difficulty already referred to in the present distribution of marine terraces and raised beaches. Whichever way we view the question, we seem to come back to the conclusion formulated long ago by Hugh Strickland in regard to the Severn Valley beds. "The marine shells," he says, "which have been found in the gravel in Cheshire, Staffordshire, Shropshire, and Worcestershire, belong chiefly to existing species, and we must therefore assign a very recent epoch to the formation of these deposits. It appears also that the causes which transported the gravel were comparatively transient, for we can hardly suppose the sea to have occupied the central plain of England during a very long period without leaving some traces of Tertiary strata (Strickland wrote before the Quaternary deposits were separated from the Tertiary beds), especially in small valleys and basins, which might be sheltered from the action of the northern current" (Strickland, Mems. and Papers, p. 107).

I have now examined, I hope with fairness and candour, the evidence of the high-level marine drifts containing shells found at so many scattered points near the coasts of Western Europe. I cannot find them testifying anywhere to those gigantic vertical movements of the earth's crust over immense areas and within quite recent geological times, which are required by the theory of a long-continued submergence advocated by Sir Charles Lyell and his followers. Nor do I see in them effects which can with the smallest probability be assigned to the action of ice in any form. I find in them, on the contrary, a consistent testimony to the presence and action of the same diluvial movement of which such ample evidence has been accumulated from other sources, and which alone seems to me competent to explain them.

VI.—The Secret of the Highlands.

By Prof. Charles Lapworth, F.G.S.

HAVING gained a general comprehension of the probable physical and palæontological sequence among the Lower Palæozoic strata of the Southern Uplands of Scotland, as partly published in my memoirs upon the "*Moffat Series*," [1] and the *Girvan Succession*,[2] I felt myself at liberty last summer to commence the study of those rocks of the North-west Highlands, which are supposed to be of corresponding age.

The area I fixed upon for examination was the coast region of Durness and Eriboll in North-west Sutherland. I selected that especial area for several reasons. It is the only Highland district where Lower Palæozoic fossils have been obtained in comparative abundance. It lies wholly upon that enigmatical zone of country where it has been asserted that we have a demonstrably ascending succession from the basal Hebridian gneiss through fossiliferous Palæozoic limestones into the metamorphic gneiss and micaceous schists and slates of the Central Highlands. It is the only area

[1] Quart. Journ. Geol. Soc., May, 1878. [2] *Ibid.*, November, 1882.

where the rocks of this remarkable zone come out in force upon the shore-line, and where, as a consequence, the stratigraphist might expect a more than ordinary abundance of serviceable rock-exposures. And, finally, as the keener disputants in the Highland controversy have already published their views as to the physical structure of this area, I should have the advantage of working alone, and drawing my own unfettered conclusions.

The final results of my investigations in the Durness-Eriboll region during August last seem to me to indicate most distinctly the probable truth of the theory which has long appeared to myself to be the only possible solution of the Highland difficulty. I believe that we have in the so-called metamorphic Silurian region of the Highlands of Scotland a portion of an old mountain system, formed of a complex of rock formations of very different geological ages. These have been crushed and crumpled together by excessive lateral pressure, locally inverted, profoundly dislocated, and partially metamorphosed. This mountain range, or plexus of ranges, which must have been originally of the general type of those of the Alps or Alleghanies, is of such vast geological antiquity, that all its superior portions have long since been removed by denudation, so that, as a general rule, only its interior and most complicated portions are preserved by us. In the area partly worked out by myself, the stratigraphical phenomena are identical in character with those developed by Rogers, Suess, Heim, and Brögger in extra-British mountain regions. They appear to me to account so naturally for the diverse views hitherto published by those who have personally studied the stratigraphy of the North-west Highlands, and to indicate so clearly the common ground of accord upon which all parties may eventually meet, that I am emboldened to give them in outline in this place, in anticipation of a more detailed paper upon the subject, which I hope to publish elsewhere. It is for those who are interested in this great geological problem to test for themselves the truth of these conclusions, by their consonance with their own discoveries, or to point out those difficulties which at present stand in the way of their provisional adoption.

I.—*Apparent structure of the Durness-Eriboll region.* (See Fig. 1.[1])

At first sight it would appear that the rocks of the Durness-Eriboll region are easily grouped, and that they are arranged with remarkable geological simplicity.

(*A.*) Lowest of all lies an enormous formation of massive gneisses with coarse folia of quartz, felspar, and hornblende (and more rarely mica). These gneisses are almost vertical, and have a steady N.W. and S.E. strike. They form the basal or fundamental gneiss of some authorities, the *Hebridian*, *Lewisian*, or *Laurentian* of others.

(*B.*) Upon the eroded edges of the Hebridian gneiss rest unconformably the basal beds of a second formation, the strata of which have a very gentle inclination, and strike, as a whole, to the north-

[1] The illustrative Figures will appear in the second part of this paper.

west and south-west, or at right angles to the direction of the underlying gneiss. This higher formation appears to be composed of two very distinct divisions, viz.:—

1. A *Lower* division of quartzites, flaggy beds, and limestones, often greatly hardened, but the calcareous beds of the division (Durness Limestone) afford *Maclurea*, *Murchisonia*, *Orthoceras*, and other recognizable Lower Palæozoic fossils. (This division may be termed the *Durness or Eriboll series.*)

2. This Durness-Eriboll series appears to be surmounted conformably by an *Upper division* of flaggy, quartzose, micaceous and chloritic schists, with thick zones of hornblendic and micaceous flaggy gneisses and bands of so-called igneous rock (dioritic or syenitic rock of some authors). This division forms the well-known *Upper Gneiss*, or *Sutherland Flaggy Schist* series.

As regards the superiority of the fossiliferous Durness-Eriboll series (B. 1) to the basal Hebridian or Hornblendic gneiss, there has never been any dispute. But the true relation of the Sutherland series or so-called Upper Gneiss (B. 2) to the fossil-bearing rocks is not yet settled, after years of the keenest controversy. This Sutherland series not only contains beds hardly more altered than those of the fossiliferous Durness-Eriboll series, but it includes also hornblendic and micaceous gneisses almost inseparable mineralogically from those of the basal Hebridian. It stretches too, in almost unbroken mass, eastward and southward from this region over the entire area of the Central Highlands, where it covers at least an area of 15,000 square miles,[1] and has not yet afforded a trace of a recognizable fossil. Many geologists, therefore, aware that the concession of the superiority of the Sutherland series to that of Durness, carried with it, almost of necessity, the admission of the Palæozoic age of *all* the schists and gneisses of the Central Highlands, have refused to pin their faith to the apparent stratigraphy, and have sought to explain it upon the hypotheses of hidden faults, or folds, or stupendous overthrows of the strata. Others, again, have boldly accepted the visible sequence as it stands, with all its awkward consequences. It is hardly necessary perhaps to point out that the latter view, being the most superficial and the most natural, is that which has hitherto been the most orthodox and the most popular.

II.—*Theories of the Physical Structure of the Durness-Eriboll Region:*—

At least four distinct theories have been already published in explanation of the Durness-Eriboll section.

1.—*Theory of Sir Roderick Murchison.*

According to Sir Roderick Murchison, the succession in this region is composed of two distinct rock systems, viz.[2]

(*A*) *Archæan or Laurentian*: composed of the basal Lewisian or Hebridian, hornblendic gneiss of Fashven and Ben Cannabin: a true crystalline gneiss with a steep dip and N.W. strike.

(*B*) *Palæozoic or Silurian*, consisting in ascending order of:—

[1] *Geikie*, Handbook of Geology, 1882, p. 584.
[2] Quart. Journ. Geol. Soc. August, 1859.

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(*a*) A *Lower or fossiliferous* (*Durness*) *division*, composed of
1. *Lower Quartzite* and flaggy fucoid beds of Kyle of Durness, and west side of Loch Eriboll.
2. *Limestone of Durness*, with *Maclurea* (regarded as the equivalent of the non-fossiliferous limestone of Eriboll).
3. *Upper Quartzite* of east side of Loch Eriboll.

This lower division graduates upwards as a whole insensibly into the

(*b*) *Upper or Metamorphic division* of the Flaggy gneisses and schists of Fair Head and Ben Hope (*Sutherland series or Flaggy gneiss*).

2.—*Theory of Professor Nicol.*

Murchison's view of the superposition of the Sutherland gneisses and schists to the Durness series was strongly opposed by the late Professor Nicol, who held that the (*A*) *Archæan or Hebridian* of Fashven and Ben Cannabin was covered unconformably by the (*B*) *Palæozoic strata of Durness and Eriboll*, in which he recognized only three members—

1. The Lower Quartzite.
2. The Fucoid beds.
3. The Durness or Eriboll Limestone.

He held that the so-called *Upper Quartzite* of Murchison was merely the Lower Quartzite repeated by inversion, and that it was newer than the *Sutherland gneissic series*. The latter he held to be, upon the whole, an ancient metamorphic Pre-Cambrian gneiss brought up to the eastward of Loch Eriboll by a gigantic overthrow fault: running generally along a line of syenite or intrusive igneous rock, which occurred in occasional patches along the fault line from Whiten Head to Loch Maree.[1]

3.—*Theory of Professor Heddle.*

Founding mainly upon the fact that the Assynt-Eriboll, or easterly band of the Quartzite and Limestone series, is unfossiliferous, and that its most prominent bed to the south is dolomitic, while the Durness Limestone is fossiliferous, and its beds are not dolomitic, Professor Heddle agrees with Murchison in regarding the apparent ascending succession, from the basement quartzite of Ben Cannabin into the Sutherland schists, as the true one; the "igneous rocks" being interbedded, and not destroying the general continuity of the sequence. He differs from Murchison, however, in placing the whole in the Archæan, with the exception of the fossiliferous Durness Limestone, which he believes is merely an isolated fragment of an originally overlying Palæozoic formation dropped in by faults.[2]

4.—*Theory of Dr. Chas. Callaway.*

According to Dr. Callaway also, there are probably two distinct Archæan series in the region, (*a*) the massive Hebridian gneiss at

[1] Quart. Journ. Geol. Soc. 1856, p. 17, *et seq.*
[2] Heddle, Microscopical Magazine, 1881-82.

the base, overlain unconformably by (*b*) a second metamorphic series; composed, in ascending order, of the quartzite, the gneisses of Sango Bay, etc., etc., and the flaggy schists of Fair Head, Loch Hope, and Central Sutherland. He infers that the Palæozoic Durness Limestone was deposited upon the contorted gneiss, and owes its apparent infra-position to the latter merely to the effects of faults.[1]

III.—*Results in the Durness Area.*

In my study of the Durness area I ascertained that the following facts, among many others, are easily made out upon a careful mapping of the ground.

1. The Lower Quartzite rests at a gentle angle unconformably upon the almost vertical edges of the Lewisian or Hornblendic gneiss.

2. The highest bed of the Quartzite is a flaggy zone pierced by innumerable vertical annelide tubes. (*Pipe-rock* of Nicol.)

3. The Durness Limestone, though at first sight apparently homogeneous, of great thickness and of very gentle inclination, is actually made up of a few distinct lithological zones, repeated again and again in a series of faults or inverted folds. It is hardened and more or less crystalline throughout, but contains abundant relics of *Maclurea*, etc., upon one special horizon.

4. The Limestone is visibly *overlain* in excellent readable sections and at a very low angle by a series of wrinkled shales, micaceous flagstones and slaty schists, with intercalated zones of hornblendic gneissose schists; and even where transversely faulted against the limestone, this overlying series agrees precisely with the underlying limestone zones in dip, strike, and apparent amount of convolution.

As this physically overlying series is the *Upper Flaggy gneiss* series of Murchison, it would appear, at first sight, that his theory of the sequence, so far as the Durness area is concerned, is absolutely impregnable.

Such, at least, would be the unhesitating conclusion of any geologist whose field experience had been confined to the study of the gently inclined and slightly folded rocks of the Newer Palæozoic and more recent formations of Britain. But to those who, like myself, have been led again and again into error and difficulty by a too hasty reliance on *apparent* sequence among the excessively convoluted Lower Palæozoic rocks, it is needless to point out how utterly worthless is such evidence as this, in highly plicated and inverted strata, unless it be confirmed by other and more convincing testimony. And the folding, wrinkling, and inversion in the Durness area is excessive. The laminæ on almost every slab from the schistose and gneissose rocks exhibit the most extraordinary wrinkling and puckering; while the geographical distribution of the petrological zones of the Durness Limestone can only be satisfactorily interpreted upon the hypothesis that they are arranged in a number of flattened arches and troughs, whose very oblique axes all dip in one and the same general direction. Before discussing, however, the most natural methods of developing the true sequence of the beds in a complicated

[1] Quart. Journ. Geol. Soc., May, 1881.

area of this character, let us first examine the corresponding strata, as shown in the parallel valley of Loch Eriboll, where, if the visible phenomena are reliable, we again find an unmetamorphosed limestone and quartzite series, lying between the two generally metamorphic formations of the Hebridian gneiss and the Sutherland Series.

IV.—*Appearances in the Loch Eriboll Area.*

The long and narrow valley of Loch Eriboll lies a few miles to the eastward of the Strath of Durness, from which it is separated by the steep mountain ridge of Ben Spionna and Ben Cannabin. The northern and central parts of the valley are filled by the waters of the beautiful sea-fiord of Loch Eriboll, which is about ten miles in length, by two in breadth. The southern extremity of the valley is formed by the marshy flat of Strath Beag, which is shut in on all sides, except to the north, by the converging heights of Craig Erail and Conamheall.

The western wall of the valley of Loch Eriboll—the range of Ben Spionna and Ben Cannabin (2537 ft.)—is composed of the almost vertical Hebridian gneiss, overlain by sheets of the Lower Quartzite, which dip gently eastward and finally subside below the waters of the loch. Some islands in the loch itself, and the promontories along its eastern shore, are formed of thick-bedded limestones. These, like the underlying quartzites of Ben Spionna, dip generally at gentle angles to the eastward towards the mountain ridge of Ben Poll and Whiten Head, which forms the eastern wall of the valley, and constitutes the most westerly buttress of the great plateau of Central Sutherland. In the lower parts of this ridge the limestones appear to be generally surmounted by a second series of quartzites and flaggy beds (Upper Quartzite of Murchison and others). In its higher slopes this Upper Quartzite plunges in its turn below the flaggy schists, metamorphic gneisses and so-called igneous rocks, that make up the *Upper or Flaggy Gneiss* Series of Central Sutherland and the Highlands generally.

V.—*Sections West of Loch Eriboll.*

In my study of this area I ascertained that upon the western side of the Loch, the *Lower Quartzite* rests unconformably upon the Hebridian gneiss of Ben Cannabin.

I. a. The *basal* zone (*a*) of this lower quartzite is a well-marked breccia, or conglomerate, rarely more than a foot or two in thickness, filled with small quartz pebbles, angular fragments of vein quartz, and flakes of grey and greenish shales.

The main mass of the Quartzite itself is divisible into two primary zones, viz :—

I. b. A lower zone, of thick-bedded and occasionally flaggy quartzites usually weathering to a faint pink or buff colour. (Tinted Quartzite.)

I. c. A higher zone of massive quartzites, usually of a pure white. (White Quartzite.)

I. d. The highest zone, as in Durness, is composed of flaggy

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Quartzites pierced by innumerable vertical worm-holes (*the Pipe rock*).

This last-named band is the highest bed exposed on the western side of the Loch, the superior beds having been removed by denudation.

VI.—*Sections East of Loch Eriboll.*

On the opposite side of the Loch, however, a magnificent section of the naturally succeeding strata is exposed in the cliffs of Hielem roadstead or Camas Bay. In this section, which occurs at the little headland of Ant-Sron, the strata are thrown into a long and broad arch, the beds dipping in opposite directions at a very gentle angle. They are laid bare in a continuous exposure nearly a quarter of a mile in length, in the cliffs and in the coast platform below, and every bed admits of easy study and admeasurement. Here we are presented with the following section, in ascending order:—

I. (*d*). *Lower or Eriboll Quartzite,* chiefly the highest zone (or *Pipe rock*), a series of flaggy quartzites, often iron-stained, and filled with hosts of vertical annelide tubes—30ft.

II. *Hielem or Fucoid Beds.*—50 to 60ft.

(*a*) Flaggy grey shales covered with Fucoids (branching worm castings)—*Fucoid zone.*

(*b*) Calcareous shales and flags (an impure dolomitic cement-stone)—*Fucoid Limestone.*

(*c*) Quartzose flags, with occasional Annelide holes, and a remarkable zone of dark blue shale at the summit—*Upper or Hielem flags.*

III. *The Salterella Grit or Quartzite*—10 to 15ft.

A conspicuous zone of Quartzite, often gritty with small pebbles of quartz, riddled with empty wormholes, and crowded with casts of *Salterella Macullochii.*

IV. The *Eriboll or Durness Limestone*—150 to 200ft.

(*a*) A thin zone of impure dolomitic limestone of a yellowish-buff colour, graduating upwards from the *Salterella Grit,* through a conspicuous transitional zone of calcareous grit, which weathers into a ragged scoriaceous rock of a most remarkable aspect (*Scoriaceous-bed*). This transitional band afforded me *Orthoceras, Linguloid* shells (?) and the usual *Salterella Macullochii.*[1]

(*b*) *Dark* (almost black) flaggy *Limestones* and calcareous shales (the latter cleaved) filled in patches with hosts of *Salterella Macullochii,* etc.

(*c*) *Grey,* white and mottled *Limestones* of great thickness, arranged in several well-marked zones, identical with those in the Limestone series of Durness. These are the highest beds discoverable at this locality.

[1] Between the base of the *Fucoid or Hielem beds* and the top of the *Scoriaceous bed* the rocks all weather to a yellowish-buff colour upon exposure to the weather, forming a striking contrast to the white quartzite below and the dark limestone above.

This cliff-section is merely the northern edge of a long and broad basin of Limestone which occupies the flat ground of Tor Leath and Eriboll House lying to the south of the promontory. To the westward of the basin its strata are truncated by the waters of the Loch. To the eastward, however, the outer edge of the basin is bent abruptly upwards, and the underlying strata again emerge in their natural order from below the limestone, between the latter and the *Sutherland gneiss* in the mountain slopes to the south-east of Ant-Sron. The beds are more or less looped and folded, and towards the summit of the ascent are vertical or even inverted. But by a careful study of the ground, which is comparatively bare, the stratigraphist is able to read off the descending succession in regular and unbroken order.

The dark limestones (VI. *b*.) here fringe the eastern edge of the basin. These pass downwards through the yellow band (IV. *a*.) into the *Salterella* grit (III.), which is often very conspicuous. Next emerge the yellow and buff-tinted flaggy beds, dolomites, and shales of the *Hielem* beds (II.), with their fucoids and worm-tracks. Rising out from below these to the east appears the *Pipe-rock* (I. *d*.) of the Lower Quartzite, charged with its hosts of rounded Annelide tubes. Next rises to day the massive *white Quartzite* (II. *c*.) so conspicuous at the opposite side of the Loch. Below follows the faintly-coloured and more flaggy quartzites of the underlying zone (II. *b*.), and lastly from beneath the whole, rises out the thin basal conglomerate itself, with its quartz-pebbles, and fragments of coloured shales.

This conglomerate rests at once upon the highly crystalline or so-called igneous rock of the Sutherland gneiss upon the platform above the ridge, where a narrow island of quartzite is surrounded by the crystalline "*igneous rock*," and is separated from it by the basal conglomerate, the visible phenomena affording very clear evidence of a distinct unconformity between the two series.

In this locality, therefore, we have not only a complete demonstration of the identity of the so-called Lower and Upper Quartzites, but proof that the Lower Quartzite (and of necessity the whole of the fossil-bearing series) is of newer age than the "igneous rock" of the Sutherland gneiss.

Hence, whether we agree with Murchison, Heddle, and Callaway, that this so-called igneous rock is an integral part of the Upper Gneiss, or whether, on the other hand, we accept Nicol's view that it is an intrusive rock of much more recent date, the final result is precisely the same. The unaltered fossil-bearing Durness-Eriboll series is demonstrably *newer* than the Sutherland gneiss. If, therefore, as commonly believed, the *Sutherland* or *Upper Gneissic Series* is merely part and parcel of a single rock-formation which extends over the Highlands generally, then the whole of the metamorphosed and altered rocks of the Highlands must be of "Pre-Silurian" age.

Here, then, we have a result which is diametrically opposed to that which we obtained in the Durness area. That is to say, *if we rely solely upon ordinary evidences of superposition*, we can apparently demonstrate in one area of the North-west Highlands that

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the altered Highland rocks *overlie* the fossil-bearing series, and in another that they *underlie* them. By an unconscious selection of favourable sections, either of these two mutually destructive views could be supported by what a partisan would naturally claim to be an overwhelming mass of evidence.

(*To be continued.*)

NOTICES OF MEMOIRS.

THE FLOOD OF THE CONNECTICUT RIVER VALLEY FROM THE MELTING OF THE QUATERNARY GLACIER. By JAMES D. DANA. (Amer. Journ. Science, vol. xxiii. 1882.)

THE title of this paper indicates its principal contents; the author pictures the general condition of the Connecticut and its tributaries during the progress of the flood, he treats of the origin of the channel-way of the river, of its terraces, and the bearing of the facts on the retreat of the glacier. According to the process described the terrace-plains were formed during the *rise* of the waters. The following conclusions may be read with interest:—

"At the time of maximum flood the ice was not lying along the center of the valley producing the river by its gradual melting, and retreating northward as the river elongated in that direction. The amount of water flowing off with a velocity of three or four or more miles an hour, making the great flood, was too vast to have been generated from a retreating body of ice in the valley. If, as Greenland facts authorize us to believe, sub-glacial rivers of large size and energy were a universal feature of the Glacial era, these streams must have entered on a career of real progress when melting began in earnest. As they enlarged, the icy tunnels they had hitherto occupied would have become widened, and the sub-glacial chambers have extended themselves in all directions, undermining the heavy glacier. And as rapidly as this removal from below went on, the deposition of the materials of the ground moraine—the stones, gravel, earth and clay—long before initiated—would have gone forward, covering with till the glacier-buried land. But subsequently, when the rising streams had volume enough to make the lower range of terraces, along the valleys, the roofs of the tunnels were probably, for the most part, gone. The ice still lay over the land, covering deeply the hills and mountains, but the wide channel-ways were open to the day. Evidence of this is afforded by the fact that these lower terraces, like the higher, are free, with rare exceptions, from deposits or droppings of till or of bowlders, such as would have come from an overhanging glacier. But outside of the terrace plains, up the hill-slopes, wherever the ice still remained in force, the till may have continued to fall, adding later to earlier till."

At the time of maximum flood the ice melted might have reached the amount of a cubic mile per day.