## I.—*On a recent Formation of Sandstone, occurring in various Parts of the Northern Coasts of Cornwall.*

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THE investigation which I have the honour to submit to the Society, is one of very extraordinary interest, as being capable of throwing considerable light upon the importance, as well as nature and extent, of some of those changes which the surface of the globe is continually undergoing in arrangement, structure, and composition; and of offering an explanation of several of the more secret phenomena which accompany them.

The decomposition and waste of hills and mountains, and the decay of the most solid parts of the earth, have excited the attention of all ages, furnishing imagery to the poet, and lessons to the moralist; but the infancy of those sciences connected with Geology has

hitherto retarded every investigation into the immediate causes of such decay, and into the nature of those hidden processes by which Nature counteracts it. Every enquiry connected with so interesting a subject will, I trust, be received by the Society with the attention its importance merits, and with that indulgence which its difficulty requires.

The *Sandstone*, which forms the subject of this paper, occurs in various parts of the Northern Coast of Cornwall, and certainly affords one of the most splendid and instructive instances of *Recent Formation* upon record; we actually detect Nature at work in changing calcareous sand into stone; and she does not refuse admittance into her manufactory, nor does she conceal with her accustomed reserve the details of the operations in which she is engaged. It does not, however, appear that any Geologist has fully availed himself of so rare an indulgence. No complete and satisfactory explanation has been hitherto afforded of this interesting formation, nor of the phenomena which attend it. At the period that Doctor Borlase wrote the Natural History of Cornwall, the science of chemistry scarcely existed: we must not, therefore, be surprised at finding that he attributed the concretion of shelly sand to the agglutinating quality of sea-water.

Recent formations, similar to that which I am about to describe, occur in various parts

of the world. Saussure informs us, that the loose sand near Messina and the Gulf of Charybdis becomes gradually so consolidated, that in a few years it serves for the purpose of millstones; which change, Saussure, as well as Borlase, attributes to the infiltration of some cementing principle from the sea. At Guadaloupe, another example is to be seen; and a splendid specimen of the stone, containing a human skeleton, the remains probably of some shipwrecked mariner, has been lately deposited in the cabinet of the British Museum, and is well known for the geological speculations which it has excited.

In describing the recent formation on the coast of Cornwall, I shall begin by offering some remarks on the natural history of the sand itself; and then, by following the steps of Nature, gradually trace her through the successive stages of the operation by which she agglutinates its particles, and completes its induration.

A very considerable portion of the Northern Coast of Cornwall is covered with a calcareous sand, consisting of minute particles of comminuted shells. That part which lies between Saint Ives and Padstow is more immediately the subject of the present enquiry; a tract which, with a few exceptions, is entirely covered with this species of sand; and which, in some places, has accumulated in quantities so great as to have formed hills of from forty

to sixty feet in elevation. A considerable area, for instance in the parishes of Gwythian and Phillack, has been thus desolated, and several churches have been inundated. In digging into these sand-hills, or upon the occasional removal of some part of them by the winds, the remains of houses may be seen; and in some places, where the church-yards have been overwhelmed, a great number of human bones may be found.

The sand is supposed to have been originally brought from the sea by hurricanes, probably at a remote period. Amongst the Arundel Papers there is mention of such an event having happened in the twelfth century; and the disproportionately high valuation of the rectory of Gwythian in the old valors, when compared with that of other parishes, which were then rated much lower, though now of very superior value, affords a probable conjecture that much land has been lost by the influx of the sand.

At present, the progress of the sand's incursion is arrested by the growth of the *arundo arenaria*;* and it would be well if the landed

* The value of this useful rush has been long known. There was an act of parliament in Scotland, so long ago as the year 1695, to prevent persons who collected this rush, (then known by the name of *starre* or *bent*) for the purpose of making mats, from plucking it up, and thereby loosening the sands: a clause to the same effect was introduced in a multifarious act of parliament in the year 1742. The operation of this clause extends generally to the North-West

proprietors of these districts were to encourage its dissemination.

The sand first appears in a slight but encreasing state of aggregation on several parts of the shore in the Bay of Saint Ives; but on approaching the Gwythian river it becomes more extensive and indurated. On the shore opposite to Godrevy Island, an immense mass of it occurs, of more than a hundred feet in length, and from twelve to twenty feet in depth, containing entire shells and fragments of clay-slate; it is singular that the whole mass assumes a striking appearance of stratification. In some places, it appears that attempts have been made to separate it, probably for the purpose of building; for several old houses in Gwythian are built of it. The rocks in the vicinity of this recent formation in the Bay of Saint Ives are *Greenstone* and *Clay-Slate*, which alternate with each other. The *Clay-Slate* is in a state of rapid decomposition, in consequence of which, large masses of the Hornblende rock have fallen in various directions, and given a singular character of picturesque rudeness to the scene: this is remarkable in the mass of rocks which constitutes Godrevy Island.

coasts of England; but such persons as claimed prescriptive right of cutting it on the sea-coasts of Cumberland, are exempted from its operation.

It is around the promontory of New Kaye that the most extensive formation of sandstone takes place. Here it may be seen in different stages of induration; from a state in which it is too friable to be detached from the rock upon which it reposes, to a hardness so considerable that it requires a very violent blow from a sledge to break it: specimens of it in these different states are deposited in the Museum of the Society. Buildings are here constructed of it; and the church of Crantock is entirely built with it. By the inhabitants, the stone is employed for various articles of domestic and agricultural use. In the sandstone in the Bay of New Kaye, I observed several holes bored, which I learnt were for the purpose of admitting cables to which the vessels were moored. I mention this circumstance to convey some idea of the indurated state of the sandstone.

In examining attentively the structure of the stone, the shelly particles may be frequently observed to be spherical, from the previous operation of water; a circumstance which throws considerable light upon the formation of *oolite*.

The geologist who had previously examined the celebrated specimen from Guadaloupe, will be struck with the great analogy which this formation bears to it; and suspecting that masses might be found containing human bones imbedded, if a diligent search were made in the vicinity of those cemeteries which have

been overwhelmed, I made an excursion with my friend Sir Christopher Hawkins; but time and patience failed us, and the discovery is reserved for some more persevering and fortunate member of the Society.

The rocks upon which the sandstone reposes are *clay-slate* and *slaty limestone,* which alternate with each other. The inclination of the beds is S.S.W., and at an angle of 40°. Upon the plane formed by the edges of these strata lies a horizontal bed of rounded pebbles, cemented together by the sandstone which is deposited immediately above them, forming a bed of from ten to twelve feet in thickness, and containing fragments of slate and entire shells, and exhibiting the same appearance of stratification as that noticed in St. Ives Bay; above this sandstone lie immense heaps of drifted sand.

But it is on the western side of the promontory of New Kaye, in Fistrel Bay, that the geologist will be most struck with the formation; for here no other rock is in sight. The cliffs, which are high, and extend for several miles, are entirely composed of it; they are occasionally intersected by veins and dykes of Breccia. In the cavities, calcareous stalactites of rude appearance, opaque, and of a grey colour, hang suspended. The beach is covered with disjointed fragments, which have been detached from the cliff above, many of which weigh two or three tons.

If we extend our observations towards Padstow, we shall find some very instructive phenomena in Permiscen Bay, to which I shall hereafter have occasion to allude.

Such then is the nature and situation of this most interesting formation of recent sandstone. In the next place, we have to enquire into the causes which have operated in thus consolidating the sand, and into the peculiar circumstances under which this operation has been conducted.

It will appear that there are three distinct modes by which the lapidification of calcareous sand may be effected, and that the present formation is capable of affording characteristic examples of each of them.

It is my intention to consider these different principles separately: the subject is full of importance, and may, by disclosing the operations of nature, lead to improvements in art. By discovering the phenomena which attend the formation of rocks, we may be led to the improvement of the different cements in present use, or to the invention of others which have never yet been employed.

The three species of cementing matter to which I allude, are all deposited from water in which they are either held in chemical solution or mechanical suspension; the water having derived them from the substances which it has percolated: thus, the first species is obtained.

I.—*By the percolation of water through a hill of calcareous sand, by which it becomes impregnated with Carbonate of Lime.*

Carbonate of lime, without an excess of carbonic acid, is very sparingly soluble; but it is the very minute quantity of the substance, held dissolved in a large quantity of water, which renders its texture so compact and dense when precipitated, and its cementing powers so considerable; for it may be stated as a general principle, *that the density and compactness of a precipitate will vary, in an inverse ratio, with the rapidity with which it is deposited.* Thus *Calcareous Tufa,* which is rapidly deposited from warm springs, is light and spongy in its texture; whereas *Travertine Marble,* being slowly precipitated from the waters of Tivoli, assumes a solid compact form. A familiar illustration of the dense texture and cementing property of precipitates, when they are slowly deposited, is presented to us in the instances of the obstinate adhesion of calcareous incrustations to the interior surfaces of water-decanters.

A very dense and compact limestone is now forming, from slow deposition, in the vast lake of Erie, in consequence of the evaporation of its waters, that are derived from rivers which have flowed through extensive countries of limestone: this formation may be seen on the sides of the lake; and, during frosts, large frag-

ments of it, attached to blocks of ice, may be observed floating on its surface. When the Falls of Niagara are destroyed, which in the common course of geological changes must take place, this immense lake will be drained, and future geologists may be then engaged in speculating upon its limestone, as we are now with a similar one which lines the great basin of the Mississippi, and which probably derived its origin from the same cause.

I have dwelt upon this subject to shew the solubility of carbonate of lime, and at the same time to prove, that when it is precipitated by slow evaporation, it assumes a highly compact texture, and possesses considerable power of lapidification. The application of these views to the present subject is obvious:—the carbonate of lime, derived from the solution of a portion of the shells through which the water flows, affords the cement; whilst the slowness with which it is again precipitated, accounts for the extreme hardness

* At the request of my friend Mr. Whidbey, the intelligent director of the Plymouth Breakwater, I have lately examined the water which is to supply the British navy. A reservoir has been formed capable of holding sixteen thousand tons of water. The water, which is constantly running into it, is extremely pure, containing only a very minute proportion of carbonate of lime, which it must have acquired during its percolation through the transition limestone of that district. The effect of this will be the deposition of a stratum similar to that in Lake Erie, and consequently it will give a permanent security to the reservoir, and effectually prevent any leaking.

and compact texture of the sandstone; striking examples of this fact may be seen in Permiscen Bay.* Had the cementing principle been held in solution by an excess of acid, it would have been deposited in a larger quantity, as well as with greater celerity, and the sandstone would probably, under such circumstances, have been spongy, friable, and scarcely indurated.

Let us proceed to the second source whence a lapidific principle may be obtained.

II.—*The percolation of water through strata containing Pyritical Substances, by which it becomes impregnated with Sulphuric Salts.*

I was led to suspect that the cementing principle might occasionally be a *sulphate* of lime, from discovering in a specimen of the sandstone small transparent crystals of selenite, disseminated through its substance. The loose sands, which are said to be found lapidified in volcanic districts, may possibly derive their principle of solidification from the action of sulphuric

* It is a curious circumstance that water thus impregnated with carbonate of lime, from its infiltration through shelly sand, should from time immemorial have enjoyed a reputation in the neighbourhood for curing diseases. I examined the waters of Holywell, so called from its supposed virtues, and those of Permiscen Bay, equally extolled for their medicinal qualities, supposing that I might possibly detect in them the presence of iron: but I found only *carbonate of lime*, in minute quantities.

waters; but I have not had any opportunity of ascertaining the fact by experiment. The sulphatization of pyrites in the presence of calcareous matter, is a universal source of gypsum: the circumstances under which the elements of these substances combine, and the various chemical changes which accompany them, I consider as amongst the most interesting facts which have been disclosed by the researches of the mineralogist.

The granular gypsum from the Falls of Niagara, which Dr. Kidd describes as being "as white as snow," owes its origin to a natural process of this description. I am informed by Mr. Maclure of Philadelphia, who has visited the spot, that it is formed in consequence of the action of water upon decomposing slate which contains numerous veins of *carbonate of lime* and *sulphuret of iron*.

I have in my possession a series of incrustations which were taken out of the boilers of several steam-engines;* one of them presents an admirable instance of the formation of sulphate of lime, and its surface is beautifully studded with well defined crystals of selenite; the water which supplied the boiler, and from the evaporation of which this substance was deposited, was drawn from the depths of a mine,

* An account of these specimens is recorded in the Minutes of the Society, and published amongst the Scientific Notices at the end of this Volume.

the country of which I ascertained to be clay-slate, intersected with veins of *pyrites*, and small runners of *carbonate of lime*.

There would seem to be a singular disposition in all the combinations of iron to pass successively through a series of complicated arrangements; a property which has evidently been bestowed upon them in order more effectually to ensure the general distribution of an element so essential to animal and vegetable existence, and so active in producing many important changes in the mineral œconomy of the globe; some of which will form matter for consideration under our third and last, but most general, principle of lapidification, viz.

III. *The percolation of water through decomposing slate, or any other ferruginous strata; by which it becomes impregnated with iron, alumina, and other mineral matter.*

The infiltration of water which has previously traversed a country of decomposing slate, or of other strata, into loose sand, is a very common and extensive cause of lapidification. At Pendeen cove, in the parish of St. Just, a stratum of granitic sand is at this time gradually hardening into sandstone, or granitic *breccia*, in consequence of such an infiltration; strata of pebbles may be also seen agglutinated from the same cause.

The sandstone upon which the town and castle of Nottingham are situated, is evidently of recent formation, owing its aggregation to the presence of iron and clay. The calcareous sand may be seen in a state of encreasing induration from the same cause, in numerous parts of the coast of Cornwall, especially in the cliff of Saint Ives Bay, about a mile north of the estuary at Hayle; where a stream of water is slowly percolating decomposing slate, and dripping upon the loose sand on the beach, which is gradually becoming indurated in the direction in which the water diffuses itself. It has been long known that in the induration of mineral substances, iron acts a very important part, and we shall also find in the course of the present enquiry, that this element is no less active in effecting their decomposition and decay.

In alluding to its cementing property, the most superficial observer must have noticed the concretions which constantly appear on the beach around a rusty nail, or any fragment of iron; and the mineralogist is well acquainted with the proofs which Mr. Kirwan has collected in support of the fact. Dr. Fothergill also states, that stones already formed may be still farther indurated by the infiltration of slightly oxidized iron. Thus having repeatedly washed pieces of Portland Stone with water impregnated with iron, he found them in a few

years to have gained such a degree of hardness, as to yield a metallic sound when struck, and to resist the impression of any ordinary tool: this result also clearly explains the cause of the superior hardness of coloured to white marbles. It is unnecessary to multiply examples. It cannot be denied that iron, in a certain stage of oxidation, possesses the property of cementing and indurating the particles of bodies with which it may be combined; nor is it less certain that this operation is limited, and that iron not only ceases to produce such an effect by combining with more oxygen, but that, by such a change, it acquires an opposite property, and becomes the immediate and active cause of decomposing the very rock which it formerly consolidated. One instance may suffice to illustrate this truth. The sandy soil in the neighbourhood of Ommersley, Halesowen, and many other parts of Worcestershire and Shropshire, is derived from the *Sandstone* of the Midland Counties, the disintegration of which has been effected by the peroxidation of its iron, as is shewn both by its red hue, and by the green colour which it imparts to the glass of Stourbridge, of which it constitutes the principal ingredient. The Count de Bournon appears disposed to believe that the decomposition of primitive rocks has been the only source from which the iron has been derived, that is now so universally spread over the

surface of the earth.* We recognise in these facts the operation of a most beautiful and important law; we learn that the most opposite effects are produced by the modification of but one principle, and that FORMATION and DECOMPOSITION are not, as the ignorant suppose, the beginning and end of material existence; but terms expressive of well regulated operations, which extend through ages of endless duration, maintaining and perpetuating the harmony, beauty, and integrity of the universe. The ruin therefore of our hills, and the various catastrophes which the surface of our earth continually undergoes, must be no longer considered as the awful type of frailty and decay, or as preludes to the more fearful changes which the superstitious observer is ever ready to anticipate; but they must be regarded as wise provisions to ensure on the

* Some French Philosophers have imagined that iron owes its origin to decayed plants and animals. I would take this opportunity to observe, that vegetables appear to possess the power of deoxidizing the compounds of iron, and thereby of rendering them soluble in their juices: this apparently explains the conversion of vegetable matter into pyrites, by the infiltration of chalybeate salts. May not this be one of the means employed by nature for rendering iron again useful in the scheme of creation, by restoring that portion into circulation which has become, during its agency, insoluble and inert by peroxidation. That animal matter possesses similar powers has been shewn by Mr. Pepys,—(see Transactions of the Geological Society of London.)

surface of the globe that circle of changes so essential to animal and vegetable existence.

> " By ceaseless action, all that is, subsists.
> Constant rotation of th' unwearied wheel,
> That Nature rides upon, maintains her health,
> Her beauty, her fertility.—She dreads
> An instant pause, and lives but while she moves.
> Its own revolvency upholds the world."

Since this paper was read before the Society, my friend, Mr. Boase, has enabled me to add another striking and beautiful illustration of the peculiar views which I have endeavoured to maintain. " I have," says he, " lately visited the Islands of Scilly; no where is the operation of the elements, in decomposing rocks, more visible and striking; indeed so rapid is the progress of disintegration, that unless some regenerating operation be instituted by nature, this land of rocks will, at a period which in the language of Geology may be styled not very remote, be a range of sand banks. Struck with such an appearance, and bearing in my recollection the principles developed in your memoir upon the recent Sandstone formation, lately read before the Society, I was sanguine in the hope of discovering in these islands, an additional testimony of their truth. My search has been rewarded by complete success; a process similar to the one you have described, may be detected in its progress, on an extensive scale, in the Island of St. Mary,

behind the quay, and between the front of the Garrison Hill and Rat Island. In these places the granitic sand is becoming indurated by the slow infiltration of water holding iron in solution, which appears to be derived from the decomposing hills above it."

Many instances of "*regenerated granite,*" as it has been termed, similar to that which Mr. Boase has described as occurring in the island of St. Mary, have been placed upon record. Pallas is of opinion that all stratified granite is formed from the decomposed grains of the primitive mass. Dr. MacCulloch has also observed that the whole of the southern and western parts of the island of Alderney are composed of a *grit,* which is evidently an aggregate, derived from the debris of granite.

Lasius found granitic sand, employed in filling a dyke in the Elbe, hardened to such a degree in the space of sixty years, as to present a solid mass, scarcely distinguishable from primitive granite; he also found that where both were in contact, they were with difficulty separated by a blow. Saussure found it in the fissures of Gneiss. Lavoisier also discovered, near the mountain of Hypolite, two beds of indurated granite, or, as he calls it, *true* granite, alternating with two beds of granitic sand that lay over each: this can have been no other than *regenerated* granite, formed by infiltration from the superior granitic sand.

That the harmony of the universe is maintained by the reciprocal operation of the power of creation and of destruction, was a favourite opinion of the ancient philosophers, and we find constant allusions to it in their writings.

> "Sic omnia Fatis
> In pejus ruere ac retro sublapsa referi."

Nor have they omitted to perpetuate such an idea by symbolical images; we recognise it in the emblem of a Lyre supported by a Bull and Lion; thus expressing that Apollo was worshipped under the double character of the Creator and Destroyer.

It was, however, reserved for the researches of modern science to bring to light the nature of those operations, by which such a harmony was preserved. The views which have been offered in this memoir seem to afford some clue to the investigation. To discover order and intelligence in scenes of apparent wildness and confusion, is the pleasing task of the geological enquirer; in contemplating the circumstances connected with the formation of the sandstone, a most beautiful and unexpected demonstration of design is afforded; like the mariner cast upon an unknown shore, we discover the traces of a footstep upon the sand, and may exclaim with rapture—'A GOD DWELLETH HERE.'