CHAPTER XII.

Difference between the transporting power of springs and rivers—Many springs carry matter from below upwards—Mineral ingredients most abundant in springs—Connexion of mineral waters with volcanic phenomena—Calcareous springs—Travertin of the Elsa—Baths of San Vignone and of San Filippo, near Radicofani—Spheroidal structure in travertin, as in English magnesian limestone—Bulicami of Viterbo—Lake of the Solfatara, near Rome—Travertin at Cascade of Tivoli—Ferruginous Springs—Cementing and colouring property of iron—Brine Springs—Carbonated Springs—Disintegration of Auvergne granite—Caverns in limestone—Petroleum Springs—Pitch Lake of Trinidad.

We have hitherto considered the destroying and transporting power of those atmospheric waters which circulate on the surface of the land; but another portion which sink deep into the earth, present phenomena essentially different in character. Rivers, as we have seen, remove earthy matter from higher to lower levels, but springs not only effect this purpose, but sometimes, like volcanos, carry matter from below upwards. Almost all springs are impregnated with some foreign ingredients, which render them more agreeable to our taste, and more nutritive than pure rain water; but as their mineral contents are in a state of chemical solution, they rarely, even when in great abundance, affect the clearness of the water, and for this reason, we are usually unconscious of the great instrumentality of these agents in the transfer of solid matter from one part of the globe to another. The specific gravity of spring water being greater than that of rain, it augments the carrying power of rivers, enabling them to bear down a greater quantity of matter in mechanical suspension towards the sea. Springs, both cold and thermal, rise up beneath the waters of lakes and seas, as well as in different parts of the land, and must often greatly modify the mineral character of subaqueous deposits.

The number of metals, earths, acids, and alkalies, held in solution by different springs, comprehends a considerable portion of all known substances, and recent observations have tended continually to augment the list; but those alone which are most abundant, need be regarded as of geological importance. These are lime, iron, magnesia, silica, alumine, soda, and the carbonic and sulphuric acids. Besides these, springs of petroleum, or liquid bitumen, and its various modifications, such as mineral pitch, naptha, and asphaltum, are largely distributed over the surface of the earth, but usually in close connexion with volcanos. The relation, indeed, of almost all springs impregnated copiously with mineral matter, to the sources of subterranean heat, seems placed beyond all reasonable doubt by modern research. Mineral waters, as they have been termed, are most abundant in regions of active volcanos, or where earthquakes are most frequent and violent. Their temperature is often very high, and has been known to be permanently heightened or lowered by the shock of an earthquake. The volume of water also given out has been sometimes affected by the same cause. With the exception of silica, the minerals entering most abundantly into *thermal* waters do not seem to differ from those in cold springs. There is, moreover, a striking analogy between the earthy matters evolved in a gaseous state by volcanos, and those wherewith springs in the same region are impregnated; and when we proceed from the site of active to that of extinct volcanos, we find the latter abounding in precisely the same kind of springs. Where thermal and mineral waters occur far from active or extinct volcanos, some great internal derangement in the strata almost invariably marks the site to have been at some period, however remote, the theatre of violent earthquakes.

Springs, are in general, ascribable to the percolation of rain-water through porous rocks, which, meeting at last with argillaceous strata, is thrown out to the surface. But, in all likelihood, they sometimes descend by fissures, even to the regions of subterranean heat. Michell, in 1760, suggested that those pent-up volcanic vapours which cause earthquakes, penetrate also through rents and cavities, and drive up water impregnated with sulphurous and other matters, whereby springs are charged with their mineral ingredients. Nor is it by any means improbable, that the same power which when intense is able to lift up a column of lava many thousand feet in height, should even in its more languid state be capable of raising to the surface considerable quantities of water from the interior. But as the geographical limits of mineral waters are not confined to volcanic regions, being coextensive with the whole globe, as far as is hitherto known, we must consider them apart, and in their connexion with rivers rather than volcanos. We might divide the consideration of springs, like that of rivers, into their destroying and reproductive agency; but the former class of effects being chiefly subterranean, are beyond the reach of our observation; while their reproductive power consists chiefly in augmenting the quantity of matter deposited by rivers in deltas, or at the bottom of the sea. We shall, therefore, arrange the facts of geological interest, respecting mineral springs, under the head of the different ingredients which predominate in their waters.

CALCAREOUS SPRINGS.

Our first attention is naturally directed to springs which are highly charged with calcareous matter; for these produce a variety of phenomena of much interest to the geologist. It is well known that rain-water has the property of dissolving the calcareous rocks over which it flows, and by these means, matter is often supplied for the earthy secretions of testacea, and certain plants on which they feed, in the smallest ponds and rivulets. But many springs hold so much carbonic acid in solution, that they are enabled to dissolve a much larger quantity of calcareous matter than rain-water; and when the acid is dissipated in the atmosphere, the mineral ingredients are slowly thrown down in the form of tufa or travertin. Calcareous springs, although most abundant in limestone districts, are by no means confined to them, but flow out indiscriminately from all rock formations. In Central France, a district where the primary rocks are unusually destitute of limestone, springs copiously charged with carbonate of lime rise up through the granite and gneiss. Some of these are thermal, and probably derive their origin from the deep source of volcanic heat, once so active in that region. One of these springs, at the northern base of the hill upon which Clermont is built, issues from volcanic peperino, which rests on granite. It has formed, by its incrustations, an elevated mound of solid travertin, or calc-sinter, as it s sometimes called, two hundred and forty feet in length, and, at its termination, sixteen feet high, and twelve wide. Another incrusting spring in the same department, situated at Chaluzet, near Pont Gibaud, rises in a gneiss country, at the foot of a regular volcanic cone, at least twenty miles from any calcareous rock. Some masses of tufaceous deposit, produced by this spring, have an oolitic texture.

Valley of the Elsa.—If we pass from the volcanic district of France to that which skirts the Apennines in the Italian peninsula, we meet with innumerable springs, which have precipitated so much calcareous matter, that the whole ground in some parts of Tuscany is coated over with travertin, and sounds hollow beneath the foot.

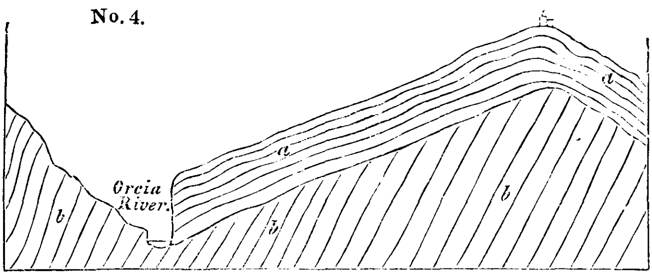
In other places in the same country, compact rocks are seen descending the slanting sides of hills, very much in the manner of lava-currents, except that they are of a white colour, and terminate abruptly when they reach the course of a river. These consist of the calcareous precipitate of springs, some of them still flowing, while others have disappeared or changed their position. Such masses are frequent on the slope of the hills which bound the valley of the Elsa, one of the tributaries of the Arno, which flows near Colle, through a valley several hundred feet deep, shaped out of a lacustrine formation, containing fossil shells of existing species. The travertin is unconformable to the lacustrine beds, and its inclination accords with the slope of the sides of the valley*. The Sena, and several other small rivulets which feed the Elsa, have the property of lapidifying wood and herbs; and, in the bed of the Elsa itself, aquatic plants, such as charæ, which absorb large quantities of carbonate of lime, are very abundant. Carbonic acid is also seen in the same valley, bubbling up from many springs, where no precipitate of tufa is observable. Targioni, who in his travels has mentioned a great number of mineral waters in Tuscany, found no difference between the deposits of cold and thermal springs. They issue sometimes from the older Apennine limestone, shale, and sandstone, while, in other places, they flow from more modern deposits; but, even in the latter case, their source may probably be in, or below the older series of strata.

* One of the finest examples of these which I saw, was at the Molino delle Caldane, near Colle.

Baths of San Vignone.—Those persons who have merely seen the action of petrifying waters in our own country, will not easily form an adequate conception of the scale on which the same process is exhibited in those regions which lie nearer to the modern centres of volcanic disturbance. One of the most striking examples of the rapid precipitation of carbonate of lime from thermal waters occurs in the hill of San Vignone in Tuscany, at a short distance from Radicofani, and only a few hundred yards from the high-road between Sienna and Rome. The spring issues from near the summit of a rocky hill, about one hundred feet in height. The top of the hill is flat, and stretches in a gently-inclined plateau to the foot of Mount Amiata, a lofty eminence, which consists in great part of volcanic products. The fundamental rock, from which the spring issues, is a black slate, with serpentine (*b. b. b*, diagram 4) belonging to the older Apennine for-

Baths of San Vignone.

No. 4.



mation. The water is hot, has a strong taste, and, when not in very small quantity, is of a bright green colour. So rapid is the deposition near the source, that in the bottom of a conduit pipe for carrying off the water to the baths, inclined at an angle of 30°, half a foot of solid travertin is formed every year. A more compact rock is produced where the water flows slowly, and the precipitation in winter is said to be more solid and less in quantity by one-fourth than in summer. The rock is generally white: some parts of it are compact, and ring to the hammer; others are cellular, and with such cavities as are seen in the carious part of bone or the siliceous meulière of the Paris basin. A portion of it also below the village consists of long vegetable tubes. Sometimes the travertin assumes precisely the botroidal and mammillary forms, common to similar deposits, in Auvergne, of a much older date, hereafter to be mentioned; and like them it often scales off in thin, slightly undulating layers.

A large mass of travertin descends the hill from the point where the spring issues, and reaches to the distance of about half a mile east of San Vignone. The beds take the slope of the hill at about an angle of 6°, and the planes of stratification are perfectly parallel. One stratum, composed of many layers, is of a compact nature and fifteen feet thick; it serves as an excellent building stone, and a mass of fifteen feet in length was, in 1828, cut out for the new bridge over the Orcia. Another branch of it (*a. a.*, diagram 4,) descends to the west, for two hundred and fifty feet in length, of varying thickness, but sometimes two hundred feet deep; it is then cut off by the small river Orcia, precisely as some glaciers in Switzerland descend into a valley till their progress is suddenly arrested by a transverse stream of water. The abrupt termination of the mass of rock at the river, when its thickness is undiminished, clearly shews that it would proceed much farther if not arrested by the stream, over which it impends slightly. But it cannot encroach upon the channel of the Orcia, being constantly undermined, so that its solid fragments are seen strewed amongst the alluvial gravel. However enormous, therefore, the mass of solid rock may appear which has been given out by this single spring, we may feel assured that it is insignificant in volume, when compared to that which has been carried to the sea since the time when it began to flow. What may have been the length of that period of time, we have no data for conjecturing. In quarrying the travertin, Roman tiles have been sometimes found at the depth of five or six feet.

Baths of San Filippo.—On another hill, not many miles from that last mentioned, and also connected with Mount Amiata, the summit of which is about three miles distant, are the celebrated baths of San Filippo. The subjacent rocks consist of alternations of black slate, limestone, and serpentine, of highly inclined strata, belonging to the Apennine formation; and, as at San Vignone, near the boundary of a tertiary basin of marine origin, consisting chiefly of blue argillaceous marl. There are three warm springs here, containing carbonate and sulphate of lime, and sulphate of magnesia. The water which supplies the bath falls into a pond, where it has been known to deposit a solid mass *thirty feet thick*, in about *twenty years**. A manufactory of medallions in basso-relievo is carried on at these baths. The water is conducted by canals into several pits, in which it deposits travertin and crystals of sulphate of lime. After being thus freed from its grosser parts, it is conveyed by a tube to the summit of a small chamber, and made to fall through a space of ten or twelve feet. The current is broken in its descent by numerous crossed sticks, by which the spray is dispersed around upon certain moulds, which are rubbed lightly over with a solution of soap, and a deposition of solid matter like marble is the result, yielding a beautiful cast of the figures formed in the mould†. The geologist may derive from these experiments considerable light, in regard to the high inclination at which some semicrystalline precipitations can be formed; for some of the moulds are disposed almost perpendicularly, yet the deposition is nearly equal in all parts.

A hard stratum of stone, about a foot in thickness, is obtained from the waters of San Filippo in four months; and, as the springs are powerful, and almost uniform in the quantity given out, we are at no loss to comprehend the magnitude of the mass which descends the hill, which is a mile and quarter in length and the third of a mile in breadth, in some places attaining a thickness of two hundred and fifty feet at least. To what length it might have reached, it is impossible to conjecture, as it is cut off, like the travertin of San Vignone, by a small stream, where it terminates abruptly. The remainder of the matter held in solution is carried on probably to the sea. But what renders this recent calcareo-magnesian limestone of peculiar interest to the geologist, is the spheroidal forms which it assumes, offering so striking an analogy, on the one hand, to the concentric structure displayed in the calcareous travertin of the cascade of Tivoli, and, on the other, to the spheroidal forms of the English magnesian limestone of Sunderland. Between this latter and many of the

* Dr. Grosse, on the Baths of San Filippo. Ed. Phil. Journ., v. 2, p. 292.

† Ibid., p. 297.

appearances exhibited at San Filippo, and several other recent deposits of the same kind in Italy, there is every feature of resemblance; the same combination of concentric and radiated structure, with small undulations in each concentric ring, occasional interferences of one circle with another, and a small globular structure subordinate to the large spheroidal, with frequent examples of laminæ passing off from the external coating of a spheroid into layers parallel to the general plane of stratification. There are also cellular cavities and vacuities in the rock, constituting what has been termed a honeycombed texture. The lamination of some of the concentric masses of San Filippo is so minute, that sixty may be counted in the thickness of an inch. Yet, notwithstanding these marks of gradual and successive deposition, the symmetry and magnitude of many of the spheroidal forms might convey the idea, that the whole was the result of chemical action, simultaneously operating on a great mass of matter. The concretionary forms of our magnesian limestone have been supposed by some to have been superinduced after the component parts of the rock had been brought together in stratiform masses; but a careful comparison of those older rocks with the numerous travertins now in progress of formation in Italy, leads the observer to a different conclusion. Such a structure seems to be the result of gradual precipitation, and not of subsequent re-arrangement of the particles*. Each minute particle of foreign matter, a reed, or the fragment of a shell, forms a nucleus, around which accessions of new laminæ are formed, until spheroids and elongated cones, from a few inches to several feet in diameter, are produced; for, as the precipitate is arranged by the force of chemical affinity, and not of

* The structure of the English magnesian limestone has been described, in an elaborate and profound paper on that formation, by Professor Sedgwick. Geol. Trans., vol. 3, second series, part i., p. 37. Examples of almost all the modifications of concretionary arrangement, together with the brecciated and honeycombed structure to which he alludes, may be found either in the deposits of travertin springs in various parts of Italy, or in the subaqueous travertins of Auvergne and Sicily,—the former of lacustrine, the latter of submarine origin. These will be alluded to in their proper places, and I shall merely observe here, that, after examining these more recent deposits, I visited Sunderland, and recognized a degree of identity in the various and complicated forms there assumed by the magnesian limestone, which satisfied me that the circumstances under which they were formed must have been perfectly analagous to those under which the mineral springs of volcanic countries are now giving birth to calcareous, calcareo-magnesian, and calcareo-siliceous rocks.

gravity, the different layers continue of the same thickness, and preserve the original form of the nucleus.

Bulicami of Viterbo.—We must not attempt to describe all the localities in Italy where the constant formation of limestone may be seen, as on the Silaro, near Pæstum, on the Velino at Terni, and near the Bulicami, or hot baths in the vicinity of Viterbo. About a mile and a half north of the latter town, in the midst of a sterile plain of volcanic sand and ashes, a monticule is seen, about twenty feet high and five hundred yards in circumference, entirely composed of concretionary travertin. The laminæ are extremely thin, and their minute undulations are so arranged, that the whole mass has at once a concentric and radiated structure. This mammillon has been largely quarried for lime, and much of it appears to have been removed. It seems to have been formed by a small jet or fountain of calcareous water, which continued to rise through the mound of travertin, which it gradually raised by overflowing from the summit. A spring of hot water still issues in the neighbourhood, which is conveyed to an open tank, used as a bath, the bottom and sides of which, as well as the open conduit which conveys the water, are encrusted with travertin.

Campagna di Roma.—The country around Rome, like many parts of the Tuscan States already referred to, has been at some former period the site of numerous volcanic eruptions; and the springs are still copiously impregnated with lime, carbonic acid, and sulphuretted hydrogen. A hot spring has lately been discovered near Civita Vecchia, by Riccioli, which deposits alternate beds of a yellowish travertin, and a white granular rock, not distinguishable, in hand specimens, either in grain, colour, or composition, from statuary marble. There is a passage between this and ordinary travertin. The mass accumulated near the spring is in some places about six feet thick *.

In the Campagna, between Rome and Tivoli, is the lake of

* I did not visit this spring myself, but Signor Riccioli, whose acquaintance with the geology of the environs of Rome is well known, favoured me with an inspection of a suite of specimens collected from the spot. Brocchi, a few years before his death, visited the locality in company with Signor Riccioli, and was much struck with the phenomenon, of which he had intended to publish a description.

the Solfatara, called also Lago di Zolfo, (lacus albula,) into which flows continually a stream of tepid water, from a smaller lake situated a few yards above it. The water is a saturated solution of carbonic acid gas, which escapes from it in such quantities in some parts of its surface, that it has the appearance of being actually in ebullition. " I have found by experiment," says Sir Humphry Davy, " that the water taken from the most tranquil part of the lake, even after being agitated and exposed to the air, contained in solution more than its own volume of carbonic acid gas, with a very small quantity of sulphuretted hydrogen. Its high temperature, which is pretty constant at 80° of Fahr., and the quantity of carbonic acid that it contains, render it peculiarly fitted to afford nourishment to vegetable life. The banks of travertin are every where covered with reeds, lichen, confervæ, and various kinds of aquatic vegetables; and at the same time that the process of vegetable life is going on, the crystallizations of the calcareous matter, which is every where deposited in consequence of the escape of carbonic acid, likewise proceed.—There is, I believe, no place in the world where there is a more striking example of the opposition or contrast of the laws of animate and inanimate nature, of the forces of inorganic chemical affinity, and those of the powers of life *."

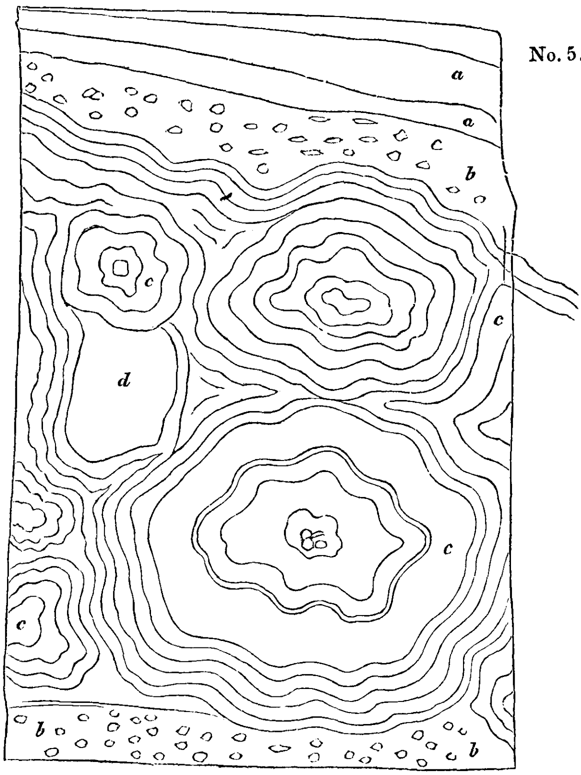
The same observer informs us, that he fixed a stick on a mass of travertin covered by the water in May, and in the April following he had some difficulty in breaking, with a sharp-pointed hammer, the mass which adhered to the stick, and which was several inches in thickness. The upper part was a mixture of light tufa, and the leaves of confervæ: below this was a darker and more solid travertin, containing black and decomposed masses of confervæ; in the inferior part, the travertin was more solid, and of a grey colour, but with cavities probably produced by the decomposition of vegetable matter †. The stream which flows out of this lake fills a canal about nine feet broad, and four deep, and is conspicuous in the landscape by a line of vapour which rises from it. It deposits tufa in this channel, and the Tibur probably receives from it, as well as from numerous other streams, much carbonate of lime in solu-

* Consolations in Travel, pp. 123—125.

† Ibid., p. 127.

tion, which contributes to the rapid growth of its delta. A large portion of the most splendid edifices of ancient and modern Rome are built of travertin, derived from the quarries of Ponte Leucano, where there has evidently been a lake at a remote period, on the same plain as that already described. But, as the consideration of these would carry us beyond the times of history, we shall conclude with one more example of the calcareous deposits of this neighbourhood,—those on the Anio.

Travertin of Tivoli.—The waters of the Anio incrust the reeds which grow on its banks, and the foam of the cataract of Tivoli forms beautiful pendant stalactites; but, on the sides of the deep chasm into which the cascade throws itself, there is seen an extraordinary accumulation of horizontal beds of tufa and travertin, from four to five hundred feet in thickness. The following seems the most probable explanation of their formation in this singular position. The Anio flows through a deep, irregular fissure or gorge in the Apennine limestone, which may have originated from subterranean movements, like many others of which we shall speak when treating of earthquakes. In this deep narrow channel there existed many small lakes, three of which have been destroyed since the time of history, by the erosive action of the torrent, the last of them having remained down to the sixth century of our era. We may suppose a similar lake of great depth to have existed at some remote period at Tivoli, and that, into this, the waters, charged with carbonate of lime, fell from a height inferior to that of the present cascade. Having, in their passage through the upper lakes, parted with their sand, pebbles, and coarse sediment, they only introduced into this lower pool, drift-wood, leaves, and other buoyant substances. In seasons when the water was low, a deposit of ordinary tufa, or travertin, formed along the bottom; but, at other times, when the torrent was swollen, the pool must have been greatly agitated, and every small particle of carbonate of lime which was precipitated, must have been whirled round again and again in various eddies, until it acquired many concentric coats, so as to resemble oolitic grains. If the violence of the motion be sufficient to cause the globule to be suspended for a sufficient length of time, it would grow to the size of a pea, or much larger. Small fragments of vegetable stems being incrusted on the sides of the stream, and then washed in, would form the nucleus of oval globules, and others of irregular shapes would be produced by the resting of fragments for a time on the bottom of the basin, where, after acquiring an unequal thickness of travertin on one side, they would again be set in motion. Sometimes globules, projecting above the general level of a stratum, would attract, by chemical affinity, other matter in the act of precipitation, and thus growing on all sides, with the exception of the point of contact, might at length form spheroids nearly perfect and many feet in diameter. Masses might increase above and below, so that a vertical section might afterwards present the phenomenon so common at Tivoli, where the nucleus of some of the concentric circles



No. 5.

has the appearance of having been suspended, without support, in the water, until it became a spheroidal mass of great dimensions. The section obtained of these deposits, about four hundred feet thick, immediately under the temples of Vesta and the Sibyl, displays some spheroids which are from *six to eight feet in diameter*, each concentric layer being about the eighth of an inch in thickness. The annexed diagram exhibits about fourteen feet of this immense mass as seen in the path cut out of the rock in descending from the temple of Vesta to the Grotto di Nettuno*. The beds (*aa*, diagram No. 5) are of hard travertin and soft tufa; below them is a pisolite (*b*), the globules being of different sizes; underneath this appears a mass of concretionary travertin (*cc*), some of the spheroids being of the above-mentioned extraordinary size. In some places (as at *d*), there is a mass of amorphous limestone, or tufa, surrounded by concentric layers. At the bottom is another bed of pisolite (*b*), in which the small nodules are about the size and shape of beans, and some of them of filberts, intermixed with some smaller oolitic grains. In the tufaceous strata, wood is seen converted into a light tufa. It is probable that the date of the greater portion of this calcareous formation may be anterior to the era of history, for we know that there was a great cascade at Tivoli in very ancient times; but, in the upper part of the travertin, is shewn the hollow left by a wheel, in which the outer circle and the spokes have been decomposed, and the spaces which they filled have been left void. It seems impossible to explain the position of this mould, without supposing that the wheel was imbedded before the lake was drained.

Our limits do not permit us to enter into minute details respecting the various limestones to which springs in different countries are continually giving birth. Pallas, in his journey along the Caucasus, a country now subject, from time to time, to be rent and fissured by violent earthquakes, enumerates a great many hot springs, which have deposited monticules of travertin precisely analogous in composition and

* I have not attempted to express, in this drawing, the innumerable thin layers of which these magnificent spheroids are composed, but the lines given mark some of the natural divisions into which they are separated by minute variations in the size or colour of the laminæ. The undulations also are much smaller, in proportion to the whole circumference, than is expressed in the diagram.

structure to those of the baths of San Filippo, and other localities in Italy. When speaking of the tophus-stone, as he terms these limestones, he often observes that it is *snow-white*, a description which is very applicable to the newer part of the deposit at San Filippo, where it has not become darkened by weathering. In many localities in the regions between the Caspian and Black seas, where subterranean convulsions are frequent, travellers mention calc-sinter as an abundant product of hot springs. Near the shores of the Lake Urmia (or Maragha), for example, a marble is rapidly deposited from a thermal spring, which is much used in ornamental architecture*. We might mention springs of the same kind in Calabria and Sicily, and indeed in almost all regions of volcanos and earthquakes which have been carefully investigated. In the limestone districts of England, as on Ingleborough Hill, in Yorkshire, we often see walls entirely constructed of calcareous tufa, enclosing terrestrial shells and vegetables, and similar tufa still continues to be formed in that district. The growth of stalactites, also, and stalagmites in caverns and grottos, is another familiar example of calcareous precipitates. To the solvent power of water, surcharged with carbonic acid, and percolating various winding rents and fissures, we may ascribe those innumerable subterranean cavities and winding passages which traverse the limestone in our own and many other countries.

In the marshes of the great plains of Hungary, horizontal beds of travertin, including recent fresh-water shells, are continually deposited, and are sufficiently solid to serve for building-stones, all the houses of Czeled being constructed of this material †. To analogous deposits in the lakes of Forfarshire, in Scotland, we shall refer more particularly when speaking of the imbedding of plants and animals in recent deposits. The quantity of calcareous rock which results from mineral waters in volcanic regions, conspicuous as it is, must be considered as insignificant, in comparison to that which is conveyed by rivers to the sea; and our inability to observe subaqueous accumulations resulting from this source, is one of many

* Hoff, Geschichte, &c., vol. ii., p. 114.

† Beudant, Voyage en Hongrie, tom. ii., p. 353.

causes of our inadequate conception of the changes now in progress on the earth's surface. It has often been supposed, that the greater part of the coral reefs in the Indian and Pacific oceans were based on submarine volcanos,—which seems indicated by the circular shape so frequently assumed by them; but perhaps a still stronger argument in favour of this theory might be deduced from the great abundance of carbonate of lime required for the rapid growth of zoophytic and shelly limestones,—an abundance which could only be looked for where there are active volcanos and frequent earthquakes, as amongst the isles of the South Pacific. We may confidently infer, that the development of organic life would be promoted in corals, sponges, and testaceous mollusca, by the heat, carbonic acid, lime, silica, and other mineral ingredients in a state of solution, given out by submarine springs, in the same manner as the vegetation is quickened in the lake of the Solfatara, in the Campagna di Roma, before described.

Gypseous springs.—All other mineral ingredients wherewith springs in general are impregnated, are insignificant in quantity in comparison to lime, and this earth is most frequently combined with carbonic acid. But as sulphuric acid and sulphuretted hydrogen are very frequently supplied by springs, we must presume that gypsum is now deposited largely in many seas and lakes. The gypseous precipitates, however, hitherto known on the land, appear to be confined to a very few springs. Those at Baden, near Vienna, which feed the public bath, may be cited as examples. Some of these supply, singly, from six hundred to one thousand cubic feet of water per hour, and deposit a fine powder, composed of a mixture of sulphate of lime, with sulphur and muriate of lime *.

SILICEOUS SPRINGS.

Azores.—In order that water should hold a very large quantity of silica in solution, it seems necessary that it should be raised to a high temperature †; and as it may retain a greater heat under the pressure of the sea than in the atmosphere, submarine springs may perhaps be more charged

* Prevost, Essai sur la Constitution Physique du Bassin de Vienne, p. 10.

† Daubeny, on Volcanos, p. 222.

with silex than any to which we have access. The hot springs of the Valle das Furnas, in the Island of St. Michael, rising through volcanic rocks, precipitate vast quantities of siliceous sinter, as it is usually termed. Around the circular basin of the largest spring, called "the Caldeira," which is between twenty and thirty feet in diameter, alternate layers are seen of a coarser variety of sinter mixed with clay, including grass, ferns, and reeds, in different states of petrifaction. Wherever the water has flowed, sinter is found rising in some places eight or ten inches above the ordinary level of the stream. The herbage and leaves, more or less incrusted with silex, exhibit all the successive steps of petrifaction, from the soft state to a complete conversion into stone; but, in some instances, alumina, which is likewise deposited from the hot waters, is the mineralizing material. Branches of the same ferns which now flourish in the island, are found completely petrified, preserving the same appearance as when vegetating, except that they acquire an ash-grey colour. Fragments of wood, and one entire bed from three to five feet in depth, composed of reeds now common in the island, have become completely mineralized. The most abundant variety of siliceous sinter occurs in layers from a quarter to half an inch in thickness, accumulated on each other often to the height of a foot and upwards, and constituting parallel, and for the most part horizontal, strata many yards in extent. This sinter has often a beautiful semi-opalescent lustre. One of the varieties differs from that of Iceland and Ischia in the larger proportion of water it contains, and in the absence of alumina and lime. A recent breccia is also in the act of forming, composed of obsidian, pumice, and scoriæ, cemented by siliceous sinter *.

Geysers of Iceland.—But the hot springs in various parts of Iceland, particularly the celebrated geysers, afford the most remarkable example of the deposition of silex. The circular reservoirs into which the geysers fall, are filled in the middle with a variety of opal, and round the edges with sinter. The plants, encrusted with the latter substance, have much the same appearance as those encrusted with calcareous tufa in our own

* Dr. Webster, on the Hot Springs of Furnas, Ed. Phil. Journ., vol. vi., p. 306.

country. The solution of the silex is supposed to be promoted by the presence of some mineral alkali. In some of the thermal waters of Iceland a vesicular rock is formed, containing portions of vegetables, more or less completely silicified. Amongst the various products also of springs in this island, is that admixture of clay and silica, called tripoli.

It has been found, by recent analysis, that several of the thermal waters of Ischia are impregnated with a certain proportion of silica. Some of the hot vapours of that island are above the temperature of boiling water; and many fissures, near Monte Vico, through which the hot steam passes, are coated with a siliceous incrustation, first noticed by Dr. Thompson under the name of fiorite.

In some places where silicification is in progress, the sources from whence the mineral matter is derived are as yet unknown. Thus the Danube has converted the external part of the piles of Trajan's bridge into silex; and the Irawadi, in Ava, has been supposed, ever since the time of the Jesuit Padre Duchatz, to have the same petrifying power, as has also Lough Neagh, in Ireland. Modern researches, however, in the Burman empire, have not confirmed, but have rather thrown doubt upon the lapidifying property of the Ava river *. The constant flow of mineral waters, even when charged with a small proportion of silica, as those of Ischia, may supply certain species of corals and sponges with matter for their siliceous secretions; but when in a volcanic archipelago, or a region of submarine volcanos, there are springs so saturated with silica, as those of Iceland and the Azores, we may expect beds of chert or layers and nodules of silex, to be spread out far and wide over the bed of the sea, and interstratified with shelly and calcareous deposits, which may be forming there, or with matter derived from the wasting cliffs or volcanic ejections.

Ferruginous Springs.—The waters of almost all springs contain some iron in solution; and it is a fact familiar to all, that many of them are so copiously impregnated with this metal, as to stain the rocks or herbage through which they pass, and to bind together sand and gravel into solid masses. We may

* Dr. Buckland, Geol. Trans., second series, vol. ii., part 3, p. 384.

naturally, therefore, conclude that this iron, which is constantly conveyed into lakes and seas from the interior of the earth, and not returned again to the land by evaporation in the atmospheric waters, must act as a colouring and cementing principle in the subaqueous deposits now in progress. When we find, therefore, that so many sandstones and other rocks in the sedimentary strata of ancient lakes and seas are bound together or coloured by iron, it presents us with a striking point of analogy between the state of things at very different epochs. In the older formations we meet with great abundance of carbonate and sulphate of iron; and in chalybeate waters at present, this metal is most frequently in the state of a carbonate, as in those of Tunbridge, for example. Sulphuric acid, however, is often the solvent, which is in many cases derived from the decomposition of pyrites.

Brine Springs.—So great is the quantity of muriate of soda in some springs, that they yield one-fourth of their weight in salt. They are rarely, however, so saturated, and generally contain, intermixed with salt, carbonate and sulphate of lime, magnesia, and other mineral ingredients. The brine springs of Cheshire are the richest in our country; those of Barton and Northwich being almost fully saturated. These brine springs rise up through strata of sandstone and red marl, which contain large beds of rock-salt. The origin of the brine, therefore, may be derived in this and many other instances from beds of fossil salt; but as muriate of soda is one of the products of volcanic emanations and of springs in volcanic regions, the original source of salt may be as deep seated as that of lava.

The waters of the Dead Sea contain scarcely anything, except muriatic salts, which lends countenance, observes Dr. Daubeny, to the volcanic origin of the surrounding country, these salts being frequent products of volcanic eruptions. Many springs in Sicily contain muriate of soda, and the "fiume salso," in particular, is impregnated with so large a quantity, that cattle refuse to drink of it. If rivers or springs, thus impregnated, enter a lake or estuary, it is evident that they may give rise to partial precipitates of salt.

A hot spring, rising through granite, at Saint Nectaire, in Auvergne, may be mentioned as one of many, containing a large proportion of muriate of soda, together with magnesia and other ingredients *.

Carbonated Springs.—Carbonic acid gas is very plentifully disengaged from springs in almost all countries, but particularly near active or extinct volcanos. This elastic fluid has the property of decomposing many of the hardest rocks with which it comes in contact, particularly that numerous class in whose composition felspar is an ingredient. It renders the oxide of iron soluble in water, and contributes, as was before stated, to the solution of calcareous matter. In volcanic districts, these gaseous emanations are not confined to springs, but rise up in the state of pure gas from the soil in various places. The Grotto delle Cane, near Naples, affords an example, and prodigious quantities are now annually disengaged from every part of the Limagne d'Auvergne, where it appears to have been developed in equal quantity from time immemorial. As the acid is invisible, it is not observed, except an excavation be made, wherein it immediately accumulates so that it will extinguish a candle. There are some springs in this district, where the water is seen bubbling and boiling up with much noise, in consequence of the abundant disengagement of this gas. The whole vegetation is affected, and many trees, such as the walnut, flourish more luxuriantly than they would otherwise do in the same soil and climate,—the leaves probably absorbing carbonic acid. This gas is found in springs rising through the granite near Clermont, as well as in the tertiary limestones of the Limagne †. In the environs of Pont-Gibaud, not far from Clermont, a rock belonging to the gneiss formation, in which lead-mines are worked, has been found to be quite saturated with carbonic acid gas, which is constantly disengaged. The carbonates of iron, lime, and manganese are so dissolved, that the rock is rendered soft, and the quartz alone remains unattacked ‡. Not far off is the small volcanic cone of Chaluzet, which once broke up through the gneiss, and sent forth a lava stream.

The disintegration of granite is a striking feature of large districts in Auvergne, especially in the neighbourhood of Cler-

* Annales de l'Auvergne, tom. i., p. 234.

† Le Coq, Annales de l'Auvergne, tom. i., p. 217. May, 1828.

‡ Ann. Scient. de l'Auvergne, tom. ii., June, 1829.

mont. This decay was called, by Dolomieu, "la maladie du granite;" and the rock may with propriety be said to have *the rot*, for it crumbles to pieces in the hand. The phenomenon may, without doubt, be ascribed to the continual disengagement of carbonic acid gas from numerous fissures. In the plains of the Po, between Verona and Parma, especially at Villa Franca, south of Mantua, I observed great beds of alluvium, consisting chiefly of primary pebbles percolated by spring water, charged with carbonate of lime and carbonic acid in great abundance. They are, for the most part, encrusted with calc-sinter; and the rounded blocks of gneiss, which have all the appearance of solidity, have been so disintegrated by the carbonic acid as readily to fall to pieces. The Po and other rivers, in winding through this plain, might now remove with ease those masses which, at a more remote period, the stream was unable to carry farther towards the sea; and in this example we may perceive how necessary it is, in reasoning on the transporting power of running water, to consider all the numerous agents which may co-operate, in the lapse of ages, in conveying the wreck of mountains to the sea. A granite block might remain stationary for ages, and defy the power of a large river; till at length a small spring may break out, surcharged with carbonic acid,—the rock may be decomposed, and a streamlet may transport the whole mass to the ocean.

The subtraction of many of the elements of rocks by the solvent power of carbonic acid, ascending both in a gaseous state and mixed with spring-water in the crevices of rocks, must be one of the most powerful sources of those internal changes and re-arrangements of particles so often observed in strata of every age. The calcareous matter, for example, of shells is often entirely removed and replaced by carbonate of iron, pyrites, or silex, or some other ingredient, such as mineral waters usually contain in solution. It rarely happens, except in limestone rocks, that the carbonic acid can dissolve all the constituent parts of the mass; and for this reason, probably, calcareous rocks are almost the only ones in which great caverns and long winding passages are found. The grottos and subterranean passages, in certain lava-currents, are due to a different cause, and will be spoken of in another place.

Petroleum Springs.—Springs impregnated with petroleum, and the various minerals allied to it, as bitumen, naphtha, asphaltum, and pitch, are very numerous, and are, in many cases, undoubtedly connected with subterranean fires, which raise or sublime the more subtle parts of the bituminous matters contained in rocks. Many springs in the territory of Modena and Parma, in Sicily, produce petroleum in abundance; but the most powerful, perhaps, yet known, are those on the Irawadi, in the Burman empire. In one locality there are said to be five hundred and twenty wells, which yield annually four hundred thousand hogsheads of petroleum *.

Fluid bitumen is seen to ooze from the bottom of the sea, on both sides of the island of Trinidad, and to rise up to the surface of the water. Near Cape La Braye there is a vortex which, in stormy weather, according to Captain Mallet, gushes out, raising the water five or six feet, and covers the surface for a considerable space with petroleum, or tar; and the same author quotes Gumilla, as stating in his "Description of the Orinoco," that, about seventy years ago, a spot of land on the western coast of Trinidad, near half-way between the capital and Indian village, sank suddenly, and was immediately replaced by a small lake of pitch, to the great terror of the inhabitants †. It is probable, that the great pitch-lake of Trinidad owes its origin to a similar cause, and Dr. Nugent has justly remarked, that in that district all the circumstances are now combined from which deposits of pitch may have originated. The Orinoco has, for ages, been rolling down great quantities of woody and vegetable bodies into the surrounding sea, where, by the influence of currents and eddies, they may be arrested and accumulated in particular places. The frequent occurrence of earthquakes and other indications of volcanic action in those parts, lend countenance to the opinion, that these vegetable substances may have undergone, by the agency of subterranean fire, those transformations and chemical changes which produce petroleum, and may, by the same causes, be forced up to the surface, where, by exposure

* Symes, Embassy to Ava, vol. ii.—Geol. Trans., second series, vol. ii., part 3, p. 388.

† Dr. Nugent, Geol. Trans., vol. i., p. 69.

to the air, it becomes inspissated, and forms the different varieties of pure and earthy pitch, or asphaltum, so abundant in the island *.

The bituminous shales, so common in geological formations of different ages, as well as many stratified deposits of bitumen and pitch, seem clearly to attest that, at former periods, springs, in various parts of the world, were as commonly impregnated as now with bituminous matter, which was carried down by rivers into lakes and seas. We may indeed remark generally, that a large portion of the finer particles and the more crystalline substances found in sedimentary rocks of different ages, are composed of the same elements as are now held in solution by springs, while the coarser materials bear an equally strong resemblance to the alluvial matter in the beds of existing torrents and rivers.

* Dr. Nugent, Geol. Trans., vol. i., p. 67.