Thesis for D. Sc.

X

On the Old Red Sandstone of Shetland,

a dissertation
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by
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by

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In examining the geological characters of the Shetland Old Red the rocks have been looked at from the following points of view —

1. Physiographical;
2. Lithological;
3. Petrological;
4. Historical; including
    a. Stratigraphical relations, and
    b. Palaeontological evidence;
5. Dynamical.

Berlin. 27th January 1877.

1. Physiographical Geology.

In order to obtain as clear an idea as may be of the position occupied by the Old Red Sandstone rocks in Shetland we must repair to some elevated seat. Choosing the summit of Brassay Ward as the best for our purpose we gain that point of vantage and from it gaze out on all sides. It is easy to determine clearly the localities of the rocks. Immediately around us are the dark undulating hills and vales of Brassay dotted with silvery lochs. Northwards no sandstone districts appear, the prospect being closed by the sinuosities of the mainland coast, over which loom its uplands, and by the sea-line broken by Whalsay and the Out Skerries. To the east the watery horizon is unbroken save by the picturesque little Isle of Noss. In a southerly direction rise rounded metamorphic hills, on the eastern flanks of which rests the Old Red of Hadibister and that of Aith terminating in the sharp point of Daly Ness. Outside of these we catch the bluff Bard of Mousa rising into a swelling dolphin's back

and over them in the thin blue haze of the distance towers the lofty Sumburgh. To the westward are the three bays of Bruick, Sound Wick, and Gulberwick bounded by bold sandstone headlands; and we may regard the town of Lerwick as nestling in the centre of an Old Red amphitheatre, and girded on the west by the swelling conglomerate hills. Far, far away, over the Ness of Sound, and seen as a faint blue line, are the three lofty peaks of the distant Foula.

The scenery around Lerwick presents no striking features. Beginning with the low headland of Rova, at the north, the coast attains no elevation as far as the town, and presents a succession of slight indentations separated from one another by blunt and almost imperceptible projections. Immediately to the south of the Point of Scotland is the wide Bay of Grimnister which ends in the docks and the North Ness. The quaint houses of Lerwick appear to rear their gables out of the waters, but they are founded

upon the rock, which rises here and there above the sea. To the south, even before the town is left behind, the coast becomes more impressive gaining height as the South Ness is passed and ending in the bold and rugged Nab Head, whose frowning precipices are continued up to the back of Lerwick along Breiwick. These are succeeded by an expanse of sandy beach, skirted by the road which passes between the sea and the loch of Clickamin. The coast then runs out as vertical cliffs to form the stern Ness of Sound, after which comes the narrow bay named Dick of Sound with perpendicular sides, which end opposite Sound Ness in the Ness of Grebister. The softer outlines of Gulberwick follow, and just at Brimister the coast undergoes a change as well in scenery as in structure, for the schistose rocks which appear in this locality have low and ragged outlines.

The inland scenery around the Shetland metropolis is of an undulating character. The low lands along the coast-line are fertile and dotted with the thatched

cots and carefully tended patches of the crofters, and as the ground is followed inwards it soon begins to take an upland character, assuming the swelling wave-like appearance so well known in Scotland. The hills attain a height of three or four hundred feet, and are covered above by rough grass and stunted heather, whilst their lower slopes and the valleys which intersect them are enveloped in one dense mantle of peat, through which meander many little rivulets to the sea. Small lochs, gleaming in the sunlight, appear at intervals, and their bare bleak shores well suit the wild scene and complete a picture of solitude and desolation. During the season for the peat-gathering the scene is changed, for then may be met long strings of hardy ponies marching in single file and bearing heavy burdens of fuel under the guidance of numerous ruddy-faced Shetland women, who also on their backs carry loads of the same material.

When the Island of Bressay is looked at from a short distance, particularly from the Ward of Shoredown above Sound Wick, it

presents a very striking resemblance, on a colossal scale, to the popular representations of the larger cetacea. Here in the towering cliffs of the Bird we have the upraised and blunt-nose of the mammal, the gentle slope upwards to the Wart may well be the rising forehead culminating in the blowhole, and there, to the north, the slight declivity which is interrupted by the rounded Auder Hill is a perfect whale-back sinking into the waters. If after sunset a slight-cloud-wreath should encircle the Wart the resemblance is complete, for then appears the spouting phenomenon, and the breath of the monster of the deep is condensed.

It may seem ludicrous to compare Ross Island also to an inhabitant of the ocean, but it is a fact that when this little isle is seen from Bressay Wart it gives the idea of a skate from Nature's Statuary. The hoop is an enquiringly-uplifted nose, the northern and southern headlands well represent the lateral fins, and in the low point at Ross Sound the slender tail of the fish may be held to terminate.

In sailing round the Island of Bressay one feel-is very noticeable, that the shores of the sound are low. No sooner however is this secure haven left-than the island begins to take on an iron-bound aspect and to rear up its cliffs as threatening ramparts. At-Kirkabister there is a pretty mural archway crowned by the useful Pharos, and after passing this the cliffs are found to begin. Quickly they rise into the tall Ord Head whose frowning heights are the loftiest cliffs in the island, and whence they sink on either side. The Bard of Bressay stands upin front, a high headland running out to the south, against which, as a Gothic buttress, rests the angular pillar far-famed as the Giant's Leg.

A square opening in this headland, with a low skerry across its mouth proves to be the door of an arcade. Entering the vestibule the height of its ceiling is found to be considerable. To the right is a long corridor of narrow breadth and Egyptian gloom, along which the boat is guided until the mast grates overhead. Then the boatmen light their flambeaux and

the flickering unsteady light reveals the outline of the cavern. Above, the roof is covered by white glistening calcareous stalactites, below, the shingle of the bottom can be clearly seen, whilst the walls are clothed with verdant green; and the uncertain light, as it rises and falls and dances over the pellucid wave, throws a charm over the cave, accompanied as it is by the gentle moaning of the waters.

Emerging from the Orkneyman's cave, and rounding the Barel the Isle of Ross bursts full upon the view. The coast of Bressay as far as Ross Sound is one continuous bulwark of beetling crags with here and there angled indentations. Over these pour several rivulets, which are broken up into spray long ere they reach the base of the cliffs. Ross begins with a low and rocky plateau which gradually gains height with distance from the Sound. The cliffs of Ross have a charming effect due to their warm tints and picturesque forms. At the south-east corner is the famous holm separated by

a narrow strait, over which, in times gone by, the islanders were wont to ferry themselves and their sheep through mid-air by means of the "cradle." At the holm are two or three rectangular Grecian arches piercing the points, through which the waves surge in boiling foam. Then the Horse is approached, and its proud heights, calmly confronting the ocean stir the spectator. The whole scene is interesting, and the wild shriek of the sea-fowl mingling with the melancholy wail of the waves confers an air of romance upon the spot. On the north side of Hoss is a holm in process of formation by means of two parallel fossae.

Again the shores of Bressay draw near, and after passing the tall cliffs of Cullensburgh Ness, the wick of the same name appears on the left. Then the dome-shaped Score Hill tails away in the low Score Head; from which point to the north inlet of Bressay Sound the shores are low, and guarded at intervals by sentinel skerries.

Internally Bressay has the billowy

characters so common in Shetland. In the troughs between the dark waves of peat-are several lochs; in the case of one or two of these, but particularly at the foot of Scalloch lying east of the Ward, are mounds of gravel which reveal one time acted as a dam, but which are now cut through.

The Ord is the seaward end of the central ridge of the island and by aneroid has a height of 550 feet. From this head the ridge ascends to the highest point of the eastern sandstones of Shetland in the shapely conical Ward of Bressay, whose summit is 712 feet above the level of the sea. From it the high grounds run more towards the east to end in the rounded Auder Hill.

From the crest of the cliffs around Bressay the prospect is grand. Far beneath, the sea laves the rugged rock masses at the base or dashes itself against the iron precipices. But from the Noup of Noss is obtained the most sublime view, for the ocean is seen tossing up its white manes 577 feet below. Should this aerial perch be visited

when an eastern fog is driving before the gale the outlook is appalling, for the mist pouring up the precipice and over its summit obscures everything, and there is only seen a frightful abyss with constantly shifting clouds. The hoarse roar of the tempest, and the faint murmur of the ocean borne up along with the screech of the sea birds, as they dart out of or into the wreathing fog, are fitting accompaniments to the dreadful scene.

Further along the eastern coast there is for some distance nothing noteworthy. At Hadibistan there are very rugged conglomerate cliffs relieved by tall stacks in the form of magnificent obelisks. Inland there is a belt with desolate and bleak shores.

The Aith Deds are bounded by precipices and form the far stretching point of Hafy Ness.

Sanduick presents a repitition of the same characters with another marked feature that to the south the shores slope towards the sea in the same direction and with the same angle of inclination as the dip of the

strata. The island of Mousa is in outline dolphin-backed and surrounded by steep cliffs.

From the beautiful and safe haven of Levenwick the coast-line is precipitous and broken up. Mid-is the little voe of Boddam, and the high cliffs of Sumburgh Head; after which the land is so low that the imposing Sumburgh appears to rear up its majestic head distinct from the main. Surmounted by the mariner's warning light-this headland has a stirring effect-upon the ideas. West-Voe and the east side of Quendale Bay have steep boundaries. Inland the outline of the ground is as elsewhere, rounded, hummocky and with lochs, save around Quendale where everything is wrapt in a covering of sand.

On the Atlantic coast, the cliffs of Sandness are in form merely a repetition of what we have so often seen, and the surface has the usual characteristics. The turbulent and narrow strait of Papa Sound, with its two rocky holms, separates the mainland from the low island of Papa Stour.

Starting by sea from the Kirk Sands of Papa Stour, the coast to the westward is for a short distance low but precipitous, and surrounded by a narrow belt of yellow sand. Bosses of grey amygdaloid project up through this sand, and are worn by the waves into varied and curious forms, potholes being abundant. The cliffs gradually rise in height, and the sandstones forming the first part of these present interesting features in their reticulated pattern, brought out by the weathering. As the cliffs attain a greater elevation the beach ceases.

Seeing a low and narrow cavernous entrance in the face of the precipice the boat's head is directed towards it. On a nearer approach the tunnel is found to be well lighted, and as the skiff glides through it the cause is obvious, for a large quadrangular trough is entered, with vertical sides, and for canopy with the blue sky above. Turning and making exit from this, the course is continued, passing the prominent Skeiper's Ness and the gio bearing the same name, with its windowed stack and cave. Then comes Mo gio, an angular recess whose lofty over-

hanging cliffs of deep salmon-tinted felstone are almost-columnar; and, as many of these indistinct columns are apparently kept in position after the manner of Damocles' sword, the visitor must beware. Too intimate an acquaintance with the hardness and density of these rocks might indeed prove unpleasant or dangerous. After this gio has been left on the boat's quarter, Nelinna Voe is reached flanked on either hand by a rocky battlement; and covered by the outwork of the low rocky Swarta Skerry. Inside, the Voe opens out and shows nothing remarkable in its flat shores of sand and shingle.

From the voe of Nanna the coast trends to the north in a succession of fine cliffs, which with their warm ruddy hue, sharply cut gios, and low caverns are very striking. The beetling precipices cut into by these narrow gios have very much the appearance of a long line of frowning fortresses guarding the island. Here and there detached blocks of the semi-columnar rock have fallen down and lean against the base of the natural fortifications as massive buttresses. Many

of the gios separating the battery-like squares of rock appear as if dug out of a partially solidified mass of molten matter by a giant spade, so sharp are their angles.

Steering towards the lofty entry of a cave in Francis' gio, it is entered and, although short, is so interesting as to raise curiosity as to the next. A deep narrow inlet leads to the Sound of Gatta, a natural harbour surrounded by lofty walls. When inside it is found that there are three entrances separated by two grand stacks, one of which has an aperture. Turning into a contracted passage, after leaving Gatta Sound, a magnificent and nearly circular amphitheatre is entered. At one part of this marine quarry is the entrance to a cave, which has a squat square pillar in its doorway, with chambers opening around.

Then up a deep sea gorge the boat is guided. In this water paved ravine stands a solitary stack, in form, like an oriental obelisk, tapering gradually and gracefully to a point and, like the famous tower at Pisa, leaning over to one side. Looked

al in profile from abreast - it most resembles the bow of an Aberdeen clipper; and, on a still closer scrutiny, the pillar is found to be completely cut in two by a crack running from base to apex. Under the overhanging crags, gilded by the rosy beams of the setting sun, and through the shades of a contracted culvert, and an aisle through is gained, roofed by the azure of the heavens. Ahead is a spacious archway, the ceiling of which gets lower on advancing, while chambers open on either hand dimly seen in the deepening gloom; further on however the darkness is dispelled for an instant by a gleam of light from a window to the left, and soon after the boat enters a wide cavern and the prow grates on the shingle at its extremity. Listening to the muttering of the gentle swell, the visitor waits until his eyes get accustomed to the darkness, and then finds that he is in a large chamber of circular form, and covered by a dome-shaped roof.

It is hardly possible to describe in words the charming effects produced in these caves. The evening sun as it lights

up the warm orange-red of these western cliffs sends also a few rays to illumine the shades of the tubular caves. Its beams, reflected from the rippling wavelets, gild the bronzed water-line, warm the cold grey limpets and acorn-shells, and dance over the delicate greens and yellows of the lichened walls and ceiling. Here the rock may have assumed a cream-like hue; there it is tinted a deep maroon. In the one place it is invested by a thousand forms of calciferous life; in the other it is decked with varied thalloids. The pellucid water too of the faintest green permits the bottom at the depth of many fathoms to be seen with perfect definition, and the rolled shingle and fine sand of pale shades, intermingled with the dark coloured sea-weed, seem to form a fairy bower for the swiftly darting gilbek, or the more leisurely crab. In the caves the algae do not intrude, and the mosaic is exchanged for a continuous pale pavement. The ear as well as the eye obtains enjoyment for the scarcely perceptible roll of the Atlantic resounds in the fiords and

caves. Sometimes there is heard a seething hiss as the wave-crest tumbles over upon the shingle, again may be caught a bubbling gurgle as the ripple catches some sharp point; or a dull and heavy thud echoes along, like a well timed volley, when the waters rush in and fill a recess.

Shortly after departing from this curious and interesting "Christie's Gio" and cave, the most prominent object is a tall peninsular stack whose large opening is not unlike an imperfectly formed window in the rounded Gothic style, and just off this is the low and rugged Sula Stack. In front is an interesting group of holms. Outside is the large Fowlee Huff and square in outline, the undulating surface of which is bordered by high and ragged precipices, save at one point, where the Papa people land the summer flock. Internally is the lesser Sera whose contour is that of a rectangular battery. Both of these holms are interesting from their verdant surfaces contrasting with the ruddy tint of their sides, which are

perforated by numerous caverns, and supported by flanking buttresses. Besides, in the foot, Sierra has at its S.E. angle a slender stack equal in height to itself, with a natural and angular loophole. To the north rises solitary and alone a tall and graceful stack of quadrangular form, called the Saldee.

And from this point the Horn of Capea can be seen nigh at hand. It is a bold point through which has been carved a magnificent arch wide and lofty, having all the appearance of the principal gateway to an old baronial hall; or, perhaps better and with greater truth, of the triumphal arch commemorative of some ancient Roman victory. Upon the summit sits in calm repose the rude stone effigy of a sitting bear, as seen from one point, or of an Egyptian sphynx, as looked at from another.

Passing this sculpturesque point, and leaving the deeply excavated Acreógio, and many caves, which have the same interesting features as those already described

As one of these has hitherto been unvisited by any extra-insular except the writer, it were unfair to leave it unmentioned. The bark is guided into a tunnel lower if possible than any of the former, and down along a narrow passage, which grows darker and darker until it becomes obscured by darkness that might be felt. In this narrow channel the echoes of the faintest sound are reflected around, and the murmuring gurgle of the waters is borne along. Suddenly a gleam of light streams in from the right when in the same instant the boat's prow thumps against the cavern's wall. Here the cave turns at a right angle towards the right and the passage becomes lighter as the boat advances along it. The roof rises in many places into cupaliform chambers, dyed by vegetable agents in many varied tinges of colors. When the exit is reached it is found to open below the stupendous and overhanging cliffs of Bordie, which are here the highest in the island.

From this N[illegible] point of Papa Stour

eastwards the cliffs, very lofty and rugged, are much cut into by fiords. Cuillia Voe a long and narrow inlet is separated by a bold and savage headland from Rea's Voe, which although comparatively contracted outside widens into a broad bay inside, with tame outlines and sandy beaches. Onwards from the voe the coast possesses grand cliffs, vast angular fiords, dark caverns, rough and jagged skerries, and slender commanding stacks. As Hoosa Voe with its numerous skerries and stacks is at hand the indefatigable Cox proposes the invasion of one more cavern, and although many have been seen he prevails. A wide portal, surrounded by smaller doorways, opens into an entrance hall, lighted up by passages from the other doors. The channel is short and the roof elevated, and at the other extremity the cave debouches, through a labyrinth of pillars and porches, into a large quadrangle, the middle of which is occupied by an isolated stack.

Leaving this, and skirting the inlet to Hoosa Voe, which has low flat shores

dotted with many houses, and alive with numerous inhabitants, the boat passes between Fowick Ness and its little holm and slackens not its course until the keel grates once more upon the Kirk Sands.

The surface contouring of Papa Stour is undulating and tame. The two hills, named Kilyfield and Verdefield, are merely gentle elevations totally uncovered by peat, a circumstance rare in Shetland in the case of hills so low. They have the hummocky appearance of dolphin-backs in their superficial sculpturing. The lower grounds have several lochs, and are covered by a rich alluvium.

In walking around the cliffs it is found how very much they are invaded by the sea. From the recession of these from their summits the spectator sitting on the verge of the overhanging precipices appears to himself to look out from mid-air upon a watery world. The troughs entered by tunnels from the sea are well seen. Several of these tunnels have blow-holes opening upwards, and in one well mark-

ed cave at Bordie the moaning surge can be heard issuing from the opening, through which can be seen the green waters churned into foam a hundred feet below.

From every part of the mainland of the Shetland Isles the observer cannot fail to have his attention arrested, when he looks across the western sea, by the imposing majesty of the solitary Foula. This isolated island, as seen from an opposite point of the coast, presents the appearance of three lofty cones drawn up in échelon and rising up almost from the centre of an elevated plateau, which has an abrupt commencement in a sea-cliff facing the north and which tails away to the south. From Fitful Head these three peaks seem merged into one, whilst the view from Papa Stour or Hillswick affords the front elevation. A nearer approach to the island reveals the fact that there are in reality five hills, three of which form what may be called the axial chain, the other two standing out alone.

To inspect the magnificent coast the visitor must go round it by means of a boat.

In this way pulled by the sturdy oars of Foula, and favoured by Jove as well as Neptune, an impressive view is obtained. Starting from Ham, the coast-round to the north is low, but with marked features not wanting in rugged beauty. The gneissose rocks are of dark colour and gracefully contorted outlines, varied by granitic veins either of bright-ruddy, or cold grey hues. They present sharp jagged points, separated by deeply indented gios, which frequently terminate in low caverns forming fitting habitations for the sombre scarf or cormorant. Round the north-easterly point, Stromness, a large square holm stands out of the sea, and its dark sides of gneiss, with brilliantly tinted veins of granite, cause it to assume an interesting aspect. The low cliffs, after this point has been reached, are seen to die away, and are succeeded by a short expanse of coarse shingle.

And now tower up, in their cold grey colouring, the lofty perpendicular cliffs of Foula. At their feet, and forming the extreme north, lie several wedge-like stacks.

all present-a bold bluff precipice to the sea and a slope, which in all lies the same angle of inclination, towards the island. Of the three larger stacks one is solid throughout. Another, named the Bough from a ruined fort on its summit, is perforated by an aperture, which, being divided into two parts by a comparatively slender mullion has, all the appearance of a window to some mouldering cathedral vault. The third and largest, as it stands up in picturesque decay, presents in its angled recess and pair of windowed openings, a most striking resemblance to some crumbling chancel remaining as a last wasted remnant of former ecclesiastical glory.

Leaving these weatherbeaten monuments of natural architecture, the voyager's little bark passes into the shadow cast by the tremendous cliffs. Beginning with that of Soberly, these sink for a short distance and then quickly rise to a higher and yet higher altitude, culminating in the stupendous Kame. Language is inadequate to portray the emotions excited by these

fearful heights, the outline of which is so sharply cut that they look as if formed by a race of ancient Titans in the same way as the peat-mosses above are shaped by their modern possessors. The eye, in looking up these precipices, wanders bewildered over the vast masses of their solid masonry. Below, may be made out two or three strata of thick sandstone little weathered forming a massive architrave, and overlaid by softer shaly flags, which have been sculptured into the varied honeycomb forms of a rude frieze, this in turn being capped by a cornice of harder flags; and so on there runs an endless repetition of such an entablature. Regiments of marine birds occupy the ledges, and from their position in line look calmly down upon the intruders. Near the base the darkly plumed cormorants have their station, high up may be seen, as faint white lines, the little nories, while the intermediate posts are filled by various mews. The air too seems alive with these birds, from the low-living diver to the proudly soaring skua-gull. But a very little way

up however and all the minor irregularities of the successive strata, with their feathered inhabitants, sink into one bold and stern front overhanging the Atlantic.

Such then are the features repeated around the northern and western coasts. The height of the cliffs gradually lessens as the points of Rebefield and West Hirra are passed, and, on rounding the latter, the stately Horns of Foula comes into view. This grey headland attains a considerable height and bears on its lofty crest a mass of yellow rock; it has an aspect so mural as to suggest the idea of a well-chosen stronghold crowned by a massive fortress. These weatherworn battlements passed the South Ness is seen, low in elevation and slanting into the sea in the same manner as do the southern surfaces of the northern stacks. The remaining part of the eastern side does not reach any height, and becomes gneissose near Ham, at the same time changing its outline, so as to resemble the rocks to the north of that place, which have been seen before.

The hill chain begins at the north-west with the majestic Kame, which by aneroid measures 1150 feet over sea level. From this giddy height the most fearful chasm in Shetland is looked down into, appalling in its sublimity. From the Kame the ground falls on all sides, but soon rises again abruptly to form the summit of the island in the Sneug, a peak attaining an altitude of 1250 feet, and situated to the south-east of the Kame. The ridge then sinks down until Lioracfield raises its crest, in an east-south-easterly direction, to the less ambitious height of 1000 feet. The hill of Loberly, seen before as a sea-cliff, may be regarded as a spur from the main chain of hills. It is 650 feet in height, and only separated from the Kame by a slight depression.

All these four hills have sharply-cut peaks and ridges, and to the east and north-east present sides with remarkably steep slopes reaching an angle of more than 30°. To the north and west they are broken up into the line of precipitous

cliffs. Southerly the slopes are more gentle, and here the deep valley of Southdale completely separates the chain from the fifth eminence, the Knap, 700 feet high, which differs from the other four hills in having a rounded dome-shaped summit.

The island to the east is low and undulating, covered in great part by a thick layer of peat-moss, but with here and there a patch of arable ground. Through these lower levels runs the entire drainage of the island. Numerous water-courses, dry in summer but foaming torrents during winter, as proved by their deep channels, traverse it. The most considerable stream is the Blober Burn, which receives a brook from the small lake of Uora Vandale, nestling at the base of the Sneug, subsequently joins the rivulet from the Loch of Ham and finally ponds itself into Ham Voe. Its bed is like the rest very deeply cut, and in some places cuts through small fields of fine gravel and alluvium. It brings down the drainage from Soberly and the north-eastern slopes of the axial

chain; the contiguous sides of Lisrafield and the Norfs being drained by a brook running through Southdale.

2. Lithological Geology.

This section includes the consideration both of the simple uncombined minerals, and their compounds the rocks. It must be more or less a mere enumeration, and this is all the more necessary from the circumstance that in the monograph of Professor Jameson as well as in the classical work of Dr. Kibbert, this subject has been most carefully elaborated.

In the first place the minerals must be glanced at. There occur —

1. Quartz, which is generally massive, but in cavities prismatic with pyramidal terminations. Its colour is white or very slightly tinged. The situations in which quartz is found are fractures and cavities in sandstone.

2. Calcite, both massive and crystalline. The colour is white or faint grey. The localities of this mineral are the same as in the case of quartz.

3. Haematite, or specular iron ore taking the botryoidal form, with a rich dark brown or black colour, and found both in quartz and calcite

4. Siderite, or spathic iron only in the massive form. It has a brownish-red colour, and is found along with haematite in the form of amorphous chocolate lines.

5. Limonite, or brown iron. This is massive, friable, and brown or ochreous. It is found as the result of the oxidation of siderite.

6. Arsenopyrite, as crystals scattered through calcite, and as patches. It is silvery-white, and always occurs along with the following.

7. Chalcopyrite, brass yellow and found in the same forms as arsenopyrite. It always accompanies the specular or spathic iron ores.

8. Malachite in two forms. The crystalline has lovely green radiating crystals; while the other is botryoidal and pale in colour. Malachite is found in cavities surrounded by limonite, whence the conclusion may certainly be drawn, that a double change in chemical composition has taken place, the carbonic acid when set free by the oxidation of spathic iron seizing upon the copper ore to form malachite.

All these minerals of the Old Red Sandstone may be found at Sandlodge mines, always free to visitors through the kindness of Mr. Walker.

Secondly, the rocks have to be briefly examined, of which all three subdivisions are formed.

I. Aqueous rocks.

A. Mechanically formed.

1. Conglomerate occurs in two forms, according to its origin.

a. Puddingstone. This has all its pebbles of a rounded outline, generally granitic or quartzose, varying in size from that of an orange to that of a man's head, and embedded in a siliceous or felspathic matrix. The degree of consolidation differs, but it is generally easy to detach the rolled-looking blocks by a sharp tap of the hammer.

b. Breccia, like the last, is very abundant at the base of the series and passes also gradually into grit. Its pebbles are of gneiss or mica-schist, always with a few of quartz and granite. The former are flat and blotty in outline, and firmly welded together by a matrix of very variable composition.

2. Grit is merely the transitional form between conglomerate and sandstone. In its origin it may be quartzose, granitic,

or schistose, and its composition depends upon this.

3. Sandstones. These may be siliceous, hard and compact; granitic, roughly granular and of a pale pink colour; or micaceous, grey in colour with glistening faces.

4. Shales, soft and fragile and of many colours. A bluish-grey tint is most common, but they are to be found of greenish, reddish, and dark tints.

5. Gravel forms a covering for the sandstones in many places. Along the shores it varies in roughness, in the bed of the little streams, and as mounds especially near lakes.

6. Clay of stiff dense material is also found.

7. Alluvium occupies many of the valleys through which meander the brooks.

8. Soil forms the outer mantle.

B. Chemically formed. Here fall only to be noticed the stalactitic and stalagmitic forms of the caves, which consist of concentric layers of calcareous carbonate. As these vary in colour a fragment presents the appearance of the coats of an onion.

C. Organically formed.

1. Peat-is universal; in most of the hollows thick masses are found, light-at-the top but-hard and dense below

2. Turf covers in all the other rocks.

II. Igneous rocks.

1. Felstone of a bright-ruddy colour and porphyritic texture is intrusive in Papa Stour and Sandness.

2. Porphyrite, dark in colour, and varying from compact-to amygdaloidal, is interbedded in the same island.

3. Tuff occurs loose and crumbly, and of a dark grey or brown colour. Papa Stour also.

III. Metamorphic rocks.

1. Quartz-rock is generally massive, with angular joints, but-indistinct stratification. It-is seen chiefly along fractures.

2. Clay-slate of a dark blue is found. It-is fine grained and fissile but-it-is not-easy to determine whether the cleavage planes are original or superinduced. It-is best-seen near Rovey Head.

3. Petrological Geology.

Petrology, or Architectural Geology, has now to be taken up. Turning from that branch of the science which may be studied in the cabinet and museum, the department now entered upon can only be worked aby with the hammer in hand, in the field. In the Old Red Sandstone of Shetland, small in area though it is, there are many interesting illustrations of the characters, structures, and accidents of rocks, well worthy of attention.

In the aqueous rocks, of course, the most prominent feature is their regular stratification. This is a character originally impressed in deposition, and presents a very considerable variety in its details. It may be well to begin therefore with this as a most essential point.

Laminae occur in a very beautiful manner in Foula, where the blue shales are very thin and fissile, so that they would be useless as stone.

Flaggy structure is exceedingly common; great part of the eastern beds are of so well

split - a character as almost - to outrival the famed Cuttmess flags.

Massive strata of sandstone generally overlie the almost - unstratified conglomerates.

Very perfect - ripple markings characterise the rocks in several localities, the most - notable on the naked faces of the strata, exposed on the back of the Foula stacks, and also in many parts of Papa Stour, Bressay, and the Mainland. They present both the long wave - tracing and also the dimpled appearance of little swellings and sinkings.

With these are associated radiating sun-cracks often of large size, occurring both as the fracture and as its impression.

Clay nodules are exceedingly frequent especially in the very micaceous sandstones.

Instances of false bedding are rare but may be seen in the magnificent - sections exposed in the cliffs.

The phenomenon of alternation of beds is of course common. In the Kame of Foula is the finest - example, for there are no less than 1150 feet - of sandstones, flags, and shales succeeding one another, in colours as dif-

ferent-as red, grey, and blue.

That relation of rocks to each other termed affinity is illustrated everywhere along the east-by the conjunction of conglomerate and sandstone, the latter ever following in the wake of the former.

Conformability between the schistose and sandstone rocks nowhere occurs.

True unconformability is only to be found in one locality— Hachibistan. There the conglomerates rest-on the tilted and wornout chloritic schist-below, almost-unchanged since the long-bygone days which saw their origin.

And here also overlap is naturally an accompanying phenomenon, each stratum of the conglomerates and of the grits, along the base, reaching a little over the immediately adjacent bed beneath it, as will be more fully described along with the stratigraphical relations of these rocks.

The appearances cited above then are those belonging to the stratified rocks from their birth. And, having looked at them, there are now to be briefly considered some phenomena which have been super-

induced by causes acting at a later date, and which may therefore be classed as accidental.

Among these there are two which belong to individual strata.

The thick beds of sandstone exhibit other lines of subdivision than the planes of stratification. These are the joints. They run in many directions, but always with an inclination more or less nearly at a right angle to the bedding planes. There is however no definite relation either to dip or strike, so that they deserve no distinctive name. The joints are seldom open save when loosened by weathering, water, ice, or plants, and they cut the massive sandstones into more or less quadrangular blocks.

The other structure is cleavage, which can only be seen at one place in the Old Red. This is near Rovey Head, where a double fault has occurred in conglomerate rocks, and the dark blue argillaceous rocks thrown up have taken the cleaved character. This appears, from the dip of the micaceous rocks containing the band, to agree in its planes

with the lines of original stratification.

When to changes involving more than one individual stratum attention must be given.

With regard to the position of these sandstones it may merely be said that they lie at all angles of inclination from the horizontal, as shown above Fleedibister, to the vertical, well seen in the case of the Bressay and Ross faults.

There is no important example of a synclinal basin although there are undoubtedly many small ones. The most northern part of Bressay Sound appears to occupy the depression of a large syncline as the rocks dip towards it on either side, it is more probable however that the westwardly dips of the eastern side is due to the fault near it, which runs through Bressay approximately parallel to the great fault, to be spoken of immediately.

The opposite case has a very good illustration in the anticlinal axis of Fleedibister which will be fully described under the head of historical Geology.

Many instances of faults occur. Besides the great fault, which everywhere — save at one point — separates the sands from the schists, there are numerous dislocations amongst the sandstone rocks themselves Around Lerwick, in Bressay and Noss, and at Sandwick they are very frequent.

Mineral veins, the contents of which have already been noted, fill the much disturbed and dislocated strata forming the point of Sandlodge, opposite the island of Mousa.

Amongst the igneous rocks there are a few petrological facts to be noticed.

In the case of the tuffs of Papa Stour regular stratification occurs.

Unstratified sheets of crystalline rock form great part of that isle under two very different conditions. The porphyrite, very compact and crypto-crystalline in some places, becomes at others amygdaloidal, while again it assumes the form of a very rough and scoriaceous slag, much jointed and broken up. On the

other hand the felstone constitutes one vast and continuous sheet, thoroughly crystalline from base to summit. The joints in it assume the prismatic structure, forming in elevation tall columns of graceful and angular outlines, and, when seen in horizontal section, showing an irregularly polygonal structure.

4. Historical Geology.

This section well deserves such a name. For now, ceasing to regard the Old Red rocks as exhibiting picturesque tracings from the hand of nature, or as a museum containing different specimens of mineral forms, or, finally, as an edifice illustrating varied architectural designs, these rocks must be studied as the chronicles of a time long passed away. And in the stony pages of these memorials are unfolded the circumstances attending the life of the ancient inhabitants while here and there, hidden amongst the thick leaves of the volume, may be found their remains.

Naturally therefore the subject divides itself into two inquiries; the one bearing upon the relations of these rocks, the other having regard to the old forms of life.

A. Stratigraphical relations.

These can best be seen in the beautiful sections which the cliffs present to the rolling surge of the ocean. In them tier after tier rises up, perfectly revealing their positions and relations.

The base of these Shetland sandstones can only be seen at that part of the east coast lying between East Quarff and Hadibister, but nearer the latter. Here, as has been already observed, there is an unconformability between the crystalline rocks and their stratified successors. The mica-schist, prettily foliated, dips to the west. Upon its worn edge, and upon the up turned ends of its beds, rests a coarse breccia, which passes into a grit-rock; this last in turn becomes less pebbly and more massive so that it passes gradually into sandstone, overlaid by fissile flags. This may be taken as the type of the sandstones; an imperceptible gradation from the conglomerates to grits, sandstones and flags, the two latter being very frequently interstratified with shales. In this locality, along the coast the dip is E S E, and inland, around the small loch, its direction is W S W. An anticlinal axis then runs nearly from north to south between the sea and the loch, and turns a little westward when nearing Hadibister, as will be seen on referring to the map. Fig. 1 is a diagrammatic section

across the rocks there, and shows how they dip away from the antiedinal axis on either hand. While the angle of inclination on the coast-side is from 26° to 25°, it never on the other side exceeds 10°.

Everywhere else in Shetland the metamorphic series is separated from the sandstone by a powerful fault. The Lerwick beds are bounded by this fault, which begins just round the point of Rova Head, and runs across the hills towards the south-west. Owing to the covering of peat which envelopes the ground there are few places where rock comes to the surface, and the fault after its commencement is never seen. About three miles from Lerwick, on the road to Scalloway, it crosses the turnpike, for the gneiss, as the rock is here, can be seen almost in apposition with the stratified beds. Then another fault, beginning at the point south of Gulberwick, separates the two series, and meets the former fault on the west of the Sumburgh road, forming with it almost a right angle.

All along these faults the Old Red

appears as conglomerates. At Robey Head and also at the opposite point of Bressay there are magnificent specimens of very coarse puddingstone, in which the embedded fragments are of large size. This continues along the Sound until it crosses the Scalloway road, after which the conglomerate is of the brecciated schistose material described in section 2.

The order of succession conforms to that just stated to be typical. All the hills surrounding Lerwick are of conglomerates, its immediate neighbourhood is formed of grits, and the town itself rests upon puddingstone, worked in the quarries near the harbour. Then across in Bressay the northern conglomerates gradually become sandstones as they pass higher in the scale, and are covered by the flags of Aith, while the massive sandstones which build up the grand headland of the Ord graduate in the same way into flags. All these blue flags of the centre of Bressay are very micaceous. They are overlaid by red sandstones which form the bold eastern coast and are continuous

the Isle of Noss, composed entirely of massive red and grey sandstones.

The general direction of dips is S.E. with one or two exceptions. Along both sides of the northern part of Bressay Sound it veers round to the W. of S., at the back of Lerwick and out to the Isle it inclines slightly to the N. of E., under the hamlet of Sound it varies from N.N.E. to N.N.W., while, in Bressay, the south-western cliffs and the West dip more or less constantly N.E., and the eastern coast almost entirely E. A very small portion of Noss has its inclination to the W. of N., which is caused by two faults.

Several faults traverse the strata of the Lerwick basin. Three may be counted along the coast from Rovey Head to Lerwick itself. The most northerly of these brings dark clay slate to the surface through the conglomerates between its doubly fractured axes. The town itself is built upon the upturned strata along the east side of a fault, and the district of Sound is cut through by another dislocation. None of these fractures appear to have any great throw. In

Bressay there are two considerable dislocations which approach parallelism with the great-fault: one of these runs along the west-coast from the northern point to near Kirkabister, while the other affects the east-traversing the cliffs opposite the Sound of Noss. Both of these greatly disturb the strata and, in several places along their lines, break up the sandstone into a peculiar breccioid mass of fragments, whose angular debris is thrown together in wild confusion. Along the west-the downthrow is westwardly, but on the eastern side it is to the east. At Funnister again there is a fault whose axis runs from N.N.W. to S.S.E. and along the eastern side of which the strata are thrown down, being inclined at a very high angle. The promontory of Cullensbro' is cut through by a fracture. Noss has two faults running across its narrow neck, and the intervening portion upthrown differs in dip from the rest of the island

The thickness of the Lerwick beds is considerable. In estimating it the longest

line along the dip is that along A. B. in the sheet of sections accompanying this paper. This is traversed by five faults but as these have throws in very opposite directions they may be left out of account. What is worse however is the irregular dip of the strata east of Bressay Sound, and the little piece of Noss. The length of this section is more than six miles, from Rova Head to the North of Noss. Deducting the sounds and allowing for the breaks the length may be taken as five miles. The average angle of dip is between 10° and 30°. If it be held to be 20° the thickness of the Old Red Sandstones of the Lerwick basin must be 8800 feet.

Passing the already-described beds of Quarff and Fladdabister, the nearest to the south are those of Aith. They also are bounded by the fault which can be determined on the second promontory south of Scraquay. It is not distinguishable over land but is beautifully exhibited at its other termination just east of Aith Voe.

The beds consist of massive grey, yellow,

and red sandstones which along the line of fault- have a dip of 30° and 40°, which however soon fall to 20° as they run out towards Holy Ness.

Again the fault- is soon seen on the opposite shore of Cunningsburgh wick, about half a mile north of Sandlodge. It appears on the face of a high rugged cliff. As usual it- cannot- be traced over the peat- and cultivated patches, but- it- comes out in the corner of Hoswick, and may be seen in a little creek through which a brook runs into the sea.

The strata of Sandwick, as well as of the Island of Mousa are massive sandstones of a dark grey colour. The point, on which Sandlodge is built, is much broken up by a dislocation. This has formed a convenient vielus for the deposition of iron, copper, and arsenic salts, which have an outer coating of calcite and quartz.

The direction of dip here differs from the greater part of the eastern rocks in being S.W., except along the fault- where the rocks are very highly inclined to the S.E.

The fault appears to have cut through these Old Red and Lower Devonian beds somewhat further from the old shore line than is the case with the Lerwick beds; this being sufficiently proved by the total absence of conglomerates along the fracture.

Shetland has its southern termination in Old Red Sandstone rocks. Across the Wick of Cunla these begin with the sunny haven of Levenwick, from which stretches one unbroken expanse of sandstones to the stern Sumburgh, at whose base repose the little Horse. Here again the fault is the boundary, although curiously it differs in one point from the two last situations. For it cannot be traced at either end, only in the middle does it make its presence known. At Levenwick the soil comes down to the pretty yellow sands of the beach, while at Quendale the dense sand-drift has totally obscured the dislocation as it has almost everything else. However, at the base of Skeabrough, the fault is seen and here the conglomeratic grits are metamorphosed into quartz-rock

along its line. The writer has not had time to visit Little or Cross Holm, but from the reference to the latter in the excellent work of Dr Hibbert, there can be no doubt that the Sound traverses this little isle.

The strata consist along the base line of conglomerates, which at the northern half of this are of schistose materials. Near Lweddale appear some very beautiful granitic conglomerates which rise out of the sand-mantle in several places. Both of these gradually assume the characters of grit and later of sandstone, so that the eastern coast is a bulwark of variously coloured massive sandstones. The section along the line E.F. accompanying shows the relative positions and heights of the sandstones. Their dip is uniformly E.S.E. varying in angle from 15° to 45°.

Casting a brief restrospective glance over these eastern sandstones, it is to be observed that, with the true base at Fladibister, there is in the beds extending south from Rovey Head a very close approach to this base. Again in the Dunrossness conglomerates the disturbance

does not seem to have been great. With reference to the other two localities it may be laid down that the Aith beds are somewhat further removed from their old coast than are those of Sandwick, and this is from the fact of these latter being somewhat more gritty in their texture, supported also by their lying more nearly placed to the central axis.

Then with regard to comparative age, so as to determine the total thickness of the Old Red in Shetland, it can only be said that of these strata Quarff shows the oldest, next come pari passu the Lerwick and Dunrossness, while those of Aith and Sandlodge, are most certainly to be included between the time of origin of the Rovey Head beds and of the strata forming Ross Kemps.

So then it comes to this that the total ascertainable thickness on the east side is that along the section A.B.

The development of the Old Red Sandstone on the western side of these islands has few remnants left to show its old extent; these however are of the greatest interest. Whether they are regarded with reference to the scenic

effects described in the surpassingly grand mural cliffs of Foula, and in the picturesque stack-ruins and dungeon-caverns of Papa Stour, or are looked upon in their relations to the disturbing igneous rocks, they fairly outrival the sandstones of the east.

At Sandness there is a fault between the two series and great disturbance of the strata has ensued. At Norbie North the sandstones rest upon gneiss, but at the other termination of the fault not far from Deepdale the older rock is a compact quartzyte in texture very closely resembling that of the Loch Maree district but in colour a pale fawn. The fracture cannot be followed over the hill.

The beds consist of dark and pale flags intermingled with pale blue shales, which are very fissile and would be excessively prone to decomposition.

The dip at Melby is W.S.W. but this gradually veers round southwards along the cliffs until at the other end of the fault it becomes S.S.E. It is however very difficult to determine exactly the direction of

dip in these cliffs from their summit.

At Melby there is a boss of the intrusive igneous rock so soon to be described in the opposite island.

There is in Papa Stour a magnificent example of that volcanic action, which in the Ochil, Sidlaw, Pentland, and other hills has reared up such memorable monuments of its activity in the age of the Lower Old Red.

The strata of Papa Stour are flaggy and shaly. As will be seen on reference to the map they are only seen here and there. At the point opposite Hucksetter the beds are of a deep chocolate colour and brittle texture, evidently caused by igneous action. On either side of Hamna Voe there are a few strata also somewhat brown in tint. All along opposite the skerries of Leera and Foraloe are dark coloured fringes which will be referred to presently. These also appear on the north near Cullier Voe. In Housea Voe and on both sides of Forwick Ness the sandstones are flaggy and of a pale hue than these just spoken of.

The direction of these strata varies very considerably.

All around the island wherever the stratified rocks appear they are found to rest upon contemporaneous porphyrite of a very dark colour. Along with this there is very crumbling tuff. The section along the line GH gives upon a true scale the order of superposition in Papa Stour. It is however small and the diagram, fig. 2, shows the positions and relations of the rocks more clearly.

As above said the lowest rocks are always composed of porphyrite and tuff, the latter being stratified. These are marked 3 in the diagram. The former is proved to be a regularly interbedded contemporaneous flow by the two facts, first, that its texture, when seen at some depth, is perfectly compact, while at the surface it varies from amygdaloid to a roughly scoriaceous material, and second, that it is accompanied by the tuff which evidently has been poured out into the sea.

Over these repose the sandstones, flags,

and shales (α') which have already been noted at Fowick, Kirk Sands, in Hamna Voe, at the most southerly of the points opposite Seera and in the Voe of Housa.

Then over these spreads (γ) one vast sheet of brilliantly tinted felstone. This rock is evidently intrusive both from its being crystalline as well as columnarly jointed from top to bottom, and from its cutting through and disturbing the Old Red beds here and there. The felstone forms the entire surface of the island, which is able to boast of some of the richest land to be found in Shetland. Nowhere can the dyke be seen, but it is probable that the intrusion has taken place from some point not far from Verdefield the highest point in the island.

The highest beds are the few remnants of the sandstones (α^2) which have been forcibly separated from those beneath. They may be seen capping the Horn of Papa, and the other points opposite Seera, and also crowning one or two points on the north side of the island. These as well as the

sandstones beneath are always very much changed by the intrusion of the felstone, and have a somewhat baked and hard consistence.

The diagrammatic section, fig. 2, is from the Hom Sound Hamna Voe to the point opposite Huckster.

And now remains alone to be described the stratigraphy of Foula.

Along great part of the eastern coast of this interesting, but little known isle there is a succession of highly crystalline gneiss, whose foldings and contortions present most picturesque objects. These rocks are much broken up by a number of faults and are intersected by veins of bright-pink, and pale grey granite.

The Old Red Sandstones as developed in Foula consist of arenaceous and argillaceous rocks, and are separated from the crystalline by a fault. This begins at the north in the Bay called Wardwick, but cannot be traced over the island from the impenetrable covering of peat. It is visible

at its other extremity in Skobel Voe to the south of Heam and it cuts across the next two points to the south. The axis runs from N.N.W. by N. to S.S.E. by S. The stratified rocks have undergone a great disturbance, and all along the line of fracture have been metamorphosed into a very hard and tough quartz-rock.

The lowest rocks in this series are pale gritty sandstones. These are succeeded by grey sandstones of finer texture, and softer material, and these again are overlaid by blue argillaceous flags, as are well seen at the Blober Burn. Coarser flags follow and when the rock is next seen, near the summit of the Sneug it is found to be a coarse and gritty flag. The face of the cliffs is formed of massive sandstone, argillaceous and soft shales, and hard as well as frequently gritty flags; all pass through shades of red, blue, and grey.

These rocks have in the main a dip to the S.S.W. whose angle over the greater part of the island is 30°, along the fault this rises to one of 45°, 50°, or even to 55° or 60°.

Along the cliffs it may easily be supposed that the dip is often difficult may sometimes even impossible to make out. It never passes out of the arc between S.S.W. and S.S.E. except in the Horup whose strata have a direction to the S.W. and an angle of inclination of 20°. Its upper beds are more nearly horizontal.

A slight disturbance of the strata seems to have occurred between West Hora and the Horup, but excepting it no fault or dislocation breaks the regular succession of these beds. Taking then this unbroken stretch of sandstones and flags for somewhat more than two miles at an average angle of dip 25° the thickness of strata in the island cannot be less than 4400 feet.

In the sheet of sections are two which are explanatory of this island.

When casting a general glance over the Old Red Sandstone of Shetland one is at once struck by the fact of its great resemblance to that developed in Caithness. At the base in both cases are conglomerates, resting similarly upon older and contorted metamorphic rocks, and passing

into massive sandstones. In these isles also there is the same gradation into pavement-flags differing only from those of Caithness in their being more micaceous. And finally the upper beds of Shetland are light red and yellow as at Dunnet and in Moray. Thus stratigraphically both show similar conditions, and appear to point to a widely stretching sea to the north of the chain which in Silurian times occupied, as now, the position of the Grampian Mountains.

It is also most interesting to find that the volcanic activity characteristic of the Old Red has been the cause of disturbance in this extreme north of Britain.

B. Palaeontological evidence

Unfortunately the materials for this branch of the subject are few and imperfect. It has been seen how very similar both lithologically and stratigraphically these beds are to those of Caithness. In their fossil contents however it is not so.

Of the organic remains none are animal. The fish of Cromarty, Caithness and Orkney — these wonderful armour-plated

denizens of the deep, are all conspicuous only by their total absence. The massive sandstones and the pavement-flags have been thoroughly examined in the quarries, the shales have also undergone careful investigation, but no remains testify to the advent of the higher kingdom in the seas of ancient Shetland.

In all of these rocks however fossil plants are found. They are never in good preservation and are always imperfect. They occur under three conditions; firstly, as mere impressions in which a pictorial representation remains imprinted upon the rock; secondly, as casts in which outwardly is presented the appearance of the original while no trace is left internally of its structure; lastly, as a conversion of the vegetable structures into a black carbonaceous material resembling coal.

Under one or other of these conditions the plants appear, and present three forms.

There are long stems of very varying thickness but attaining at least a diameter of about a foot. These are marked externally by longitudinal striation, the lines running perfectly

parallel and unbroken by the faintest trace of a joint. Sometimes they end below in a root, but it is always worn and imperfect from having been drifted. Never are they to be seen branching. Impressions as in Fig. 3, and casts, Fig. 4 are very frequently met with, and carbonised specimens are also common. Sometimes, as in Fig. 5, the casts have interrupted transverse lines. Such markings are due to the existence of cracks on the exterior of the plant at the time of its interment.

The second form has dichotomously branching stems, as shown in Fig. 6. These are also longitudinally striated, with now and then faint transverse lines, which must also be attributed to cracks. The re-entering angle formed by the branching is usually small, and the lines externally are always parallel.

Lastly there are slender terminal branchlets which also bifurcate, but with very variably sized angles. The surface is perfectly smooth in most instances or has, as in Fig. 7, longitudinal lines. In some specimens branching is seen to go on continuously as in Fig. 8. Foliage is not unfrequently attached to these slender twigs, but is indistinct. However Fig. 9 would appear to show that this is

composed of leaves which have a central axis and lateral pinnae.

When these plants are examined microscopically the results are unsatisfactory. For in the case of casts no trace of the original texture is retained, and only an irregular aggregation of mineral grains can be seen as shown in Figs 10 and 11. On preparing slices of the black carbonaceous material, and looking at them either with high or low powers, nothing is visible except the dark substance destitute of any organic structure which is represented in Figs 12 and 13.

Now what are these different forms of vegetation?

The larger stems and branching boughs are probably referable to the same form, they have the same external markings and are found together.

These are longitudinally sculptured as in the genus Calamites. But they have none of the transverse articulations which characterise the Horse-tails and cannot thus belong to the Equisetaceae. And these plants

moreover subdivide whilst in Calamites this never occurs.

The genus Lepidodendron branches in a manner very similar to these fossils; but no one could for a moment dream of comparing them, the external contrast being so great.

Only one hitherto described fossil corresponds to the appearances of these Shetland plants. It is the Psilophyton, described by Principal Dawson.

The slender twigs with their ill-defined foliage certainly belong to the order of the Ferns. The leaves are not sufficiently preserved to hazard a conjecture as to their exact affinities

5. Dynamical Geology.

In this section of the paper these forces of nature whose agency has produced the swelling hill and sinking dale, as well as the lofty cliff and shingly shore have to be passed in review. And in it must be investigated both the causes which have built up the land, and the agents engaged in giving to it its diversified contours. In other words, the origin of the block, upon which the sculptor Nature has carved the present lineaments must first be sought for; and the method of working, by means of which these picturesque features have been imprinted must then be studied.

Undoubtedly the best plan which can be adopted in such an inquiry is the analytical. That is to say, that instead of taking any one agent and gathering together all its actions and their results by synthesis, a phenomenon is observed and all its causes are looked at seriatim.

Beginning then with the formative process it is to be observed that before the first layer of the Old Red building was laid the

older rocks had already been metamorphosed. This fact is sufficiently proved by the conglomerates being formed out of such altered materials.

Again the foundations were deposited in the ocean. These same conglomerates can never have had their origin in any lake.

It has been said of America that the form of that vast continent was determined in Archaean times. So in Shetland the outline appears to have existed very much in its present form when the Old Red Sandstone was laid down along the shores. The coast-line of that age is seen at Quarff, and the fault at Lerwick and Dunrossness is most certainly not far from the ancient boundary of the land. On the western side it is more difficult to determine the position of the old shore and all that can be said is that the rocks both of Foula and of Papa Stour with Melby have been deposited at a greater distance from land than is the case on the eastern side.

Fig. 14 gives a diagrammatic representation of the probable bounds of land and

water in the south of Shetland at the commencement of that subsidence which accompanied the deposition. The purple colouring shows the old land surface, the pale-red tint represents the ocean. The dotted line is the supposed shore, while the dark line is the present demarcation between the metamorphic and the sandstone rocks.

It is highly probable that the acrogenous plants whose remains are found flourished on the land. It is not however to be regarded as certain since none of these organisms are in their natural positions and so many of them appear to have been drifted.

But did no animal exist in these northern seas? A reluctant answer in the negative is at present the only possible response, since in the total thickness of eight thousand feet the faintest trace of the higher kingdom has never been detected. And yet, as curious Ganoids are so abundant in very similar rocks elsewhere, they are most naturally expected also in Shetland. If it be assumed that the presence of no remains is to be accepted as evidence that no animals lived

at all the reason why such should have been the case must be found.

It may be suggested that some barrier has prevented the spread of fauna from Orkney to Shetland. This at first sight is a plausible supposition. The nature of such a partition-wall may be supposed to be a reef of the older rocks. There is not however the slightest ground for such a hypothesis. That a sand-reef may have separated the two localities is supported also by no evidence. So then although fancy may conjure up such baseless images it is impossible to believe in any such mode of separation. But different physical conditions may well have been the cause of such a difference, and the following argument is advanced to account for the absence of any animal life in these seas.

Between the Old Red Sandstone of central Scotland and that of the north-eastern districts there is very great difference. Professor Geikie has shown how the Grampian range has completely separated the two areas. It is in the highest degree probable that in the former locality between the Highlands and the

Southern Uplands a large lake existed in which the development of this age took place On the northern shores of the former were laid down the Caithness and Orkney sandstones. These certainly began as a marine formation. They continued to be so with a long and gently sloping muddy shore slowly subsiding. Whether before the termination of their origin some encircling sandbank shut the area in as a lake does not require any discussion here.

Now why did the inhabitants of these waters not reach Shetland? These armour-plated fish have no narrow limits of distribution For instance the Asterolepis of Stromness is frequently found in the rocks of Russia and has left evidences of its presence as far as America. The following must have been the reason why these fish, chiefly frequenters of mud, in which they buried themselves entirely save the head, found no place in Shetland.

The whole of the Shetland Old Red is marine. Not only do the flags differ from those of Caithness in being much more gritty

in texture, there is further but a feeble reproduction of the deep red tints of the southern Old Red. The fainter shades here may perfectly well have arisen from ocean deposition. Iron abounds in the metamorphosed rocks, and it is not too much to suppose that variations of temperature, such as must have occurred during the long period occupied by the formation of these rocks, may have caused at one time so great evaporation as to leave a very briny and saturated sea, at another time may have permitted a comparatively fresh ocean to wash these shores.

Moreover Papa Stour testifies to contemporaneous volcanic disturbances accompanying the deposition of these rocks.

Southern Shetland has been separated from the Mainland and surrounded by a deep sea. This perfectly accounts for the absence of the helmed and cuirassed mud-fishes. At the same time this sea has been too much saturated with salts, and too often disturbed by subterranean causes to be a congenial habitat for invertebrates. And thus it would appear to have been uninhabited.

Ripple markings are of extremely frequent occurrence in Shetland, a fact showing that in many parts the ebbing tide receded from a sandy beach. Emeraldes appear much more rarely.

The picture which imagination summons is a low and rocky coast having at intervals long sandy shores, rising up into a barren wilderness, and laved by a tenantless ocean. These waters lie still and dead under the scorching glare of a furnace-sun and blazing skies, or wildly dash themselves against the melancholy shores while the driving clouds chase one another over the scene and mingle with the spray. Here a volcanic cone with its environs of ashes relieves the tiresome uniformity of outline, there a lava-stream varys the monotony of the prospect. Are the elements at peace then perfect stillness reigns, and the only sounds which at any time break the silence are the mourning wail or the fierce roar of the ocean and the howl of the blast, save when some volcano, as if waxing impatient of the oppressive quiet, raises its voice in a thundering growl when its fiery

streams pour forth.

Later may be pictured another igneous disturbance which remained subterranean and appeared at the surface only as an earthquake. And during one or more of the many elevations, which have alternated with depressions of the land, rents have occurred along either side, accompanied by a subsidence of the lateral portions, in accordance with the law that faults are the result of the elevation of a curved surface.

In looking for the causes of the physiography the coast-features will be taken up first.

Of the factors having an influence upon the formation of this scenery there are, firstly, a number of subaerial causes which are most naturally to be regarded as active. They are usually grouped under four heads — air, water, ocean, and life. Secondly, there are properties belonging to the rocks themselves and which are to be looked upon as passive. These are the nature of the material and its position as rock masses. Perhaps it is more methodical to examine the second group before going into the first.

The texture of the rocks influences in a very marked degree the outlines assumed by headland and bay, by skerry and cave. In the old schistose rocks all the cliffs are low and receding. When any height is attained as for example in Fitful Head the features are in the large rounded but on closer inspection have numerous jagged projecting points. In the same way the promontories may run far into the sea but they are low and rugged in form. The skerries are similar. All the caves in these rocks are more or less rounded and irregular. How all these appearances are dependent upon the crumbling nature of the material, and its varying power of resistance in different parts. Thus in a mass of gneiss a boss of granite may often be found forming a point, the granite withstanding the action of the attacking agents much better than the gneiss. Still even the granite crumbles and gives much the same resulting outlines as schist.

On the other hand the sandstone rocks tower up into lofty and perpendicular cliffs with clearly cut features. The headlands are

bold and massive, the stacks sometimes tall pillars or obelisks, and sometimes resembling angled fortresses, the caves ever square in form and never rising into dome-roofed halls. All these characters result from the facts that the siliceous material building up these objects is very enduring and that weathering goes on through quadrangular blocks becoming detached at the joints and falling down.

But in the description of Fonla scenery note was taken that different tiers possessed varied resisting powers. This in itself assists destruction, for when a soft stratum has given way underneath a harder, the latter must of necessity fall down in time.

In weathering too the texture of the rocks is brought out and in Papa Stour especially many varieties of reticulated pattern are to be seen.

The position of the rocks also has a most potent bearing upon the resulting form. A law may be enunciated that the cliffs are always highest towards that side from which the strata dip. As an example in Fig. 15 is a diagrammatic section of Fonla. The

dotted line represents the island before the removal of a great part by denudation, and the dark lines are the present form. In it may be seen that the strata dip southerly. Towards the north face bold and lofty cliffs, whilst to the south the coast is low. The explanation of the law is very simple. When the strata are horizontal or dip from the face exposed, the wasting process must begin below and extend upwards, by which means a more or less nearly perpendicular wall is produced. But when the strata dip towards the face the upper layers becoming loosened slide downwards over the lower, and thus comes a less prominent outline.

Leaving the passive influences, the subaerial must now be examined.

The Atmosphere, in its chemical action, causes a further oxidation of the iron colouring in the red sandstones, and its gradual disappearance as it becomes washed away.

In its purely mechanical or physical action it has but little to do with rock weathering in Shetland, under present conditi

as the extremes of temperature are so little removed from one another.

As wind the air very often blows down blocks which have been previously detached by other agencies.

Surface water has not a great action upon the formation of this coast. As rain it washes down the detritus caused by weathering, but except in layers of shale this waste is very slight. But the rain enters the joints and by trickling down through them it assists in loosening blocks of the strata. And when frost occurs this water exerts the force of frozen water in separating these masses of rock. In Shetland however the frosts are of an exceedingly mild nature.

The Ocean is a much more potent power in Shetland. During the winter solstice on the exposed Skerryvore Rock a pressure by the waves of a ton and a half upon every square foot is common, and this rises in gales to as much as three tons. Upon the western shores of Shetland also how tremendous must be the force of the waves, especially upon Foula where the people must crawl

upon hand and knee when out in the gale. As a powerful force battering the rocks the ocean's action is great; and yet without a quantity of hard detritus to hurl against the coast the resulting effect can not be very marked. And, as will be later proved, the action is alone to be observed above low water mark. When any weak point exists the ocean enlarges the cavity, the air which enters at ebb is compressed afterwards and rushes along any lines of less resistance, blocks are detached and fall down leaving caverns often, as seen in Papa Stour, with blowholes; and the fallen blocks serve as material for the ocean-artillery to use as projectiles.

In the removal of detritus also the ocean leaves fresh surfaces for the attack of the other sub-aerial agents.

Further the ocean assists destruction by augmenting the watery-vapour saturation of the atmosphere and the consequent rainfall.

But great though the destructive action of the waters is they have also a conservative

influence. When the tidal currents are by a headland or a skerry prevented from setting upon any portion of the coast there is below low water-mark a platform extending as far from the shore-line as the limit of calm and non-current water. This is well seen in Yorkshire along the exposed western cliffs of which are several such platforms. In Fig. 16 is a section of such a phenomenon. These are due to the protective covering of the calm watery depths, for the waves are purely superficial. Fig. 17 is an explanatory sketch showing how in these localities promontories divert the to- and fro- tidal currents and allow the submarine platform to exist.

Again the proximity of the circumjacent ocean causes the climate of Shetland to be singularly equable and mild for its latitude. This of course is assisted by the clear blue waters of the Gulf-Stream. Thus frosts and snows are much rarer than in most places on the same line.

The last of the sub-aerial agents is organic in its nature. Destructive action solely depends upon the retention of damp by lichens and

mosses on the coast-line. This action is very insignificant as both classes of plants are somewhat more rarely seen in these islands than in Scotland. The conservative influence is greater. At Quendal the sandhills which form the coast are bound together by grasses and carices, without which they would disappear with the first gale which arose. And along the sealine the algae which cling to the rocks have a very considerable action in preventing the sea from rolling about the stones in its bed.

Thus both the ocean and atmospheric agents with life have been instrumental in modelling the now existing form of the coast. If I be asked whether the oceanic influences or the latter have been most powerful, the question must be answered by saying that it entirely hinges upon one condition — the nature of the material forming the coast. When this is of an enduring character as in sandstone the coast assumes the form of more or less lofty cliffs. These never have a lower angle than that of the dip of the strata, and this is most that in such rocks the ocean at the bottom

is to the full as destructive as the other forces above. If on the other hand the rocks consist of crumbling and destructible materials then the coast is low and irregular, here with a bluff projection where the waves have not been so successful in their assaults, and there having a deeply cut fiord or inlet. This shows how impossible it is to establish any absolute comparison between the two sets of agents.

In analysing the inland scenery the same agencies are met with.

The hills of the Old Red run in chains which are always parallel with the line of strike. It is not very difficult to find the reason of this. Parallel with the line of strike are the lines of weakness. For instance in the direction of an anticlinal axis it is easy to see how solutions of surface continuity should occur through the stretching of the outer strata. And when such less resistent axes have once been established the surface agencies come into action and remove the old external features. It is from this cause that mountains and elevations in general are so frequently coincident

with synclines. The rocks are much less apt to be broken when folded so as to form a concavity than when they are raised into a convex curve. The hills of the Shetland sandstones however cannot be said to agree with any synclinal fold for there really is no such appearance. But they are in Bressay and Foula formed of rocks which do not dip at a high angle, the strata on either hand being more inclined.

So much for the position of the hill masses. Their outlines are due to two factors, as in the case of the coast — the texture of the rocks and the position of the strata.

In a great measure the form of the hills and valleys depends upon the material out of which the rocks are built. When this is schistose billowy undulations of a rounded and monotonous character stretch for miles. The scenery is of the most bleak and desolate kind, the herbage scanty and the bare rock protruding everywhere. Such outlines depend upon the crumbling manner in which these rocks weather. If however the rocks are sandstone the features are

very different. The hills assume bolder as well as sharper outlines, and are better clothed with verdure, whilst the valleys are floored with better soil. It is most interesting from the middle of the Shetland Mainland to look eastwards and westwards. All around are the barren lumpy masses of the metamorphosed rocks but further off on the one hand is the sharp peak of Bressay Wart, on the other hand the pointed summits of the Foula Hills. As seen before the cause lies in the enduring nature of the jointed rocks.

But the contour of the hills in a great degree is due to the dip of the strata. Here comes into play the law which was stated with regard to the coast. It may in reference to the inland features be modified and is then that the side of the hill from which the strata trend is the more abrupt. For example in Foula the three central or axial hills were described as presenting to the east and north-east faces of great steepness. And the strata of these hills dips more or less to the south-west. The reason of this result is the same as that described for the coast.

And now must be examined the subaerial agencies.

The action of the atmosphere as a destructive agent is not great. The rocks have little or no calcareous matter, and it is only when they contain much iron that waste due to the air chemically can go on. And wear also due to physical causes as expansion and contraction cannot be worthy of note as the changes of temperature are confined to so limited a range.

Wind has a destructive influence by blowing away detritus and soil, by preventing a protective covering of vegetation, and also by carrying the spray of the ocean over the land.

The next agent is surface water.

From a chemical point of view rain is unimportant for the reasons stated above. But the mechanical action of rain is very different; as here, besides being very frequent, rain is very heavy. Along the hill sides peep out very often the bare rock showing how this agent washes away the covering and wears the rock beneath.

Next part of this rain-water sinks under ground. It does not appear in Shetland to penetrate the solid rocks but merely courses through the debris with which they are covered and reappears at a lower level as springs. In its transit it loosens such detritus and as a natural consequence landslips are a not unfrequent result. Both rain and this underground water bring down a great deal of sandy material.

With the exception of such an amount as may disappear by means of evaporation all the rain which falls is ultimately gathered together into brooks, which cut through the lower lands on their way to the sea. During the rains of winter every rivulet here is a foaming torrent bringing down much detritus in suspension, transporting the pebbles in its bed towards the sea and cutting its deep channel yet deeper. These beds rocky and rugged testify to the force of the moving water. Sometimes in Shetland they are through alluvial plains on a small scale, but much more often they have been eroded in peat-mosses and show the rocks below.

Lastly, the surface water is a powerful agent when it becomes frozen. Under present conditions in Shetland it has not a very important rôle, from frost being extremely moderate in intensity. Still the freezing of the water which occupies the joints of the rocks must play some part in the waste of the land.

There are in these islands proofs of a former reign of cold. Firstly, the whole surface shows, in spite of later weathering, the outline of roches moutonnées. This is always better preserved by the metamorphic rocks, from their more equal disintegration. In the hollows between the billowy swells nestle many little lochs, which evidently have ice-worn rocky basins. Next there are many fine examples of moraine remains, and in Bressay there is a loch which owes its existence to a dam of such nature. Thirdly, good specimens of boulder-clay are exhibited on the coast a very short distance to the south of Lerwick. It is of a stiff firm consistence, and contains worn and polished pebbles. Lastly, in one

instance in the Tingwall district during the summer of 1876 a landslip exposed a very beautifully striated surface. It was not a sandstone rock but schistose, and from being well covered the imprinted lines were well preserved.

As a destructive agent the ocean merely has an influence through augmenting the rainfall.

In the last place life must be inquired into, and firstly the action of plants. Sometimes along the side of a hill the roots both of grasses and of such plants as the Empetrum and Vaccinium are found separating the flaggy strata, and permitting water to enter. Peat-mosses retain water which re-acts upon the rocks; besides, these bogs keep the atmosphere moist, and some writers hold that they attract rain. Animal influence is only exerted in a local way by the burrowing of rabbits.

But now many of these destructive causes have also a conservative side, which it is well to remember.

Passing over air and surface waters, as not from this point of view important, the ocean has a distinctly conservative tendency upon

the land by mitigating the climate. Bearing in remembrance that Shetland lies on the parallel of latitude occupied by Cape Farewell in Greenland, and by the extreme north of Labrador, this action can be appreciated.

Then plant-life has two protective actions. Turf forms a very admirable shield against the assaults of the atmospheric powers. And the power exercised by the roots of plants in binding loose materials together is very well shown in the sand hills of Quendal.

And now, finally, many of these factors have under present conditions in these islands a reproductive side.

Soil is formed in suitable localities by the united action of the air and of surface water, assisted by earth-burrowers such as worms

Then as before seen at Quendal the wind has blown up sand-mounds, which not only are the coast; but which extend for a considerable distance inland. And this geological reproduction is economically the most perfect destruction possible, for the once fertile soil is enveloped in a sandy death-shroud.

In a few places the streams, small and apparently insignificant as they are, have when in flood deposited alluvium by their overflow and now course through plains on a small scale of this nature.

The abounding peat-mosses of Shetland are due to the unproductive action of plants. The mosses which build up these bogs die below and continue to grow above, thus forming great depths of fuel. Many of the hollows occupied by these mosses have probably been at a former time lakes.

Such then are the causes of that tame wildness of outline which characterises the inland views of Shetland, as well as so much of the Highlands of Scotland. The cliff scenery is of course the most striking and interesting feature of the islands, abounding as it does in romantic caverns and quaint stacks or skerries.

Undoubtedly the most favourable opportunity to see Shetland is during a gale. Then from Fitful Head may be seen the watery mountains of the Atlantic with their snowy crests rolling onwards and madly breaking below upon

the rugged points which fringe the coast, while the rude blast roars up every chasm and whistles through every crack, carrying with it, sheer over the cliff-summit, the spray of the ocean.

And yet very lovely appears the scenery when the air is still and the depths unruffled save by the dive of the shrieking sea-bird, the leap of the silvery fish, or the gambolling of the playful porpoise. On calm evenings a sweet beauty steals over the scene, when the golden sun lights up the sombre hills with a purple glow as he sinks into a calm sea, which, from the deepest blue at the spectator's feet gradually shades into the faintest green of the distance, and finally blends with the delicate rose of the evening sky.