THE MINERALOGICAL MAGAZINE

AND

JOURNAL

OF THE

MINERALOGICAL SOCIETY OF GREAT BRITAIN AND IRELAND

No. 15. DECEMBER, 1879. Vol. III.

XVII.—*The Geognosy and Mineralogy of Scotland.*

By Professor Heddle.

THE ORKNEY ISLANDS.

Part I.

JAMESON tells us that it took him six weeks to survey Orkney geologically, and that the journey was the most uninteresting he ever made; his journal, indeed, is little more than a record of disappointments. Jameson's statement, so far from concealing, disclosed an indubitable fact, that to relieve the tedium of the hammer through weeks of wandering, some impulse,—some attraction of a different nature must be associated with it. Jameson himself showed that such attraction was present with him, though he seems to have put a restraint upon himself as regards the alluding to it.

In his preface he says—"I hope that I have not been insensible to the emotions which naturally arise from the retired and striking scenes which often burst upon me in the unfrequented tracks which my pursuits led me to explore:"—and though he expressly states that it is not his "purpose to obtrude these things," still "these things"—the stimulus of the grandeur of nature—the secrets of nature acting as the loadstone to his desire to unfold their workings,—these things do occasionally break through even his reserve, but not obtrusively.

That the impulse necessary for alleviating the burden of the hammer should have been comparatively dormant if Jameson had visited Orkney after having left Shetland might not be surprising. In comparison

with that land of many diverse strata, the unvarying monotony of the glaciated contours, and half-submerged sandbanks of an Old Red Sandstone country must have proved tame indeed; but there can be little doubt that if Jameson had made his survey of *Caithness* anteriorly to that of Orkney, his expressions of discontent and disappointment would have been so thoroughly expended on that more monotonous and most mineralogically-barren land, that a feeling of relief if not of interest would have been experienced while Orkney was being surveyed.

It is sufficiently significant in this connection to notice that, while the survey of Orkney occupies seventeen pages of his work, Caithness is dismissed in six.*

But while admitting that Orkney is to the mere mineralogist a comparatively uninteresting country, it must be allowed that now that mineralogy is marching hand in hand with chemistry as the handmaid of geology, Orkney comes to be far from devoid of interest.

Geikie writes:—"In quitting Orkney I would refer to the many admirable sections exposed along the mural sea-cliffs of that storm-swept group of islands, and to the endless instructive lessons furnished by them on stratification, jointing, and other elementary questions in physical geology, as well as on the progress of weathering, its relations to rock structure, and the proportional share taken in it by the sea and the atmosphere."

The Orkneys are composed almost solely of rocks, till lately assigned wholly to Old Red Sandstone age.

This formation, though of the highest interest as regards its fossil ichthyology, is usually singularly barren in those rock features which aid in elucidating the changes through which the crust of the earth has been formed, and by which it has been affected; while it is also markedly barren as a field for the researches of the mineralogist.

The monotony which attaches to a single formation is, however, relieved somewhat by the occurrence of a narrow strip of older rocks in the west of the county;—by the unmistakable evidence afforded in one island that these Old Red Sandstones are not here to be assigned to *one* geologic epoch;—and by a great development of the system of trap-dykes, which occurs so markedly along our western coasts,—that namely of tertiary age and which has a W. and E., or W.N.W. and E.S.E strike.

* Jameson quits the Orkney Islands with a warm acknowledgement of a hospitality which was "confined to them"—a hospitality which "seemed to look for no return;" while of Caithness he has no hospitality to record; he designates it a "mean looking country, the tedious unformity of the bleak scene being only varied by the appearance of old ruinous castles, or recluse gentlemen's seats situated amid brown desert heaths." We find him say in one place—"we could get little to satisfy our craving hunger."

These rocks are considered by Geikie to have been laid down in the same basin as those of Shetland; and, so far as the sandstones of the west side of Shetland are concerned, this is doubtless true.

The sandstone rocks of Orkney however differ widely in lithological aspect from those of Shetland.

The grits and conglomerates, which were there seen in immediate contact with the older rocks, here find no place. If the deposited sands have been laid down in the same oceanic lake, the beds here seen occupy a much higher zone. Except at one spot where local circumstances alone have produced it, no bed of heterogenous or coarse-grained material, or containing recognisable fragments of an older rock, is to be seen. The beds which would appear to be the deepest-seated, are those which consist of the most highly-comminuted materials; argillaceous and slimy-looking silts and blue flags—sometimes glimmering from minutely interspersed mica, or "bituminous" from having been the recipients of the products of the death and decay which were taking place in supernatant waters which teemed with animal life*

The general dip to these beds is to the west; they are frequently however not far removed from the horizontal; undulating folds also run across the islands from east to west; and on both of these extremes the dip is, in the north of the county, at least towards the centre.

Up that centre, moreover, there runs a well marked trough which bears about N.E. to S.W., and the upper beds of this trough are markedly different from the rocks of the other parts of the islands.

This trough is in many parts submerged, but the beds which define it are well seen in their eastern limits, though to a much inferior extent in the western.

These beds consist of loose arenaceous freestones, with silicous granules sometimes so coarse as almost to entitle them to the designation of grits.

*Jameson divides the beds into sandstone, sandstone-flag, schistose-clay, and indurated clay. Jameson's sandstone-flag he defines as schistose sandstone with a argillaceous cement.

His "schistose-clay" he thus defines.

"This rock has a black colour; is always intermixed with mica; and passes on the one hand into sandstone slate. and, on the other, into clay, where the schistose character is more difficultly distinguishable. It acquires by the action of the weather, an iron-brown covering; so that the rocks at a distance have much the appearance of the weathered serpentine rock in the Shetland Islands. It is quarried to a considerable extent in different parts of the island, particularly near to Stromness, and the slabs are used for roofing houses, but they are vastly inferior in every respect to the ardesia which is raised at Ballyhullish and Easdale."

This is the description of perhaps an unusually bitumenous variety of what is now called Caithness-flag, and it unquestionably passes into "sandstone-flag." Jameson makes it also pass into 'indurated clay.'

The lower series of beds are of a deep-red colour, from their containing much of a reddle-like mud disposed between the quartz grains, but this mud is of so clay-like a substance that it cannot be said to act the part of a cement to these grains. The upper beds are of a distinct yellow colour; the interstitial material is here not so large in quantity, but it partakes more of the nature of a cement.

The lower red bed is first seen in the north, on the west side of the bay of Pool in Sanday. It here forms low cliffs to the east, and strikes southward through the island in the direction of Spurness. It reappears to pass through Shapenshay from north to south, is again seen in low cliffs on the west shore of Birstane Bay in the mainland, re-appears (here associated with the yellow bed) at Scalpa, and finally forms the north-west corner of South Ronaldsha.

The cliffs of the Noup Head of Westray, 240 feet in height, appear to be of the same yellow rock. By Sir Rhoderick Murchison they are laid down as on the same horison as the strata of the Hoy hill-tops. There should in such a case be a great fault to throw them down over the thick beds of the flags in Rousay. No such fault is to be seen upon the shore; and, moreover, the igneous rock which in Hoy is seen to underlie the upper sandstones, is nowhere that I know of here present.

As the dip of the Noup Head rock is to the east, it may be one of the beds to be afterward noticed as occurring in the island of Fara; and if this be the case, the strata included between the beacon on North Ronaldsha and the Red Head in Eda represent the total thickness of the Old Red formation in Orkney; and, as it can be seen, by a section along Sanday, to be thrown into repeated folds between these points, that thickness cannot be great.

These red beds repose perfectly conformably upon the ordinary blue flags of the islands.

In Sanday the yellow beds are not of great thickness, they are conformable with the red, and at a spot called Heclabir are overlaid, also perfectly conformably, by thin beds of a conglomerate.

Observations made during two visits to this spot, and an examination of specimens brought therefrom, leave a strong impression in my mind that this is a *volcanic* conglomerate.

Its extent is small, being about 35 yards in length by 41 in width, and its total thickness is under 14 feet.

A fairly good section is exposed in a chasm of the rocks; as a road leads directly to the spot, this would seem to have been an old quarry. The stone may have been used as a burstone in mills.

The general dip of the rocks here is to N.W. by N., at the angle of 40°. The chasm has been cut at the angle of 30° ; an opposite affect to what would have been produced by sea-breaching.

At the bottom of the section visible at the locality, there are yellow sandstone beds with ripple-markings. Above these, six feet of sandy flags, very fissile at the top. Over this, one foot of sandy clay containing small pebbles lying in every direction: over this, one to two feet of green volcanic (?) mud, slightly wackenitic, also with small pebbles lying in every direction. There is next a few inches of sandy grit, capped by by about five or six feet of a tough conglomerate.

This conglomerate is made up of nodules considerably rounded, and of sizes varying from the size of millet grains up to that of the fist.

The rock-rents cut the pebbles, sometimes shifting them to the extent of an inch ; but I saw no pebbles in which the fractures were not connected with the rock-rents.

The conglomerate-cap shows false bedding in the layers of its pebbles, with occasional basin-like bands of grit.

The pebbles consist of *granites*, of more than one variety ; *gneisses* often chloritic ; porphyrys ; and seemingly of *quartzite* ;—rocks which are altogether different from the primitive rocks near Stromness, and therefore rocks *not occurring in the islands.*

Both the pebbles and the cementing paste have a highly vitrified aspect.

I have been informed that a conglomerate identical with this is to be seen on the coast-line at the south end of the Calf of Eday, which bears N.W. by N. ; and, at low water mark, on the shore of Eday, directly opposite to Heclabir, *i.e.* W.N.W.

Be this as it may, the conglomerate underlies a much thicker series of beds of the Red Sandstone ; these come in on the Island of Eday, forming its Red Head, and giving this portion of the series a thickness of about 200 feet—the dip remaining much the same. The Grey Head of the Calf of Eday may be a local expansion of the yellow beds, but a fault may run between Sanday and Eday.

Yellow beds with an opposite dip are to be seen in the island of Fara.

Quarries of both of these coloured sandstones have long been wrought in the Island of Eday ; from these probably, the high-tinted stones of "the beautiful gate" of the Cathedral of St. Magnus, if not indeed of the whole of that structure, have been taken.

It has been stated that a narrow strip of older rocks occurs in the west of the islands.

This is, to the south, first seen in the island of Gremsa, of which these rocks form perhaps a fourth part ; it re-appears on the opposite shore of

the Mainland, extending in width from the Point of Ness on the west, to the mill-water of Cairston on the east,—probably about a mile. Thence it runs north for about four miles towards Inganess point, where it has thinned away to a breadth of a few yards, and where it is sharply cut off by a trap-dyke.

The exact horizon of the beds which repose upon the flanks of this wedge (they have been removed by denudation from off its surface) could only be ascertained by a careful section across the whole island.

This primitive belt consists for the most part of a fine-grained granite, with a dark mica: towards the eastern side there is a tendency to a passage into syenite, while on the western there are gneissic beds, though of no great thickness, superimposed upon the granite.

Upon the west side of this mass there lies a conglomerate, gradually passing into a gritty sandstone. This conglomerate is formed of highly brecciated particles of the gneissose and granitic rocks; it is over-laid by flaggy beds which dip uniformly and persistently to the west, as far as the land continues.

The beds in contact with the primary belt upon the east also dip away from it for some space; but, at some points of the easterly contact, ferruginous argillaceous-flags are seen with a N.W. dip of about 8°.

The details of the section to the west of the belt of primitive rocks as seen on the sea shore in the vicinity of Stromness is as follows:—

Immediately at the Point of Ness—best seen at low water—there is granite possessing much of the features of granulite. This is overlaid by lepidomelane-gneiss which dips S.W. at the angle of 15°.

The beds of gneiss are very thin and are succeeded and overlaid by conglomerate, composed of fragmentary nodules of the underlying gneiss. This conglomerate has a thickness of only about 20 feet; its dip is as great as that of the gneiss, but it is to W.S.W.

The conglomerate is succeeded by argillaceous-flags, which are somewhat gritty when in contact with the conglomerate. The argillaceous beds are overlaid by ordinary fissile flags, up to a small bay near a life-boat house. There is now, however, a fault with a considerable upthrow, granite tending to eurite re-appearing. The granite is traversed by interlacing veins, and continues for a distance of 40 yards. It is succeeded by a conglomerate, which contains nodules of gneiss and granite—these nodules lie in all positions. This rock continues for 100 yards. It is overlaid by thin beds of a gritty conglomerate, to which there succeed flags containing plants, some of which were considered by Dr. Fleming to be fucoides.

These flags are succeeded by others showing many sun-cracks; while some beds are profusely sprinkled with rain-drop pittings. The dip of the beds which supervene upon the fault gradually turns to the west, while the angle of the dip, never so high as that of the beds eastward of the fault, is gradually diminished to 7°. These beds continue for half-a-mile, when they are succeeded by others of a finer grain, in which are entombed multitudes of fishes. These fishes are converted into a substance of a pitchy blackness, which but seldom retains more than the general form of the organism. In such as are sheathed in a bony carapace, the blue tint imparted by phosphate of iron is frequently observable.

In these beds *marcasite* nodules are rarely found, *calcitic* veins fill cracks which run south: Thin veins of *stromnite* occur both in the flags and in the conglomerate. Two trap-dykes with associated *lydian-stone* cut the strata from west to east.

The *lydian-stone* occasionally has a structure resembling fossil-wood.

The conglomerate rents are small: they cut the nodules rarely, but do not shift them.

Piecing together this evidence, and reading therefrom the record of the rocks, it is evident that, though in no place do we see the basement layers, the Orkney beds were deposited upon a very uneven bottom—the bottom, so far as Orkney discloses, of a shoreless sea—a bottom from which in one spot there protruded first a rocky gneissic islet, converted by a sinking land into a skerry-like ridge, against which the surf of a westerly-sea beat, so as to form a fragmentary shingle. That through the continued sinking of the land there had been deposited upon the conglomerate so formed, first, the muddy silts which, exposed to sun and rain, became the pabulum of plant life; and secondly, the still muddier deposits into which the remains of animal life sank and were entombed. Lastly, the dipping away of the strata from both sides of the supporting ridge,—and that at an angle which, in the immediate contact is higher than that which is normal to the series,—speaks unmistakably of local elevation and protrusion of that ridge, probably anteriorly to, but at least independently of the general elevation of the land.

As a locality of special geognostic interest, the coast line from the Bay of Skail half way to the Black Craig, on the west side of the Mainland, may be instanced.

The various points of interest along this shore are not only numerous in themselves and diverse in their nature, but they are also seen with very unusual facility; they moreover present themselves with very unusual clearness.

The locality is, in the first place, an open book of illustration of the *warfare of nature*—of sea and air sapping the foundations, and scalping the cornices of the bulwarks which confine the former in its bed.

These illustrations are very different in their mode of operation to those noticed when speaking of the coasts of Shetland; *there* the assault was direct, and unmistakeable; here, on the other hand, it is insidious, and is carried into effect frequently by what may be called a flank movement.

This diversity in operation is due to the difference in the nature and bedding of the rocks. Here the strata, consisting of thin-bedded and unusually-fissile schists, repose in sheets, which are nearly parallel to the waves at their base; the dip being only 2°, and to the N. ½ E ,—that is at right-angles to the line of coast. The seams of the rock are thus as open to the insinuation of the wave-wedges, as are the leaves of a book to the thrust of a paper-cutter.

Again, the beds are cut at right-angles to their dip, by a series of trap-dykes which have filled up pre-existent rents. These rents were merely the most widely-gaping of a system which cuts the rock with very unusual frequency. The slabs of rock thus lie almost unattached to one another in two directions, like a number of closely adjacent packs of cards, —ready to be displaced whenever the disrupting force is sufficient to separate them by merely overcoming their gravity.

But gravity may even aid the displacement, should the circumstances admit of its coming directly into play. At the southern corner of the Bay of Skail, the circumstances are such. Here two closely-adjacent dykes have cut the interstitial beds loose from any but their own adhesion. The surface-waters, playing upon the jointed and rhomboidal blocks, first widened the open joints by their solvent soak, and then lightly lifted them out of their seats, towed them from the land, and thus gradually tunelled a low and deep-water cave between the dykes. As these cut a promontory from side to side, the straight-sided tunnel so formed passes through the land, forming what is called the Hole of Rowe.

Heavier surfs and loftier surges forthwith lashed their spray against the roof of this low passage, opening out the rents between block and block, and between these blocks and the retaining igneous walls. Gravitation now aided the rending, and slice after slice of the sandstone was dropped into the waters, just as card after card falls from a horizontally held pack, when the grasping fingers are gradually relaxed.

The falling in of the roof of this tunnel is but a question of time; ultimately a *stack* of Rowe will appear,—the sides of the intervening chasm being sheathed with trap,—leading perchance to the false conclusion that a dyke of unusual width had yielded to the assaults of the sea.

Doubtless it is on account of this unceasing widening of the horizontal crevices in flatly-bedded rocks, through the sap of the waters, that we so generally see a dip of these rocks away from the land and towards the sea,* whatever be the dip further inland. Gravitation closes up the open joint *pari-passu* with the widening,—folds the land prone to the waters,—till the *nodding* tears open a longitudinal rent, and the dissevered mass gradually "topples to its fall."

It has been said that the agents of destruction often operate by flank-attack; the cutting out of the Hole of Rowe has been indeed much of that nature, but a more decided illustration is in the near neighbourhood to be seen.

The cliff, marked in the Admiralty Chart as 180 feet in height, is capped by a shallow covering of turf, with underlying ochery-clay. The land rapidly falls landward to a hollow, scarce a hundred yards distant.

This slope is cut into wide and deep channels,—the beds of streams which must sometimes rush in brimful fury. But these channels commence but a few feet from the brink of the precipice; and the water-shed is so narrow that in the most rainy weather merely a trickling stream follows their landward course. Not so, however, when the Atlantic surges top the verge, and the overflow of the loftier billows, sweeping along in salt-water rivulets, fills them to the brim, and by rutting out an ever-widening channel, acts as a pioneer to the ordinary operation of the waves in cutting sea-stacks from the land.

Still another illustration of the battle of the elements is here to be witnessed.

Higher up upon the grass-clad banks, a gun-shot and more from the brink of the precipice, lying loose and lightly-poised upon the sward, there lie numerous flakes of stone. Around them, and between them and the sea, the grassy banks are all unbroken; the surges therefore did not lay them there,—but the wind, forcing itself wedge-like into the crevasses of the many-jointed and thin-bedded strata, had torn them from their beds and scattered them over the land like winter leaves.†

* I am indebted to Dr. Joass, of Golspie, for *pressing upon my attention* this too-much disregarded fact,—it is far from universal, but is very general. The explanation is patent.

† The Revd. Dr. Clouston thus describes the aspect of an ordinary gale at this spot. "During a storm from the west the scene is awfully grand. The large accumulations of water that then roll after each other, foaming with terrible violence to the shore, impress the mind with irresistible power, and might well give a stranger a feeling of insecurity; and, when they dash themselves against the precipice, it seems half sunk, for a time, like a wrecked vessel amid the waves; sheets of spray are thrown far up into the air, and carried over all the country, making springs a mile from the coast brackish for some days, and encrusting everything with salt, even fifteen or twenty miles off. I

At some spots of the coast, the numerous joints and cross-rents of the rocks have produced an appearance much resembling a shattered tesselated pavement. Jameson, Fleming, and many older writers have noticed it.

In Wallace's "*Account of the Orkney Islands*" published in the year 1700, he thus describes the locality.

"At the West-end of the *Mainland* near *Skeal*, on the top of high rocks, more than a quarter of a mile in length, there is something like a street all set in red clay, with a sort of reddish stones of several figures and magnitudes, having the images and representations of several things, as it were, engraven on them; and, which is very strange, a great many of these stones when they are raised up have that same image engraven under, which they have above. This causeway is all along the tops of rocks, and though they be otherwise of a very considerable heighth above the sea, yet the West Ocean in a storm leading that way, does dash with such violence against the rocks that the sea breaches do wash the ground on the tops of the rocks. If these stones had not the same figure on that side next the ground as they have above, I should think the sea washing over them might occasion these different figures, by washing away the softish parts of the stone and leaving the harder, and so accordingly give them these accidental shapes and figures. Tho' there are a great many of them still remaining, yet the gentlemen living near that place have taken the prettiest figures to set their chimnies with, as they use to do in *Holland* with painted bricks and tiles."

Dr. Fleming, in the 8th vol. of the Edin. Phil. Jour., thus describes it.

"The strata have an inconsiderable dip, and consist of thin slaty sandstone, abounding with argillaceous and ferruginous matter, with minute scales of mica. The uppermost layer or even layers when exposed to the action of the atmosphere, aided occasionally by the spray of the sea, becomes divided into numerous tabular pieces, by means of vertical rents, and exhibits the appearance of mosaic work. These tables are irregular, but differ in the number and relation of their angles, although they sometimes exhibit regular geometrical forms. Upon the layer being thus

am told by those living a few hundred yards from the spot, that the floors of their cottages are shaken by the violence with which the waves strike the crags. and I have seen innumerable sea insects alive on their summits, and even a limpet adhering to them after such a storm also numerous fragments of slaty stone, some of them a foot long which had been whirled into the air, and had penetrated six inches into the soil in falling.

On the top of one of these crags I once picked up a lump of India-rubber covered with barnacles.

Not far from Rowe, is an immense rock which is well known to have been carried a considerable distance by the sea; it is 16 feet long, 6 broad, and 3 thick, and weighs, according to my calculation, 24 tons.

divided, decomposition speedily takes place. It proceeds from the sides towards the middle, and as the decomposed matter is washed off, the table exhibits a depressed border, marking the extent of the decay, having the middle raised, and consisting of unaltered matter. In some cases there is a well-marked groove, separating the two portions. In both varieties there are prominent irregular pieces of the rock, which seem little liable to decomposition."

To me there seemed to be a greater amount of regularity in the cleavages and angles than Fleming seemed to have observed. The rock almost always splits up into lozenge-shaped fragments. At one locality these were generally pretty uniform in size,—being 7 inches by 6; at another the general size was 6 inches by 5.

The averages of many measured angles of the lozenge were 109° 30′ and 70°30′—the greater angle varied from 106° to 114° the smaller from 67° to 72°30′. Dr. Fleming remarked that the number of angles differs. This would, however, appear to be due to the simple truncation of the acute angle of the lozenge.

The depressed border, generally of a bright yellow, is about an inch in width and is usually margined on its inner side by a trench and raised ridge, each differing in colour; there is thus produced a structure of singularly artificial appearance.

The splitting up of this rock and the manner of its weathering is assigned by Dr. Fleming to the action of the air and the spray of the sea; the splitting up of the rock at least might with greater probability be assigned to a certain amount of definite structure in the stone; and when it is observed that both the thick and the thin flags of the country show a general tendency to a rhomboidal arrangement between their strike and dip-joints, there can be little doubt that this is the true cause.

Indeed the very marked regularity and persistence of the jointing of these Orkney flags determines to a very great extent the marginal contours of the rock as a whole, and its endurance or decay under the influence of the agents which are free to affect it where exposed in the rock fringes which mainly gird the islands.

A long familiarity with the sea-cliffs of this formation, and a close consideration of those of other formations, has convinced me, *first*, that whether the agencies of decay operate singly or cumulatively, the rapidity of the decay, destruction, or local transfer, is to be assigned *far more to internal weaknesses*, either physical or chemical, than to external agencies. *Secondly*, that in our attempts to interpret the operations of nature, *there is far too great a tendency to ascribe change to the sudden and violent operation of the forces of convulsive effort,—to the almost total disregard of*

the gentler and continuous operations which, through their being protracted in time, come to be insidious in their workings.

That the precipices which girdle our shores are in one sense *sea-cliffs* is most true, but that they were all or to any great extent *sea-cut* cliffs is more than doubtful.

The sea maintains the perpendicularity of the cliff, it is true, by sweeping away the debris from the foot; but very seldom has the sea formed the cliff, by a continuous battering of the looser rock-layers at the summit; or by the breaching of an undercut recess at the foot, so that gravitation by the rent of a sudden fracture hurled the overhanging mass into the ocean. The rent was an open joint,—a component feature of the rock-structure,—independent altogether of gravitation's working, and while yet the sea was far off from that portion of the land.

On studying all the varieties of cliff which are to be seen in these islands, the observer will note that they group themselves into three forms,—that these forms are invariably associated with the dip of the strata,—and are only well defined if the dip is decided on the one hand, or if the stratum is horizontal on the other.

In those cases in which the dip is seaward, an outlying tidal-skerry with its wedge-like slope, forms a breakwater for the land; the surges are for the most part spent in force in the intervening channel; and but a low fringe of broken cliff protrudes from the land,—which, in such circumstances, thrusts itself beyond the usual line of the shore.

When again the dip is towards the land, a lofty precipice with step-like front, formed of the strike-joints usually at right-angles to the bedding, is the form assumed.

But the form which far most commonly arrests the eye, is a straight-lined and truly mural sheet of rock, which stands erect out of the waters, either directly in the general line of the shore, or projecting boldly seaward nearly at right-angles thereto.

Brief inspection shows that these sheeted, and wonderfully smoothly-cleft faces of rock are merely the joints of the stratum; longer inspection shows another set of open joints to run far inland at right-angles to the coast-line, and rents continuous with these or parallel thereto to succeed one another, with scarce any diminution in their frequency, till the sward conceals them.

These "backs and cutters" then—the shrinkage cracks of the rock—determine the nature of the frontlet of cliff. That the face of the cliff has been formed by a sudden falling away of outside material is evident,—that the material which fell was borne off by the waters is equally so,—but that the waves *by their battering* produced the fall, is far from evident.

The jointing is an element of weakness; in certain circumstances it may become an actual agent in the destruction.

Should these be any seaward dip of the stratum so that the strike-joints overhang, should these joints reach to the lower stratum, and should their frequency be such that the centre of gravity of any of the slices thus about to be cut from the land overhangs its base, then its fall is prevented merely by the molecular adhesion of its basement layers. This, feeble at all times, may be overcome by the vibration into which a single billow may throw the whole mass; or the wind may overwhelm it in a gale; or air-rotting may crumble its support.

Even indeed where the jointing is not so frequent or so close as to produce such toppling masses, they may be brought into a toppling condition by a process of wedging from above.

Near Hoy Head at a height of over 1000 feet, parallel to but far back from the cliff edge, long gaping chasms are to be seen, more or less filled with earth, clay, and jambed blocks of stones.

Into what was first of all a mere line of cross-cleavage, the entering air, by peroxidising the iron compounds, threw scale after scale from the mouldering rock, widening the crack above, and supplying material which hereafter would perform the function of a wedge. The process is one in which the operation progressed in ever increasing ratio of speed:—the downward progress of the rent opened a way for the operation of a water-wedge. Here the fashioning of the line of cliff, left to the operation of such agents alone, depends upon the relative amounts of the adhesion of the rock laterally and vertically. If greatest laterally, then will the wedge displace but a small depth of the stratum, dislodging it along the lines of bedding. If the bedding be not distinct and free, then must the wedge find a slow passage till the waters entering from beneath dislodge the material which plugged the rent.

In such a situation the waves could take no immediate, or at least primary part in the remodelling of the cliff; but it is not meant to be insisted on that the sea plays no part in the circumstances ordinarily obtaining.

There the ocean is ever lying in wait, surging and seething round the foundation-strata, sapping into every chink, and ready to spring at every weakened joint. Rushing with concentrated force up two closely-adjacent cross-rents it may lift out the intermediate blocks to make a widened *geo*, simulating a washed-out trap-dyke; or it may and often does remove the material of true dykes. No weakness can be hid from it; and, as the gales run round the different points of the compass, a crevice cut at right-angles to the first, allows the waters to meet those circulating in

it, and a quadrangular sea-stack now stands apart from the land. The waves, moreover, ever remove the debris of each fall, and so allow no prop to impede the continuance of the destruction.

But while thus admitting the part they must thus play, too much stress cannot be laid upon the assertion that the special conformation of the cliff-scenery of the Old Red Sandstone is due, as Geikie puts it, "not so much to the breakers (though their force is enormous) as to the less conspicuous action of atmospheric agents, which cut slice after slice from the edge of the land."

The situations in which among these islands the waters would at least appear to be the chief factors in breaching the land, are three.

First, water-floored caves; the second in the case of lofty projecting headlands, such at least as are not protected by a boulder-beach of stones; and thirdly, deep re-entering bights into which the waves converge as into a funnel, and up and over the converging cliffs of which they rush with heaped-up volume, and almost incredible might.

The first of these cases or localities are those in which a superficial observer would decline to accept the conclusion—that it was not the operations of the sea which had alone to betaken into account. I advert to those deeply-burrowing caverns—frequently with rounded, widened, and roofless terminations,—called *gloups* or *syngens*, in the language of the north.

As there is no part of Scotland in which there are so many or so fine illustrations of these, I take from the "Statistical Account" of the islands, and elsewhere, the following descriptions of such.

In the description of Westray, we read—"Here (Noup Head), besides many curious excavations in the apparently solid rock, are to be seen subterraneous caverns, formed by the influx and reflux of the sea. In some of these, the water at high tide, and in tempestuous weather is forced up through narrow crevices of the rock to the distance of nearly a quarter of a mile landward, and bursting out at the surface from orifices of its own formation, springs up in the air to a surprising height.

"Among the natural curiosities of the kind here to be met with, that called The Fort, evidently formed by the action of the sea, may not be deemed unworthy of notice. This remarkable place is situated on the northern boundary of that part of the island called Akerness. Here, standing upon a lofty precipice, you see, underneath, an immense cauldron in perpetual agitation, from which a hideous and gorging noise ever and anon ascends, stunning the ear. You can walk nearly half way round this mighty cauldron, on high pillars of solid rock, arched over with the same solid material. One or two broken or separated columns standing

out furthest in the circle, from which the arches seem to have been swept away by the agitated element, heightens very much the grandeur of the scene, and gives to it an appearance truly picturesque."

"On the north extremity, Papay Westray terminates in a headland, bold and lofty, called the Mull of Papay. At this headland, is a cave, deemed one of the greatest natural curiosities of the kind to be met with perhaps in all the country. Its interior presents the appearance of an immense amphitheatre. The roof, upwards of 70 feet in height, is somewhat like a regular built arch,—the beds of rock on every side rising the one above the other, in the form of steps in a stair. The entrance is about 50 feet in width, the breadth of the middle part about 60, and the most interior 48. The floor has a little inclination outwards, but its surface is smooth and even to the foot. It is called the How of Habrahelia."

"In the vicinity of Halcro Head, in South Ronaldshay, there is a remarkable cavity known as the 'The Gloop.' In a heath-covered mound, some two hundred yards or so distant from the shore, there is an opening like the crater of a miniature volcano, and far away down in the abyss you hear the sullen plunging, gurgling, and groaning of the imprisoned sea. The waves have excavated a long subterranean passage or gallery, which echoes with their thunder-boom in the day of storm."

"On the west side of Scalpa Bay, there is a cave called the Salt Pans, which runs parallel to the shore to the distance of twenty paces. The front has the appearance of freestone pillars, placed at irregular distances of about five feet. Above and below, and also behind these pillars, there are *rocks of harder stone.*"

"At the Vat of Kirbuster in Stronsay, the sea has broken a magnificent archway through the front barrier of rocks, and, having once forced a passage the waves dashing and lashing through the archway for centuries, have formed an enormous excavation among the rocks behind, which being open to the sky, presents on a huge scale some resemblance to a vat. The archway may be likened to some work of massive Titanic masonry, and there is a wild sublimity in the hollow echoing boom of the waves as they bound from side to side of the arch, and break in foam within the mighty caldron of stone."

Similar to these are the "Syngens," near Scabrake Head in Rousay, and near Snelsetter, in Walls: in one of the latter, the communication with the ocean is always below low-water mark, notwithstanding which the mast of a vessel was once found floating in the land-encircled basin.

Other similar ocean-floored caverns have been noticed at Scraada, in Shetland, and in Fair Isle; and those of the Gellie Pot, near Arbroath, and the Bullars (boilers) of Buchan are well known.

In all of these, though the sea is directly the instrument of destruction, —as even the description of the Fort in the "statistical account" would indicate,—yet it is equally evident thatsome local peculiarity, conformation, or weakness of the rock, as directly accounts for the *exceptionality* of that destruction.

Where the sea penetrates it the extraordinary distance of "nearly a quarter of a mile" beyond the ordinary coast line, as vouched for by the pastor of Westray, there must have been some extraordinary softness or looseness, or facile-solubility in the mass removed. In this case, a crumbling dyke of trap, in that, columnarly-crevassed basalt, here, a soluble calcareous-seam, and there,—as at the Gally Pot,—a vein (baryte) with loose attachment to its walls.

So that in these cases, even more than in the circumstances which ordinarily obtain, we are brought back to the same conclusion—*inherent weakness* in the ordinary case,—*exceptional weakness* in the extreme cases.

The Bery Head in Walls, and the cliffs of Foula are instances of the second of the situations in which water would appear to have been the active trencher upon the confines of the land: here the sea by undercutting, may have induced a true rent from top to bottom.

Rackwick Little, and other points between Melfea Hill and the Bery on the west side of Hoy, are instances of the third. In the riven and crumbled rocks, the torn up turf, and the subsoil gashed far back from the cliff edge, the spectator will see evidence of the operation of some agent of terrific might; but when, he contemplates the height of the cliffs, he will be slow to believe that the waters of the ocean sleeping at their foot can have been so elevated as to have been that agent. Only the seeing them in the work of destruction, or the observing live limpets adhering to the summit of the rock after a storm, would help him to believe in so tremendous a displacement.

Yet in the ordinary case their effect is but small. Some estimate of the amount of its action may be arrived at from what the writer was so fortunate as to witness during a storm of unexampled violence which occurred in the winter of 1851.

The locality at which the effects of this storm was witnessed, was the Scabrake Head in Rousa,—one to which strangers visiting the island are frequently conducted to witness the spectacle of the ocean in wrath.

This headland consists of a mural wall of rock of about 120 feet in height, which faces the north-west. At the southern extremity of this extended wall there is a projecting bastion, termed from its form The Knee; from this, as it is thrust at right-angles to the main cliff some distance oceanward, the lash of the waves against the great wall, and the turmoil of the waters beneath can be viewed to advantage.

The cove between these opposing fronts of rock is a very place of storms: except in the calmest weather, the agitation is here incessant, and this is occasioned by two circumstances.

The first, that across the ocean, and right in front of this cove, the *röst* of one of the swiftest tidal races in the islands* runs with its curling waves and resistless rush of waters, in the very face of the incoming billows of the Atlantic. The second, that the moving mass of oceanic water, somewhat broken in its continuity and irritated into increased volume by the convergence with itself of the huge masses of the rollers of the *röst*, finds itself, as it enters the funnel sides of the cove, suddenly shot up from a depth of fifteen fathoms, to one of four. The result is that, there no longer being depth commensurate to the amplitude of its oscillation, it *peaks into a breaker*, and flings itself at the cliff with a volume and a violence which is altogether exceptional.

In an ordinary gale of wind then, there are four circumstances which here combine to enable the force of an ocean-billow to operate with extreme and abnormal violence.

There is *first*, the directness of the exposure to a mass of water of say 20 feet in height,† the undulation of which is rushing over the ocean surface at the rate of from twenty to thirty miles per hour.

Second, that undulation has to run diagonally across the rush of the waters of the tideway, which are moving in an opposite direction at say 7 miles per hour,—and it catches right in the teeth, and coalesces with the rollers of that tideway, which are as lofty as itself, though far from as ample.

Third, its waters come to be heaped up latterally, by the sides of a widely extending and converging V shaped shore.

Fourth, they are thrown vertically upward by the rise in the bottom, but there is still depth enough, and perhaps just depth enough for them to submit the cliff to the full concentration of the blow.

On the occasion refered to by the writer, a succession of westerly gales had continued for about eight days; on the morning of the last, the tide rose to a greater height than it had done for twenty-eight years, and the gale

* This Röst has thus been described by Gorrie in his "Summers and Winters in the Orkneys."

"Listen! and you hear a roar from the nor-west, as if the Atlantic were about to burst down upon us with the thunder and tramp of irresistible waves. It is the Roost of Enhallow, swirling, tossing, and boiling in the ebb-tide—a terrible sea-cateract from which unskilled navigators might well pray to be delivered; happily for us, our course did not lead us near the foaming lips and roaring throat of this Maelstrom of Enhallow."

† Dr. Scoresby measured, in the Hibernia Atlantic waves 33 feet in height. In the Royal Charter he measured waves at the Cape of Good Hope 45 feet in height. The highest wave which the writer measured during several months in the Atlantic was 21 feet.

raged with a fury which exceeded that of any within the memory of the islanders.

It is altogether beyond the power of the writer, if not beyond the power of language, to convey any idea of the spectacle which was seen from the summit of The Knee upon that day,—beyond saying that the violence of the blows which the cliff received, the height of the billows, the distance to which the broken waters were wind-borne landward, the size of the masses of flying foam, and the lashing and seething turmoil, altogether surpassed anything he had seen either there or elsewhere.

Though, however, description fails, some of the *actings of the waters* may be in bare language stated.

There was no regularity of motion whatever in the embayed water—it was a tortured mass which was twisting and tossing in an unceasing turmoil. Into this seething mass the greater billows would roll, as usual in sets of three; the upper waters of the first would spring back like a shower of snowy bullets discharged from the stricken rock; the back-tow of its recoiling mass would meet the upheaval of the second, and the united volume would spring aloft in a lighthouse-like form, level with or over-topping the main cliff. The third wave would throw itself headlong into the falling and subsiding vortex. So frequently did this happen, that it seemed to be worthy of consideration whether this habit of the ocean of rolling ever in three giant-waves, followed by a succession of minor wavelets, was not a provision for checking the power of the billows to rend the shores,—there being, in this mode of their action, a clear indication of self-destructive effort;—certainly so as regards this special locality.

But the rock did not always escape the full force of the blow of the greater wave, though during the time it was watched, it was so struck only some six or seven times. About one half that number of times, the wave was beaten back; the other half *it topped the cliff*.

With a seeming rush, as if it were pervaded with an actual intention, it would fling itself against the cliff and strike it in full force. On these occasions the shattered water shot up into the air erect, but in such ponderous masses that they were uninfluenced by the gale, falling vertically back to the spot from which they rose; these masses of water were thrown to a height apparently two-and-a-half times that of the cliff itself.

When it topped the cliff the spectacle was an inconceivably grand one. Like a solid but plastic mass, it curled over the verge,—a wondrously beautiful mixture of pellucid emerald, streaked with the purest white. The waters rushed with seemingly resistless force far up the land-slope—returned with a noise like the roll of many wheels, and fell back along

the whole extended line of the cliff, muddied and discoloured, bearing great slices of the turf and stones,—a perfect Niagara of clay and water.

A somewhat similar development of power was seen at an adjacent locality. A projecting tongue of land,—narrow, but eighty or one hundred yards in length, 90 feet high at one end and 70 at its extremity,—landlocks a bight, which, from its proving a safe shelter for boats in ordinary storms, is called Providence Geo.

On every other occasion in which the writer had seen it in a gale, its sombre waters were smooth as those of a mill-pond. On this occasion a long extended billow, rolling towards its seaward side, suddenly erected itself, rushed at the cliff like the charging front of a regiment of soldiers,—seemed hardly to touch the basement of the cliff, but flung itself with curling cap right over the tongue, and fell into the Geo. In the Geo the waters were not greatly agitated,—a Cunard liner could have lain without much motion, but the pent up foam would have been mantling over her bulwarks.

Such a storm as this has never occurred since—it was the spasmodic effort of half a century. And what did it *accomplish?* It has been seen what it could *do*, but that was all froth and fury. *It did nothing in the way of altering the old landmarks!* When the waves struck the cliff the blow resounded like the discharge of far-off cannon, but the rock did not shake:—the crest of the cliff when examined afterwards showed much riven earth, and scalped soil, with a surface clean-swept of stones; but no mass was disjointed, there was no rock rending. In a few summers the turf would grow again—has grown again; *the ocean battery had accomplished nothing!*

Surely then we must conclude that the ocean is not the direct agent in the fashioning of the fringes of the land; that the chisels which cut the huge bastions of Foula and of Hoy, rank with the ceaseless and the abrading grasp of oxygen, the expanding dislodgement of the summer's heat, the soak of the raindrop, the influence of the balmy dew; that they are the agencies of the calm, and not of the whirlwind and the storm.

Among the beds in the neighbourhood of Yestnaby there are some thin layers of limestone, sometimes impregnated with bituminous matter and radiating *pyrite*, and one of these beds is possessed of a structure which I believe to be unique.

In the localities in which I saw it, it appeared to have been somewhat acted upon by the weather, so that the peculiarity of its structure was advantageously disclosed.

It could be raised in slabs a couple of feet in dimensions, by three to four inches in thickness. Its upper surface exhibited a *pustular* and a *pitted* appearance. The pustules were the terminations of finger-like projections of calcareous matter; the depressions were due to the washing out of the dark blue laminated silicious and micacious rock which filled in the interstices between the projections. These were about one and a half inches in length.

When the laminated matter was uniformly chipped out from the calcareous, there remained a structure which *when inverted* bore a great resemblance to the roof of a limestone cavern from which there depended a multitude of regularly-spaced stalactites of nearly uniform dimensions.

When the slabs were broken into fragments, these bore a marked resemblance to a number of elephant's grinders, laid so that the fangs *presented upwards*. They are called the "horse-tooth stone" in the district.

When this calcareous band was fractured, it exhibited a structure similar in all respects to that of a stalactite—both the laminated structure of the dependent stalactite, and the circularly zoned and radiated structure of a transversely broken stalactite.

But the acuminated terminations of the processes which I have compared to stalactite *project upwards*. Had they been dependent, their formation would have been most difficult of explanation; as it is, it appears to the writer *inexplicable*.

The calcareous portion of this singular bed is of a dull ochery colour.

Sketches of this singular structure are given in Plates XIV & XV. The one shows the mastodon-like appearances of the cross fractures; the other the aspect of the surface of the bed. The hollows with the volcanic-like cones are the calcareous portions, doubtless dissolved out somewhat, and leaving a harder or less soluble core.

The interest connected with the trap-dykes of this locality lies in the very different nature of their lithological composition. Seven dykes are to be seen between the Bay of Skaill and the granite of Inganess.

Of the two which are closely adjacent at the Hole of Rowe, the more northerly shows merely crystals of *augite*, imbedded in the usual labradoric and augitic doleritic paste, the other contains in addition much *olivine*.

The three which follow have a direct magnetic east and west course. The first shows augite with imperfectly developed *zeolites*. The next is of a dense structure devoid of imbedded crystals, and has a highly-marked blue colour. The third is a ringing clinkstone.

The dyke which follows exhibits a marked departure from that rectilinear course, which characterises the great system of Scotch dykes. From a W. by N. it suddenly curves round to W.S.W. course, and as

suddenly regains its original direction, exhibiting thus a bold sigmoid flexure: its structure is amygdaloidal.

The seventh dyke, which cuts off the granite to the north, is almost white in colour from excess of its felspar, and minutely cryptocrystalline in structure.

Jameson mentions another dyke, (of this I however only found loose fragments), namely, one containing "crystals of hornblende more than an inch long by half an inch broad." These crystals are of a grey brown colour, and very lustrous,—the cleavage seems to be that of hornblende, but I failed in my endeavours to pick it sufficiently pure for analysis.

These dykes vary in width from two to about ten feet: the small distance to which the rock is indurated on the contact surfaces,—about a yard,—is much the same at both the narrow and the broad dykes.

The southern front of a cliff near to the Hole of Rowe exhibits an interesting mass of stalactite: the calcarious waters have found their escape solely at one spot of the surface of a single stratum of the rock, about forty feet over the face of the cliff. From the open bed of this, the concreted masses twine in wavy curves downward, like the curlings of a huge beard.

As the rock approaches the termination of the granitic masss at Inganess Point it becomes less argillaceous, till at one headland it is of the nature of a grit, and has been to a small extent quarried for millstones. As regards its hardness and toughness it is well fitted for such, but it is hardly of a sufficiently coarse grain.

The immediate locality where the granite terminates well deserves a close inspection, as it is a locality which will probably throw some light upon the metamorphism of gneiss into granite,—there being little doubt that such a change has here occurred.

From an angle in the shore-line the rocks have been exposed in cross and also in longitudinal section. A sketch has been appended. (See Plate VIII.)

The long wedge of granite previously described, seems to have nearly thinned off immediately to the south of a trap-dyke; but the sea has intruded here, so that at the spot where the central rib of granite presents itself, this cannot be absolutely determined.

On the north and south cliff-line a white trap dyke, which runs nearly at right angles thereto, separates the horizontally-bedded grit from a shattered mass of granitic-gneiss. The westerly continuation of this dyke shews itself as a small sea-stack, and it thereafter cuts the same gneiss which at Stromness is seen to overlie the granite.

The central rib or core of granite which fronts the trap-stack is amorphous, and is rent by promiscuously disposed fissures; but to the west it becomes distinctly bedded and slabby, before it passes into laminated gneiss. The slabs dip to the west. In the central part of this east and west section, a conglomerate, formed from gneiss, passing upward into gritty flags, overlies the gneiss, with a dip to the north.

The gneiss which is cut by the dyke is much altered for four or five feet at contact, but it does not appear to have been faulted.

There is a small amount of disturbance both in the sandstone and the granitic-gneiss where it cuts the bank, so there probably is here a small fault which dies out to the west.

From the grit coming-in immediately to the north, the upthrow must be but small; but that a fault really exists may be deduced from this that there is no continuation of the granite north of the dyke along that which is its medial line: it is seen at Steinicknow in mass, and if it were not cut off it should appear (which it does not) still further to the north.

Turning the western point of Inganess, we find at a short distance south, the ordinary rhomboidal-jointed blue-flags reposing with a westerly dip upon the gneiss; and these blue-flags continue, with occasional parallel dykes, southward to the Point of Ness. They reach their greatest height at the Black Craig; and either here,—at Costa Head,—or at the hill of Blotchinfield in Rousa, we must have the greatest thickness of the blue-flag formation in Orkney.

The dip to the west of the strata which on that side are in immediate connection with the gneiss at Inganess,—the dip to the north of the strata lying northward of it,—and the continuation of that northerly dip as far as Rowe, lends additional countenance to the view that the islet of primary rocks had been subjected to local elevation, independent of the general elevation which raised the whole basin of the sandstones above the waters.

Dr Clouston remarks—"On the east side of the granite, it is only the strata in immediate contact with it which dip east; for, in the course of 100 yards, they gradually dip more in conformity with the general dip of the country; but they may be seen dipping east on the shore of Græmsay, and at the point of Garsen, in Stromness; and again they dip north-east at the Burn of Cairston, and at the north-east boundary of the granite."

The strata thus dip away from the granite and gneiss on every side, unless it be on the southern extremity; and the first of Dr. Clouston's observations points *almost conclusively* to there having been an upward thrust of the granitic islet after the schists had consolidated upon its flanks.

Taken in conjunction with the general dip of the whole series to the west, as first seen in Stronsay and last near Cairston, it shows also that the Stromness flags are far up in the series,—that the granitic reef protuded long above the waters,—just as, away to the westward, the Stack and Skerry do so still.

Now this is exactly the conclusion which has already been arrived at by Professor Geikie from a consideration of the Hoy sections, as will be noticed further on.

NORTH RONALDSHAY.

In this low-lying island the rocks show but two varieties—the flaggy and the argillaceous.

The flags have been wrought in a quarry at the north-eastern end of the island. They are of somewhat tougher consistence than the flags of Caithness,—are less bituminous, and cannot be split into such thin slabs.

They can be raised here probably of greater size than at any other quarry in the islands.

A dressed slab, which of itself went a long way to form one side of the roof of a cottage, was found upon measurement to be 14 feet long by 8 broad, and about 2 inches in thickness.

The dip in this quarry is to the east, at a low angle; but east and west dips are equally frequent, and would in some spots at least appear to be in some degree connected with the disturbance caused by dykes which have no connection in any way with the great west and east system of western Scotland.

I was much struck by observing that the chief material of these dykes, which generally cut the strata at right-angles to the line of the dip, consisted in chief part of *limestone*,—indeed most frequently of *calcite* in large cleavable masses. So preponderating, indeed, is the quantity of lime relatively to the other material of the dykes—a soft green tufa—that it cannot be regarded as an exfiltration therefrom; and we are almost forced to the conclusion that the calcarious matter had itself been erupted in a fluent condition.

The amount and nature of the surrounding disturbance, putting out of account the adhering tufa, altogether and alone precludes the view that there are pseudo-dykes,—the result of exfiltration into a tear or cross-rent.

So interesting are the appearances, that I thought it desirable to obtain independent evidence, and I therefore requested the proprietor, Dr. Traill, to favour me with a description of one of the largest of the dykes.

Dr. Traill is a most observant naturalist, and a careful recorder—he writes:—"The position of the limestone at Howar is on the shore below high-water mark, about a quarter of a mile south of the house, or S. by E. It seems to be an erupted mass of crystalline limestone, in some parts largely mixed with fragments of the blue flagstone, through which it appears to have forced its way. Length about 65

paces,—its direction S.S.E. by N.N.W., extending at the northern extremity perhaps half as far again in several small indistinct veins. Greatest breadth about 6 feet, but mixed with fragments of flagstone or shale, or impure blue limestone. The greatest breadth where it is comparatively pure or unmixed (calcite) is about two feet or rather more. Perhaps the average breadth of the extended mass is between $3\frac{1}{2}$ and $4\frac{1}{3}$ feet, but the measurements are only approximative on account of the admixture of other rocks. As I have said, it tailed off indefinitely at the north end, but at the south it came to an abrupt termination on account of the rock ending there. The position of the strata is there much disturbed."

The shelving rocky shores on the west of this island afford illustrations of the manner in which the Atlantic surges tear from their connections. and transport huge masses of rock.

The illustrations differ here in their nature from those noted in Shetland; they may not be so astounding, but they do not yield to them in instructiveness.

In speaking of the huge blocks of stone which on the coast of Shetland hang toppling on the verge of the cliff, I said that they had been *flung* there by the surge: all the circumstances of their position convey the impression of a sudden and supreme exertion of force; those to be seen on the shore of North Ronaldshay again convey the impression of transference by flotation. The first are in fact *perched* blocks,—the latter *transported* masses. The difference in the character of the shores accounts for the difference in the mode of projecture.

Here, the dip being at a gentle angle to the west, the flaggy shelves form a most perfect breakwater:—the smooth surfaces oppose no roughness, and no broken face which can receive and be shattered by the force of a blow. The curling billow, after its first crashing fall, sweeps unresisted in hissing and creaming foam, like a gradually thinning wedge, far above sea-level. The polished rock-surfaces in no way oppose the upward rush, in its vain fight against gravitation. The same gravitation which sweeps the undulation in speedy course along the ocean-level, calls back all individual particles which have transgressed the limits thereof.

As the rock is of two and a half times the gravity of water, a mass of 250 tons weighs but 150 while held in its grasp; and the tremendous pressure *a tergo* more than counterbalances the difference in gravity; so that every loose mass which presents a surface sufficiently broad in comparison to its weight, is floated off and onward, bouldering along

the unimpeding floor, until some portion of its thickness, by protruding upward through the thinning water-wedge, has *its superadded air weight* lodged upon its shoulders, to sink and settle it upon the bottom.

No second billow, unless it be one of a greater storm or at a much higher tide, can again float it; so that of the many shifted masses upon a shelving shore, few have had more than one dislodgement and shoreward rush.

It has been assserted that there are no raised-beaches in Orkney Several localities may however be pointed out where the sea can be shown to have stood for some time at a higher level than it does at present; while there are also numerous localities which prove a no very distant subsidence of the land. Of the former of these, two exist in North Ronaldshay.

Immediately to the south of the lighthouse, there are to be observed winding trenches depressed considerably below the general surface of the island; these trenches have rough and craggy sides, their bottoms being strewn with loose stones. They bear a most perfect resemblance to the channels of lanes of water left by the retiring tide.

The other locality occurs at a point or turning of the north-west shore. Here, at some little height above high-water mark, there is a flat, beach-covered, for a space of about 100 yards in length, with huge tabular masses of rock, undistinguishable, in appearance, form, and relative position, from those which are, in the near neighbourhood, to be seen on the shore at low water.

Dr. Traill thus writes of them. "They look at first as if they had been tossed up by a mighty tempest; but as many of them were at least 10 feet long, by 6 or 8 feet broad, and 2 or 3 feet thick, I felt inclined to doubt whether it was possible that they could have been tossed up by the sea, on such a shore;—and, on examining them more closely, I was more confirmed in this doubt by observing that several of these rocks were covered with grey lichen of considerable length, particularly those masses which are nearest to the sea. From this it would appear that the sea rarely if ever reaches to so high a level, except perhaps an occasional dash of spray in winter."

On the southern side of a picturesque geo about the spot where the crags are highest, concretions, probably investing some organism or coprolitic matter, are to be found; they much resemble a potato in size, colour, and form. Their internal structure is obscure—the investing rock-layers curve round them, in infolding them.

Jasper or a jasper-like chert is the only mineral body I have seen in this island. It apparently, from the line in which I observed loose masses of it, forms veins ruuning nearly N.W. and S.E. Its structure is very close and fine. It is usually of a bright yellow colour, with occasional heliotropic patches of a vivid green, both colours being disposed in a minute moss-like arrangement. Veins of pale-blue quartz crystals ramify through it.

ISLAND OF SANDAY.

Apart from the occurrence of the red and yellow freestone beds on the western shore, and the conglomerate of Heclabir, the chief point of interest as regards this island is connected with a boulder of gniess which lies imbedded in the soil of a field which slopes to the east, about 200 yards west of the house of Saval, and about 45 feet above the sea.

The writer is indebted to the Rev. Mr. Fisher of the parish of Cross for sending the following measurements of this stone.

"The boulder which lies N.E. and S.W. in the direction of its greatest length is of uneven shape. It is embedded in earth to a depth conjecturally of 2½ to 3 feet. Its circumference at the level of the surrounding earth is 24 ft. 3 in.; but, as it appears to shelve out under the ground, its circumference may considerably exceed this.

Its greatest height (above the ground) is at one end 2 ft. 6 in., at the other hardly 2 feet."

It appeared to me that the greater part of this stone lay underneath the ground; and, from the slope, that if dug round its greatest length would prove to be from east to west; its greatest height is to the west.

This does not appear to be a British rock. It consists in greatest amount of white finely-striated *oligoclase*, the crystals of which are penetrated by fine filaments of actynolite,—glassy quartz in much smaller amount,—dark green finely-foliated lustrous hornblende, in well marked crystals,—very little of a pale-green mica,—a minute amount of crystals of a pale brown mineral, which may, but does not appear to be *sphene*,—and a speck or two apparently of *thorite*.

The mass also contains a single crystal of pale-green *apatite*, five or six inches in length by over an inch in width; and this apatite contains imbedded *cryptolite*. The oligoclase has occasionally the moonstone lustre.

The only Scotch rock I know which has any resemblance to this, is the gneiss which occurs, with a N.E. dip, on the N.W. slope of Ben Spinnu, in Sutherland;—this however, has orthoclase as its felspar, and does not contain apatite.

The rock has much resemblance to a Norwegian one, and, if it has been brought on floating ice, the carry most probably was from the east, or north-eastward.

ISLAND OF EDAY.

In this Island the yellow and red upper-beds attain at the Red Head, which is somewhat more than 200 feet in height. a greater thickness than at any other point in the islands, unless it be the south shore of Scalpa Bay.

A boulder, which lies on this island, is described in the "Reports of the Boulder Committee," which are published in the "Proceedings" of the Royal Society of Edinburgh.

ISLAND OF WESTRAY.

The situation of a large stone called the Earne's Cup, was pointed out to the writer from a distance. It lay on the NNE slope of the Neuker Hill, near Pierowall. This probably is a boulder.

ISLAND OF ROUSAY.

This island consists almost entirely of beds of argillaceous flags; these attain here to a greater thickness than in any of the other islands; its highest hill being about 811 feet in altitude.

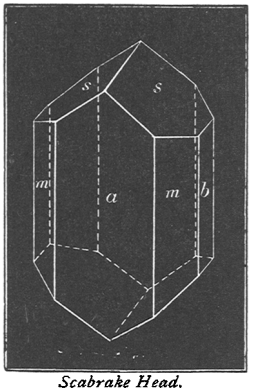
So horizontal is the bedding, so thin the beds themselves, so step-like, that it has been said that in order to walk in the island, the pedestrian would require to have a long leg and a short one.

The hills of the island, arranged in horse-shoe form, show little diversity in their rocks: at the mouth of a stream which flows from two central lakes, the rock is somewhat slabby; while at one point about a mile south of the point called Scabrake Head it is more arenaceous, the silicious grains being united by much *sideritic* matter.

At the shore below the house of Westness, it is so much jointed and indurated as to form almost a tesselated pavement.

Perhaps the finest piece of cliff scenery in the whole of the islands, though it be on comparatively a small scale, is the headland above mentioned. Here a geniculated prop stands like a flying-buttress thrown with wide-spread span apart from the main body of a mural cliff. A crush with a tilt in the bedding may be seen at the very point of the geniculation. A dyke which cuts off the southward continuation of the prop, may have had some share in troubling the stratification.*

* Mr. Gorrie seems to think that it may come to be the source of other and greater troubles, for he writes,—"There are volcanic indications about the island of Rousay, and the inhabitants need not be greatly surprised although they should find themselves and their belongings tilted up fifty or sixty yards, some fine morning before sunrise." Notwithstanding the precision of this prophecy, both as regards time and space, we would venture to assure the islanders that the foundations of Rousay are somewhat sounder than Mr. Gorrie's geology.



Scabrake Head.

This dyke is of a soft porphyry, which contains well-formed crystals of *augite* (H) of the size of peas, in the simple form depicted.

The hill faces, and corries about a mile north-east of this, contain *galena* in well formed cubo-octohedral crystals (H.)

Ichthyolytic schists, opposite an outlying stack called the Lobust, contain *bitumen* of the consistance of tar. (H.)

This is one of the best fossil localities in the islands.

About midway between the houses of Westness and Viera Lodge, a vein with a fine-granular barytic gangue, very similar to that of the Fair Isle, carries *malachite* with *azurite*, and apparently small quantities of *Smithsonite* and *pyromorphite*.*

---

* Through the courtesy of Col. Burroughs, the proprietor, I am able to subjoin analyses of the galena and "copper ore." The first by Dr. Macadam, the second by Mr. Andrew Aitken.

The galena yielded Lead, 79·572; Silver, ·047; Antimony, ·014; Copper, ·013; Sulphur, 12·352; Gangue 8·002. As this percentage of silver is equivalent to over 16 oz. to the ton, this comes to be a most valuable ore.

The "copper ore" yielded—

Copper	3·03
Copper Oxide	3·75
Zinc Oxide	1·15
Lead	·76
Iron Oxide	5·5
Baryta	27·08
Lime	3·72
Arsenic	1·4
Sulphur	4·55
Sulphuric Acid	6·54
Carbonic Acid	9·65
Water	·60
Gangue	31·2
	98·93

This (of course presented as a mere commercial analysis,) affords hardly sufficient data whereon to speculate upon the grouping of the components. It however gives some ground for supposing that what I had from ocular inspection set down as Smithsonite, is *calamine*; and what I supposed to be pyromorphite may be the much-rarer *mimetite*.

"Concretions," similar to those of North Ronaldshay but of larger size—some singularly resembling the cast of a human foot—have been sent from this island to the Industrial Museum in Edinburgh, by Col. Burroughs.

ISLAND OF STRONSAY.

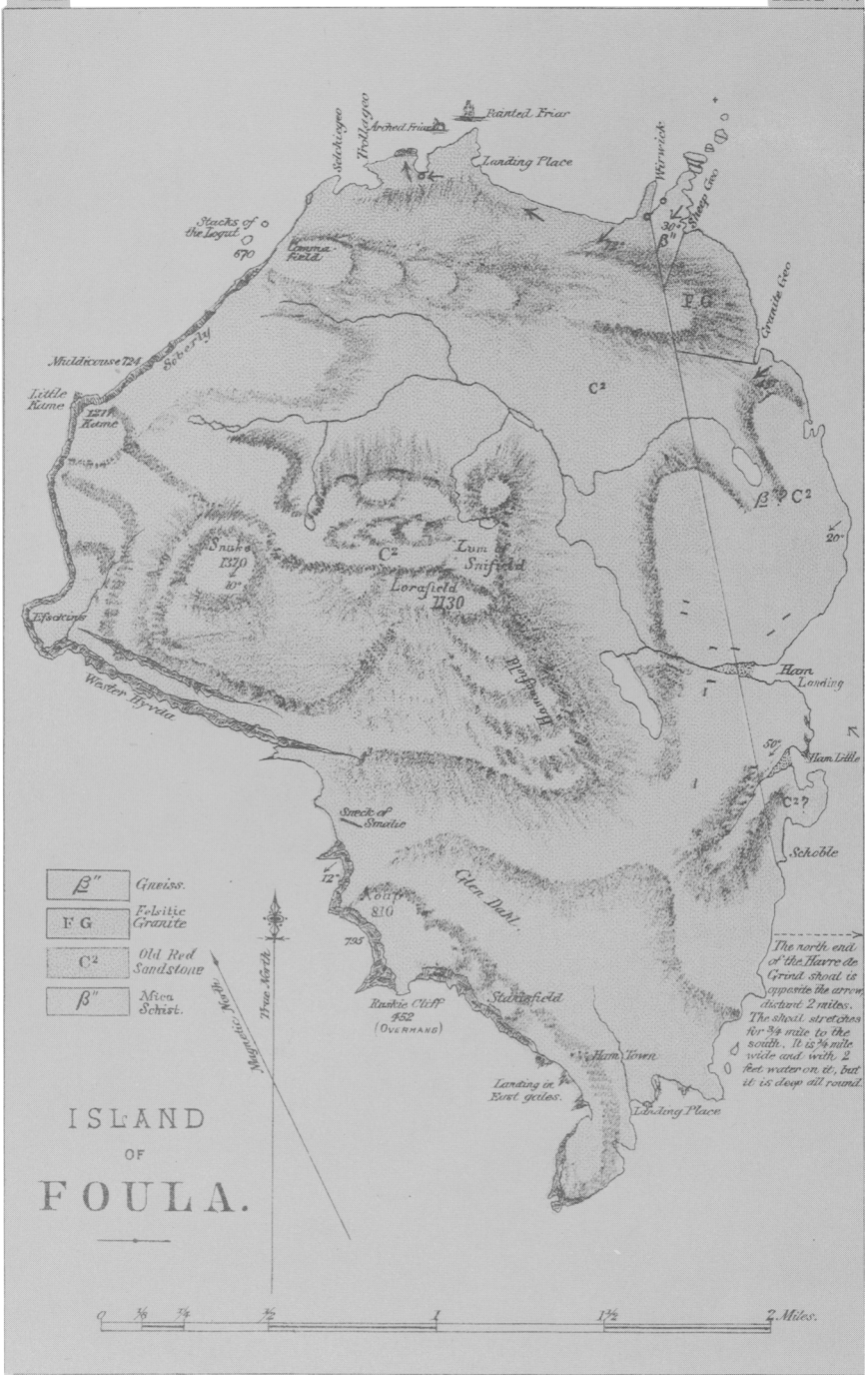
From Dr. Neill's "Tour through Orkney and Shetland," the following extracts are made. "Upon the north-east shore of Stronsa, near the Ness of Odness, there is a very large bed of shells, which I was assured was thrown up by the sea in the course of a single stormy night about twenty years ago. The shore here is very rocky, and the people say that, till that event, it was a rarity to find on it any kind of shell. Upon examining the bed, I found that a great proportion of the shells consisted of single valves of the *arca glycimeris*, of uncommon size, twice the size of Pennant's figure of the shell. Besides the aca, I picked up many water-worm and broken specimens of *ostrea maxima*. Neither of these kinds is to be found recent on the beach.

Between the Ness of Odness and Kerbuster, there is a large bed of limestone, the inclined base of which is washed by the sea. It is of a bluish colour, but not very rich, containing probably not fifty per cent. of lime in some places; however, it is traversed by broad veins of calcareous spar. This bed of limestone lies between strata of coarse sandstone-flag, with which it is in immediate contact both above and below, though marked by a well-defined line.

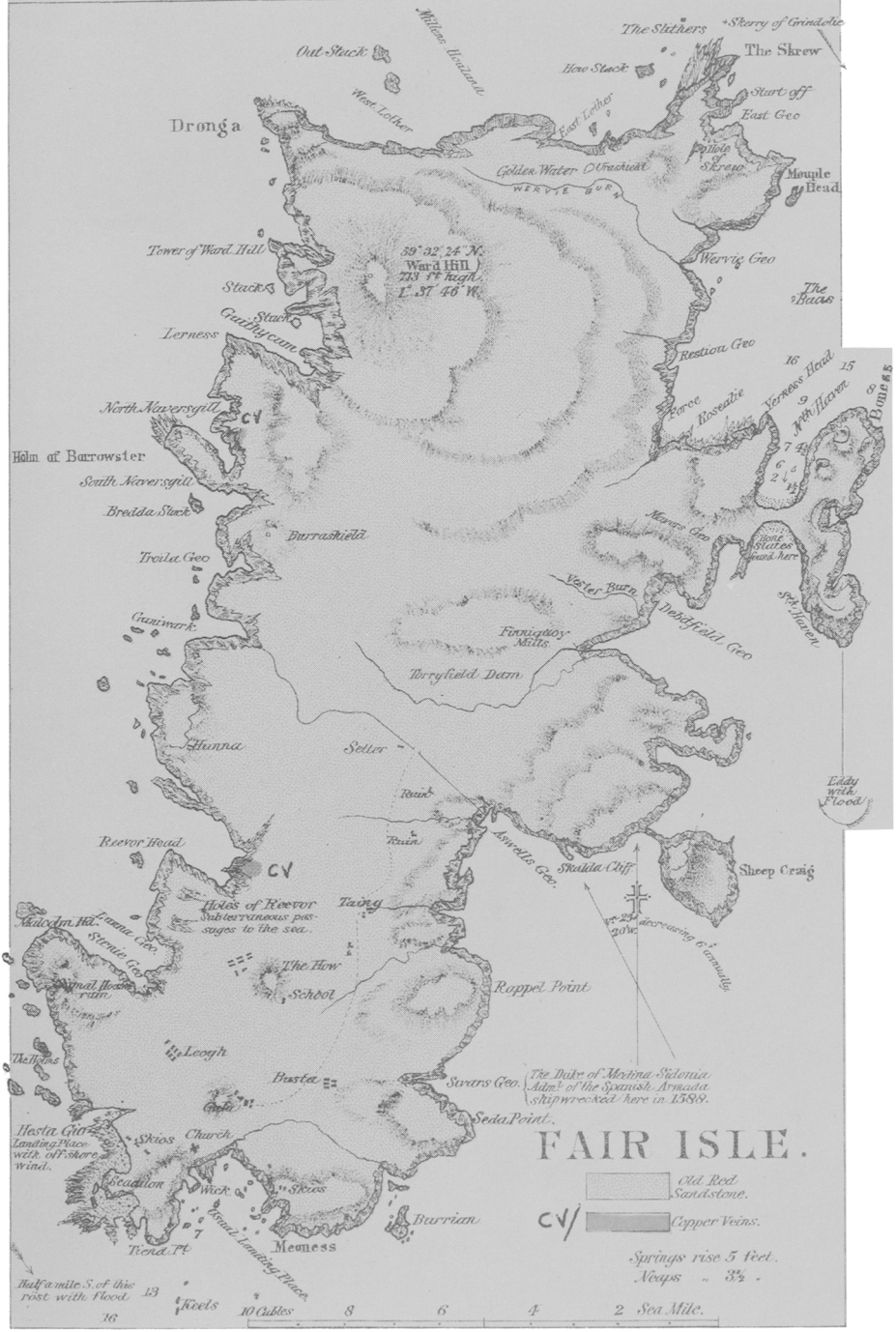
"A little way from the Brough, we saw the prodigious effects of a late winter storm: many great stones, one of them of several tons weight, had been tossed up a precipice twenty or thirty feet high, and laid fairly on the green sward."

ISLAND OF SHAPINTHAY.

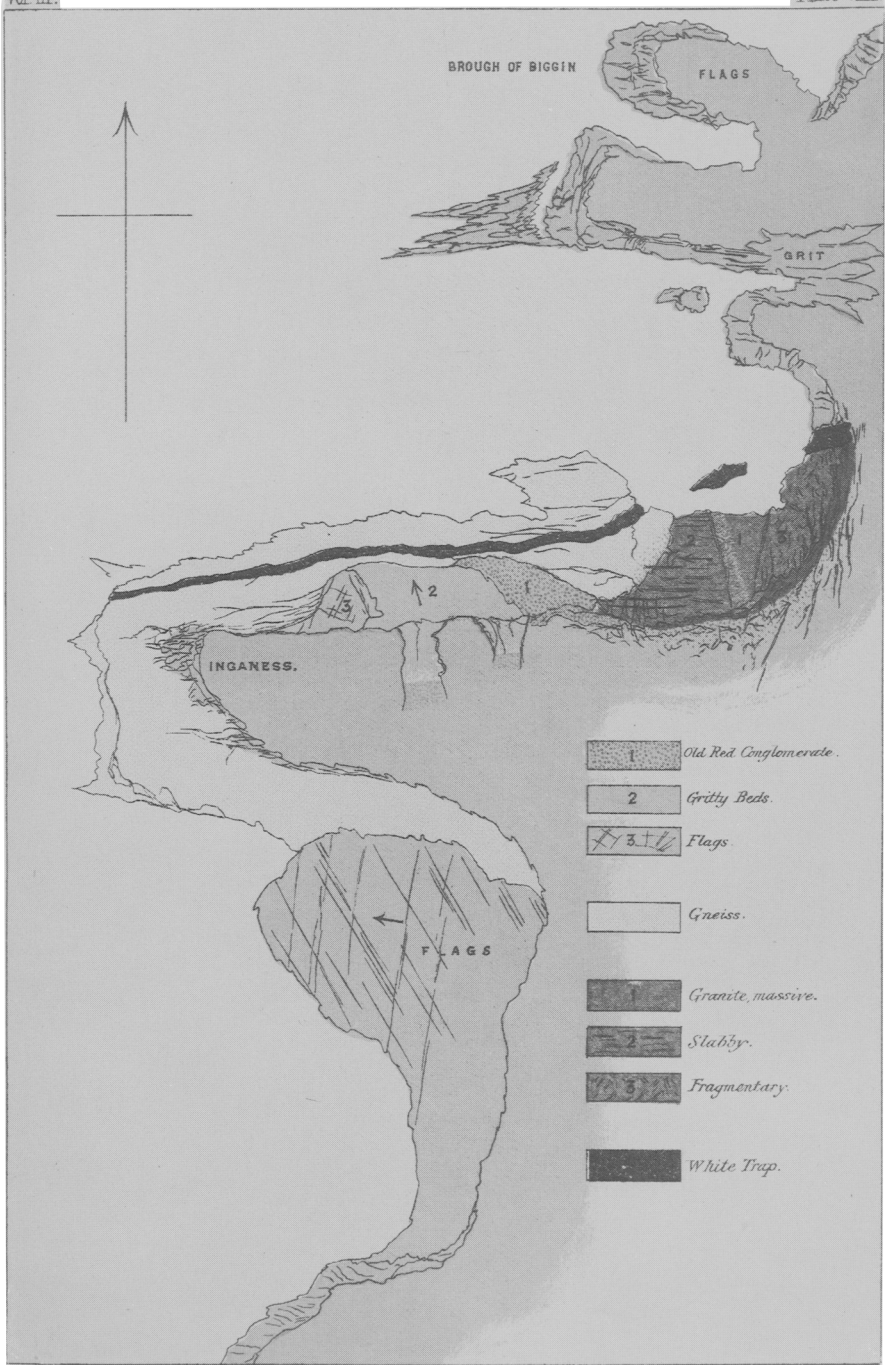
Many trap-dykes cut the strata at the south east end of this island, having a magnetic east and west strike. A very limpid *naphtha* (J) occurs in small quantity in some of these.



Copied from original partly coloured plates.



Copied from original partly coloured plates.



Copied from original partly coloured plates.

FIG. 4.

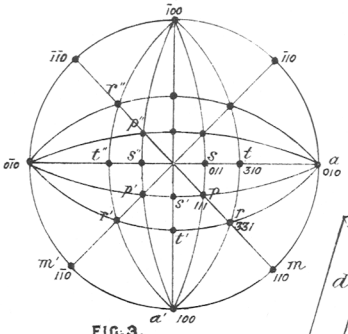


FIG. 5.

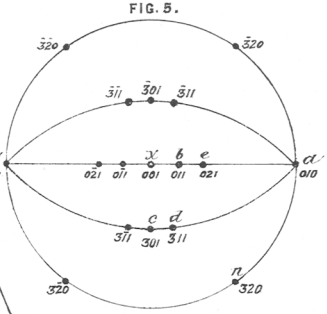


FIG. 3.

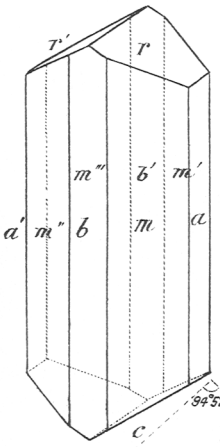


FIG. 2.

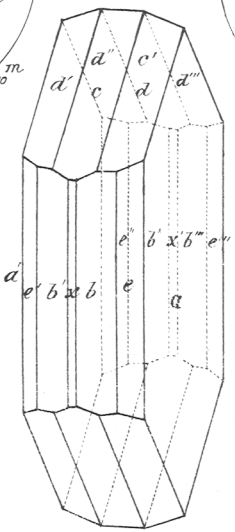


FIG. 2a

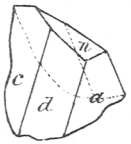


FIG. 7.

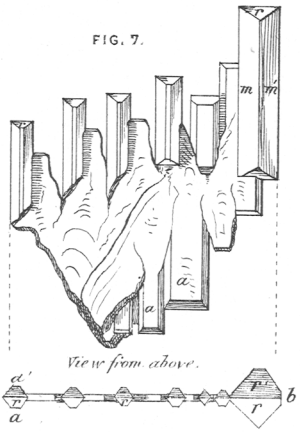


FIG. 6.

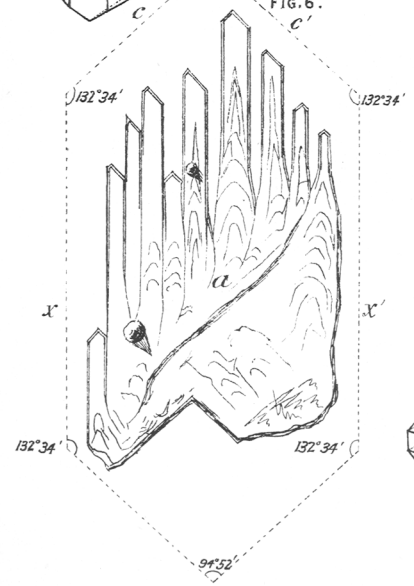
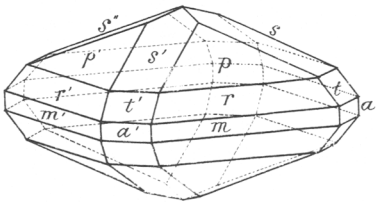
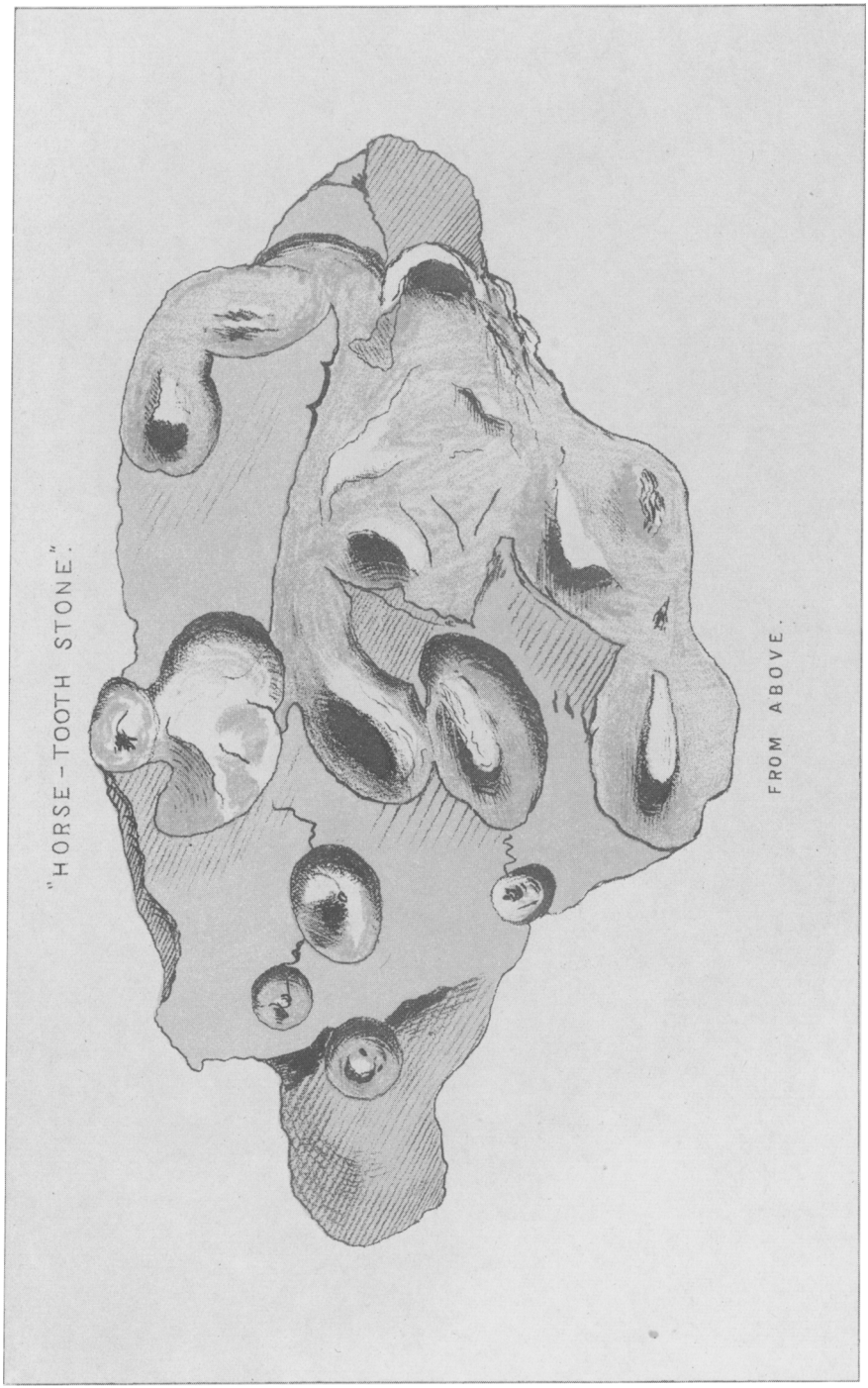


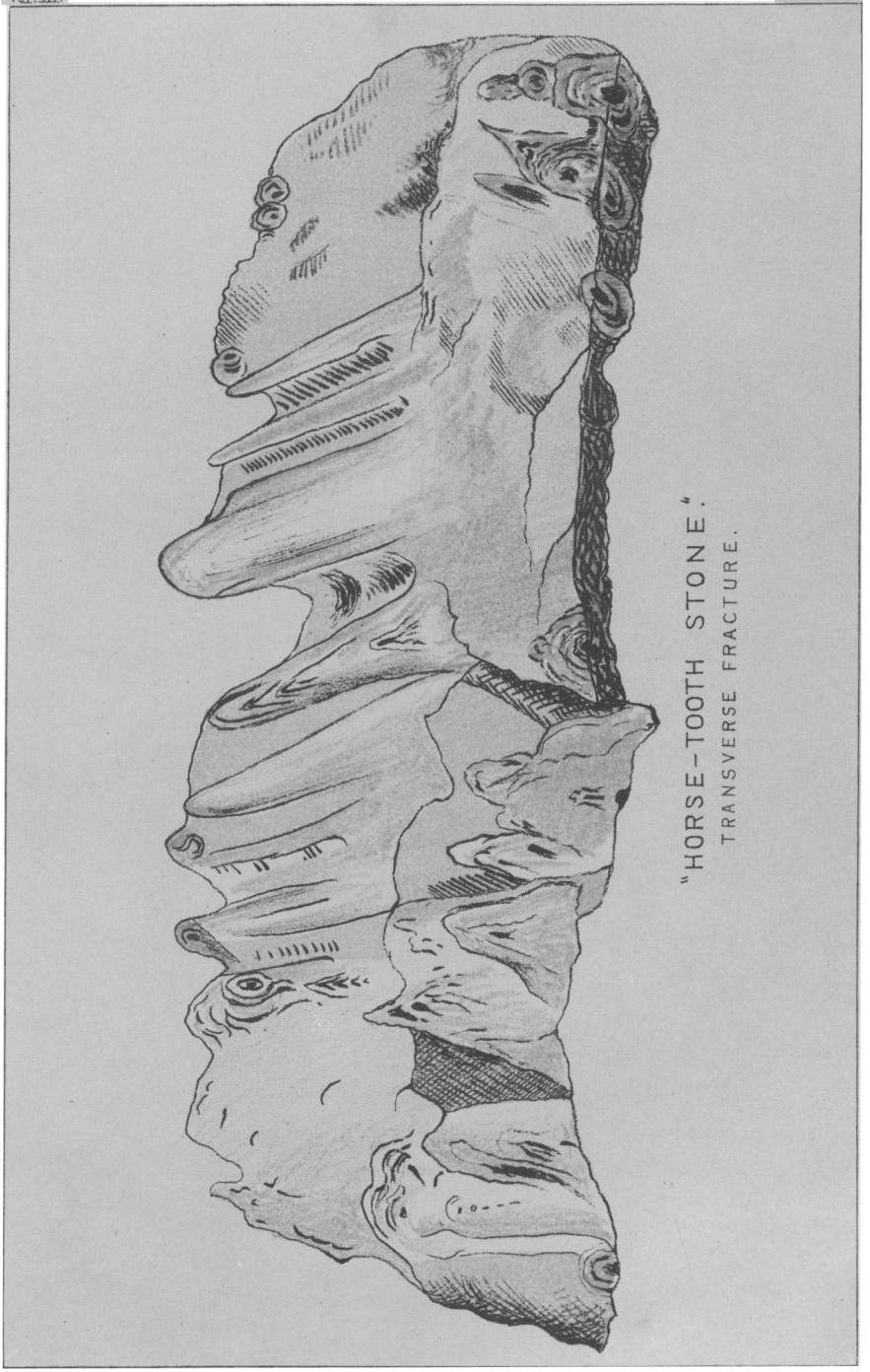
FIG. 1.



LAKE & LAKE, LITH. TRURO.



Copied from original partly coloured plates.



"HORSE-TOOTH STONE."
TRANSVERSE FRACTURE.

Copied from original partly coloured plates.