beneath the theater of external changes, and still occupy their primeval position. This appears to be manifest from the two facts to which we have constantly to refer: the ejection of identical chemical compounds in all countries and ages, and the exhibition by eruptive rocks, in each country, as well as over the entire globe, of a series of compounds the specific gravity of which increases in inverse ratio with the amount of silica. The suggestion that eruptive rocks, in virtue of these facts, represent the arrangement of matter in the interior of the globe, those which are rich in silica and of little specific gravity being derived from places nearer to the surface than those in which a smaller proportion of silica is attended by a higher specific gravity, was first distinctly made by Sartorius von Waltershausen, who attempted to prove this theory by mathematical calculation, and has at least succeeded in demonstrating its adaptation to the nature of eruptive rocks. The assumption, hypothetical as it may still appear, has an eminent degree of probability, and is of the highest importance for the geology of these rocks, for the reason that it is capable of explaining numerous observed facts which have failed to be satisfactorily explained in any other way.

We may still draw a line of negative argument in corroboration of this theory. It is perfectly clear that the source of eruptive rocks must either have been below the lowest depth at which rocks of sedimentary origin occur, or above it. We found that the former assumption gave a satisfactory explanation of prominent facts, and it is just as conspicuous that the second fails to give any explanation at all. If eruptive rocks had had their original seat within the crust of sedimentary rocks, and had been generated from their substance, they must be analogous to them in chemical composition, that is to say, they would vary in this respect within very wide and complex limits in any single country, and we should encounter no lesser differences when comparing the totality of eruptive rocks in one part of the globe with that in other parts. The fact that no arithmetical relations can be recognized as connecting the various sedimentary rocks in their composition, would hold equally good among eruptive rocks, since it is impossible to conceive a progress from the indefinite to the definite, from that which is void of any recognizable relations in respect to the composition of matter to that in which such definite relations are plainly evident, by the mere influence of such agencies as would cause fluidity, (that is, the combined action of heat, pressure, and water.) As no agency, indeed, is known to which such a result may be ascribed, this argument removes beyond the limits of probability the assumption, that the original seat of eruptive rocks has been above the foundation of the gradual accumulation of those rocks which have been produced by external changes, and therefore allows only the other alternative, that it has been below that boundary.

While the theory of Sartorius will explain the causes of the prominent mutual relations existing among eruptive rocks in regard to their composition and general similarity in all countries, we have still to trace those causes which effected their ejection from a deep-seated original place to the surface. This question is more abstruse than the foregoing, inasmuch as the manner in which forces have formerly been acting beneath the earth's crust, is a subject more involved, and allowing a larger range of hypothetical explanation, than we met on a field where the observed properties of matter offered a comparatively safe guide. Complicated as the processes appear to have been, to the coöperation of which massive eruptions were due, it seems that they may severally be traced back to one common cause of a higher order, of which all, or most, of them are but different modes of manifestation. Probabilities accumulate to point out as this fundamental cause, the process of the gradual cooling of the earth and the solidifying of its crust toward its interior.

Since the early day of the ingenious speculations of Descartes, this great and general cause has been considered as the main agency to which the disturbances on the surface of the globe are due; and, though having been more or less in favor at different times, the doctrine has at no time been completely abandoned. The various aspects which it has periodically assumed, the latitude given to it on one side, and the objections raised against it on the other, mark one feature of the phases of the gradual progress of science. It has been applied in different forms to explain the mode of origin of ancient eruptive rocks; and, since Dolomieu and, in a more elaborate way, his pupil Cordier, have assigned the same original source to volcanic activity, the contraction of the interior of the globe, by radiation of its heat into space, has been considered as offering a sufficient explanation for the majority of the phenomena which are often united under the term "vulcanism." But, giving all due consideration to the vast effects of which it has undoubtedly been the cause, the conception of the *modus operandi* of this agency (contraction) *alone* meets with considerable difficulty. An outward tension might, indeed, result in the formation of fractures on elevated places; and, supposing for a moment that these fractures would descend into regions where matter was in a liquid state, then the latter might possibly be ejected, and caused to accumulate on the surface. But such would hardly be the effect of an inward tension. It may, too, cause the rending of the crust and, possibly, the filling by liquid matter of those rents which are in the lowest places; but it does not explain the extrusion of this matter to the surface, nor the fact of its particular accumulation on elevated parts of the same. It would take too much of our space fully to detail the numerous mechanical difficulties which occur, if one attempts to explain all the phenomena comprised in the name "vulcanism" by the exclusive assumption of the contraction of the interior of the globe. Some of the more obvious objections against this theory will be briefly mentioned in the course of the following considerations.

A number of facts point towards the existence of some unknown force below the earth's solid crust, which counteracts in a considerable measure the permanent subsidence of the latter by contraction. It is perfectly evident that the secular rising of parts of the surface of the globe above the level of the sea cannot be merely the apparent effect of the different degree of its general subsidence, as has been maintained by very distinguished geologists; but that elevation, that is, the periodical increase of the distance of parts of the surface of the globe from its center, must be a reality. Considering the amplitudes of the changes of level that have taken place in historical time, they will be found to sum up to such figures as, if reduced altogether to subsidence, would indicate a far greater shortening of the radius of the globe within that time, than is compatible with astronomical calculation. It is true that the retardation of the rotation of the earth by the tidal wave must counteract, in some measure, the acceleration caused by any shortening of the radius of the planet; but this retardation is insignificant if compared with the amount of the changes of level. The reality of elevation is forced more directly upon the mind, if those cases are taken into consideration where certain portions of continents are rising above the level of the sea at a more accelerated rate than neighboring regions, which is of very frequent occurrence in volcanic countries, and conspicuous in those numerous instances where elevation is, or has been in former times, proceeding more rapidly along the crests of mountain ranges than at either foot of them. Adherents of the theory, that all oscillations of the earth's crust are only due to its contraction, consider elevation as real in these cases, and have tried to explain it by the assumption, that folds must be formed by the subsidence of the ample shell on the contracted nucleus; that these folds would increase in amplitude in consequence of a lateral pressure caused by further subsidence, and thus an absolute rise would be effected. It is, indeed, very probable that this process is of vast importance in the formation of mountain ranges; but it cannot explain the total amount of the changes of level. If Fourier's calculation, that, taking the present loss of heat by the globe as standard, the radius of the latter should have shortened seventeen centimeters in twenty-five centuries, is correct, the diminution would have been 1,700 centimeters in 250,000 years, and about six hundred feet in one million years. It is manifest how utterly insignificant would be the corresponding diminution of the earth's circumference, when compared with the vast changes of level which the surface must be supposed to have undergone during such a length of time.

We are bound, for these reasons, to consider, not alone the process of elevation of mountain ranges, but also the secular rise of extensive regions, as realities which cannot be exclusively explained by the contraction of the globe. But if so, there must exist another force, the effects of which oppose those of contraction. The united action of both, and the periodical prevalence of either of them, would then be capable of explaining the alternation of elevation and subsidence at every single place, and the contemporaneous action of both in neighboring regions. This antagonistic force consists, probably, in an increase of volume attending the slow and perfect crystallization of matter, by cooling down, during immense periods, from a viscous state. With a great number of bodies, contraction by loss of heat appears to continue to the very moment of solidification, and to increase during the latter when no time is allowed for crystallization, but to be diminished, and finally reversed, in the same measure as opportunity is given for a slow and perfect crystallization. In the special case of rocks made up of silicates, this must remain a supposition which is not proved, but is eminently probable.[18]

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[18] An increase in volume by crystallization has been found, by experiment, to take place in numerous instances, in fact in most cases when a perfect crystallization from a molten state has been obtained, provided that the volume of the substance experimented on could be determined immediately before the act of crystallizing. In respect to those silicates which make up crystalline rocks (not taking into account the water entering into their composition), experiments could hitherto not be made, because it is impossible, with our present means, to allow the viscous mass sufficient time for crystallizing. Yet, there are some suggestive facts which have, in some measure, the value of experiments. We mention among them particularly one which was observed by Ferd. Zirkel in analyzing, with the aid of the microscope, the texture of the minerals participating in the composition of eruptive rocks. He found that "glass cavities" contain ordinarily several of those vacuities which are also exhibited by the cavities filled with water, and have been supposed by Sorby and others to have originated from the contraction, by cooling, of the enclosed matter. If the substance contained in the glass cavities bears signs of an incipient crystallization, by having partly a "lithoid" texture, the vacuities are of rarer occurrence, while they are entirely wanting in the so-called stone-cavities, when the lithoid texture pervades the whole mass filling the cavity. It is scarcely possible to make an experiment more convincive than this natural occurrence, which is more open to subtle observation and measurement than is ordinarily the case with experiments on cognate subjects. It needs hardly to be mentioned, in connection with this question that those experiments which have been made by Bishof

We may then distinguish as eminently probable, the following immediate effects of the cooling of the globe: 1. Contraction of the liquid portion of the interior, by cooling down to the temperature required for solidification under the respective pressure. 2. Expansion by slow and perfect crystallization. 3. Contraction of the crystallized masses by further cooling. We may add to these as a secondary effect of greatly inferior importance, the flow of heat or change of chthonisothermal planes, at those places where subsidence causes an accumulation, or elevation an abrasion of matter on the surface. This process, to which a truly wonderful importance has been ascribed by some, must be going on continually and everywhere. Being itself the result of motions of the crust, its proximate cause must be the processes attending the cooling of the globe, while in its totality, it may have a further, though very insignificant, effect in shifting the areas of elevation and subsidence.

Other agencies, with which we are yet unacquainted, may probably result from the same common cause. But taking into consideration only those already mentioned, it may appear difficult to form a clear conception of the mode in which they must coöperate, in order not to counteract each other, and thereby to result in a general movement of the crust in one direction only, but to bring about that variety of effects which manifests itself chiefly in the change of elevation and subsidence, and in other modes of dislocation of the crust. It is perfectly evident, that the aggregate effect of those agencies is different under different portions of the crust of the globe, contraction prevailing in some parts, and expansion in others; the former causing subsidence and deposition of sedimentary matter, the other elevation and denudation. But if we consider how gradual is the passage in the state of aggregation from the liquid interior of a current of lava to its solid crust, and if we bear in mind how immensely vaster in volume are those masses which constitute the interior of the globe, and what immensely longer time is given for their cooling and crystallization, the conclusion is irresistible, that the passage in the states of aggregation from solid to liquid must extend there over an immensely greater space. Crystallization will very probably take place next to those portions of the crust which are already solid. If it is attended by an increase of volume, and this increase produces tension, it is very likely that the next adjoining masses, though not yet crystallized, will offer too much resistance to allow this tendency for expansion to find immediate relief by yielding to the general tendency to contraction which may prevail in liquid masses at greater depths. It may thus be explained why, in different parts of the crust, a motion, independent and in opposite directions, may result from the two-fold tension attending changes of volume which take place at different distances beneath the surface, and which

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and others with a view of ascertaining the increase in volume which different rocks undergo by melting, do not affect our supposition. In the first place, the molten state may be quite different from that in which the same substance would be immediately before crystallizing, and the passage from one to the other may be attended by a decrease in volume which is not counterbalanced by the subsequent increase taking place by the passage of the substance into the crystallized state. Then, the rocks on which the experiments were made had been solidified under a great pressure, while, when in a molten state, they were only exposed to the pressure of the atmosphere. Finally, it has not been ascertained whether all the water which is contained in the rocks does escape on melting or not. If not, then it will probably have the effect of inflating the molten mass.

would oppose, and, to a certain degree, destroy each other, if the state of aggregation of subterranean matter allowed of a free conduct of motion.

These slow and continuous agencies, chiefly those among them which give origin to the process of elevation, must have been, too, instrumental in causing the massive eruptions of rocks. At least, no other force supposed to act beneath the surface can account as fully for certain facts connected with them, such as the gradual changes in the mode of their geographical distribution, or the connection of the manifestations in any certain system of fractures, or the fact that ages of comparative repose have been interrupted by paroxysmal actions of great violence which have taken place during certain eras in the history of each separate country. The latter circumstance points clearly to the assumption, that during the eras of repose, or at least their later portion, a constantly increasing amount of potential energy must have been accumulated under the crust of the globe; since the subterranean agencies called into existence by the cooling of the globe did of course never rest, nor can they be reasonably supposed to have been more intense in the Tertiary than they were in preceding periods. It is self-evident that the increase of tension must have been much more considerable under areas of elevation than under the more extensive regions of subsidence. In the latter case, when a downward tendency is caused by contraction, the weight of the crust must come in its aid; the essence of the resistance to that tendency may therefore be concisely expressed as cohesion minus weight; while weight added to the cohesion will give approximately the resistance to elevation by expansion. The tension under a crust of great thickness must therefore, in the latter case, increase to a stupendous intensity, until it is sufficient to overcome the resistance, and will then be able to result in such paroxysms as that by which the volcanic era has been inaugurated, and the main feature of which consists in the formation of fractures which, by their mode of association, constitute distinct systems or belts, separated by areas in which the existence of fissures in the crust cannot be recognized on the surface.

Although the processes suggested may furnish us the cause for the prime condition to the emission of rocky matter from below, namely, the periodical opening in the earth's crust of such fissures as widened with the approach to the surface; yet they fail completely to explain, by themselves alone, the more immediate causes and the mode of that emission. It may be presumptive to extend speculation upon this topic beyond those limits which we have reached; but a safer guide to conjecture on the same than had been known at any former time was given during the last few years by the experiments of Daubrée, and the microscopic examinations of the texture of rocks by Sorby. It has been held quite generally till of late, that the opening of a fissure to a liquid mass below, would be sufficient by itself to cause the ascending of the liquid through it to the surface;[19] but this supposition is utterly irreconcilable

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[19] It must here be remarked that some of the most eminent writers on the subject of volcanoes, chiefly Poulett Scrope, Prof. Dana and others, have suggested long ago, that the ascending of lava in a volcanic channel must be due to both the fluidity and expansion imparted to it by the globular state of the water which finds ingress to the channels of the lava and enters into its composition. They have anticipated, by this suggestion, in some measure, the results of

with physical laws. Supposing for a moment that theory to be correct which considers all the changes of level as originating in contraction alone, then it is quite probable that fissures would be formed in the center of the areas of subsidence. But as they must be closed near the surface, and open in their lower parts, it is difficult to see in what manner the liquid matter could ascend through them to the surface, while no better account could be given for the occurrence of eruptive rocks on high tablelands. In order to explain it, recourse has been had to the most arbitrary assumptions. It may even be read in our time in various geological books, that the crust below might give way from the overload, and the whole be "plunged" into the semi-fluid mass beneath, causing it to overflow. Mountain ranges of a thousand miles in extent have been assumed to subside suddenly upon the liquid mass, and to "splash it out" through fissures. Leaving out of consideration these fantastical theories, there remains a number of others, according to which the weight of portions of the crust would cause the ejection of liquid matter. If the substance composing the crust exceeded in specific gravity the liquid matter below, then this mode of ejection would be probable, and we should be indeed surprised that large portions of our globe were not flooded over repeatedly by molten masses from below. If the specific gravity of the crust and the fluid matter below was the same, then it would require the most extensive fracturing of the crust and uplifting of its fragments, in order to make the liquid mass overflow the latter. But all that we know in regard to the subject goes to show that the masses below the crust are of greater specific gravity than those composing it. To suppose the weight of the crust to cause the protrusion of liquid matter through fissures, is therefore to suppose an action which is mechanically impossible.

We arrive at no more satisfactory conclusion in regard to our present problem, if, besides the contracting forces, we assume the existence, beneath the crust of the earth, of others which have their origin in the increase of volume by crystallization, and thus produce expansion. I attempted to show that they furnish the most probable agent to which may be ascribed the opening of the systems of fissures, which partly served as the channels for the extrusion of rocky matter. These fissures would have to be open at the surface and to decrease in width below, because formed by an outward tension on areas of elevation. It cannot be assumed that they would descend to any greater depth than the lowest limits of solid rocks; they would, therefore, not reach down to any matter sufficiently liquid as to be capable of being forced up through them. And if it should be able to ascend, then it would solidify within the fissure, almost instantly, by loss of heat, and long before reaching the surface. There is, however, even a more forcible argument to demonstrate why it should not have been capable of ever entering the fissures. For, if our supposition that the silicious masses beneath the crust increase in volume by crystallization is correct, the relief from pressure by the formation of fissures must have the immediate effect of rapidly pro-

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experiment established by Daubrée. But the supposition was only made for the case of lava, and not for that of rocks which were ejected without volcanic action proper. Yet even in regard to volcanoes it did only explain the extrusion of lava to the surface from a place at a limited distance below it, and failed to give a clue to the manner in which the constant supply of matter to those places was kept up.

moting the crystallization of vast masses which had been held in a viscous state before, by the existence of the tension itself. It needed, for all these reasons, another agency which would not alone force up molten matter through the fissures, but also cause it to arrive at the surface in that particular state of aggregation which it has had, according to the observations of Sorby. This agency is indicated, by the experiments of Daubrée, to have been water, the descending of which into the fractures is indeed a necessary consequence of their formation. There it would convert the state of aggregation of the masses surrounding the lowest parts of the fracture into that called by Daubrée "aqueous fusion," which appears, indeed, to have been the state in which all eruptive rocks have been immediately before their consolidation. The process of aqueous fusion, as has been shown by the same eminent geologist, is attended by a very considerable increase in volume of the masses affected. It would, therefore, give rise to processes totally different from those which had preceded. For this expansion would immediately cause a motion of the masses rendered liquid, in the direction of least resistance, that is, upwards in the fissure, and would, if continued for a sufficient time, make the same overflow on the surface of the crust, even if unassisted by other ejecting agents, such as the vapor of water.[20]

We may carry these deductions still further, if we revert to our previous conclusion, that the relief from pressure by the fracturing of the crust would have caused the crystallization of masses below it, which had been held before in a viscous state by the tension itself. This process would extend in depth as well as laterally, and gradually affect the viscid masses beneath an entire belt of fissures. It would have had again to be attended by an increase of volume. But those crystallizing masses not being in a state of aqueous fusion, the resistance could in this case not be overcome by the extrusion of that portion of them by which they were increased in volume, and the effect would be, as in the case first mentioned, accumulation of potential energy. I will attempt to

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[20] If we consider the geological features of all large accumulations of eruptive rocks, such as the great andesitic ranges of Hungary, or the quartzose porphyry composing a plateau of great dimensions in southern Tyrol, or those granitic masses which, by overlying the edges of stratified rocks, give evidence of having been ejected to the surface in a liquid state—it would appear that their emission has been a slow and mainly a quiet process of long duration, hardly attended by those convulsions and paroxysms which form the prominent features of volcanic action, and should have been no less characteristic of massive eruptions if they had been due in any large measure to the expansive force of vapor. The process of the emission of the rocky matter has, it is true, been evidently intermittent in most cases, as may be inferred from the occurrence of vast accumulations of breccia, and it appears that an extensive solfataric action has frequently taken place through neighboring fissures; but the manner in which the matter was protruded through the main fissures and deposited on the surrounding parts of the surface, had evidently no similarity to the mode of ejection of scoria, ashes, and lava from most of the active volcanoes. The mode of action described, which may be inferred from geological observation, is perfectly in accordance with what we should expect it to have been by reasoning *a priori* on the basis of our previous suppositions. For, if G. Bishof's calculation is correct, that the elastic force of steam is at its maximum when it has the same density as water, which it would acquire under a pressure of 8,300 atmospheres, the loftiest column of lava (taking its mean specific gravity to be 3) which should be supported by it, would be, according to Jukes, 88,747 feet. The original seat of those eruptive rocks which were protruded without being accompanied by volcanic action, must necessarily have been at a much greater depth, and we should therefore, also from this point of view, be led to suppose that the expansive force of steam has had only an insignificant part in their protrusion from greater to lesser depth. It must, of course, have come into action when the liquid masses arrived near the surface, but will have caused hardly more than an ebullition, even in viscid masses, on account of the extent of the openings. The formation of conglomerates could thereby be vastly promoted, but their final deposition and consolidation must have been quite different from the manner in which similarly subdivided matter would be deposited around a volcanic orifice.

demonstrate in another chapter that the changes of level which have been connected with the ejection of rocks, appear to confirm these suppositions. Suffice it here to draw the necessary consequence, that the increasing tension must finally have had the effect of rupturing the newly consolidated masses. If in the intermediate time the masses filling the fissures of the first epoch had, at least partially, been consolidated, then a new system of fractures would be opened, within the limits of, though not coinciding with, the first. These fractures of the second epoch would descend to greater depth than those of the first, and in allowing the access of water to masses situated in lower regions and being of a more basic composition, would open for these the way to the surface. By the repeated occurrence of this or similar processes, the theater of action from which the rocky masses were conducted to the surface, might descend, by steps, into considerable depth within a comparatively short period, and thus there could be produced a great diversity among the rocks emitted through one system of fractures, though this diversity would be regulated by definite relations in regard to the nature and succession of the rocks ejected. The process would come to an end when the solidification of matter and the formation of fractures had descended to those masses, the state of aggregation of which was such as no longer to allow them to crystallize when the pressure was diminished, and in this way any further increase of volume would be prevented. The matter filling the fractures would now solidify, and the communication of the interior with the surface be cut off, with the exception of the volcanic channels. The resistance offered by the crust of the globe would hence be greater than it had been before, and there would follow another era of repose, longer than that which had preceded the era of eruptive activity.

The application which may be made of these processes suggested by theory, to the explanation of the actual correlations of eruptive rocks in regard to their age, chemical composition and geographical distribution, is obvious. We may, indeed, venture to deduce *à priori* the history of eruptive action, in its main features, from the hypothesis of Sartorius, and the assumption that silicates will increase in volume by perfect crystallization. We should have to conclude that in a remote period, when the crystallized crust and the sedimentary shell of the globe were inferior in aggregate thickness, fractures and eruptions of rocky matter would have been of frequent occurrence, and that highly silicious compounds should have prevailed among the ejected masses. Little, if anything of them, is probably visible at the present surface, as the rocks of the Azoic and Palæozoic formations are probably the monuments of an already far advanced stage of the development of our planet. All the distinguishing features of the eruptive rocks of these periods (including of the Palæozoic age only the Silurian and the first part of the Devonian), such as the great number and individualization of the granitic districts, the independence of each of them in the subtler differences regarding the commencement and further development of the eruptive activity as well as the peculiar nature of the rocks ejected, the great preponderance of highly silicious compounds, the common association with them of small quantities of basic rocks, and the slight increase of the proportion of the latter in the Devonian period—all these phenomena are easily understood, without further explanation, in the light of our hypothesis.

Let us now direct our attention at once to the volcanic era. The conditions of the globe must have been very different in the Tertiary from what they had been in the Palæozoic period. A longer time of comparative repose had in most parts of the globe preceded the inauguration of the violent manifestations of vulcanism in the Tertiary period than had ever before elapsed between any two eras of eruptive activity. The globe had cooled down. Volumes of sedimentary matter had accumulated, and added externally to the thickness of its crust, while it had increased in a vastly greater measure by the crystallization of liquid matter below. Those silicious compounds especially, of low specific gravity, which had formerly yielded the material of the vast accumulations of quartziferous eruptive rocks, would have been consolidated, and the limit as it were between the solid and the viscous state of aggregation receded into regions where the matter would be of a less silicious composition and of greater specific gravity. The similarity in distant countries of the rocks first ejected (propylite and andesite) goes to show that the recession of that limit into greater depth must have proceeded in a nearly equal ratio in all those regions where volcanic rocks are distributed. When the tension below had increased sufficiently to overcome the resistance, it would now no longer manifest itself in the formation of small and differentiated systems of ruptures. In the direct ratio of the increase of the resistance the fractures would have to be of greater extent, and those elongated belts of them would be formed which even now are partially distinguished as the belts of volcanic activity. The first rocks ejected would necessarily be of a more basic composition than the predominant rocks of the granitic era, while the repetition, at a later epoch, of the process of fracturing would give rise to the ejection of rocks in which silica would be contained in a still lower proportion. The greater portion indeed of the ejected rocks consisted of propylite and andesite, in the first, and of basalt in the second half of the volcanic era. A notable but only apparent anomaly in the regular order of succession has been the emission of trachyte and rhyolite between the andesitic and basaltic epochs. But if it is considered that these rocks were ejected partly from the same fractures through which andesite had ascended, and partly from others in their immediate vicinity, while the distribution of basalt has been independent, to a certain extent, of all foregoing eruptions, it is evident that the occurrence of trachyte and rhyolite is closely dependent on that of andesite, and bears only a very remote relation to basalt. It appears that after the ejection of the chief bulk of andesite, when other processes ending in the opening of fractures into the basaltic region were being slowly prepared in depth, the seat of eruptive activity ascended gradually toregions at less distance from the surface. There is, within the limits of conjecture based on physical laws, no lack of processes which could coöperate to that effect. The consolidation of the ejected masses within the fissures would probably proceed simultaneously, by loss of heat, from the surface downwards and, by pressure, from below upwards. The opening of new branches from the main fractures, the remelting (by the aid of the heat of the molten mass within the latter, and of water finding access to it) of solidified matter adjoining the fracture, the emission of that remelted matter through those branches: all these are secondary processes depending on the first almost necessarily. The supposition that to these is due the order of time in which trachyte and rhyolite have been ejected to the surface, is corroborated by the fact that these rocks occupy generally a subordinate position in regard to quantity, and have had, to a great extent, their origin in volcanic action. When treating about the latter, we will come back upon this subject. There remain some peculiar features of volcanic rocks which cannot be satisfactorily explained at the present time. We mention, among them, the fact that the three modes of texture of rhyolitic rocks are often severally limited to certain localities; the mode of formation of the laminated structure of rhyolitic and trachytic rocks; the occurrence of the compounds of hornblende and oligoclase in that threefold form to which we have repeatedly referred; the fact that basalt has been followed only to a very limited extent by rocks bearing to it a similar relation, as trachyte and rhyolite do to andesite.

As regards the long lapse of time intermediate between the Devonian and the Tertiary periods, the mode of occurrence of eruptive rocks in the same shows in nearly every respect a gradual transition from that which was peculiar to the granitic to that which we just described as being characteristic of the volcanic era. This intermediate period may be designated as the porphyritic era, though this name appears to apply more properly to its first part only. Quartziferous rocks were not so predominant in it as in the granitic era, porphyrite and melaphyr having nearly equaled quartzose porphyry, in point of quantity. Augitic porphyry was ejected in a much larger proportion to the aggregate bulk of the porphyritic, than diabase to that of the granitic rocks. Where it occurs, it was the last in the order of rocks erupted, while quartzose porphyry was generally the first among them, though this place is sometimes occupied by porphyrite. In reference to the general features of their geographical distribution, porphyritic rocks occupy no less distinctly an intermediate position, as may be seen by what we have said on this topic on another page.

There are exceptions to the order of general development as here specified. They regard chiefly the texture, and are almost exclusively to be found among the rocks of the porphyritic era, though the recurrence, in propylite, of the properties of ancient diorite, is a phenomenon of a no less exceptional nature. Leaving this rock (propylite), or rather only some of its varieties, out of consideration, the volcanic rocks have their peculiar characters, by which even the most basic rocks are to be recognized when seen in large accumulation. In the rocks of the granitic era, if we consider its end to be within the Devonian period, the characteristic features of porphyritic and volcanic rocks are probably never to be observed. Among the exceptional occurrences within the porphyritic era, may first be noticed the fact that perfect granitic texture is still occasionally encountered, as, for instance, near Predazzo and on the Monzoni in southern Tyrol, where some subordinate masses of rock resembling granite and syenite have been ejected in the Triassic age, together with the well-known porphyritic rocks of that region. There are similar instances known from other places on the European continent, but they are scattered, and the respective rocks always quite limited in extent. The grandest exceptional instance that is known up to this time, is the recurrence in the Jurassic period of perfect granitic texture in the eruptive rocks of the Sierra Nevada. But as regards their mineral composition, these rocks belong to the family of syenitic granite, containing hornblende as a very characteristic ingredient, while silica enters into their average composition probably in a much lower proportion than it is contained in ordinary granite. The varieties known as granitite are of rare occurrence. In another respect, namely, the mode of geographical distribution, the Jurassic granite of the Andes marks an advanced stage, if compared with the Permian and Triassic porphyries of Europe, inasmuch as the area of its distribution excels the porphyritic regions of the latter continent in regard to their extent and the unity of their inner relations, while it does not come up, in these respects, to the properties of the great volcanic belts.

2. *Origin of Volcanic Action.*

I have tried to demonstrate in another chapter, that volcanic activity is intimately connected with massive eruptions in a three-fold way, namely, in respect to the epoch of its commencement, the mode of its distribution, and the nature of the rocks ejected. Basaltic volcanoes occur in ranges built up by the massive eruptions of basalt, or in their vicinity, in such connection as to make obvious the nearly contemporaneous origin of both. Andesitic volcanoes are found in the neighborhood of those masses of andesite which had been ejected without being attended by volcanic action; while volcanoes which have emitted rhyolitic or trachytic lava are so situated as to justify the inference of a close connection between the first opening of their vents and the origin of neighboring accumulations, either of rocks of similar character or of andesite, but which are due to massive eruptions.[21]

No distinct line of demarcation can be drawn between the two modes of mani-

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[21] This affinity in regard to petrographical character and geographical distribution is probably the cause why both agencies have ordinarily been confounded. It has been a current notion, strongly advocated at times, that all volcanic rocks have come to the surface in a similar way to that in which lava is being ejected from volcanic vents, and that the cause of the ejection has been the same in all cases. In regard to the fact that extensive mountain ranges are completely built up of volcanic rocks, it was argued that it is by no means necessary, and in fact erroneous, to suppose them to have originated in events surpassing in magnitude those of the present day, as the length of geological time would explain how they could be built up by the gradual accumulation of innumerable currents of lava. Where traces of former volcanic vents could not be found, the easy destructibility of the matter of which the sides of craters are usually composed, afforded a convenient and apparently just argument for explaining their absence by denudation. The same doctrine was applied for explaining the mode of formation of ancient eruptive rocks where we see mountain masses made up of them, while others have arrived at the conclusion that they were the "roots" or "cores" of volcanoes; granite itself is by them considered to have had formerly, and to have now this function, even in the case of those volcanoes the lava of which consists of basalt. Both these doctrines have been adopted the more readily, as they appear to be in harmony with the favorite hypothesis, that at no time have any changes on the surface of the globe been more violent than those going on at the present day, nor different from them in mode. However ably this theory, which contributed so much to the advancement of science by checking the phantasmagorias of former time, has been advocated, an unbiased comparison of the grand manifestations recorded in the geological structure of an andesitic mountain range, with the mode and degree of activity of present volcanoes, must lead to different conclusions. In the endeavor to sustain the *à priori* assumption of the equality of force in all ages, too little stress has been laid on the circumstance, that, however nearly equal the aggregate amount of force acting on the globe may have been, its modes must have undergone a change, chiefly by the partial conversion of the heat of the globe into other forces. At the same time, the degree of the intensity of the manifestations of subterranean forces must have varied in a two-fold way. With the continuous increase of resistance, the aggregate motions of the crust must have decreased, since a growing amount of these forces was required for overcoming the resistance. On the other hand, the manifestations of the same forces had to become periodical and paroxysmal, and periods of violent action had to be separated by others of repose. The violent activity of the Tertiary period has passed, and our present volcanoes appear to mark the transition into another period of repose. I will try to demonstrate that the causes of their action are utterly inadequate for explaining the grander phenomena and correlations of massive eruptions.

festation of subterranean energy, as some of the monuments of the grand volcanic action of the past indicate the former existence, at certain places, of a stage intermediate between both. But in those numerous instances where the nature of either of them can be distinctly recognized, some conspicuous differences may be noted between them. Volcanoes are provided with a channel connecting the seat of volcanic action with the surface. The matter which they eject consists either of stratified layers of ashes and scoria, or of currents of lava in the shape of flat sheets superimposed over one another, or of alternating layers of both kinds of material, the latter structure being most frequent. A low dip, verging on horizontality, of all planes dividing substances of dissimilar nature, or marking successive deposition, and homogeneity of material parallel to those planes, together with a structure of the mountain masses distinguished by the radiation of all mineral matter from one common center, may be considered as those features by which even extinct volcanoes, or fragments of them, may unmistakably be recognized. The center may shift, or have shifted, within narrow limits, or a series of centers may follow each other in close succession, but this will obliterate the true character only in a slight degree. Similar rocks, when they came to the surface by massive eruptions, do not present these distinguishing features. They usually compose ranges of small width in proportion to their length, and in the place of one or more distinct centers an elongated axis may be detected, from which the structural and morphological features originate. As regards the interior structure, there may be observed a certain massive character of the rocks, which is partly produced by the prevalence of their compact varieties, and partly by the circumstance that homogeneity of lithological character may be traced to a great distance in a vertical direction. In sections, masses are frequently found thousands of feet in height, which do not vary perceptibly in character, and show no horizontal structure. If the slopes of the ranges are examined, the rocks will be found preserving a homogeneous character chiefly in a direction parallel to the axis, while it is less persistent at right angles to the latter. The planes dividing dissimilar rocks are inclined at all angles, and have very frequently a steep or nearly vertical position. Breccias even, which sometimes occur in very large masses, are bounded in this way towards the adjoining compact varieties; they are of irregular shape, and do not often occur in stratified layers or in elongated currents, as is the case when they are produced by volcanic action. The ranges made up by massive eruptions show no signs of craters. Yet they are frequently the foundation of volcanoes. Oftener still do volcanoes occur on the lower portions of their slopes, or they may form a series parallel to the axis of the main range, and even greatly exceed it in elevation.

Notwithstanding these points of difference, there are not only stages of transition between the distinct geological features resulting from either mode of action, but a similarity in character may be produced under certain circumstances, which makes it difficult to decide what was the mode of origin of an accumulation of volcanic rocks. In the first place, the matter extruded through fissures may have been so liquid as to expand at once in thin sheets. This is very frequently the case with basalt, in the great accumulations of which, whether they be due to massive eruptions or to volcanic activity, the prominent differences wrought by both modes of action in the external features are generally least conspicuous. This basic compound is not only more fusible than the more silicious rocks; but, it appears that the admixture of superheated water will increase its fluidity more than that of the other compounds, while those unknown influences which cause the mass to solidify in the particular form of basalt must be still more potent in increasing its fluidity, since lavas consisting of dolerite, leucitophyre, and trachydolerite, which are quite or nearly identical with the former in chemical composition, are never so liquid as those of basalt, and are not unfrequently quite viscous. These rocks, together with all those of a more silicious composition, exhibit more distinctly the differences in origin, and this is probably due, in a great measure, to the peculiarity just mentioned. The great fluidity of basalt, which is also made evident by its frequent occurrence in very thin and yet very extended dykes, causes it, even when confined in the narrow space of a volcanic vent, to let the vapors of water escape, in quiet ebullition, in its orifice, as Dana has so beautifully illustrated in his description of Kilauea, while, at intervals, it will break out and cover the surrounding country with flat sheets of lava. The action connected with the ejection of the same rock from larger fissures, in former time, appears to have been similar to this. Yet, the numerous instances of the occurrence of basaltic cinder cones, and, on the other hand, of large accumulations of solid basalt with no perceptible horizontal structure, go to show that also in the case of this rock the modes of occurrence may be different when they are the result of different modes of ejection. Other instances of a similarity of the manner in which the matter has been deposited, when due to either mode of ejection, are frequent on the flanks and at the ends of the andesitic ranges of Hungary, where currents of andesite as well as of rhyolite have been emitted through fissures in andesite, at little elevation above the foot of those ranges. They appear to be due to processes intermediate in kind between both modes of ejection. We may, finally, mention those cases where massive eruptions were sub-aqueous, and layers of fine-grained tufa formed, alternating with coarser conglomerates, between which may be intercalated solid layers of the same kind of rock of the fragments of which those are composed. The similarity of this kind of depositions with the sediments of submarine volcanoes is often very great.

The principal point of difference between massive eruptions and volcanic action appears to be the depth of their source under the surface, and all the minor differences are probably dependent upon that. The region from which the former have derived their material, is, as we tried to prove, at a great depth beneath the deepest sedimentary rocks. The seat of volcanic action appears to vary within wide limits in regard to its distance from the surface, but to be, on an average, at much less depth than that of the massive eruptions: though there are circumstances which render it probable that it is in all cases beneath the shell composed of sediments. Evidence has been gathered by Prevost, Dana, Scrope, Hopkins, and others, in favor of the assumption that volcanoes are not connected with the molten interior of the globe, and are therefore not to be considered as safety-valves. The comparatively little distance of the seat of volcanoes beneath the surface is rendered particularly evident by the small area of the earthquakes attending their activity, when compared with the wide extent of others which must be dependent on some deep-seated action, but have no recognizable connection with any particular volcanic vent. It is no less obvious from the fact that two neighboring volcanoes may not only eject, contemporaneously, different kinds of lava, but also be, to some extent, independent of each other in their manifestations.

We may base further conclusions in regard to the origin of volcanoes upon the following premises, which we repeat from the foregoing pages: First, several facts appear to indicate that the source of volcanic action is at a comparatively limited depth; second, all volcanoes, whether active or extinct, are intimately connected with massive eruptions; third, this connection is of such a character as to establish, in the majority of cases, the close similarity and chemical identity of the mineral matter ejected by the volcano in its first epoch of activity with that of neighboring hills or of its own foundation, which had been accumulated by massive eruptions; while in other cases these neighboring hills or the foundation of the volcano are composed of volcanic rocks not identical with the lava, and then the latter will belong lithologically to a kind of rock which, according to the order of succession of massive eruptions, would be of a more recent origin than the former; that is, trachytic or rhyolitic volcanoes were frequently opened at those places where only andesite had been accumulated before, and basalt where either andesite or trachyte had preceded; but the reversed order appears not to occur, no basaltic volcano having been succeeded, in its own neighborhood, by massive eruptions of trachyte or andesite; fourth, many of those volcanoes which have been active through a long period, have undergone a periodical change in regard to the character of the mineral matter ejected by them, and this change is in general (though with exceptions) conformable to the order of succession observed in regard to massive eruptions.

From these facts may be inferred the complete dependency of volcanoes upon massive eruptions. The latter, as we attempted to show, were due, firstly, to the opening of systems of fissures which extended throughout the solid crust; and secondly, to a quiet outflow, which was caused by the expansion attending the change of aggregation of solid or highly viscous matter around the lowest part of the fissures into that of aqueous fusion. The relations of volcanic activity to massive eruptions are indicative of a process by which the elongated and extensive vents of the latter were gradually differentiated into isolated and narrow channels feeding isolated orifices on the surface. It has been observed that cinder eruptions mark generally the last stage of volcanic action. We may go a step further back, and say that volcanic action is the last stage of massive eruptions.

In order to arrive at a conception of the manner in which the change from one mode of action to the other could be effected, let us suppose that a main fissure was filled with matter from below, and mountains of volcanic rocks accumulated above it by the long continued overflow. Solidification would at once set in, and proceed downward whenever a cessation of the extrusive action occurred, independent of the question whether it would not simultaneously proceed upwards from the depth. Its progress would not be equal in all parts of the fissure, since this must be wider at some places, and more contracted at others. In this condition we should have one of the causes for the isolation of centers of action, for the length of time during which different portions of the matter would remain in a fluid condition, must, of course, depend in a great measure upon the width they would severally occupy within the channels, and those filling its wider parts must for a longer time remain susceptible of renewed expansion by accidental circumstances. Another cause which would have the same general effect, is the localization of the ingress of water. Some of its channels would, to all probability, become obstructed, and the rate at which new ones would be opened in their place would probably diminish in nearly equal ratio with the total amount of the manifestations of energy connected with the phenomenon of ejection in its different stages. As it appears that the supply of water, which may be either constant or intermittent, is, next to an elevated temperature, the chief condition for entertaining volcanic action, it may be inferred that the cause mentioned would contribute greatly towards the isolation of certain portions within the main fissure, by helping to keep the matter within them in a liquid state. If this second cause was coincident with the first, by the restriction of the ingress of water to a place where the fissure expanded, then both circumstances would combine to prolong the state of liquidity at that point. The connection between the bottom and the surface may have been kept open in a certain part of the mouth of the fissure, while solidification was proceeding over the rest of it. An isolated vent would then gradually be formed, and narrowed down to the size of a volcanic orifice. Obstructions of the outflow, by periodical consolidation, would become more frequent, and thus would proceed a slow change of the mode of action of massive eruptions to that which is peculiar to volcanoes.

This is probably the simplest manner in which volcanoes can originate. It will apply particularly to a number of those which have undergone no change in regard to the character of their lava, and the lofty cones of which rise over mountain ranges consisting of the same material with their own lava and cinders, though owing their origin to massive eruptions. We must now consider a third cause which would aid in promoting volcanic action, and probably come very often into play. It is indicated by the frequent occurrence of series of volcanoes extending in lines parallel to the axis of the main outbursts. Their only possible cause is the formation of fractures, parallel to the main fissure, and branching off from it. In order, however, that these could be formed, solidification must have proceeded downward in the main fissure, without any communication with the liquid portion in depth having been kept open. This process would necessarily imply a temporary cessation of the process of extrusion. That this could take place may be the more readily understood, if it is taken into consideration, that the liquid masses filling the fissure in its whole extent must contract considerably by constant loss of heat, and that any additional expansion produced by the promotion of aqueous fusion at certain places had first to equalize this loss of volume, before it could manifest itself in a rise of the whole mass. This twofold action, which is probably one of the main causes of the intermittent character of volcanic activity, must produce an alternating motion of matter within the fissure, and there would be given ample opportunity, during a period of its subsidence, for the consolidation of the upper portion to a great distance down from the surface.

If a period then followed in which, by dislocations of some kind, a change took place in the conditions subterranean, and expansion began again to prevail within the fissure, the new supply of force would manifest itself at the upper limit of the liquid portion, where the least resistance was offered, and new fractures would be opened branching off at that depth from the main fissure. The liquid matter would ascend through these secondary fractures, and, if these were of sufficient dimensions, give rise first to the formation of parallel ranges of volcanic rocks by massive eruptions, and then only to a gradual isolation of channels of volcanic action, as in the case first explained; or, if the fracture consisted of a series of smaller ruptures, cause at once the formation of a series of volcanoes. The activity in these secondary fissures could continue long after any manifestations had ceased over the main fissure, and even after the consolidation of the matter contained in this, with the exception of the volcanic hearths, had proceeded into far greater depth. The formation of secondary fractures, branching off from the main fissure, might be repeated at different depths, and fissures of a third order be formed, branching off from those of the second. Subterranean reservoirs of liquid matter, which may either be isolated or connected, would thus be formed at different depths, and be arranged after a similar plan below ground, as we notice among the active and extinct volcanic orifices above ground. The hypothesis of the existence of such subterranean seas of melted matter, as they have been called, has also, though in a very different meaning, been arrived at by the adherents of the theory of a metamorphic origin of volcanic rocks. This coincidence increases the degree of its probability. But unless the nature and distribution of those reservoirs is made dependent on grander phenomena having connection with the interior of the globe, they will not be capable of explaining the harmony prevailing either in one volcanic region or between all these regions. We have been led, by arguing on our suppositions, to the same conclusion at which we arrived before by induction from observed facts, namely, that the seat of volcanic action must be at a comparatively limited depth. Yet it appears that this depth is in all cases below the shell of sedimentary rocks. Among the reasons supporting this assumption, we mention only one. This relates to the chemical composition of lava. The volcanic is typically the era of andesitic and basaltic compounds. The occurrence of trachyte and rhyolite among the ejected rocks goes to show, that the seat of action receded at certain places from the andesitic regions to those of the compounds corresponding in chemical composition to the two kinds of rock named. But if it had been partially above those regions where matter is still in its primaeval position, then we should expect that there would be volcanoes the lavas of which, being derived from sedimentary rocks, would, as a whole, deviate in composition from the law of Bunsen. No such volcanoes are known, and it is, therefore, not probable that the seat of any of those the lava of which has been analyzed is within the shell of sedimentary rocks. It is true that subordinate deviations from the composition as required by theory occur; but it has been found sufficient to ascribe them, as in the case of Vesuvius, to a mechanical destruction of the rocks surrounding the channel of ejection by the ascending lava.

Active volcanoes themselves furnish an illustration in evidence of their own origin as here advocated. It is well known that small cones are frequently met with on the slopes of larger volcanoes. If they occur in larger number, as on Mount Etna, they are usually situated in lines which radiate from the crater. Each of them is built up of layers of scoria and ashes sloping away from the center, where a crater is immersed, and such cones will occasionally emit currents of lava, and be in fact the repetition on a small scale of the mother volcano. The usual and probably correct explanation of their mode of occurrence is this: That, through crevices or by passage through porous rocks, water gets access to glowing lava, and, by its action on the same, causes the opening of a fracture, and, in immediate succession, the repetition of the same phenomena which the mother-volcano presents when active. Just as these parasitic volcanoes have their roots in the glowing lava, volcanoes in general must, as is demonstrated by their mode of occurrence, be considered as parasites on certain subterranean portions of the material of massive eruptions, which still possess a high temperature and are kept in a liquid state by the molecular combination with water which finds access to them. This mode of origin of volcanoes, however, is only a repetition on a small scale of the manner in which massive eruptions themselves originated, inasmuch as volcanoes bear a similar relation to the latter as these do to the primeval substance composing the interior of the globe, to which the fractures descend. These main fissures, which are probably very few in number in every volcanic belt, form the great arteries in this harmonious system. Their common origin will furnish an explanation of the general similarity of the phenomena presented by different volcanic belts; while the varied and possibly very intricate mode of their ramifications towards the surface, together with the different conditions of the rocks which they intersect, the various rate and local diversity of the access of water, the different circumstances which may determine the depth in which the expansive force of vapor can be brought into action (among these may be the relative proportion in which chlorine, fluorine and sulphur are present), and other influences unknown, would give ample means for explaining the diversity of all the phenomena of vulcanism within each separate volcanic belt: such as the apparently intricate, and yet to a certain degree harmonious, mode of distribution of the rocks ejected; the correlations existing among the latter in regard to their composition; the dependency of volcanic action on massive eruptions; the mode of distribution of hot springs, solfataras, geysers, and other phenomena which were apparently associated with both modes of action; the different phenomena connected with the occurrence of earthquakes; the small size of their area of disturbance when connected with volcanic action, its varying, and sometimes very great extent in other cases where no connection with any one distinct volcano can be discovered; the singular correlations, finally, which have been observed to exist between different volcanic vents situated on the same belt. Some hints may even be got in regard to the remoter correlations which apparently exist between the phases of volcanic action on neighboring belts, though it must be conceded that in respect to the latter numerous facts have been observed which cannot be satisfactorily explained in the way here proposed, and rather appear to indicate the influence of the phases of magnetic currents on the manifestations of vulcanism.[22]

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[22] An extremely valuable contribution to the elucidation of these correlations respecting the phases of volcanic activity was lately given by Dr. Emil Kluge, in his work, *Ueber den Synchronismus und Antagonismus von vulcanischen Eruptionen, Leipzig*, 1863. The clear and able compilation of facts will be of lasting interest, though grave objections may be raised against the author's views on the origin of volcanic action, which are not based on any inferences drawn from the correlations demonstrated in the same book.

The foregoing considerations may explain what appears to have been the most probable way in which volcanic activity was developed at and near the places of massive eruptions. They apply without difficulty to those cases where volcanoes have undergone no change in regard to the character of their lava. We have still to consider those more intricate cases where the latter has periodically changed. There are volcanoes which exhibit a regular succession of andesitic, trachytic, and rhyolitic lavas, followed in a later period by the outpouring of basaltic lava, either through the same, or through other vents in the immediate vicinity. There are others in which only a part of this series can be observed, such as the succession of basalt to trachyte or rhyolite, which appears to be of the most frequent occurrence, or of rhyolite only to andesite. As the order of succession is generally the same as that exhibited by massive eruptions, it would appear that it must be due to the same causes in both cases. If we take it for granted, that those extensive reservoirs of melted matter, from which was either continued its quiet protrusion, or volcanoes were fed, have had their seat in those concentric layers of the crust composed of silicious masses which correspond to trachyte or rhyolite in composition, then there is little difficulty in explaining the protrusion of portions of them. For there must be a limit to the expansion of a substance such as a given mass of andesite, by aqueous fusion, and thereby a limit to its ejection. The eruptive activity might then either come to rest or continue. As it is very improbable that water takes originally a part in the composition of those masses below the shell of sediments which have crystallized from a molten state, its access to them at places contiguous to a source of heat, such as must be given by a fissure filled with molten matter from below, must be attended by a powerful influence on them. It would exert itself in aqueous fusion and expansion. But the viscidity peculiar to these highly silicious substances would not allow their extrusion until after the more liquid andesitic masses had been ejected. Supposing the reservoir in which this first change was effected to have been in the trachytic region, further action from the same could be cut off by the cessation of the ingress of water to it. Another reservoir, situated in the rhyolitic region, might then be isolated within the educting channel, filled now with trachytic matter, and the same process repeated, as before, ending with the change of trachytic into rhyolitic rocks. As regards the succession of basalt to these silicious rocks, we refer to the fact established before, that the fissures which gave vent to basalt, have all been formed at a much later epoch than those through which andesite had ascended, and that they were only partly coinciding with them. It would appear that subterranean reservoirs of liquid matter, connected with the surface by channels of ejection, should have offered, in many cases, the places of least resistance. It may, therefore, be inferred, that basalt, the great comparative liquidity of which is a well-known fact, would enter many of those reservoirs, and be emitted through the same, or through newly-formed channels, in preference to any matter of a more viscous consistency; and it will not be difficult to understand why basalt should, in many instances, have again been followed by, or alternated during long epochs with, lavas of a rhyolitic composition.

These considerations, which may be equally applied to the order of succession of massive eruptions and to that of volcanic lavas, are not given with a view of explaining this intricate subject, but only to show that natural occurrences may, with the aid of the theory here advocated, be explained without having recourse to any forced assumptions. There is no one of the processes pointed out which is not within the limits of those we are accustomed to consider as highly probable in regard to that part of volcanic action which is removed only a little way beyond immediate observation, and therefore more accessible to well-founded speculation than is the remoter connection between volcanic action and the fissures through which the massive eruptions of volcanic rocks took place.

3. *Other Theories respecting the Origin of Eruptive Rocks.*

The various theories which have been proposed in regard to the origin, not only of the volcanic but of all those non-foliated crystalline rocks which are made up of silicates, diverge in different directions. Most of them, however, leave unnoticed the most essential features of those rocks, such as their nature in regard to the details of chemical composition, their similarity in character in distant countries and different ages, the laws of their mode of succession and distribution, and the fact of their periodical emission after long periods of repose ; and no one undertakes to account for all of them. There may be distinguished two classes of these theories : the first comprehends those which assume the original seat of eruptive rocks to have been beneath the sedimentary rocks, while the second embraces those which would have it to be within the shell composed of the latter. It was the purpose of our foregoing theoretical considerations to point out, that it is exclusively in the direction followed by the theories of the first class that we may at all look for a satisfactory explanation of the relations presented by the eruptive rocks. But, though the views here advocated belong altogether to this class, the leading theories embraced in it have a very different scope. That form of them which was held by Buch, Humboldt and others of the most prominent geologists, and is still quite largely adopted, starts from the assumption that all eruptive rocks were ejected in the same condition in which they are supposed to have been when at their original place in the earth's interior, that is, molten by dry heat ; while the contraction of the globe by loss of heat is regarded as the sole cause of their ejection. Among the weighty objections which may be raised against these theories, may be mentioned : that the eruptive rocks on their arrival at the surface have evidently not had a temperature which would be sufficient for their dry melting ; that they contain a certain proportion of water enclosed, which was formerly not brought into account ; that the ejection from the depth to the surface of masses molten by dry heat is a process impossible of explanation, and that, if it was possible, the rocks should have a different texture from that exhibited by granite, diorite or propylite ; that, finally, contraction alone is as little capable of furnishing an agent for the rending of fissures opening towards the surface, which is the prime condition of eruptive activity, as is the cooling of the globe of giving the conditions requisite for the process of ejection itself. The theories mentioned have been longest maintained on the European continent, where they are even now advocated by many. Though approaching nearest of all to the most probable mode of origin of eruptive rocks, the reasons why they are untenable, with our present state of knowledge, are too obvious to be made an object of a more detailed explanation.

More numerous and more obvious objections may be raised, chiefly from a geological point of view, against those theories of the second class, according to which all the rocks under consideration, with the exception of those lavas which we actually see being ejected from volcanoes, would have derived their origin exclusively from metamorphism *in situ*; be it that the change is supposed to have been mainly of a chemical nature, and effected on or beneath the surface, by the action of water alone containing certain substances in solution, or that refuge be taken to the coöperation of superheated water and pressure at a great depth. A large amount of positive facts as well as of sagacious reasoning have been applied in their defense; but viewed in the light of those observations which present themselves continually to the geologist in the field, in evidence of an essentially intrusive and extrusive nature of those rocks, the premises on which argumentation is based must appear extremely deficient. Also will the reasons which we shall adduce against the leading theory of our day, be applicable *a fortiori* against the assumption of an origin of our "eruptive" rocks only by metamorphism *in situ*. Before entering upon that leading theory, we have still to mention the existence of a number of others, which, though acknowledging the probability of an origin of all lava and "trap-rocks" from the liquid interior of the globe, assume that granite, syenite, diabase, diorite and certain porphyries are so-called hypogene rocks, that is, have originated by metamorphism of sediments *in situ*. Against these theories may be raised the collective objections which apply severally to the others.

The obvious objections which may be made to the theories hitherto mentioned have given more and more ascendency to another doctrine, which we may designate as the metamorphic theory of eruptive rocks, and which owes its great influence upon modern geology to the fact of its starting from a certain number of established geological facts and lithological observations, and from the results of experiments. It is eminently a theory of the second class. No arguments against it will be more potent than those which prove the fallacy of the basis of all the theories of this class, as they will show that we must look for the origin of eruptive rocks altogether in a different direction from that followed by them.

The metamorphic theory is essentially to the purport, that all eruptive rocks, whether of recent or of ancient age, whether ejected by volcanic action or carried into their present position without any sign of the latter, were originally sedimentary rocks rendered liquid by the coöperation of heat, pressure, and water. It is supposed that these rocks, by the continued superposition of immense masses of sediment, had arrived at a great depth under the surface, where the agencies mentioned would coöperate to modify and transform their state of aggregation, resulting either in a molecular change alone, or in their conduction into a state of fusion. In the former case, the sediments would be simply metamorphosed, while in the latter, they would either crystallize in depth, with a total loss of their original structure, and form "plutonic," or "hypogene," or "indigenous" rocks, or be forced upwards through fractures, and solidify partly in the conducting channels and partly on the surface, when they would form "trap rocks" and "lava." One common cause is thus assigned to both metamorphic and eruptive (including volcanic) action, the latter being considered an advanced stage and ultimate result of the former. The immense action of metamorphism is an undeniable fact. But while formerly, on account of the violent agencies which were supposed to have been required for it, and the growing conviction that heat alone could not produce effects on such an enormous scale as had been suggested, the subject had to be treated with caution, and any extreme assumption was received with doubt, if not with a certain repulsion, the condition of things, in this respect, has of late undergone a great change, as scientific experiments, and especially those of Daubrée, have demonstrated the extent of the influence of water and pressure in producing metamorphic action. They have proved the remarkable fact that, at a comparatively low temperature, and with the aid of pressure, the effects of water, if continued for a sufficient time, particularly when it is charged with alkaline substances, will be able to produce changes in the nature of rocks which surpass even the most audacious assumptions of former time. An apparently safe foundation was now given to the widest generalizations, and the consequence is, that an almost unlimited action is at the present time brought to the account of metamorphism.[23] The least founded conception, however, of the faculties ascribed to it, we consider to be its supposed sole instrumentality in the production of volcanoes and the eruptive action of former ages from portions of the shell of sedimentary rocks. It is true that a great additional degree of apparent probability has been given to the metamorphic theory of eruptive rocks by the results of the microscopic examination of rocks so successfully instituted by Sorby, since they prove a remarkable similarity, in the minutest texture, of the minerals constituting granite and some cognate non-foliated rocks, with the main ingredients of certain foliated rocks made up of silicates, such as gneiss and micaschist. These had been observed long before to form the last link of a series which may be traced, by slow gradations, from unmetamorphosed sedimentary rocks, through those which are undoubtedly metamorphosed, up to the crystalline foliated rocks mentioned. The newly discovered facts appeared to indicate that granitic texture is the most advanced stage in a progressive series of molecular changes, and, carrying the argumentation still farther, the assumption was apparently justified that a corresponding origin must be ascribed to other rocks, such as those of volcanic origin, which are connected with granite by another long and gradual line of passage.

In drawing up our argument against this theory, (including all those doctrines

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[23] It may be frequently noticed, that those eminent men who, by creating a firm basis for induction, have pointed out the path through regions in the field of science the knowledge of which had consisted before of a confused accumulation of facts and suggestions, did themselves apply the newly acquired views within moderate limits, while sweeping generalizations on the same basis were usually made by others. It is so in the present case. The limits within which Daubrée himself has applied his ingenious conclusions from his experiments on the action of superheated water and pressure upon silicates, will probably never be drawn any closer. No discovery, however, could have been more opportune to those who had advocated before the origin of eruptive by the remelting of sedimentary rocks. Against the form of this theory which was first proposed by Hutton, and enlarged by Lyell, Babbage, Herschel and others, similar objections could be raised as against that form of the theories of the first class which was held by Buch. With the aid of the new views acquired, however, it was remodeled and brought into its present shape. A far greater extent is thus being given to the conclusions from Mr. Daubrée's experiments than their author ever intended.

which assume either all or a part of the massive crystalline rocks composed of silicates to have originated by the metamorphism of sediments) we will first point out some reasons against its general tenor, which may be conclusive in regard to those rocks the eruptive nature of which is almost generally conceded, while we will have to bring some additional arguments against its special application to those which are often designated as "hypogene" or "plutonic."

The metamorphic theory starts from the assumption of an alternating progression from the center of the earth, and recession towards it, of the chthonisothermal planes, the former being caused by sedimentary deposition, the latter by denudation.[24] It is then argued that, by the progression of these planes, sedimentary strata would acquire a more and more elevated temperature, and, being permeated by water, would be metamorphosed, and finally rendered liquid. It is demonstrated that heat, generated by the plication of the strata in the lowest and central part of an area of subsidence, would aid in promoting these changes, which would end in the rupturing of the crust and the protrusion of liquid matter. Eruptive activity should, according to these views, be confined to areas of subsidence, in particular to their central portions. Geological observation does not favor this conclusion, since the emission, at least of the volcanic rocks, has taken place on the borders of those areas, on high table lands, and, in general, in places which have undergone elevation before and since the time of the first commencement of the eruptive activity.

It would appear that the experiments of Daubrée should not be too freely applied to reasoning on processes within the shell of sedimentary rocks. They have been made with relatively large quantities of water, such as can scarcely be expected to be present in solid rock at some distance below the ground. Supposing that that quantity naturally enclosed in it would, under great pressure, cause its fusion, then no reason can be adduced why there should not prevail a liquid state of all matter at a limited depth below the surface, and over extensive regions, if not over the whole globe. That such is not the case, is evident from the want of any signs of subterranean tides. Leaving this difficulty out of consideration, another presents itself concerning the periodicity of eruptive activity. If processes such as those suggested by the adherents of the metamorphic doctrine were its cause, then it would be impossible to give an explanation, why there have been long eras of rest intervening between others of violent eruptive activity, or why the latter was of general distribution over the globe during the Tertiary era, and preceded by a period of rest which was probably no less general. The phenomena of vulcanism might have manifested themselves at a certain time more in one country than in another, if metamorphism had been their cause, since their principal theater would be constantly shifted to the places of the most violent metamorphic action; yet they should, at least in the aggregate, have been continuous.

These objections, however, against the metamorphic theory of eruptive rocks are of little weight when compared with another, respecting their nature as chemical

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[24] It is needless to enter here upon a discussion of the causes and effects attributed to these phases in the "flow of heat" by the adherents of the metamorphic theory, since this topic has been made lately the subject of a paper by the skillful hand of Professor Dana.

compounds. It is from this point of view, as we have repeatedly remarked, that are offered the chief and most deeply-founded differences between the eruptive and the stratified and foliated rocks. Definite numerical relations on the one side, complete absence of them on the other, and a transition between both, marked by the gradual disappearance of those relations with the passage from granite, in which they are very distinct, to gneiss and micaschist—these are in short the prominent characters of the great divisions of those rocks which are accessible to the observations of the geologist. We alluded at another place to the corollary of this distinction, namely: that it is impossible that eruptive rocks are remelted sediments, because, if they were, they would necessarily have to participate in the varied and indefinite chemical composition of these. This important argument appears to have been completely overlooked by the adherents of the metamorphic doctrine, and it would be sufficient by itself to make the latter appear to be in contradiction with the true state of facts.[25]

If we descend from this general tie embracing the totality of eruptive rocks, to those relations which either separate or connect distinct groups of them, in regard to the time at which they came to the surface, we are unable to find any explanation of the peculiar uniformity of these relations, if we adopt the metamorphic doctrine. Rocks of great mutual similarity might have been occasionally ejected at different places; but the repetition of the same order of succession in distant regions would be just as inexplicable, and contradictory to the nature of sedimentary rocks, as the perfect chemical identity of rocks which are widely separated in space, but occupy a similar position in the order of succession.

Another geological consideration may be mentioned which appears to weaken the metamorphic theory. It is known that the most ancient rocks are distinguished, in general, by a much greater similarity among each other in respect to chemical composition than is the case with those of more recent origin, and that one prominent feature of the majority of them is the presence of silica in a similar proportion to that in which it is contained in granite. The formation of sedimentary rocks having been due, at all times, to the disintegration of rocky matter antecedent to them in age, it is obvious that ancient sediments would have participated in the silicious nature of the

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[25] It can hardly be comprehended that it should have been maintained, and be believed, with our present state of knowledge, that clayslates were, by metamorphic action, converted into granite and syenite, and sandstones into porphyry; since granite and (quartzose) porphyry are chemically identical, while clayslate and sandstone differ in this respect not only among themselves, but each of them represents a large number of different accidental compounds, without any law of mutual connection. The supposition that "the presence of the sandstone formations affords the conditions required for the occurrence of the great porphyry-masses," gives evidence of an interpretation of natural occurrences by preconceived ideas. There are, it is true, numerous instances of sandstones having acquired, by metamorphic action, a more or less perfect porphyritic texture, so as to be hardly capable of being distinguished, in specimens, from true eruptive porphyries; but geological observation will seldom leave any doubt in regard to their true mode of occurrence; and, as a generality, it is not difficult to distinguish these metamorphic rocks with porphyritic texture from "the great porphyry-masses," such as those of southern Norway, or middle Germany, to which the above-mentioned supposition has been especially applied. It is evident that the eruptions of the porphyritic rocks were there subaqueous, and that the true relation is exactly the reverse of that suggested: the ejection of great masses of quartzose porphyry afforded all the conditions required for the formation of sandstone beds. Quartzose porphyry did overflow vast regions, and, by its immediate disintegration into tufaceous matter, gave origin to those red sandstones by which it is so often accompanied. These cover the porphyry often in horizontal beds, and bear to it similar relations of gradual passage and interstratification, as trachytic tufa does to trachyte, where the eruptions of the latter were subaqueous.

rocks by the destruction of which they originated, and should have had a tendency towards an average between them in regard to chemical composition. If such sediments were afterwards rendered liquid by metamorphic processes, and either carried to the surface as eruptive rocks, or solidified beneath it, so as to form part of it only after ages of denudation—if they were then again partially disintegrated, re-deposited and reërupted, and so forth, down to our time, the final result should be an ever-increasing uniformity in composition of both eruptive matter and sediments. It may be objected, that this tendency towards uniformity must have been checked by the formation of chemical sediments, as by them a portion of certain elements was eliminated, and must have become almost irrecoverably lost for further participation in the supposed revolving process. The substances prevailing in chemical deposits are lime, soda and magnesia. Recent eruptive rocks should, therefore, besides showing a uniformity of composition, be somewhat deficient in those substances, and contain in proportion more of silica, alumina and potassa. The facts are exactly reverse. Not alone has the variety of eruptive rocks rather been constantly increasing: but, among those most recent in origin, such are greatly predominant as contain lime, soda and magnesia in larger proportion than ancient rocks, while they are relatively deficient in silica, alumina and potassa. We arrive by this last line of argument at the conclusion, in the first place, that the present variety of rocks, especially of those of eruptive origin, can in no way be explained by, but is contradictory to, the assumption that they originated by the repeated destruction and reformation of the material which constituted the surface of the globe in the most ancient time. From this it follows, in the second place, that, even supposing that the theory should be admissible for the majority of eruptive rocks, entirely new matter must have come repeatedly to the surface, in order to replace the constant loss, as it were, of substances such as lime and soda. Eruptive rocks ascending from sources beneath the deepest sediments are the only means imaginable for the performance of this function. The enormous extent to which matter must have been supplied from that source is especially evident, if it is considered that there must have been a time when no sediments existed on the face of the globe, and that the disintegration of preëxisting matter is the prime condition to their formation. The entire mass of the sediments which make up the exterior shell must, therefore, have been derived from the destruction, partly of the original crust which solidified on the globe, and partly of those rocky masses which protruded through that crust to the surface. It is eminently probable that the mass of matter derived from the latter source exceeds very far that which is due to the first. This consideration shows that it is hardly possible for us to form an adequate idea of the vast importance which the periodical emission of rocky matter from places beneath the primordial surface must have had in the history of the formation of the crust of the globe.

We may thus start from any point of view within the range of positive knowledge, and we shall find that there is not one line of argumentation which does not go to show that the doctrine of the origin of eruptive rocks by the metamorphism of sedimentary matter is irreconcilable with the most prominent established facts. Not only does it fail completely to explain them, but with most of them it is in obvious contradiction. But as a metamorphic origin has been proved to evidence in regard to certain foliated rocks, and as it appears no less safe to conclude that those rocks, the intrusive or extrusive character of which is generally admitted, originated from below the sedimentary rocks, we have still to examine where is the limit to which the theory of such an origin may be safely applied. A line of gradual passages connects the foliated rocks with gneiss, and through it with granite, and another line of gradual passages can be traced from the volcanic through the porphyritic to the granitic, and through them again to the gneissoid rocks. The affinity of granite and gneiss may therefore be said to be the central point from which all other lines of passage in the nature of rocks diverge; and it must be ascribed to this relation, that many geologists, while admitting the origin from below the crust of the globe of "trap-rocks" and "lava," still consider granite, syenite and cognate rocks to have been generated by the metamorphism of sediments, and to occupy now the same position which these sediments had before being metamorphosed. The peculiar character of granitic texture, which is nearer allied to that of foliated crystalline than to that of volcanic rocks, the geological occurrence of granite in intimate connection with those and its apparent independence of position in reference to the latter, the singular order of solidification of the minerals constituting granitic rocks—these and other reasons of a similar kind would indeed appear to support the assumption that granitic and volcanic rocks differ in regard to their origin; while, on the other hand, additional probability is apparently given to the connection of granite and foliated rocks in regard to their mode of origin, if it is taken into consideration that many varieties of gneiss resemble granite closely in chemical composition, although others deviate from it in this respect and do not conform to the law of Bunsen.

According to the theory here advocated, all those rocks will be the true representatives of the primordial mass of the globe, which are subject, in regard to their composition, to the law of Bunsen, and occur, besides, in positions which place beyond doubt their intrusive or extrusive origin, so far as they no longer occupy their original place. As regards the first distinguishing mark, it is known that granite, syenite, diorite, diabase, and nearly all those porphyritic rocks which have been considered as of hypogene origin are subject to the law of Bunsen, as far as their composition has been ascertained. In this respect, therefore, they are fundamentally different from sedimentary and metamorphic rocks. Although believing this to be conclusive evidence of their origin from below the shell of sediments, we must enter into a short discussion of the chief objections which have been raised against the necessary corollary from this mode of origin, which is the eruptive character of those portions of granite which we see on the surface, and the assumption of the existence of this as the foundation of all sedimentary rocks.

It is argued by the adherents of the metamorphic theory of eruptive rocks, in the first place, that granite cannot be the fundamental rock in the crust of the globe, on which those of sedimentary origin are resting, since even very ancient masses of it are frequently found to overlie stratified rocks. But this fact, which was known long ago, shows only that it is impossible, on account of the great thickness of sedimentary rocks, to know by ocular observation of what nature is the fundamental rock. It is logically absurd to assume the non-existence of a foundation consisting of rocks differing in origin from sedimentary rocks; and the conclusion is inevitable, that it must be composed of rocks which were generated by the solidification of such masses as formed part of the primordial substance of the globe, next to the surface. Probabilities accumulate to point towards the assumption that very silicious granite composes that foundation, together with such gneissoid rocks as must be supposed to have been formed in an incipient sea of very high temperature, and under the pressure of the superincumbent atmosphere of aqueous vapors, at a time when the cooling of the globe had advanced far enough to allow of their first condensation, and when pressure, water, and heat could coöperate to produce on its surface similar effects to those which the same agencies are supposed to have wrought in later periods at an ever-growing distance from it. The most probable mode of these ancient processes has been pointed out by Daubrée. The true nature of the foundation rock can, of course, not be positively known, but must remain a matter of conjecture. No solution of this problem will, however, be more satisfactory than that which is based on the hypothesis of Sartorius, because it is in harmony with all the phenomena of vulcanism. The probabilities in favor of a granitic foundation are, therefore, very great, while no valid objection has yet been raised against its having the nature indicated.

It is further argued that, the position of granite being always in the midst of sedimentary, or of such foliated crystalline rocks as are connected with the former by gradual passage, and often conspicuously above such rocks, the only material from which it could be generated are the sedimentary rocks themselves. The arguments brought in evidence of these assertions are among the most potent which can be adduced against them. Granite, in Norway, is superposed on Laurentian rocks turned upon their edges, and, as no channel can be found by which it ascended, it is argued that it must have been generated by metamorphism *in situ*. But as, on the other hand, it has justly been remarked, that no position is more favorable for metamorphic action than that of upturned strata, it is difficult to comprehend why the Laurentian rocks, which were evidently nearer to the source of heat, should not have been metamorphosed in a much higher degree than the overlying granite. The same objection may be made in other instances, as in the case of the Huronian and Laurentian rocks in Canada, which were found to be overlain by granite thousands of feet in thickness. The negative evidence, apparently afforded by the fact that no channels have been discovered through which the granite could have protruded, is of very slight value, if it is taken into consideration how rare are the instances where the conducting channels can be seen, in the case of overflows of volcanic rocks, or even in that of currents of lava. There are a few more instances known where granite can be distinctly observed to overlie the upturned edges of stratified rocks, and must, therefore, have overflowed the same in a liquid state. In some other cases, as in those of the extensive granitic areas of Bessarabia and Western Australia, the true geological position of granite escapes observation; while, in a number of others, it has the appearance of an intrusive mass.

The strongest objection which may be made to the eruptive nature of granite relates to its lithological characters, which are different from those of the eruptive rocks of the present era. The metamorphic theory suggests that enormous volumes of those masses which it supposes to have been rendered liquid by metamorphism, and small portions of which were occasionally emitted to the surface, did solidify below ground with a total loss of their previous structure, and may arrive at the surface by elevation and denudation. Granite is supposed to have been in all cases a hypogene rock, generated by metamorphism in those same positions in which it is found at the present time, and to be still formed continually in the same way; though it is admitted that the tension which may have attended its former state of liquidity, may have caused it to ramify into rents and fissures of the overlying rocks. We have, of course, to assume the existence of an immensely greater amount of hypogene matter corresponding in composition to all the different eruptive rocks, but buried so deep beneath the present surface, that, possibly with the exception of a few granite masses, it never does, nor ever will, form part of it. We have, for this reason, to consider all non-foliated crystalline rocks made up of silicates, and which are visible on the surface, as having been removed far from their original seat, and therefore as being eruptive. It is a matter of course that only a very small portion of all matter protruded from the depth would be ejected to the surface, as by far the greater portion would solidify within the channels of ejection. Granite occupies frequently the latter position quite distinctly. But if we consider those large accumulations of the same rock covering hundreds of square miles, we can only explain them in two ways. Either they must occupy their primeval position, as is supposed by the adherents of the metamorphic doctrine, or they must have been ejected and spread in a liquid state over the underlying rocks. The objections against the first supposition are, the adaptation of granite to the law of Bunsen, and the fact already noticed, that it overlies the upturned edges of strata; the objection against the other is the peculiar mineral character of granite. But we should always bear in mind that our knowledge in regard to the conditions required for producing any certain kind of mineral character within a compound of silicates of any certain composition is very limited, as is illustrated, among others, in the cases of propylite or dolerite; and the inferences based on subjects which are imperfectly known to us should, in geology, always be made subordinate to those which we can positively establish by observations. It is not on the ground of the latter that a hypogene origin is ascribed to all granite, but on the ground of its mineral characters. It is said that granitic and volcanic rocks offer quite generally a different appearance, and that the texture of the former indicates crystallization under great pressure, while the volcanic rocks were evidently solidified on the surface. As regards the first assertion, such rocks only should be compared together as have a similar composition, that is, granite with rhyolite, or diabase and augitic porphyry with basalt; not, as is ordinarily done, granite with phonolite or basalt. We referred already to the similarity in character between certain varieties of rhyolite and granite. It is corroborated by the microscopic examination of these rocks by Ferd. Zirkel, from whose memoir[26] I quote the following passages: "Quartziferous trachytic

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[26] Dr. Ferdinand Zirkel, Mikroskopische Gesteinsstudien, in *Sitzungsberichte der Kais. Acad. der Wissenschaften zu Wien, vol.* 47, 1863.

porphyry (rhyolite) cannot be distinguished under the microscope in any respect whatever from felsitic porphyry. If one dare not doubt the eruptive origin of the former, one cannot but acknowledge the same mode of origin in regard to the latter." And again: "Let us here remark, that the microscopic structure (texture) of trachytic quartz does not differ in any respect from that of granitic quartz; there is no difference between these two families of rocks so widely separated in time, either as regards the number or the appearance of the water and glass cavities." Considering the second of the before-mentioned assertions, it is true that Mr. Sorby has, by his sagacious observations, come to the conclusion that granite solidified at a temperature of about 600° Fahr., and that the various granites have been formed under a pressure equivalent to a depth of from 40,000 to 69,000 feet. The calculation by which these figures were obtained, is made upon the basis of the proportion between the bulk of the water contained in the microscopic cavities, and the size of the vacuity, the latter being supposed to indicate that the water had formerly filled the entire cavity and contracted within it after the solidification of the surrounding rock. The laws of hydrostatic pressure, however, as Daubrée justly remarks, are in such a case not applicable in the same way as they would be in a column of water ascending through a fissure; temperature and pressure may, in a mass of rock solidifying from a viscous state, be preserved, as in a closed vessel, to within a few feet from the surface; "it is, therefore, possible that many processes, such as the crystallization of granite, may have been going on under pressure, though at a very limited depth." Considering that a mass of granite, after the solidification of its exterior portion, will indeed be enclosed within walls that may offer a strong resistance equivalent to a great pressure, it may be inferred that it will assume, in crystallizing, a similar texture to that which it would have obtained if the same process had been going on at a great depth below the surface. It can hardly be suggested what must have been the texture of the crust of a granitic mass. But the age of the granite is sufficient to justify the conclusion that the crust of those masses which solidified on the surface of the globe must have been completely abraded, and only those portions be preserved to observation which consolidated under considerable pressure.

Though these arguments may show that the difference in the character of a large mass of rock need not necessarily be proportionate to the depth under the surface of the globe at which it solidified, and that granitic and volcanic rocks are nearly related as regards their microscopic texture; yet, the conspicuous external differences between these two classes of rocks must remain a problem difficult of solution. The proportionate rapidity with which volcanic rocks, on account of their usually small volume, must have cooled, may be among the reasons. But it is not the only one. There are differences in the nature of rocks, which escape our present means of explanation. Hornblende-propylite, though no doubt at all can be entertained in regard to its subaërial solidification, has completely the character of the so-called Plutonic rocks, and yet lacks their supposed principal distinguishing mark: crystallization in depth. Considering that certain varieties of propylite, andesite, and trachyte are modifications of the same group of chemical compounds; and, though having been solidified on the surface of the globe within a short period, yet exhibit marked external differences, we cannot be surprised to see, that other rocks composed of silicates, which are so widely separated in time as is the case with granite and rhyolite, should offer even greater differences. Some further clue to a better knowledge of this subject may be expected from the study of the nature of volcanic rocks. We see the same chemical compound forming highly viscid lava in one volcanic crater, while it is quite liquid in another. There, it solidifies to dolerite or leucitophyre; here, to basalt. Similar influences appear to work greater differences in more silicious compounds. We should therefore put little value on the doubts entertained in regard to the solidification of granite, as of a rock ejected on the surface and expanded over it, until we are better acquainted with the causes of the lithological differences among volcanic rocks; and the evidence regarding the mode of origin of granite should, till then, be mainly taken from its geological occurrence and its chemical composition.

RELATION OF THE DISTRIBUTION OF THE VOLCANIC ROCKS TO THE CONFIGURATION OF THE SURFACE OF THE GLOBE.

If we embrace in a broad review all those relations mentioned in the foregoing chapters which regard the history of eruptive action, we arrive at the general conclusion that, in reference to the entire globe, it is one homogeneous and harmonious whole, and has been attended by such gradual changes only as were necessarily occasioned by the progress of the physical development of the globe itself, while, in regard to every different part, it presents a series of distinct phases intimately connected by mutual relations. It would be a subject worthy of the closest investigation, to trace the effect which the events of these phases have had severally upon the structure and the configuration of any separate country. A comparison of these effects as they are manifested in different regions would then aid in establishing some of the chief causes of the differences of structure peculiar to each; and the knowledge of these would make us better acquainted with the laws governing the evolution of the globe, and prepare the way for a more thorough understanding of its physical geography. I will only attempt at this place to trace the effects referred to in regard to the last of the phases of eruptive activity, the only one which was nearly contemporaneous in all countries. It occurred at a comparatively recent date, and we can view the results in a clearer light than we can those which are remote in time and partly obliterated by the vast changes which since then have revolutionized the surface.

We have, in the first place, to trace more in detail than we have done before, the peculiarities of the distribution of volcanic rocks. It has been observed that active volcanoes are chiefly situated along the lines of the present sea-coasts, especially at the foot of mountain ranges parallel to them; or that they follow elevated submarine ranges, when they will either remain submerged beneath the sea, or protrude above it, forming chains of islands. Some of these appear to mark the lines of high mountain ranges bounding submarine continents, if we may use this expression for those areas of a shallow sea-bottom which are separated from others of great depth by wall-like elevations, as are indicated for instance in the main ranges of the volcanoes of the Indian Archipelago. Active volcanoes have also been found to be particularly numerous in those regions where the narrow terminations of two continents verge towards connection, as is the case in Central America, between Alaska and Kamtschatka, and between Australia and Farther India. The mode of distribution of extinct volcanoes has been little investigated. But as they are far more numerous than active vents, and as volcanic action has completely ceased in extensive regions, a perfect understanding of the distribution of volcanic activity on the globe can only be acquired when they shall be fully taken into consideration. The general laws of their distribution appear not to differ from those relating to active volcanoes. They, too, have been evidently dependent upon the course of the sea-coasts which existed at the time of their activity, and were in many places quite different from those of the present epoch. But we must note, besides, this additional feature of extinct volcanoes, that among the theaters of their grandest and most extensive displays are certain countries which were formerly covered with large inland basins filled with salt water, and form now mostly elevated table-lands on which may still be seen the remnants of those former inland seas. Volcanoes so situated form often crowded groups occurring at distances of more than five hundred miles from the sea-coasts which existed contemporaneously with their activity. To them belong the numerous extinct volcanoes on the plateau between the Sierra Nevada and the Rocky Mountains, a region which has probably had no equal in regard to the extent in which volcanic activity has taken place, as it comprises the States and Territories of Oregon, Idaho, Montana, Utah, Colorado, Nevada, California, Arizona, New Mexico, and continues southerly to the high lands of Mexico. Other volcanoes of high table-lands are those of the Mongolian Desert, the Thian-Shan, Armenia and, probably, eastern Africa. The volcanoes of all these regions are extinct, with the exception of a few in the southern part of the plateau of Mexico, which are in action, and some others which still exhibit solfataric phenomena.

Interesting as would be a map embracing all active and extinct volcanoes, it would give only the outlines of the distribution of those larger accumulations of volcanic rocks which were produced by massive eruptions, and have ordinarily attracted little attention.[27] Geological maps being often imperfect as regards them, it is not yet possible to distinguish any other features of their distribution than those mentioned in reference to volcanoes, as they can always be found in the vicinity of these. We may however add, that massive accumulations may eventually be found near the summits of mountain ranges, where volcanoes do ordinarily not occur.

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[27] This may be exemplified in regard to the Andes of North and South America. Humboldt (Cosmos, vol. iv) distinguishes five groups of volcanoes, separated by non-volcanic regions. They are mentioned by him as follows: 1st, volcanic group of Mexico, nearly five hundred miles in length, but occupying scarcely more than one degree of latitude, on account of its direction from east to west; 2d, three hundred and fifty miles free from volcanoes; 3d, group of Central America, having a length of over eight hundred miles; 4th, seven hundred and thirty-five miles non-volcanic; 5th, group of New Granada and Quito, five hundred and fifty-five miles in extent; 6th, the longest interval without volcanoes, being 1,133 miles; 7th, group of volcanoes of Peru and Bolivia, extending over five hundred miles; 8th, a non-volcanic space of six hundred and twenty miles .9th, the group of Chile, the most extensive range of volcanoes of America, being 1,143 miles in length. Summing up, Humboldt takes about 3,000 miles to be the aggregate extent in length of the volcanic regions, 2,838 miles that of the intermediate spaces which are free from volcanoes. If all the volcanic rocks occurring in the Andes

If we turn our attention from the mode of the geographical to that of the geological occurrence of volcanic rocks, we may first consider from this point of view the relations just mentioned. The two modes of distribution which are most conspicuous, namely, on the foot of mountain ranges and along sea-coasts, are nearly identical in a geological aspect. For most, if not all of those ranges the flanks or vicinity of which are distinguished by the occurrence of volcanic rocks on a large scale, have been contiguous to sea-coasts in the Tertiary period, or they are so at present, or they have been so in the intermediate time. This is true of active and extinct volcanoes, as well as for massive eruptions, in the Carpathians, on the southern foot of the Alps, on the borders of the plains of northern Germany, on the slopes of the central plateau of Asia, in their whole extent from Armenia and the Caucasus, passing Lake Issikul and Lake Baikal, to the vicinity of Pekin, in the coast ranges of California, in the Cascade Mountains of Oregon, and in numerous other countries. As regards the prominent occurrence of volcanic rocks on high table-lands, it is analogous to their situation on sea-coasts, inasmuch as the salt lakes occurring on them, which were of much larger size in the Tertiary period, would be an equivalent of the vicinity of the sea. Those larger regions not covered by salt lakes, which are situated in the interior of continents, and have been so since the commencement of the Tertiary period, were generally not the theater of outbreaks of volcanic rocks. This circumstance renders almost certain the influence which the neighborhood of large quantities of salt water has had upon the commencement and main phases of the eruptive activity, though its continuation in the latter phases, which are those of volcanic action proper, may in numerous instances have been maintained by fresh water.

The relations of the distribution of the volcanic to that of the granitic and porphyritic rocks have been considered in another chapter. There is probably no place distinguished by the accumulation of the first where the previous eruption either of granitic or of both granitic and porphyritic rocks may not be observed, if the conditions are such that observations in this direction are possible. But as there are porphyritic regions outside of the volcanic belts (for instance, the quartzose porphyries of southern Norway, or the Triassic trap-rocks of the Connecticut Valley), and as the same is true of a great number of known granitic districts, and probably of a far greater number of others which are not accessible to observation, it is evident that the existence of ancient channels of ejection did not necessarily imply their reopening in the Tertiary period, while there can scarcely be any doubt that the once shattered places where they were situated offered less resistance to the formation of new fractures, than other portions of those regions in which the greatest disturbances took place in the Tertiary period.

We have, finally, to mention the connection which apparently exists between the occurrence of volcanic rocks and the regions where ancient formations have been

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were laid down on a map, it would hardly show such great intermissions. The extensive fields of lava found by Capt. Fitzroy, in southern Patagonia, the volcanic rocks of the Desert of Atacama, and of northern Peru, are instances of their extensive distribution in the non-volcanic spaces of South America, while on the northern continent they are one of the main features in the structure of the great western mountain ranges, probably throughout their whole extent from Panama to the peninsula of Alaska, and are accompanied probably by thousands of extinct craters.

highly disturbed and subjected to an extensive metamorphism. It appears that the eruptive action was in a great measure, perhaps absolutely, limited to regions which offered this condition. But this connection by no means justifies the conclusion that the existence of metamorphic foliated rocks was among the first causes of the ejection of volcanic rocks. There are not only countries, such as the mountains of Scandinavia, the Ural Mountains, the Appalachians, and other ranges distinguished by the records of a very ancient metamorphism, where no trace of volcanoes has been found; but this applies even to a few, though particularly grand instances of mountain ranges which were the theater of metamorphic action on a grand scale within the most recent periods, such as the Alps, the Himalaya, and the Pyrenees.

The two last named relations, both conspicuous, yet both secondary in importance, are evidently nearly identical, since granite enters, probably in all cases, into the structure of those same countries which have been the theater of an extensive metamorphic action. It is, however, worthy of note that, of the regions so distinguished, part of those only appear to have become the theater of eruptive activity in the Tertiary period, where granite must, by the mode of its occurrence, be assumed to have formerly been extruded to the surface, as is the case in the Sierra Nevada, on the southern foot of the Alps, in middle Germany, and in central France, while no volcanic rocks arrived at the surface in other mountain ranges where granite occurs only in the shape of wedges surrounded by foliated rocks, and bears a merely intrusive character, as in the central range of the Alps.[28]

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[28] Another peculiarity in the distribution of volcanic rocks may be noticed. It is their outbreak at places of dislocation or faulting of mountain ranges, if we may apply these expressions for the immense displacements which some of the latter have undergone, along lines either at angles with or parallel to their direction. A remarkable instance of the first kind is afforded in Hungary, where a fracture, along the line Eperies-Kaschau, crosses the Carpathians in a nearly meridional direction. To the west of it, ancient formations, along with granitic, porphyritic, and volcanic rocks, make up the surface, and are elevated to high mountain ranges culminating in the High Tatra. They extend eastward close to the fracture, and there terminate abruptly. East of it, the main chain of the Carpathians continues as a range of little elevation, and consisting chiefly of Cretaceous and Eocene rocks, while the high foothills of the western part are replaced by the Hungarian plains. Immediately out of the fracture rises the Eperies-Kaschau range, of nearly one hundred miles in length, which consists exclusively of volcanic rocks. The subsidence of the land on the eastern side of the fracture must have amounted to several thousand feet in this case. A transverse dislocation of similar magnitude, by which the western side was sunk thousands of feet, is observable on the eastern bank of the Rhine, along the boundary of Switzerland and Vorarlberg. No volcanic rocks however are visible at that place, which fact appears to be in accordance with the absence of any ancient eruptive rocks in the neighborhood, and the wedge-like shape of granite in the nearest places of its occurrence. A peculiar instance is afforded by the three porphyritic regions on the southern slope of the Alps, each of which indicates a deep depression, bounded by longitudinal and transverse fractures, of that area which has in each case been the seat of eruptive action. Prof. J. D. Whitney and I had occasion to observe another instance, more forcibly striking for its grandeur than any of the foregoing. Following the crest of the unbroken range of the Sierra Nevada, from south-southeast to north-northwest, one arrives in the northern part of the County of Plumas at a sudden change of scenery and rocks. The metamorphic rocks of the Sierra Nevada are broken off and terminate in a line apparently at about right angles with the direction of the crest of the former. The rugged and wild scenery which they present, particularly in this county, gives way abruptly to one equally remarkable for its beauty and geological interest. The high volcano, Lassen's Peak, rises in the distance, amidst an intensely volcanic group of hills. Low forest-clad ridges built of lava, and separated by meandering plains covered by meadows, stretch southward from it, gradually sloping down towards the line of dislocation, and there abut against the wall of metamorphic rocks. The whole surface, though lower than the summit range, is entirely volcanic. Seventy miles northwest from Lassen's Peak rises Mount Shasta, more sublime even than the other. Between both is a deep depression, through which the Pit River takes its course from northeast to southwest, at little altitude above the sea. This depression is situated at the very place where the crest of the Sierra Nevada should pass, and is directed transversely to it. Northwest of Mount Shasta, Prof. W. H. Brewer found the continuation of the Sierra Nevada, with similar char-

These appear to be the most essential geographical and geological relations regarding the mode of distribution and occurrence of volcanic rocks. It is perfectly evident that no one of them singly was the chief cause of their occurrence, nor were all of them together; but each of them had a marked influence, either upon the direction and the location of the orifices of the fractures, or upon the mode of ejection. Keeping in view these different relations, I shall dwell, in the rest of this chapter, more particularly on the connection between the occurrence of volcanic rocks and the configuration of the surface. This subject may appear to be beyond the scope of this paper. But the examination of every question which relates to the inner connection between the phenomena attending the ejection of volcanic rocks will aid in disclosing the true nature of these, and promote the knowledge of the principles of their natural system. We will endeavor to answer the following questions: Was the particular structure of certain portions of the crust of the globe, which is indicated by the situation of elevated regions on its surface, among the causes of the eruptions of volcanic rocks? or were the inequalities of level on the surface, in the volcanic regions, due to the processes attending and the agencies causing the eruptions?

The answer to both questions must be in the affirmative. The peculiar structure of the earth's crust, at those places where mountain ranges and highlands rise on its surface, appears to have influenced in a great measure the distribution of the volcanic rocks, because those among them which are accompanied by the latter, had been elevated before the time of the eruptions, and the adjoining lowlands were not the theater of eruptive activity. But, on the other hand, it is evident that the ejection of volcanic rocks, or rather those subterranean processes of which they were one of the

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acter in rocks and scenery to that which that range has in other parts. It appears that a gap of more than one hundred miles in length has been formed in the region of the two volcanoes, by the displacement of a portion of the Sierra Nevada, which was probably bounded by two lines of fracture transverse to the direction of the mountain range, and has subsided thousands of feet, and that then an immense accumulation of volcanic rocks filled up the gap, and closed in building up the two giant volcanoes. Other lines of dislocation which have given vent to volcanic rocks, and which have more frequently been noticed, are directed parallel to mountain ranges. Of such nature appears to be the abrupt descent of the Sierra Nevada towards the Great Basin, which has been the theater of violent eruptive action; and probably the relations on the western slope of the Rocky Mountains are of a similar nature. The Vihorlat-Gutin Range, in Hungary, offers a striking illustration of an extensive accumulation of volcanic rocks along the foot of a preexisting mountain range, though the dislocation is not conspicuous in that country, on account of the deposition of recent sediments which filled up the Hungarian Basin. There may be some affinity between these modes of occurrence of volcanic rocks and the manner in which they are met with in certain areas of flat or hilly countries, surrounded by ranges composed of ancient rocks. The best illustration is afforded by the Basin of Transylvania. The undulating country of the interior is encircled by high ranges consisting of ancient formations, which are lined on their inner side with volcanic rocks. Hungary itself affords a similar instance, though less regularity is perceptible; and the same structure is somewhat approached in the geological relations of Bohemia. We may also mention, as recalling that mode of occurrence, certain depressions between the two summit ranges of the Sierra Nevada, such as the Basins of Sierra Valley and Lake Tahoe, which are encircled, first by a ring of volcanic rocks, and then only by the metamorphic and granitic rocks which form the bulk of the Sierra Nevada. Or the "Parks" of the Rocky Mountains. Their geology, it is true, is almost unknown. An interesting description of the San Luis Park, the greatest among them, recently published (see American Journal of Science and Arts, November, 1867), shows that the elevated rim of its basin, which is estimated at eighteen thousand square miles, is made up of ancient formations, and that volcanic rocks encircle more immediately the extensive plain forming its bottom, which is itself composed of volcanic sediments, thus completing a structure that reminds of that of Transylvania, in more than one respect. If we look for instances on a grander scale, we may find some analogy with the mode of occurrence of volcanic rocks as just described, in the volcanic ranges encircling the Basin of the Pacific Ocean. And it may not be out of place if we call attention to the similarity with these circular basins which is presented by the configuration of the surface of the moon.

resulting events, exerted a powerful reaction upon the further promotion and acceleration of those motions of the crust by which the irregularities of level of the surface were produced. This may be inferred, in the first place, from the fact, that in and along volcanic belts, elevation and plication of sediments have taken place, probably in every instance; both modes of disturbance have affected, partly sediments anterior in age to the eruptive action, and partly such as were contemporaneous with and posterior to it; and there may be frequently noticed a diminution of the intensity of these disturbances, in an inverse ratio with the distance from the volcanic belt.[29] But besides this fact, observation has placed it beyond doubt, that in the second half of the Tertiary period, and after it, a greater aggregate amount of relative, and probably too of absolute elevation has taken place generally over the globe than had been the case for ages before. The altitude of the rocks composing the summits of the highest mountain ranges and table-lands of the present time, exceeds that which they had in the

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[29] This evident connection, in volcanic regions, of elevation and plication, as cause and effect, appears to be one of the gravest objections against the general validity of the theory of Mr. Hall on the mode of formation of mountain ranges, though the incongruity of an explanation of the granitic wedges by metamorphism *in situ* with the chemical nature of granitic rocks, the total insufficiency of a gradual sedimentary deposition for accounting for a foot-for-foot subsidence of large areas, and the difficulty of finding any natural cause of the assumed fact that the belts of greatest amplitude within each area of subsidence should have been elevated to mountain ranges in preference to other neighboring parts, are objections of scarcely less weight. It is a well-established fact, that the Alps existed as a mountain range, at least from the time of the Jurassic period (though probably long before it), and have gained in height in later periods. Yet the Jurassic and Cretaceous strata are as much contorted as are those of more ancient age, and the same is true in a still greater measure of the Tertiary Flysch. If, therefore, Mr. Vose, in his Orographic Geology (p. 68), arrives at the conclusion: "So far as we have examined the facts, no other hypothesis than that of the slow sinking of vast masses of yielding sediments can at all satisfactorily account for the plication and other evident effects of a compressive force so invariably exhibited in mountain districts," the more recent formations of the Alps confirm this view as little as the above-mentioned example regarding the volcanic belts. It may be mentioned, in this connection, that, while Mr. Hall's theory would necessarily imply an increase in the intensity of plication towards the axis of greatest accumulation, which is considered by him to have been coincident, after the elevation, with the axis of the mountain ranges, this conclusion is not confirmed by the structure of the Alps. In Vorarlberg and northern Tyrol, which offer probably, of all parts of the Alps, the most normal and regular structure, all strata, commencing with those of Triassic age, are least disturbed where they are nearest to the axis, and the plication increases towards the foot of the range. Superposition, by contortion, of older formations on those of more recent origin, is encountered with increasing frequency of instances and growing distinctness, in crossing the parallel waves from those nearest to the axis, towards the northern foot of the range. Another objection, nearly related to the foregoing, is this, that, granting that a trough-like depression would be able to cause plication by the settling of the yielding strata towards the axis of greatest subsidence, the waves thereby formed would have their steeper inclination towards that axis, and their flatter slopes directed outwardly, since a greater resistance would oppose the motion of the lower strata than would be offered to the higher ones. The analogous instance, to which reference has been made, of a wave rolling towards the beach, shows plainly the effect of the retardation suffered by the lower portion of the water by friction, in the steepening of that side nearest to the place towards which motion is directed, and the final throwing over of the top in the same direction. A familiar instance, which repeats more exactly, though on a small scale, the conditions suggested by Mr. Hall's theory, is afforded when a viscous mass, such as resin or pitch, moves downward on a slightly inclined plane. If the necessary conditions are given for the formation of waves, their steeper sides will always be on the lower end, or, on that which would be nearest to the axis of a trough-like depression. It is obvious that this shape is the reverse of that of the waves of plication which Mr. Rogers and others have observed, and on which even Mr. Hall's theory is partially founded. This theory, which was first proposed for a mountain range in which recent formations do not occur, and where, therefore, not all of these objections could be raised, may, if somewhat modified, have its limited applicability for partially explaining the mode of formation of certain mountain ranges; but numerous arguments appear to preclude its general applicability, especially so in the case of the European Alps, and probably not less in the case of the Himalaya. It appears, too, to be quite inadmissible in the case of the Rocky Mountains; and as regards the Sierra Nevada, only a chain of the most arbitrary assumptions would be able to give it an apparent validity for the explanation of any features in the structure of that range.

Cretaceous period by thousands of feet. This is not only true for those ranges which, like the Andes and Rocky Mountains, have been intensely volcanic, but also for such as show a less immediate connection with eruptive activity in the volcanic era, as is the case with the Pyrenees, the Alps and the Himalaya. The elevation which succeeded the Cretaceous period appears to have everywhere been slow, intermittent, and partly retrograde, in the Eocene epoch, while its chief phase is traceable to the Miocene and subsequent epochs, by the relative altitude above the level of the sea to which sediments of different ages have been raised.

There can scarcely be any doubt that this acceleration of the changes of level, and the extrusion of volcanic rocks, have had an intimate connection. But the mode of this connection has by no means been ascertained, and appears to be quite an intricate subject. It was formerly believed that the eruptive rocks were themselves the upheaving agents, their intrusion and ejection having been the mechanical means of the elevation of mountain ranges. But geological observation and argumentation have conclusively demonstrated that such could not be the case, and made it probable that both elevation and eruption are the most conspicuous symptoms of different agencies which were dependent on one common cause. When that first theory had to be abandoned, another was put in its place, to the effect that the ejection of rocks must have been attended by subsidence ; and, although we shall show in the following pages that the rise of the crust greatly predominated in the vicinity of the eruptions, there can be no doubt that subsidence was probably in all cases among their intricate effects. But the cause generally ascribed to it is not at all capable of explaining it. The assumption that eruption must be attended by subsidence is usually made on the ground, that the removal of a certain volume of matter by ejection, from a deep-seated place, would cause the formation of a vacuity, corresponding in extent to the volume removed, and that consequently the overlying portions of the crust would settle down. This assumption appeared to be corroborated by the observation that the region surrounding a volcano subsides during its activity, while it rises in periods of rest. But it is evident that the size of a current of lava is not proportionate to the settling of an area of hundreds of square miles to the amount of several feet. If, moreover, the views here advocated, regarding the cause and mode of eruptive activity, are correct, that is, if the ejection of rocky matter is the effect of the increase of volume which it undergoes on passing into the state of aqueous fusion, then the eruption is only the discharge of the surplus matter which has no room within the space of the fissure ; no vacuity could therefore be formed, and the commonly adopted cause of the subsidence would not exist. There are, however, two other causes which would produce subsidence, and have probably been acting in every case of massive and volcanic eruptions. The first of them is the contraction of the liquid mass in the conduits, by cooling. Its amount must be considerable in proportion to the space of the fissure, but small when compared with the volume of a mountain range on the surface. Its effects will be local and abrupt. In the case of volcanoes, it is the probable cause of the familiar phenomenon of the subsidence of the bottom of craters, and of those less frequent cases where whole portions of the cone are suddenly engulfed. As regards extensive accumulations of rocks by massive eruptions, there are certain features of the configuration of their surface which cannot be more plausibly explained in any other way. To these belong the sudden breaks in the continuity of their surface, which consist sometimes in elongated and steep walls, thousands of feet in height, and miles in length, or in crateriform or semi-circular basins, and in other more or less abrupt depressions, which may be chiefly noticed where large regions are uniformly covered with granite, porphyry or volcanic rocks. This cause will affect the mass of the eruptive rock itself, but not perceptibly the surrounding country. Yet, this is subsiding when a volcano is active, and it can be definitely proved in the case of the andesitic ranges of Hungary, that during the epochs of the massive eruptions, the general rise has been repeatedly interrupted by the subsidence of the suroundings of the theater of activity. To these changes applies probably the second of the causes alluded to. Whenever a fissure is filled by liquid matter injected from below, its surroundings must necessarily become heated, and, by their expansion, produce a slight increase of the rise of the surface. This heat escapes, in the case of a volcano, chiefly in the epochs of its activity, by the emission of lava, vapors and boiling water, and other phenomena associated with volcanic action. Massive eruptions will have been attended by the escape of heat on a much larger scale. They appear to have been often accompanied by an extremely violent emission of hot water, as may be inferred from the great accumulation of deposits of silica in some volcanic countries, or from the immense overflows of extensive regions by volcanic mud: this occurs in Hungary and on the western slope of the Sierra Nevada on so grand a scale as to almost exclude the possibility of its having originated merely from volcanic action, especially as no volcano is visible from which they could have escaped. These processes must of course have had the effect of lowering the temperature of the masses surrounding the fissure to some distance from it, and of producing subsidence during the eras of activity. Yet they are not sufficient to explain the extent to which it has often taken place, though it had in no case, in the vicinity of the theaters of eruptive action, more effect than to reduce locally the amount of elevation.

A few examples will suffice to show how vast are the changes of level which have taken place since the commencement of the volcanic era, and to demonstrate their connection with the other manifestations of vulcanism during the same era. An instructive instance is furnished by the country situated between the Pacific coast and the Rocky Mountains. The labors of several distinguished geologists have made us acquainted with some of the main features of its complicated structure; but it is only by the detailed examination of some of the most important portions, together with the accurate determination of the age of several of the sedimentary and metamorphic formations, made by and under the direction of Professor Whitney, that the foundation has been laid for an exact exploration of the entire western part of North America, which is now proceeding with rapid steps, and promises to give important contributions towards the solution of the questions discussed in this essay. There appears to have existed, as we mentioned before, an ancient granitic era in that region. But it is as yet impossible to recognize the relation of this ancient granite and the metamorphic rocks by which it is accompanied to the ancient or to the present configuration of the surface. In the western countries, those formations are concealed by the immense overlying accumulation of Palæozoic and Mesozoic sediments, and the subsequent denudation of these, though grand in the extreme, has only been sufficient to expose to view the ancient granite in some localities, among which we mentioned that on the Colorado River. Other masses of ancient granite are visible at the surface in numerous places in the Great Basin, but their exact relations still remain to be determined, while in the Rocky Mountains they are one of the prominent features, partaking largely in their structure.

The next period of interest, in regard to the occurrence of eruptive rocks, is that of the deposition of Triassic and Liassic sediments in great aggregate thickness, which were found by Whitney to extend from the Pacific coast far into the Great Basin. They prove that all this country was then still submerged beneath the sea, while the Rocky Mountains formed probably a broad belt elevated above it. It is in this period that were ejected the quartzose porphyries of the County of Plumas, in northern California, almost contemporaneously with those of the southern Alps. Whether this event, which was probably not limited to the region mentioned, was attended by any changes in the configuration of the surface, cannot yet be decided. After it, however, they must have taken place on a grand scale, reminding one of the emergence of the central body of the Alps from the sea after the deposition of the infra-Liassic limestones. The ejection of granite found, it appears, almost the whole country embraced between the western slope of the Sierra Nevada and the eastern slope of the Rocky Mountains lifted out of the sea. But changes greater than those which had preceded them, appear to have attended and followed those gigantic outbreaks. They were probably due, in a great measure, to the intense metamorphism which was connected with them, and has completely changed the petrographical character of the preceding sedimentary deposits. When the volcanic era commenced, which was probably in the Miocene epoch, all the ancient formations of the Sierra Nevada were nearly turned upon their edges, and the depressions of the surface in the Great Basin were filled with salt water. But the altitude of the entire plateau above the level of the sea was probably insignificant at that time compared with what it is now, as may be inferred from the fact, that rivers did then flow on the present western slope of the Sierra Nevada, parallel to its crest, which they could not have done if that slope had had its present inclination. We must imagine that where the great mountain range raises now its lofty summits, a hilly country extended then, ascending slightly to the east. The first outbreaks of volcanic rocks found those rivers still flowing in their beds, as is proved by the higher sediments in the old river-channels, which consist of volcanic tufas. But great changes occurred after the first commencement of the volcanic era, changes which contributed probably more towards imparting to the western portion of North America its present features than any which had preceded them. The volcanic belt extending along the entire western coast of America, had its greatest breadth between the coast of California and the Rocky Mountains, and the eruptive activity has been violent over that vast region. It appears that to that era is due the principal part of the elevation of the high table-lands. Such, at least, is the case in their western portion. The crest of the Sierra Nevada must have been elevated at a quicker rate than its western foot, as distinct traces are left in the gravel deposits that those ancient rivers which were flowing parallel to its crest have been gradually turned from their channels, overflowing their banks at several places in succession, and taking a course down the slope, until an entirely new system of water-courses was created, at right angles to the crest, the steep ravines and gorges of which are now one of the characteristic features of the Sierra Nevada. It appears that the changes of level since the inauguration of the volcanic era have also been progressing on a grand scale in the eastern part of the Great Basin, where the eruptive activity had probably even more gigantic proportions than in the west. The central portion of the Rocky Mountains was raised, according to the estimate of Dana, about seven thousand feet since the Cretaceous; and its eastern part from one to two thousand feet, since the Miocene, according to the observations of Hayden.

These figures render evident the great elevation which the mountain mass between the Sacramento and the Missouri must have undergone since the commencement of the volcanic era. Twice in the history of that country, since the Triassic period, may there be recognized an extraordinary intensity of all those changes which we must ascribe to subterranean agencies. The first instance was in or about the Jurassic epoch, when strata, which appear to have been quietly deposited during preceding eras, were elevated, and a gigantic intrusion and ejection of granitic masses was attended by an intense and wide-spread metamorphism, by which disturbances and plications were promoted; the second, in the volcanic era. It is probable that similar phases to those mentioned will be recognized throughout the entire range of the Andes, the geological structure of which appears to offer much similarity in different parts. To the events of the volcanic era, chiefly, will have to be ascribed the connection of both parts of the continent, though it may have been prepared by that preceding era of intensified actions, which manifested itself in the ejection of the granite of the Sierra Nevada, and appears to have left no less distinct traces in other portions of the range of the Andes. We may still note a peculiar difference in the mode of the changes of level if we proceed across the continent from west to east. It appears that the narrow strip of land adjoining immediately the western coast has been subjected rather to periodical oscillations than to any lasting changes of level, while the great elevation of the mountain ranges and highlands must be chiefly ascribed to the circumstance that all changes have acted there essentially in the same direction, producing the elevation of extensive regions. This would explain why the western descent of the Andes has been periodically increasing in steepness and the strip between them and the coast is of little width. The latter appears to correspond to the boundary between an area of elevation to the east and an area of subsidence to the west, one of which was especially subjected to the manifestations of vulcanism, while in the other it has left no recognizable signs. It is quite different on the eastern side of the range of the Andes, where, in both parts of the continent, a slow rise has taken place, which has connected, during the volcanic era, that mountain range with other ranges farther east, by those extensive low-lands which are so important a feature as regards the extraordinary productivity of both parts of the continent.

Similar to these are the relations presented by the European continent, in regard to which we will only mention a few prominent facts. During the porphyritic era and the time immediately succeeding it, great changes of level had taken place on that continent. It appears that in Middle Germany the Triassic period designates the commencement of an era of repose, while in the Alps, where the porphyritic outbursts took place in the Triassic age, the Liassic strata still participated in the disturbances and elevations, which partly attended the porphyritic era and partly succeeded it. Thereafter followed another period distinguished by the comparatively small amount of disturbances which took place in it. Subsidence appears to have prevailed in its first part, while towards its end, during the second half of the Eocene epoch, that renewed rise commenced which contributed so much towards imparting to that mountain range its present configuration. In surveying the general features of the geology of Europe, it will be found that the changes of the boundaries of the continent and the sea, as produced by rise and subsidence, have, in the period intermediate between the porphyritic and the volcanic era, been inconsiderable in proportion to the length of time; and, though grand in the totality of their results, they are probably far surpassed by those which have been produced since propylite reopened the eruptive activity. None of the prominent mountain ranges, it is true, have been called into existence since then. Some of them, of little importance and consisting completely of volcanic rocks, have been formed, and sedimentary formations have been folded quite extensively, so as to form hilly regions; but the main ranges had existed before, and only underwent an increase in volume, though one of considerable magnitude, and the rate of elevation appears to have been greatest with those mountain ranges, during the period indicated, which have the greatest altitude at present. The amount of elevation which Eocene and Miocene strata have experienced in the Alps, Pyrenees, and others of the prominent mountain ranges justifies this conclusion, while the mode of occurrence of these formations in the Alps allows us to infer that their central portion was elevated at a more rapid rate than either the northerly or the southerly part. It is worthy of note that not alone in the Alps, but quite generally in Europe, the Jurassic and Cretaceous strata have undergone only little more disturbances than those of Eocene age. In the belts elevated during the volcanic era, all three formations participate ordinarily at nearly equal rates in the structure of the low ranges of the hills stretching between the main ranges and girting their foot. The conclusion appears therefore to be justified that in the volcanic belts, at least, the elevation of the Jurassic and Cretaceous has chiefly taken place during the volcanic era.

There may be distinguished a twofold mode of elevation in the volcanic era: it manifested itself either in a secular rise of continental areas, or in the elevation of mountain ranges, as may be exemplified by referring to the difference in the mode of elevation between the Andes and the countries adjoining them to the east.

The distinction is not so definite if we refer to the European continent. Among the regions elevated during the volcanic era may be chiefly noticed a broad belt extending from the Alps through the Turkish Peninsula, Asia Minor, Armenia, and Persia to the Himalaya, and continuing less distinct westward to the Pyrenees. The three main ranges have experienced the greatest amount of elevation within this belt. The rest of it, which is distinguished by the folding of the Nummulitic strata over its entire area, marks the region of the next greatest intensity of the elevating forces within a much more extensive area of continental rise. The increase of altitude has been comparatively inconsiderable over this area; yet it is, in its totality, of greater import for the configuration of the surface of the planet than the production of the mountainous and hilly regions mentioned. For it had the effect of connecting regions which were before separated by the sea, and of increasing thereby the area of continents in certain directions. It is well known that the sea, which in the beginning of the volcanic era extended in the valley of the Danube to above Vienna, bathed both slopes of the Carpathians, and reached eastward to the foot of the highlands of Central Asia, has since then considerably retired, and that the secular rise of northern Africa, Arabia, and Asia Minor has, also in these countries, enlarged the continental areas.

So much time has elapsed, in most countries, since the main phases of the volcanic era, that the influence of the events connected with them upon elevation and subsidence has probably relaxed. It appears that portions of the areas of elevation have suffered a periodical subsidence, not only since that time, but also during the volcanic era. But its aggregate amount having been in most of them less than that of elevation, the final effect manifests itself generally as a rise; though it appears that in recent times some regions, chiefly those which are situated on the northern and southern boundaries of the great area of continental elevation, are undergoing a more marked subsidence. Even now, however, those countries chiefly are rising which were distinguished by eruptive activity in the volcanic era.

These few instances will suffice to show how great have been the changes in the configuration of some portions of the surface of the globe during the relatively short geological time which has elapsed since the commencement of the volcanic era, and how much superior they appear to have been to those which had been going on during preceding periods of much longer duration. Those facts which are known in relation to this subject, allow to infer, that the changes of level were proceeding at an accelerated rate, during, and probably also in the time next preceding, the volcanic era, and that the elevation was limited to certain belts of great extent which were, in the majority of cases, distinguished from neighboring regions by eruptive activity. But this is not true for all cases, since there are some regions the elevation of which was especially grand, and in which very few rocks, or none at all, were ejected. In examining into the causes of the connection of elevation with the other events of the volcanic era, we must therefore keep in view the distinction of those cases where it was attended, and those where it was not attended, by eruptive activity.

As regards the first cases, we may refer for their explanation to our previous theoretical considerations of the causes and effects of the formation of fractures. If the increase of volume by the slow and perfect crystallization of viscous masses below the crust was the cause of the rending of fissures, a slow rise must have preceded this process. That this was so on the European continent, is verified by the fact, that the Eocene strata had been elevated quite considerably when the first of those sediments, which can be proved to have been contemporaneous with eruptive activity, were deposited. If then the relief from pressure caused the extensive crystallization, at the depth to which the fissures reached, of masses which had been held before in a viscous condition by the pressure itself, an accelerated rise would be the effect; and if the repeated rupturing of the crust caused a repetition of this process, in the way indicated before, epochs of an accelerated rise would alternate with those of a retarded elevation. This theory will explain why a very considerable rise, and of greater extent than that which had preceded, attended the phenomena of the basaltic epoch.

Although we must consider this subterranean process as the chief cause of continental elevations, so far as they attended the phenomena of eruptive activity, it was certainly not their only cause. There can be no doubt that the process of metamorphism must have promoted those changes. As far as we understand the conditions required for its production, it appears that they could not be created by any other known processes in a degree similar to that in which we must necessarily suppose them to have attended the ejection of rocks, whether its mode be that of massive eruption or of volcanic activity. Even on the surface there are no places where we can observe, at the present time, metamorphic processes of greater intensity than near the orifices of volcanoes, or in solfataras, or at the theaters of other processes attending or succeeding volcanic activity; nor is there at any other places more evidence afforded of subterranean metamorphic processes. The latter will exceed those visible on the surface in nearly equal proportion with the increase of temperature and pressure in depth; while we may conclude theoretically, that the neighborhood of fissures filled with heated substances from below would not only have a higher temperature than other portions of the crust, but also allow of a comparatively free circulation of water, on account of its shattered condition. In respect to metamorphic action, as in all other respects, the grandeur of the phenomena of massive eruptions would make us presuppose that they would have given rise to a far more extensive and intense metamorphism than the insignificant processes of volcanic activity. The occurrence of ancient eruptive rocks in belts of highly metamorphosed sediments removes it almost beyond doubt that they are connected in the relation of cause and effect. It is assumed that metamorphic processes, on account of the entering of water into the composition of rocks, and their crystallization, must be attended by an increase of volume, and will have the mechanical effect of elevating the surface.

We may thus obtain a few hints as to the causes of the changes of level which those portions of the surface of the globe which were the theater of eruptive activity in the volcanic era, have undergone since its inauguration. The agencies to which they were due must be even more intricate than the motions of the crust, because the movement in one direction may be the resultant of several forces working in opposite directions. Increase of volume by crystallization below the crust, in those regions where the formation of fractures relieved the masses from pressure, is probably the most potent of these agencies. Metamorphism would work in the same direction, while loss of heat would cause subsidence. All these agencies have their first and common cause in the formation of fractures by an upward tension, and all other phenomena of vulcanism are the immediate or mediate effects of that same cause, which itself results from the gradual cooling of the globe.

There remain those cases to be considered where some of the most prominent mountain ranges, in the structure of which volcanic rocks take no part, were elevated during the volcanic era, at a much greater ratio even than those in which these rocks occur. The Alps and the Himalaya are the most striking instances of this kind. The first of these, and probably, too, the other, had, as we mentioned before, undergone a considerable elevation in and after the porphyritic era, but have probably changed their altitude very little in the next following periods. The acceleration of their elevation during the volcanic era appears, however, to have greatly exceeded that of the Andes. The coincidence in time of these events, and of all the phenomena characteristic of the volcanic era, justifies the supposition that they are connected in their origin.

If we contemplate, in its relations to the volcanic era, the great elevated belt of which the Alps and Himalaya form the axis, we find it to consist of three parallel zones. The central one comprises those two mountain ranges and the broad mountainous country which connects them, and which owes its configuration chiefly to the events of the volcanic era. The Alps and Himalaya are free from volcanic rocks. This is also true as regards the central portions of those chains which branch off from the Alps in a southeasterly direction, and of those (as far as their geology has been explored) which extend westerly from the Himalaya. The farther one proceeds in the Turkish peninsula towards the east, the more frequent are the monuments of eruptive activity of the volcanic era; they are known in Servia and Bulgaria, in the north, and in Macedonia, Thracia and Epirus, in the south. They increase in similar ratio as one proceeds westerly from the Himalaya, through the highlands of Armenia to Asia Minor. If it is considered that active volcanoes are particularly numerous in those regions where the elongated portions of two different continents have, as it were, a tendency to connection, the analogy with the mode of distribution of volcanic rocks in the regions mentioned is conspicuous. The system of the Alps with its southeastern, and that of the Himalaya with its western branches, were disconnected before the Tertiary period, and were united into one mountainous belt during the same. The eruptive activity contemporaneous with this slow process was remote from the main axis where this had existed as an elevated range before, and approached it more and more, from both sides, increasing, at the same time, in intensity, until it culminated in that region where the connection of both systems was effected. Massive eruptions and volcanic activity have ceased completely in this central zone.

North of this, is another zone, which was distinguished in its entire length by the intensity of eruptive action in the volcanic era. It stretches from Central Asia by the Caspian Sea, the Caucasus, the Crimea, the Carpathians and, in branches, through central Germany to central France. In the European portion of this zone, there are only recognizable in thermal and mineral springs the last feeble remnants of former volcanic activity, while they are somewhat more energetic in that portion which is situated on the Asiatic continent. A third zone, not less distinguished for the intensity of eruptive action in the volcanic era, accompanies the main axis to the south. It traverses India, and, in the Bay of Bengal, is connected with the volcanic belts of the Indian Archipelago, while it continues to the west through Arabia, Syria, Palestine, to the Mediterranean, where it comprises the active volcanoes of the Grecian Archipelago and Italy, and is connected by Sardinia and southern Spain with the Azores. Volcanic activity still continues in this belt, but the period of the massive eruptions has passed long ago.

The entire belt, composed of these three zones, has to be considered as one great area of elevation, characterized, at the same time, over its greater portion, by the remnants of the eruptive activity of the volcanic era. No portion of it, however, has, as we mentioned before, experienced an amount of additional elevation during that period equal to that of those mountain ranges which existed before it, and among which the Alps and Himalaya are the most prominent. In these cases there cannot have been any connection between the elevation and the ejection of the rocks to the surface, because these do not occur. But this does not preclude the connection between the elevation and those agencies which are the causes of eruption. It has been often demonstrated that the changes of level must have been accompanied by the formation of such fractures as would be closed next to the surface, and, though allowing of an intrusion of plastic matter from below, would prevent its extrusion to the surface. It is probable that fissures of this kind may have been chiefly formed where high mountain chains are composed of metamorphic rocks, since they frequently exhibit vertical dislocations, partly parallel to their axis, and partly at right angles to it, by which the strata on one side have been moved thousands of feet above the other, and which, notwithstanding, did not give vent to the ejection of rocks. These faulting fissures appear to form frequently the lateral boundaries of mountain ranges and the limits of the manifestation of vulcanism, and both these circumstances allow us to infer that they extend downward to great depth. Though one of the main features in the geological structure of the Alps, they have hitherto been little examined. But it is probable that their formation was coincident in time with the main phase of elevation, that is, with the volcanic era. If, then, in that part of the crust over which the Alps are elevated, such fractures were formed as did not open on the surface, then all the agencies below would coöperate towards elevation alone. The expansive force produced by aqueous fusion would find no vent for the discharge of the masses by which the volume had increased, nor would there be any opportunity given for the escape of heat by hot water and other means; while, on the other hand, the masses in depth would be relieved from pressure by the formation of this kind of fractures in the same way as by those which would allow the passage of liquid matter to the surface. In the case of the latter, an immense amount of force is spent in other modes of action, while in the first case it could be applied almost exclusively to elevation. Besides this direct action, however, we must also keep in view, that in those regions where fissures would not be open at the surface, the conditions required for metamorphic action would be given on a particularly grand scale. Gases and water would not reach the surface, but be employed in depth in promoting metamorphic action over vast regions, and increasing the rate of elevation. It may be by processes of this kind that already in ancient times, contemporaneously with an accelerated elevation, were formed those granitic wedges surrounded by broad belts of foliated metamorphic rocks, which are peculiar to certain mountain ranges, particularly to those which also in the volcanic era have not been the theater of eruptive activity. The intrusion, from below, of heated masses into fissures closed towards the surface, would give all the conditions required for the exhibition, on a grand scale, of those processes of hydropyric metamorphism which Daubrée has rendered probable by his experiments and theoretical deductions.

Leaving aside these theoretical considerations, and comparing only the different facts mentioned in regard to the changes of level which have taken place on the surface of the globe since the inauguration of the volcanic era, we are forced to the conclusion that they must be intimately connected, as regards their causes, with the other phenomena by which this era was distinguished from preceding periods. Elevation and eruptive activity, even when locally not quite coincident, are coördinate effects of the cooling of the globe; but while the one is its immediate effect, the other results from it only by the concurrence of other agencies, which by themselves alone would have been incapable of producing results of such magnitude. As there are distinct phases in the history of eruptive action, dependent on and marking the evolution of the globe, so we may recognize different stages in the mode of manifestation of the elevating forces. In those elevations which took place during the volcanic era, there are certain peculiar features evident, among which may be mentioned: the increase in altitude of those mountain ranges included in the volcanic belts; the union into one main chain of several smaller ridges, the axes of which are situated on a line; the lateral connection of parallel ranges into highlands; the oblique connection of the ends of main chains, the axes of which are situated on parallel lines, but are remote from each other longitudinally, by broad belts of mountainous regions (of this character is the connection of the Alps and the Himalaya); the elevation, finally, above the level of the sea, of large areas which had been submerged before, whereby distant mountain ranges were connected by extensive lowlands, the size of the continents increased, and their outlines rendered more uniform. The mode of these great changes of the configuration of the surface of the globe was probably a repetition on a large scale of similar changes which had been going on in former eras of eruptive activity. It is not our object here to develop them. But throughout the course of these changes there appears to be conspicuous a tendency to connect, in certain directions, what was before disconnected, to increase in size and render more definite certain areas of elevation, and to separate them from other areas of subsidence, which appear to have been likewise increasing in extent. We may even recognize an increase of this tendency during the volcanic era, as the phenomena connected with the basaltic epoch have been far more widely and generally distributed over the areas of volcanic belts than those of the preceding (propylitic and andesitic) epochs. There must be certain general laws which regulate the directions in which the connection of disconnected parts takes place. Their knowledge is still very limited. The admirable manner in which Dana has laid out the grand outlines of the arrangement of the islands of the Pacific, has indicated the way by which we may look for the solution of this problem. If the structure of the crystallized crust of the globe gives the most probable cause of the definite directions which may be recognized in the outlines of continents and chains of islands, it should be borne in mind, that the direction of structural planes, if they exist, must vary gradually in depth, in the same ratio with the chemical composition, and that they may at the depth of andesitic compounds be different from what they would be in the granitic depths. The singular way in which the connections by elevation are effected, and which has been already partly pointed out by Dana, appears to find only an explanation when such changes of the direction of the structural planes are assumed to take place in depth.

The tendency to simplify beyond their present conditions the general outlines of the configuration of the surface of the globe, continues probably without intermission, though an era of comparative repose has followed the violent exertions of vulcanism of the volcanic era. The great backbone of the Eastern continent, comprising the Alps and the Himalaya, and the second great belt which comprises the Andes, and, more properly, encircles the whole Pacific Ocean, are at the present epoch the main features in the orography of the globe. Both have derived their prominent position from the events of the volcanic era. The conclusions at which we have arrived in these pages have been drawn chiefly from observations made in regions of prominent interest in either belt, and it is for this reason especially that we believe that at least some of them will be found to be susceptible of general application.

I am fully aware how imperfect is this attempt to develop, in the correlations of the volcanic rocks, the principles of their natural system. This system should be, as we remarked before, not a classification of objects by certain conspicuous properties, but a classification of objects by their definite mutual relations. We have not to make the divisions, but to find them. We shall be able to do this with greater or less perfection, in the same measure as those relations are studied and firmly established. Much is needed to arrive at this end. It can only be achieved after evidence has been accumulated by the combined and harmonious labors, in different countries, of geologists in the field as well as in the laboratory. The range over which both modes of observation extend from year to year, and the field on which their results meet, is increasing in a surprising degree. Yet eruptive rocks form ordinarily an object of less exact observation than those of sedimentary origin; and it cannot be denied that harmonious observation, by which alone can be established the principles of comparative petrology, is rendered nearly impossible, as long as no uniform system of nomenclature is applied. These pages are the result of an attempt to add one more to the many contributions towards establishing the foundation of both, and to show the value which the study of eruptive rocks and of those mutual relations which comprise their natural system promises to have for approaching the solution of some of the highest problems of geological science.

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