December 5, 1860.

William Salmon, Esq., Ulverstone, Lancashire; Peter Higson, Esq., One of H. M. Inspectors of Coal-mines, Broughton, near Manchester; John Spencer, Esq., Bowood, Wilts; Alexander R. Binnie, Esq., C.E., 7 Upper Lansdowne Terrace; George James Eustace, Esq., Arundel House, Clifton Road, Brighton; F. D. P. Dukinfield Astley, Esq., Dukinfield, Cheshire, Arisaig, W. B., and 67 Eaton Square; and Thomas Baxter, Esq., 1 Castle Place, Worcester, were elected Fellows.

The following communication was read:—

On the Structure *of the* North-Western Highlands, *and the* Relations *of the* Gneiss, Red Sandstone, *and* Quartzite *of* Sutherland *and* Ross-shire.

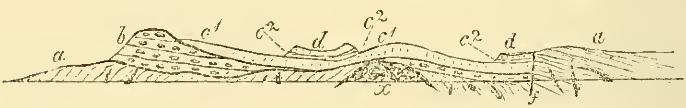
By James Nicol, F.G.S., F.R.S.E., Professor of Natural History in the University of Aberdeen.

Contents.

Introduction.—In a paper read to the Society in 1856, and published in vol. xiii. p. 17–39 of the Geological Journal, I pointed out some of the features of the Gneiss, Red Sandstones, and Quartzites which form such prominent objects in the geology of the north-west of Scotland. I then proved (contrary to the opinion previously entertained) that the Red Sandstone of the North-west Highlands, and especially that of Loch Broom and Applecross, was wholly inferior to the quartzite, which rests on it in an unconformable manner, and spreads out wider to the east. In the same paper I showed that the Assynt and Durness limestone forms the upper member of this series, and that the supposed higher quartzite of Ben More is only the same quartzite rising from under the limestone. In regard to the relation of the quartzite to the eastern gneiss, I stated that, though some of the sections appeared to confirm Dr. Macculloch's view that there are in Sutherland two formations of gneiss—an older below the quartzite, and a newer superior to it,—still the presence of intrusive rocks and other marks of disturbance in the sections I had examined rendered this conclusion less certain and satisfactory than might be wished. In order to determine this most important question, affecting the entire geological history and structure of the north of Scotland, I have subsequently visited this region four times, and examined all the principal sections and almost the entire tract of country from the north coast of Sutherland, to Loch Alsh and Skye in the south, and from Caithness on the east to the Lewis on the west. I now propose to lay the results of these investigations before the Society, as confirming or correcting the views given in my former paper. This is the more necessary, as, whilst some of my statements have been controverted, other statements may seem to support conclusions which I now feel assured are erroneous. The wide region over which these observations extend, and the great importance of the questions involved, together with the weight of authority opposed to the views I support, must form my excuse for the length of this paper and the full details given of some sections.

Object of this paper.—As it may render the bearing of the special sections noticed more evident, I may state that there is no difference of opinion in regard to the first part of the series of formations as established in my paper of 1856. All observers now admit that there is only one great formation of Red Sandstone on the north-west coast, resting unconformably on gneiss, and covered, in many cases also unconformably, by quartzite, and this by the fossiliferous limestone of Durness. But the further order is matter of discussion. I regard this limestone, in Durness, Assynt, Loch Broom, and Loch Keeshorn, as the highest member of the older formations in this region (fig. 1).

Fig. 1.—*Diagram-section of Sutherland and Ross.*



d. Limestone. c^2. Fucoid-beds. c^1. Quartzite. *b.* Red Sandstone. *a.* Crystalline schists. *x.* Granulite or syenite. *f.* Fault.

On the other hand, it has been affirmed* that it is overlain by an upper quartz-rock and limestone, and that these are in turn "clearly and conformably covered," or "followed symmetrically upwards, by mica-schists, flagstones, and a younger gneiss." This paper is designed to prove that no such clear, conformable, or symmetrical upward succession is to be found, but that the line of junction, where this conformable succession is said to occur, is clearly a line of fault, everywhere indicated by proofs of fracture, contortion of the strata, and powerful igneous action†.

Durine Limestone.—Beginning our sections in the north, the first is that of the Durine limestone. The section given in my former paper‡, though showing the true general relations of the beds, must be cor-

* Sir R. I. Murchison, 'Siluria' (3rd edition), p. 553. See also Murchison "On the Succession of the Older Rocks in the Northernmost Counties of Scotland," Quart. Journ. Geol. Soc. vol. xv. p. 352, and "Supplemental Observations," *ib.* vol. xvi. p. 215, &c.

† The diagram fig. 1, compared with the similar section fig. 2 in p. 217 of vol. xvi. of Quart. Journ. Geol. Soc., will bring out this difference of views more clearly.

‡ Quart. Journ. Geol. Soc. vol. xiii. p. 23. fig. 5.

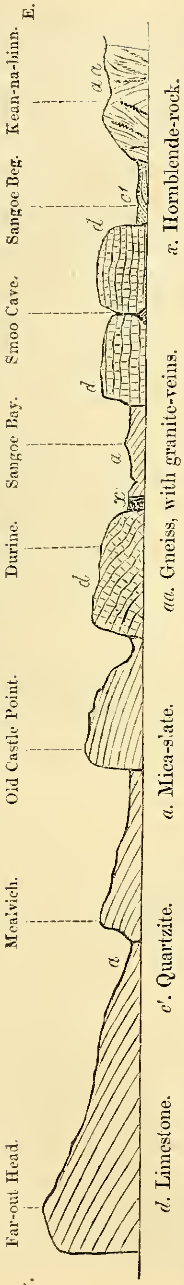


Fig. 2.—*Section of the Durine District.*

rected as to details by that now given* (fig. 2). Beginning at the western extremity, the magnificent promontory of Far-out Head, 315 feet high, consists from top to bottom of fine-grained white or light-coloured mica-slate, in thin even beds. The dip is from 20° to 25°, or rarely 35°, to E. 35° S. at the Head; but near Old Castle Point, where the rock is also darker in colour, always to the north of east (E. 25°–35° N.). From the regular dip of the beds, the thickness of this mass of mica-slate must be above 2000 feet if the section is unbroken, and not less than 1000 feet if a fault occurs between Far-out Head and Old Castle Point. In mineral character it is quite identical with the mica-slate on the east of the quartzite at Erriboll, and with the mica-slate of Melness on the Kyle of Tongue. It has on this account been said to overlie the Durine limestone; but, after repeated careful examination of the sections, which are most clearly exhibited on the coast, I have been unable to detect the smallest trace of limestone below the mica-slate, or of mica-slate above the limestone. It seems impossible to believe that a mass of mica-slate, at least 1000 feet thick, could have been so thoroughly swept away from the surface of the limestone-field for many miles in extent, had it ever existed above it.

Near Balnakeil and Sangoe Bay the mica-slate appears to dip under the limestone; but, as shown in the section, it is cut off from it by a fault. This limestone forms a great contorted mass, 128 feet high, and is in many parts a red-coloured breccia; but it dips on the whole to the S.E. The brecciated structure is due to a mass of hornblende-rock or serpentine which rises up in Sangoe Bay, bringing with it portions of altered quartzite and mica-slate. The igneous and metamorphic rocks extend south to Loch Calladale, and have evidently been forced up through

* The sections in the following paper run generally from west to east, and, for more ready comparison, are all drawn as seen from the south. The directions in this paper are also true, having been corrected for the magnetic variation, which in Sutherland is about 29° W.

the limestone, which is broken and contorted near them. The limestone again forms the coast, intersected, however, by another N. and S. line of fault at the Smoo Cave. Near Sangoe Beg the quartzite appears, forming a small wedge-shaped fragment, and is represented by Mr. Cunningham, who first figured the section, as dipping conformably under the limestone*. This is no doubt its normal position; but in this place the rocks are separated by a fault and crush, which has broken up the quartzite into an incoherent breccia. Beyond Cnoc Garrow the quartzite is succeeded by the ridge of gneiss dividing the vale of the Dionard from Loch Erriboll. The ridge runs S.S.W., but the strike of the beds is nearer N.W. (N. 48° W.), and the dip at 70° to 85°, to S.W. or N.E. It is everywhere penetrated by veins and masses of red granite and hornblende-rock, and has evidently been tilted up on the west side since the deposition of the quartzite, which rests in a thin and often-interrupted layer on its eastern side, sloping down to Loch Erriboll †. Small fragments of quartzite also occur on its seaward extremity.

This section of the Durine district is important, as proving that the limestone is the highest formation in the series, and is nowhere covered by higher quartzite or mica-slate; these rocks, where found in the centre of the section, being evidently brought up from below, and thus underlying, not overlying, the limestone. It also shows that the whole district is broken up by faults running from N.N.E. to S.S.W., and that the masses of strata have generally been tilted up on the west.

Sections on Loch Erriboll.—These facts serve to explain the more complex sections on the east side of Loch Erriboll. The first of these (fig. 3) runs from near Camas-an-duin, in an east-by-south direction,

Fig. 3.—*Section of Camas-an-duin, Loch Erriboll.*

d. Limestone. c^2. Fucoid-beds. c^1. Quartzite.
a. Mica- and talc-slates. *s.* Granulite, with fragments of slate.

across the ridge to Loch Hope. On the shore south of Camas Bay, the strata are seen in their regular normal order: first the quartzite (c^1) in curved beds, but dipping on the whole to W.; then (c^2) the fucoid-beds, and above all the limestone (d), in broken irregular strata, but also with a westerly dip. The limestone forms a low hill, sepa-

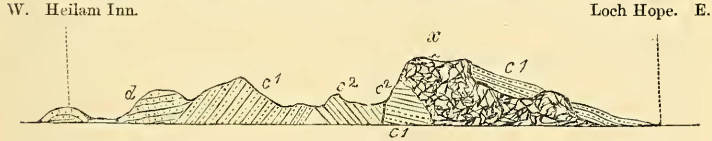
* Cunningham, Geognostical Account of Sutherland in Prize Essays of the Highland Society, vol. xiii. (1839) p. 97, and plate 7. fig. 4. This quartzite does not appear in my former section, which runs further south than it extends.

† Far too great thickness is assigned to this part of the quartzite in my old section, Quart. Journ. Geol. Soc. vol. xiii. p. 23. fig. 4*c*.

rated from the main ridge by a low marshy valley, indicating a line of fault. This fault is also proved by the quartzite, with its characteristic annelid-tubes (*Pipe-rock*), dipping first 78°, to E. 30° S., and then 70°, to W. 10° N. On the main ridge the same quartzite forms a great curved face of rock, dipping at 50°–65°, to W. 33° N., and higher up 74°, to W. 25° N. The top of the ridge consists of a granitoid igneous rock or granulite *, in part overlain by quartzite. This mass or vein varies from a few yards to above a fourth of a mile in width. Beyond it, on the east side of the ridge, mica- and talc-slates occur in thin regular beds, and often identical in character with the rocks of Far-out Head. The prevailing dip is 15° to 25°, to S. 30° E., but varies considerably near the granulite, where the beds become contorted and interlaced with igneous matter. In a deep valley to the north, a more complete section of the interior of the hill is seen; the granulite widening out to half a mile or more, throwing off the strata on each side, and involving large fragments of the mica-slate, with the laminæ turned in various directions. As these fragments of mica-slate are found in the mass of the igneous rock where it rises up below the quartzite, and, of necessity, have been derived from a still deeper formation, they prove indisputably that the mica-slate is the lower and older rock, and therefore cannot normally overlie the quartzite.

Further north, the igneous rock widens out greatly in Arnaboll Hill, and has produced some remarkable changes on the strata. Thus, on Camas Bay, in the continuation of the fault in the former section, the quartzite dips at 53°, to S. 64° E., and apparently below the igneous mass of the hill. But the openings of the annelid-tubes, and the ripple-marks, which are regularly found on the upper surface of the beds, are here on the lower faces, showing that there has been a complete reversal of the strata. Still proceed-

Fig. 4.—*Section of Drium-an-tenigh, Loch Erriboll.*



d. Limestone. c^2. Fucoid-beds. c^1. Quartzite.
x. Granulite (termed "gneiss" by Mr. Cunningham).

ing northwards we come to the remarkable section of Drium-an-tenigh (fig. 4), described and figured by Mr. Cunningham as an

* It is difficult to assign a name to this rock. In general it is a mixture of compact felspar and quartz, often with an imperfect laminar texture. With these, hornblende or talc or scales of bronzite become occasionally intermixed. But in other places it passes into a distinct crystalline binary granite of orthoclase and quartz, or into felspar-porphyry or diorite, and where in contact with limestone into a kind of serpentine. With all this diversity it exhibits a community of character, more easily recognized than described, along the whole line from Whiten Head to the Sound of Sleat. I have often used the term *granulite*, as the most generally applicable.

example of gneiss conformably overlying the limestone and quartzite. It might be sufficient to state that the rock which he describes as gneiss is the intrusive granulite-rock of the last section*; but, as illustrating the structure of the country, some further details are necessary.

At Heilam Inn, on Loch Erriboll (fig. 4), the limestone dipping 10°–20°, to S. or S.E., but in broken flexured beds, forms both the peninsula and the hill on the mainland to about the line of the road. The next ridge consists of the quartzite, dipping on the west side at 65°, to W. 10° N., and on the east of the ridge 44°, to W. 5° S. Crossing a small valley, the quartzite is again seen, dipping 83°, W. 10° N., and further on the fucoid-beds, dipping 64°, to S. 45° E. The rocks are hidden for about 100 yards by grass and detritus; but at the foot of the cliff the same beds crop out, dipping in one place at 20°, to E. 35° S., and in another at 6°, to S. 10° W. As already stated, these beds are covered, not by gneiss, as in Mr. Cunningham's figure, but by the granulite or eruptive rock forming the great mass of the hill. It has clearly broken through the strata, resting in one place on the fucoid-beds, in another on the quartzite, and further east, towards Loch Hope, is overlain by quartzose beds dipping 25°, to E. 30° S.

The relations of the rocks in this section are quite clear and consistent. No overlying gneiss is seen in it, and the mica-slate is separated from the quartzite by the whole igneous mass of Ben Arnaboll. The quartzite is, however, thrown east as far as Loch Hope; and the junction is then formed partly by the lake, partly by the River Hope to its mouth. In the hills north-east of Hope Ferry there is another outburst of igneous rock, here felspar-porphyry; and at Whiten Head it again appears in great force in the line of junction, intruding partly on the quartzite, but chiefly on the old slates to the east. In this trackless region the sections are best seen in sailing along the coast; but one single fact is decisive of the true relation of the mica-slate and quartzite series. North of Loch Hope Ferry the fucoid-beds and limestone entirely disappear, and only the lower part of the series, or the quartzite, comes in contact with the eastern gneiss or mica-slate. This is the necessary result of the beds along the line of fault having been more exposed to denudation in the north, during the gradual elevation of the land, from the wide and stormy northern ocean, but is quite inexplicable on the hypothesis of conformable upward succession. It has indeed been asserted that this is not the quartzite below the limestone, but another quartzite above it. That this is not the case is, however, proved by the quartzite near

* See Cunningham, Geog. of Sutherland, p. 99, and plate 8. fig. 2. Though a very acute observer and well acquainted with rocks, Mr. Cunningham has in this and some other instances been misled by the strong Wernerian views on the origin of certain rocks which he entertained. In consequence of this bias he entirely mistook the nature of these igneous rocks, which were altogether overlooked until I drew attention to them in the summer of 1859. This is also true of the similar rock on Loch More. Compare Note, p. 94.

Loch Craggy passing below the limestone of Heilam Hill; by the same quartzite again rising up from below the limestone on the coast near Tor-a-vu; and by the fucoid-beds and limestone overlying it in regular order in several places south of the road to Loch Hope Ferry. The occurrence of an upper quartzite in this place is thus not merely without proof, but contrary to many clear sections, and, we shall soon find, has no support in any other locality*.

The junction of the quartzite and mica-slate in the hills south of our first section towards the head of Loch Erriboll equally proves that the mica-slate is the lower formation. In this place the igneous rock has generally thinned out, or rather, instead of being concentrated in a single mass or vein, becomes intermixed with the lower mica- and talc-slates in innumerable fine threads or lines. So intimate is this mixture, that, in many places, it is difficult to say whether the rock should be classed as igneous or stratified. Occasionally, however, larger masses occur, as near the road from Erriboll to Ault-na-harrow, where it forms a boss 50 to 100 yards in diameter, and in the picturesque rock of Craig-na-feolin. Whether concentrated in mass or dispersed in threads, the igneous matter is far more abundant in the lower schists than in the quartzite, the thick hard beds of the latter having apparently resisted its upward progress and thus caused it to spread out in the inferior formation. This distribution, therefore, of the igneous rock is another proof that the eastern mica-slates are the lower formation, as, on the supposition that the quartzite was the lower formation, it ought to have been more powerfully invaded by the igneous rocks than the schists resting upon it †.

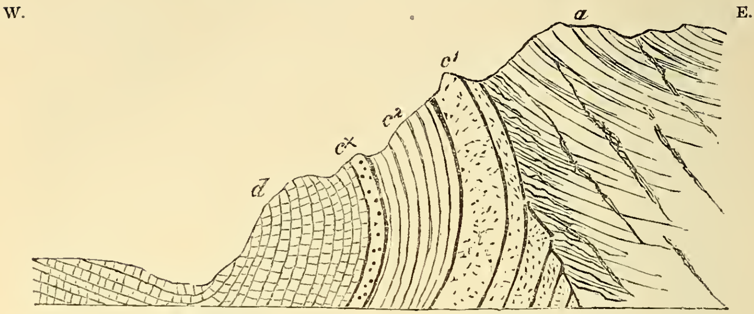
This intrusion of igneous matter, swelling out and expanding the lower schists along the line of fault, has produced some complexity in the sections. In many places the quartzites and mica-slate dip approximately in the same direction, but are separated by a fault, frequently marked by a low marshy hollow. A more interesting section is seen in a small stream above Erriboll House (fig. 5). The upper part of the ridge consists of talcose mica-slates (*a*) interlaced with lines of red felspar. The dip near the top is 50°–60°, to E.

* This hypothesis of an upper quartzite requires not merely the repetition of the so-called "lower" quartzite with its characteristic annelid-tubes and peculiar mineral characters, but also of a second group of fucoid-beds and a second limestone, identical in order and character with those below! But if such upper beds exist, they ought then to have appeared in the Whiten Head sections, and their absence is thus fatal to the notion of "conformable upward succession" in this region.

† "These strata (chloritic, talcose, and micaceous schists), whatever may be their mineral character, are riddled by the intrusive rock, and in parts much hardened and altered."—Murchison, North Highlands, Quart. Geol. Journ. vol. xvi. p. 235. In p. 233 Sir R. I. Murchison describes them as "interwoven with the metamorphic Lower Silurian strata," *i. e.* with the eastern gneiss; and also affirms that "the granitic felstones and syenites so largely developed in the eastern parts of Assynt . . . . rarely, if ever, occur between the limestones and the upper quartz, but chiefly either in the latter or in the younger or overlying flagstones" (p. 233). That is, according to my view, the igneous rocks are most abundant *in the crystalline schists below*, and *in the quartzite where in contact with them.*

30° N., but below decreases to 15° or 20°, and the beds are broken and irregular. Lower down, the burn tumbles over a thick mass of

Fig. 5.—*Section near Erriboll House.*



d. Limestone. c^2. Fucoid-beds.
c^x. Quartzite. c^1. Quartzite.
a. Mica- and talc-slate, with granitoid veins.

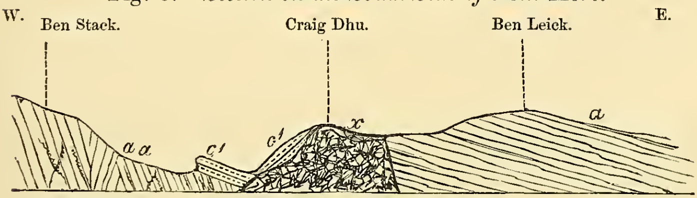
quartzite, very indistinctly stratified, but apparently dipping at 66°, to S. 10° E., and resting on the red fucoid-beds (c^2) dipping at 50°, to E. 20°–30° N. Below them is a bed of hard reddish quartzite (c^x) dipping 35°, to E. 20° S.; and further down the common dark bluish-grey limestone, much fissured and contorted, but with a dip of about 68°, to E. 30° S. The limestone appears to form all the under part of the hill and the low ground to the loch. In this place the quartzite appears to rest on the limestone and dip below the mica-slate, but the succession of the groups shows clearly that this is the result of an upheaval and inversion of the strata. The regular order in the whole north-west of Scotland, from Durness to Loch Keeshorn, is quartzite (c^1), fucoid-beds (c^2), and limestone (d); and we must either admit this inversion, or make the improbable assumption that the succession of the deposits has been completely reversed in the space of a few hundred yards, and only in this very limited zone along the declivity of this ridge.

The same relation of the beds is seen near the Ault-na-harrow road, though, from the more powerful intrusion of the igneous rock, the strata are more irregular in dip and more highly contorted near the line of junction. The quartzite is so compact as to resemble calcedony, and shows no marks of bedding. The fucoid-beds and limestone are in some places nearly vertical, in others more horizontal. The fine-grained talcose mica-slates also, which near the quartzite and intrusive rock dip at 35° and 30°, to E. 60° S., further east dip at 10° or 5°, to E. or E. 15° S. Over the hill, towards Loch Hope, the dip becomes even lower, so that the undulations of the strata cause them in many places to dip to the west.

Overlying Red Sandstone and Quartzite of Tongue.—Another proof of the true succession of the formations in the north of Sutherland appears in the vicinity of Tongue, about eight or ten miles to the east of the sections just described. On the east side of the Kyle of Tongue several remarkable masses of red conglomerate rest on the gneiss. These have hitherto been allowed to remain in the Old Red or Devonian formation, though separated from the nearest undoubted Old Red strata, on the east of Strathie, by an interval of eighteen miles. This summer (1860) I examined these conglomerates, in the expectation that they might throw some light on the history of this western region. They consist of rounded or angular fragments of coarse- or fine-grained gneiss, mica-slate, granite, felspar-porphyry, and vein-quartz; but I could find no trace of the red sandstone, quartzite, or limestone, which now form the great ranges of mountains in the west. This entire absence of any fragments of these rocks, which have formerly covered to the depth of some thousand feet a tract of country forty or fifty miles wide and more than a hundred miles long, and not ten miles distant, seems altogether inexplicable on the supposition that the two deposits are of widely different age—the one Cambrian and Lower Silurian, the other Old Red or Devonian. The conclusion seems therefore irresistible that these Tongue conglomerates are identical in age, as they are in mineral character and composition, with the red conglomerates and sandstones of the west coast. This identity is confirmed by the occurrence of the overlying quartzite on Cnoc Craggie, near Loch Laoghal. The greater part of the hill consists of the conglomerate overlain on the south side by the quartzite in thick irregular beds. The preservation of these interesting fragments seems due to the great syenite-eruption of Ben Laoghal, which has at once hardened the beds and preserved them from removal by denudation. In this place, therefore, there is clear evidence that so far from underlying all the gneiss of central Sutherland, the red sandstone and quartzite of the west are again found resting upon it ten miles to the east of the supposed overlap.

Loch More Section.—The next point to the south where the quartzite is said to be overlain conformably by gneiss is near the north-west end of Loch More. In Mr. Cunningham's section this relation of the rocks is very distinct; but on the ground the phenomena are quite opposed to this view, as shown by the section fig. 6, the result of a

Fig. 6.—*Section on the South Side of Loch More.*



c^1. Quartzite. *aa*. Gneiss with granite veins. *a*. Gneiss.
x. Granulite (termed "gneiss" by Mr. Cunningham).

careful examination of the locality in two separate seasons. At the western extremity of Loch More, the quartzite (c^1) rests in a long bold cliff on the gneiss (*a*), which forms Ben Stack and the mountainous region to the west coast. Beyond the Lodge, granulite like that on Loch Erriboll breaks up through the quartzite, and may be traced for more than a mile along the upper part of the mountain, where it is free from the detritus that covers the slopes near the road and loch. Mr. Cunningham represents this rock as gneiss*; but it is truly unstratified, and its intrusive character is shown by the quartzite having been pushed up and resting on it in broken and nearly vertical beds, dipping 85°, to N. 40° W. Higher up the lake this igneous rock meets the gneiss of Ben Leick, exposed in lofty vertical cliffs, and dipping first 20°, to E. 75° N., and then 15°, to E. 30° N. On the south side of the ridge, towards Strath-na-carrian, the gneiss, full of igneous veins and greatly contorted, has quite the aspect of the gneiss round Loch Inver and Scourie, but dips at 40°, to E. 20° S. It seems merely the continuation of the beds seen in the west part of the section, in Ben Stack. That there is in this place no conformable upward succession from quartzite to gneiss is proved not merely by the clear break in the section, but even more by the quartzite, which, on the north side of Loch Stack and Loch More, has a thickness of 800 to 1000 feet, as well seen in the front of Arkle and Foinaven,—on the south side of these lakes disappearing, except a few fragments not the tenth part of that thickness. This is the necessary result of denudation over a line of fault; whereas no amount of denudation could ever show less than the full thickness of the deposits in any section of conformable strata. As shown in the figure, I have been unable to detect any trace of quartzite or limestone on the east side of the intrusive rock.

Lochs Glen Coul and Glen Dhu, and Glasven.—The quartzite, with the same degraded dimensions, ranges across to Lochs Glen Dhu and Glen Coul†, and in the rugged mountains that surround the inner recesses of these noble sea-lochs is said to be again overlain by gneiss. This, however, is a mere optical deception, caused by the rocks being seen from the low ground or the sea; as the quartzite, though dipping eastwards, only abuts on the rounded knolls that rise up behind, and is generally separated from them by a low marshy valley. The rock too, described as conformably overlying gneiss, is in some places an intrusive syenite, in others true granitic gneiss, but rising up in nearly vertical masses with a strike at right angles to the beds on which it has been said to rest. This

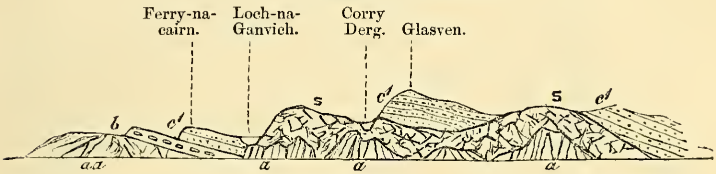
* It seems to be the rock thus described: "Another prominent variety [of gneiss] exists in a rock almost entirely composed of compact felspar and quartz, arranged, not in distinct concretions, but, on the contrary, so closely connected that their linear position can only be detected after atmospherical agents have partially abraded the felspar. This remarkable gneiss forms some hills on the south side of Loch More."—Cunningham, Geog. of Sutherland, p. 77.

† In the geological map published in No. 62 of the Quart. Journ. Geol. Soc. (May 1860), a broad band of "upper quartz-rock" is laid down in this region. It is rather remarkable that these same rocks, now described as quartz-rock, were quoted as a true overlying gneiss both by Macculloch and Cunningham. As stated in the text, the rock is gneiss (but not overlying) or a syenite.

is well seen on the south side of Loch Glen Coul, where the quartzite, which, only one or two miles south, expands into the great mountain-group of Assynt, has been denuded almost to a single bed.

The section (fig. 7) of the northern side of Glasven shows the true structure very clearly. The low hills on the west, near Kyle

Fig. 7.—*Section of Glasven.*



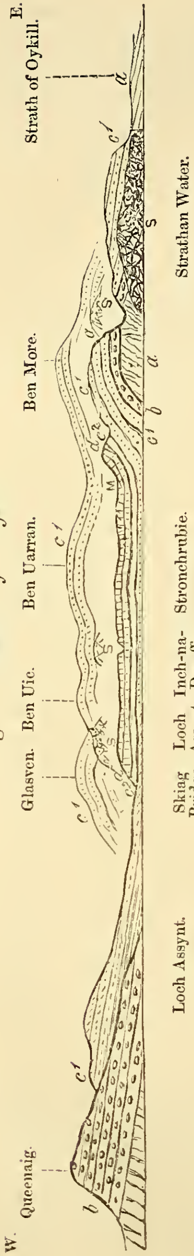
c^1. Quartzite. *b*. Red sandstone. *a*. Granitic gneiss.
aa. Gneiss with hornblende. *s*. Syenite.

Sku Ferry and Unapool, consist of gneiss and hornblende-rocks, the strata often at very low angles (dip 12° N. 15° E). They are covered by red sandstone, stretching south, in a broad terraced valley, up into the corries of Queenaig. This valley is bordered on the south-east by a precipitous cliff of quartzite, formed by a great sheet of rock, which, sloping down from the summit of Queenaig, folds over on the south to Loch Assynt, on the north to Loch Glen Coul. The quartzite is well seen on the west side of Loch-na-Ganvich, where the burn from the lake has almost cut through the cliff in a deep ravine, and forms a picturesque waterfall within a few yards of its exit*. The quartzite dips at 10°, to S. 53° E., apparently below the ridge of Glasven, hitherto represented as entirely consisting of quartzite. The east side of the lake, however, I found was syenite, intermixed with nearly vertical masses of granitic gneiss running N. 10°–15° W. This rock forms the whole north side of Glasven as far back as the tarn of the Corry Derg. The high bare cliffs on the south-east of this small lake exhibit a beautiful section. The northern extremity consists of the syenite, overlain on the south by undulating beds of quartzite†. This rock forms the summit and southern slopes of Glasven; but the syenite passes below and reappears on the other side of the mountain. I have again found it in the inner corries of Ben Uarran and Ben More; so that it probably forms the axis of the whole range of mountains. From the Corry Derg it extends north to Cnoc-na-Craig-Ganvich and the head of Loch Glen Coul, where

* We have here, therefore, a miniature of the phenomena of Niagara and the American lakes. The erosive action has only to proceed a few yards further in order to drain the lake; but from the extreme hardness of the quartzite this may require a very long period.—See Sir C. Lyell's Travels in North America, vol. i. pp. 29–46.

† The little tarn is shut in on the north-west by moraines or glacier-mounds. These on the north, opposite the syenite cliff, are entirely composed of syenite boulders; on the south, where the cliff is quartzite, of quartzite boulders, with a mixed group between.

Fig. 8.—*Section of Assynt.*



d. Limestone. *c*[1]. Quartzite. *a*. Gneiss. (The gneiss of Queenaig has granitic and syenitic veins.) *s*. Syenite.
c[2]. Fucoid-beds. *b*. Red sandstone. M. Loch Maolack Corry.

the granitic gneiss intermixed with syenite-veins is seen stretching away to the east, below the quartzite-beds of Ben Uie and Ben Uarran, and continuous with the gneiss of central Sutherland. Nothing can be more striking than the contrast between the dark-grey gneiss and hornblende-rocks forming the north-east base of these mountains and the almost horizontal beds of brilliant white quartzite, which rest upon them for miles.

Assynt.—The structure of the Assynt region is represented in the next section (fig. 8), extending from Queenaig on the west to the south-east declivities of Ben More. The middle of the section shows the strata as seen on the north shore of Loch Assynt and in Stronchrubie; but in the background I have sketched-in the northern range of mountains connecting Queenaig and Ben More, showing the continuity of the quartzite round the whole limestone-plateau.

The first formation, on the west, is the gneiss (*a*) intermixed with veins of granite and syenite. It is covered by red sandstone (*b*), beautifully seen in the western declivities of Queenaig, and this by the quartzite (c^1) sloping down from the summit of the mountain in vast, almost unbroken sheets. As well seen in Skiag Burn, the dip is about 10°, and thus probably unconformable to the red sandstone below, though the great faults intersecting the mountains and the protrusion of igneous rocks render this fact less certain than I formerly thought. Above it come the fucoid-beds (c^2), and over them the limestone (*d*), forming the whole low ground north of Loch Assynt, from Skiag Bridge by Stronchrubie to the foot of the Ben More mountains. This limestone is the highest bed in the series, being everywhere troughed by the quartzite. As this fact is of great importance, and as it has been affirmed that an upper quartzite and limestone occur in this region, a few confirmatory facts and sections must be noticed.

In ascending the road from Skiag Bridge towards Kyle Sku, the fucoid-beds and limestone may be seen resting on the quartzite, almost to the summit of the ridge. Before reaching the foot of Glasven, however, they thin out, and the quartzite of that mountain and of Queenaig form one continuous mass, as shown in the section. That the quartzite of Glasven does not overlie the limestone is further proved by no trace of limestone being seen in the Corry Derg (fig. 7, p. 95), where the syenite brings up the bottom beds, or between the quartzite and gneiss in the noble sections exposed on the north-east side of that mountain, formerly described.

The same thing is shown by the section from Loch Assynt near the School-house, in a N.N.E. direction across Cnoc-an-drein. Close to the lake the quartzite is seen cropping out below the limestone, which forms all the declivity of the hill, and dips to E. 25° to 30° N., at angles ranging from 20° to 40° or more. This diversity of dip is caused by the intrusion among the strata of irregular veins, or lenticular-shaped masses of trap, of which I enumerated not fewer than eight or ten. Near the top of the ridge the quartzite appears to rest on the limestone, but is separated from it by veins of green trap and of dark clove-brown felspar-porphyry. The quartzite (*Pipe-rock*) dips first E. at 25° to 35°, and then higher up on Cnoc-an-drein rises to 75° to 80°, at length becoming vertical, with a N.N.W. strike, having clearly been forced up by the intrusion of the syenite (shown at *s* in figs. 7 & 8).

The inferiority of the quartzite to the limestone is even more clearly seen in the Poulan-drein Burn, at the south-east end of Cnoc-an-drein; it may also be seen along the whole valley of the Traligill River, almost to the Bealach at the foot of Ben More. Everywhere the limestone, which in the plateau of Stronchrubie on the south side of the stream dips towards these mountains, is found to form a synclinal axis, and on the north side to dip away from the quartzite. The only obscurity in the sections arises from the synclinal fold in the limestone being conjoined with a great fault in the quartzite, which is thus brought up in enormous crushed masses, so broken that the lines of stratification can hardly be detected*: this is especially seen near the foot of Coniveal; but in no place have I observed the limestone dipping below the quartzite of these mountains.

In the line of the section no such obscurity exists. Immediately to the east of Loch Maolack-Corry, well known for its Gillaroo trout, the Stronchrubie limestone, continuous throughout, rises up into a hill, and is seen very distinctly dipping at 40°, to W. 40° N., in

* This peculiar combination of faults with synclinals (or what may be named a "faulted-synclinal") is very common in Sutherland. It has probably been caused by the refractory nature of the quartzite, which was more easily broken than bent. To the same cause we may ascribe the frequent combination of a crush (or broken and brecciated condition of the rock) with one or both of these faults and synclinals.

slightly undulating beds. On the east side of this hill the limestone rests on the red shales or fucoid-beds (c^2), and these in turn on the quartzite (c^1), dipping at 20°, to W. 40° N., and rising in great curved beds to the top of the next hill. The section is so clear, and the correspondence of the deposits so exact, that there can be no doubt that this is the east side of the Queenaig synclinal. Still stronger evidence of this fact may be obtained by tracing the quartzite along the shore of Loch Assynt and up the Stronchrubie valley*, everywhere dipping below the limestone, till it turns round its southern extremity and rises up into Brebag. From this mountain the quartzite may be followed along the bare ledges of rock north to Ben More, and thence, as shown in the section, round till it again joins that of Queenaig.

A more interesting confirmation of this peculiar structure of the Assynt district (the highest of its formations, filling the bottom of the valley) is furnished by the drainage of its waters. Almost all the streams from the lofty north-eastern mountains, from Brebag, Ben More, and Ben Uarran, on reaching the synclinal line in the limestone, fall into swallow-holes and disappear for a considerable space. The whole moor is dotted over with round pits, some dry, some filled with water at the bottom, through which the drainage is effected. In some places deserted river-beds, only occupied by the water in rainy seasons, are seen; in other places the subterranean torrent is heard rolling along at the bottom of a deep dark cave. Now all this underground drainage is directed towards Loch Assynt, the centre of the synclinal, proving that the strata dip to this point, and not north or east below Ben More or Brebag. The water descends through the limestone to the quartzite, and is again thrown out on the surface by this impervious stratum, often in very copious springs†.

There is thus, in this place, no "upper quartz-rock" resting on the Stronchrubie and Assynt limestone, and the hills referred to this newer formation clearly consist of the quartzite below the limestone, brought up over an anticlinal. Singularly enough, too, some of these so-called "upper" or "newer quartz-rocks" are even an *older* formation than the lower quartzite. When examining Canisp and Queenaig, I was struck by the peculiar aspect of some of the hills on the eastern side of Stronchrubie, usually classed as quartzite. From their reddish colour I thought that they probably consisted of felspar-porphyry, like that of Loch Borrolan; but on examination I found that they were formed of red sandstone, identical in character with

* In my former paper (Quart. Journ. Geol. Soc. vol. xiii. p. 25) I stated that the Stronchrubie limestone and the underlying quartzite had "probably been brought up by a fault." Several faults in the line of that section are well seen in the face of the Stronchrubie cliff; but, as shown in the present section, the limestone and quartzite are brought up rather by undulations in the beds and the general rise of the synclinal than by these faults. Compare Quart. Journ. Geol. Soc. vol. xvi. p. 221 (note ‡).

† I estimated the flow of the "Remarkable Spring" above Stronchrubie at 7000 gallons per minute, after some weeks of dry weather.

that of Queenaig and Suilven. In the corries of Ben More similar beds occur, resting on gneiss or mica-slate (as shown in the section); and there can be no doubt that this is the true western Red Sandstone ("*Cambrian*" of Murchison) brought up in the centre of the so-called "upper quartz-rock," and that the synclinal is thus complete in all the formations from the upper limestone to the lowest gneiss.

The eastern extremity of the section shows the true structure of Ben More, as exposed in the wild corries round the Dhu Loch More. Granitic gneiss and mica-slate, with intrusive igneous rocks, form the nucleus of the mountain, throwing off the quartzite all around, as from a great centre of elevation. Further west an enormous mass of beautiful binary granite rises into a group of rugged mountains, quite unlike the quartzite with which they have hitherto been confounded*. Taken in connexion with the Loch Borrolan porphyry, with which it is probably continuous, this granite must produce most powerful disturbance along the south-east border of the quartzite; and we can easily understand how observers who ignored or overlooked its existence should mistake the true relations of the stratified rocks it has affected†.

Loch Ailsh Section.—It is, again, affirmed that in the vicinity of Loch Ailsh and the higher part of Strath Oykill, the "upper quartz-rock" forming the Assynt mountains "is overlain by a second zone of limestone," and both "conformably surmounted by upper micaceous, chloritic, gneissose, flaggy strata . . . for several miles across the strata‡." My examination of the locality last summer (1860) by no means confirms these views. The "upper quartz-rock" is simply the continuation of the quartzite of Brebag and Canisp, and the "second zone of limestone" merely the repetition, in a denuded form, on the other side of the anticlinal, of the limestone of Stronchrubie and Assynt. Any slight change in the colour or character of the strata is readily accounted for by the intrusion of the red porphyry of Loch Borrolan, which probably at no great depth underlies the rocks shown in the section (fig. 9).

This section begins on the west, at Cnoc Chaorinie, with a hard reddish or clove-brown hornstone-porphyry (x) with distinct crystals of felspar, but probably only a semifused mass of the quartzite.

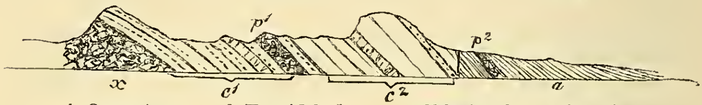
* In justice to Mr. Cunningham, it must be stated that the greater portion of these granite mountains lie in Ross-shire, and thus beyond the limits of his map.

† In the Quart. Journ. Geol. Soc. vol. xvi. p. 232, it is stated that "no igneous rock has yet been observed to be associated with the lower quartz-rock of Assynt;" and that the "large crystalled porphyry" of Canisp may be considered "for the present to be characteristic of the Cambrian age in the North-western Highlands." In 1859, I found that this very beautiful porphyry not only breaks though the quartzite of Canisp, but forms a mass more than a mile in diameter in the same "lower quartz-rock," within a few hundred yards of the inn of Inchna-Damff. It is thus of later date than either the Red Sandstone or Quartzite, and is one of those powerful agents affecting the relations of these and the other strata which have hitherto been overlooked.

‡ Sir R. I. Murchison, "Supplemental Observations on the North of Scotland," Quart. Journ. Geol. Soc. vol. xvi. p. 223.

It passes up into great masses of red hornstone or hardened quartzite (c^1) mixed with fragments of limestone, and dipping very irregularly at about 20°, to E. 10° N. A true quartzite succeeds, dipping

Fig. 9.—*Section near Loch Ailsh.*



c^1. Quartzite. c^2. Fucoid-beds. a. Chlorite-slate and gneiss.
x, p^1, p^2. Porphyries.

at 25°, to E. 10° S., and overlain by irregular masses of red limestone. Red felspar-porphyry (p^1) follows, then quartzite, dipping at 35°, and then the fucoid or slaty beds (c^2) intercalated with red limestone and quartzite, and dipping at 43° to 30°, to E. Passing over a low ridge, the next beds seen are hardened quartzite, dipping at 50°, to E. 20° S. A small stream descending from the hill marks a line of fault; and beyond it beds of chlorite-slate, beautifully contorted, and resembling marbled paper on the cross-fracture, occur. A second vein of red felspar-porphyry (p^2) follows, and then fine-grained quartzose gneiss, dipping first 20°, to E., and then 40°, to E. 40° S. From this point to Alt-Ellag (a distance of half a mile), the rocks are fine-grained slaty gneiss in undulating beds, but the dip gradually falling to 23°, 18°, and 16° at the Bridge. The same fine-grained, micaceous, undulating gneiss continues down Strath Oykill to Rosehall, but in all the lower part of the valley, beyond the influence of the porphyry and granite on the west, has a persistent N.W. strike and S.W. dip (dip 45°–50°, to S. 15°–25° W.*).

The facts just stated leave little doubt as to the true relations of the beds in this section. The only obscurity arises from the strata being much concealed by soil and grass, and only visible at intervals where they crop out on the surface, and, from the repeated intrusion of igneous masses, modifying the usual aspect of the rocks. The lower part of the section is evidently the quartzite hardened and altered by contact with igneous rocks: the centre is no less plainly the fucoid-beds, intermixed with some thin beds of red limestone and quartzite. Over these, had the series been complete, the dark-blue or grey limestone ought to have appeared, but is wanting in this place; then follows the gneiss, probably crushed out of its dominant north-west strike in the lower Strath Oykill by the intrusion of the western porphyry and granite. The remarkable change in the dip on both sides of the line of junction proves the existence of a fault; but the absence of the limestone is specially fatal to the opinion that there is here "conformable upward succession." This absence is the more remarkable from its occurrence in full strength at Elphin to the south, and also on Loch Ailsh to the north. I followed the limestone along this north line till it was cut out by the

* See also the dips on Cunningham's map.

granite, but I could find no place where it is seen to dip below the gneiss. Even in the deep ravines of the Alt-na-Caillich, close to the line of junction, where the eastern gneiss is exposed for a thickness of some hundred feet, I could discover no limestone below it. This is the more remarkable as, from the enormous protrusion of igneous rocks on the west, some such anomalous features might have been expected to occur*.

Elphin and Craig-a-Chnockan.—Having now noticed all the sections adduced in proof of the eastern gneiss overlying the limestone and quartzite, I shall pass more rapidly over some others in the southward extension of the line of fracture, though not less interesting and instructive. To the south of Loch Borrolan and the Strath Oykill road the country is flat and obscured by moss and drift, but the limestone and quartzite appear to be thrown west to the east end of Loch Urigill. The whole eastern anticlinal of Ben More and Brebag has in this region been swept away, and the line of junction is in the continuation of the synclinal passing through the Gillaroo Loch. So extensive has been the denudation of the overlying quartzite and limestone that the gneiss is almost continuous from west to east. True granitic gneiss with syenite-veins is seen very distinctly at the east end of the Camaloch, whilst, according to Mr. Cunningham, gneiss also extends from the upper part of Loch Urigill into the Cromalt Hills.

Round Elphin the limestone is very well seen, resting, as usual, on the fucoid-beds and quartzite (dip 12°–15°, to E. or E. 10° S.). These beds are very fully exposed for some miles, and their relation to the eastern gneiss clearly shown in the precipitous cliff of Craig-a-Chnockan, below which the Ullapool road passes. The section

Fig. 10.—*Section on the Ullapool Road, near Elphin.*

d. Limestone. *c*². Fucoid-beds. *c*¹. Quartzite. *b.* Red sandstone. *a.* Gneiss. *x.* Granitic vein.

fig. 10 shows the structure of this place. In the west, Coulmore consists of the Red Sandstone. The valley below is quartzite, extending up to the cliff of Craig-a-Chnockan. In the line of section it dips 12°–15°, to E. 40° S., and is covered by the limestone. Further east the limestone rises up and thins out, and the quartzite comes

* The section fig. 5 (p. 223 in Quart. Journ. Geol. Soc. vol. xvi.), though said to occur to the east of Alt-Ellag (where I am not aware that any quartzite or limestone is to be found), probably refers to this locality; but I could observe no place where the beds rest connectedly on each other as there represented. Even in it, however, the sequence is broken by "hornstone-porphyry;" and the "*gneissose limestone*" is perhaps also an intrusive rock. The absence, too, of the fucoid-beds and limestone in their normal form is opposed to any regular upward succession in that section.

to the surface, followed (still to the east) by fine-grained gneiss, much curved and contorted, but dipping at 35° to 50°, to S. 5° W. In this line a thin vein of granite or syenite, like that on Loch Erriboll, intervenes. Further south, on the Ullapool road, the line of junction intersects the front of the vertical cliff, and the strata are well exposed. The quartzite, dipping at 5° or 6°, and covered by the fucoid-beds and limestone, comes within a few yards of the gneiss. A thick, strong bed of the quartzite then dips down at 12°, as if below the gneiss, whilst the thinner fucoid-beds above are curved and fractured and the limestone broken suddenly off. The dark-coloured, thin-bedded gneiss dips at 20°, and is traversed by innumerable fissures, filled with thin lines of the granitic rock, running up the face of the cliff, from which, a little to the south, a large mass of trap protrudes. Had the strata been less clearly exposed, the gneiss might have been supposed to overlie the quartzite; but the fracture and contortion of the beds, seen even in hand-specimens, and particularly the manner in which the limestone and fucoid-beds are cut out, prove that there is, in this place, not "conformable upward succession," but a line of fault with powerful lateral compression.

Loch Broom.—The next point to the south where the rocks are well seen is the vicinity of Loch Broom, described in my former paper*. As there stated, the quartzite is cut off from the gneiss by a thick bed of intrusive rock, in some places a felspar-porphyry, in others near the limestone inclining to serpentine, but generally identical in character with the rocks in the same position in the previous sections. This summer (1860) I again visited Loch Broom, but saw little to add to my former memoir, except that the porphyry or igneous rock is more extensive than represented in the sections, and, rising up in a wider mass below, separates the eastern gneiss more strongly from the quartzite. I must also call attention to the fact, exhibited in the sections, that, whilst on the north shore the series of the quartzite group is complete, on the south side of Loch Broom the limestone above has been entirely cut out.

Loch Maree and Gairloch.—In my former paper I described some sections in the vicinity of the Gairloch and Loch Maree. I have since examined the mountains round the upper portion of that most beautiful lake, and the line of junction between the quartzite and gneiss with some care; and the section (fig. 11, p. 104) shows the facts as seen on the north side of the loch. In the west there is, first, the red sandstone (*b*), dipping west at a low angle, as seen near Pol Ewe and the Gairloch. Then follows the gneiss, as formerly stated, often a fine-grained grey rock with intercalated beds of mica-slate, in Ben Lair, with hornblende-strata. Near the head of the loch the red sandstone cone of Sleugach rises above a basis of gneiss, forming one of the grandest mountains in this truly mountain-region. The gneiss, generally red or grey and highly crystalline, where seen below the red sandstone dipped 70°–80°, to W. 20° S., and hence has

* Quart. Journ. Geol. Soc. vol. xiii. (1856) p. 18–24 and figs. 1 & 2.

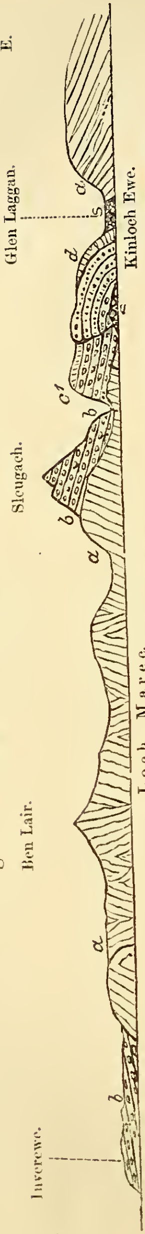
a N.W. strike. Where it meets the red sandstone the surface is very rugged and uneven, and the beds above are often, as noticed on the Gairloch, a coarse angular breccia. The red sandstone dips 15°, to S. 33° E. In the mountain, east of Sleugach, and separated from it by a deep ravine, the red sandstone is covered by the quartzite, which continues along the summit of the ridge to Glen Laggan. The red sandstone, however, forms the foot of the hill to the head of the loch; but further up a great mass of igneous rock (*s*) (a fine-grained syenite, or rather diorite) forms the base of the hill, covered by broken masses of quartzite and limestone. In the valley of the Laggan the limestone (*d*) has been quarried in several places, dipping to E. 20° S., but much altered by the diorite (*s*), which forms a wide mass, running for several miles along the valley. The other side of the valley consists of grey granitic gneiss (*a*), in some places more quartzose, in others fine-grained and micaceous, and dipping 15°–30°, to E. 30°–40° S. In the low ground, however, near the mouth of the glen, grey granitic gneiss occurs, dipping at 60°–70°, to E. 45° N., and thus with a true N.W. strike, though on the east side of the fault and of the quartzite*. In this place, though the formations are only separated by a deep and narrow valley, yet the quartzite is nowhere seen dipping below the gneiss on the east, nor the gneiss resting on the quartzite on the west.

In the low ground near Kinloch Ewe, the gneiss is seen in the bed of the river near the inn, dipping 10° to S. 45° E., and about a quarter of a mile west the red sandstone forms some low rounded knolls. The intervening space is thickly covered by detritus; but, from the dip of the beds, the red sandstone here is probably in contact with the eastern gneiss, the limestone and quartzite having been entirely denuded. The quartzite, sloping down from Ben Ey, covers the red sandstone on the south, but at the foot of Loch Clair is again thrown out, so that the eastern gneiss and red sandstone are brought into contact. The same relation also appears to occur in the wild country towards Loch Carron. Anyhow we find in this region that the limestone, forming the upper portion of the quartzite series, only occurs in rare fragments, where left behind in the denuding process, so that the phenomena are quite opposed to any theory of continuous upward succession.

In regard to the relation of the quartzite and red sandstone in this region, they seem to be generally conformable to each other. I infer this, rather from the view of the two formations as exposed in the mural precipices of the mountains, than from direct observation on the beds. This general parallelism is very marked in Leagach, one of the loftiest mountains on the west coast, and, as the appearance is the same whether the hill is looked at from the north or south, can hardly be a mere optical effect. In Ben Ey (a mountain nearly as high, but more picturesque), the same parallelism appears, and is the more striking from both the red sandstone and quartzite

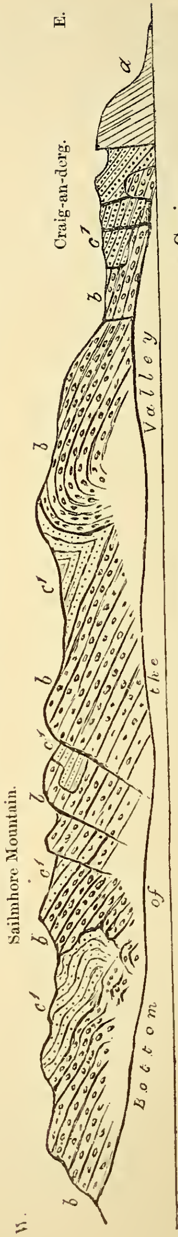
* It may thus be regarded as the other side of the anticlinal to the beds seen under the red sandstone of Sleugach.

Fig. 11.—*Section on the North Side of Loch Maree.*



d. Limestone. c^1. Quartzite. *b.* Red sandstone. *a.* Gneiss. *s.* Diorite.

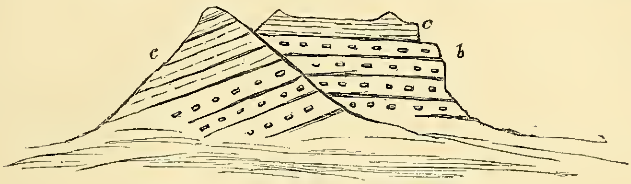
Fig. 13.—*Section in the Loch Torridon and Loch Carron country.*



c^1. Quartzite. *b.* Red sandstone. *a.* Gneiss.

having been tilted over towards the line of fault on the east, as shown in the sketch* fig. 12.

Fig. 12.—*Section of Ben Ey and Leagach.* Seen from the north.



c. Quartzite. *b.* Red sandstone.

Loch Torridon and Loch Carron.—Immediately south of Loch Maree and the Gairloch lies the wild unfrequented district of Loch Torridon. On the shores of this most magnificent sea-loch, and in the lofty mountains that surround it on every side, there is some of the grandest scenery in Scotland, and at the same time some of the most instructive geological sections. The whole structure of the mountains is clearly exposed in the naked precipitous walls of rock, built up, layer above layer, in the most majestic piles of masonry. How geologists could traverse this region, and yet believe that the great Red Sandstone formation of Applecross and the West Highlands was superior to the quartzite, is hard to understand; and yet this was regarded as an established fact up to the publication of my paper on the N.W. Highlands in 1856.

The lowest formation is, as usual, the gneiss, well seen on the narrows near Sheildag, where its dip is N.E., and commonly at a considerable angle. It rises to a height of 2000 to 3000 feet in Ben Ailigin and the Gairloch mountains, but is in most places hidden by the red sandstone. On the lower loch the red sandstone generally dips west at 8° or 10°, but often higher near the outer headlands. In many places it seems almost horizontal, as in the lofty mountain of Leagach, where it is covered apparently in conformable superposition by the white quartzite. On the upper Loch Torridon the dip changes to the east, and then retains this direction throughout. As shown in the section (fig. 13) of the mountains east of Loch Torridon, it is still overlain by the quartzite. In this most remarkable section, the red sandstone, always dipping to the east, and covered by its capping of quartzite, is again and again brought up by faults; and this not only on the summits of distinct mountains, but no less than five times in a single continuous ridge. Had only a surface-view been exposed, as each fragment of quartzite seems to dip below the next one of red sandstone, it might have been supposed that the rocks alternated with each other; but no such mistake can be made in this place, as the true structure of the mountain, to a depth of some hundred feet, is clearly exhibited in the vertical escarp-

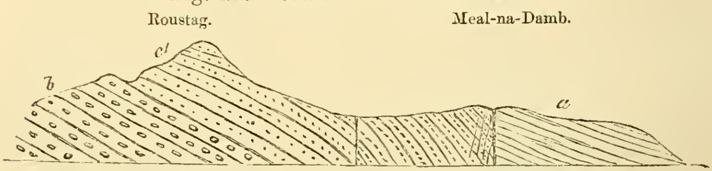
* This rough sketch, taken from the plateau on the north, shows only about half the true elevation.

ments of the mountain, and repeated with equal distinctness in the corresponding precipices on the other side of the valley. It is impossible to give verbal details; but the figure, imperfect as it unavoidably is, represents the facts more distinctly than words. It is clear that the quartzite is mere fragments of the upper formation, brought down repeatedly by faults, and in some cases even forced in below the inferior red sandstone by enormous lateral pressure. This very clear natural section thus tells us the structure of the N.W. Highlands, and the true nature of those apparently anomalous sections which have puzzled observers in other parts of the line of junction.

The most critical point of the section is at the eastern extremity, where the red sandstone and quartzite meet the gneiss or, rather, mica-slate. Near this point the quartzite, still resting on red sandstone, is thrown down some hundred feet below its former level. Repeated slips take place, still further depressing the quartzite and red sandstone, the latter dipping at about 15°, until near the line of junction, where both the quartzite and sandstone dip at 33°, to S. 55° E. An irregular, but nearly vertical, line of fault here separates them from the mica-slate, dipping on the whole at 40° or 50°, to S. or S.E., but in some parts ranging from 15° to 60°, and dipping in various directions from N.E. to S.W. It forms but a mere coating, as it were, on the front of the hill, and is in part intermixed with compact syenitic rocks, which may explain the irregularity in the dip and direction of the beds. In this place, therefore, there is no overlap of the gneiss on the quartzite, but the two formations meet, end to end, along a line of fracture. It is also noteworthy that in this section the red sandstone does not thin-out before the quartzite, as in some of the northern localities, but comes up almost into contact with the gneiss.

Another section in the hills between Loch Carron and Loch Keeshorn (fig. 14) exhibits the same relation even more clearly. In this

Fig. 14.—*Section near Loch Carron.*



c^1. Quartzite. *b.* Red sandstone.
a. Talcose or chloritic schist, with granitoid veins.

place the quartzite, resting on the red sandstone, rises into some lofty mountains. Near the line of junction it dips at 50° to 60°, to E. 20° S., but is fractured and broken, and small fragments of the limestone are involved between it and the talc or chlorite-slate. This rock is much intermixed with veins of red granitoid matter, and dips very irregularly at angles of 20° to 30°, to E. 15° to 45° S., but in part at low angles nearly north. A small stream, running down the side of the hill, along the line of junction, has fully exposed the connexion of the two rocks, but in no place could I find the talc-slate resting on the quartzite. Had the beds been continued in the dip, so as to pass below the slate, this could scarcely have failed to be visible.

In my former paper there is a section of the Loch Keeshorn limestone*. I have since examined the district more carefully than I was then able to do. I have now ascertained that the limestone rests on the quartzite, which in one place dips at 15°, to S. 40° E. The limestone is, as usual, more broken and irregular, but near the bridge to Applecross it dips at 64°, to E. 8° N. The talc-slates on the east have a dip of 20°, to E. 30° N.; and, on the whole, lower angles than those given in my former paper seem to prevail in these beds. Granulite and hornblende-rocks, however, abound near the line of junction; and I was still unsuccessful in finding any point where the talc- or mica-slates overlap the limestone or quartzite. I have now no doubt, from the facts seen at the junction in other places, that the limestone and talc-slate are divided by a line of fault. The occurrence of the limestone in this position, though quite analogous to what is seen in Assynt, is very important. It lies in a low valley at the foot of the red sandstone hills of Applecross, more than 2000 feet high, and, as its regular position is above the quartzite, it must have been thrown down from fully 3000 feet. It must at one time also have been far more widely distributed; fragments of it, some only a few feet or yards in diameter, being found in many places, let in (as it were) along the line of junction of the quartzite and crystalline schists. There is thus evidence of a most enormous amount both of disturbance and denudation in this region; and also proof that, where the quartzite meets the talc-slates or gneiss, without the intervention of the limestone, whatever may be their apparent relations, there cannot possibly be a true conformable upward succession.

South of Skye.—The section of the southern part of Skye given in my former paper (fig. 7, p. 31) offers similar proof that the red sandstone does not dip under, but rests unconformably on, the eastern gneiss, and this gneiss dipping S.E., and identical in mineral character with that of the mainland. The red sandstone dips W.N.W., and is clearly continuous with that of Applecross and the North-west. The section is so clear and decisive that I can do nothing more than refer to the description in my former paper†.

General Considerations.

The sections now noticed, at short intervals along the whole line of junction from north to south, seem quite decisive of the true relations of the quartzite and eastern gneiss. They have not been selected as more favourable to my own views than others that might

* Quart. Journ. Geol. Soc. vol. xiii. p. 29. fig. 6.

† Quart. Journ. Geol. Soc. vol. xiii. p. 31. In the sketch-map in vol. xv. pl. 12, this underlying gneiss is coloured and lettered the same as the so-called overlying gneiss in Sutherland.

have been chosen, but are those brought forward as the proofs on which the opposite theory is founded; yet in not one of them have we found that regular continuous upward succession which this theory requires, but in every one of them irruptions of igneous intrusive rocks, and other indications of faults and disturbance, depriving them of all weight as evidence of regular order. Here, therefore, I might have left the question, satisfied with this appeal to special sections; but there are a few more general facts, leading to the same conclusion, which require a short notice. In order to perceive the full force of these facts as bearing on the present question, it must ever be kept in mind that this region has undergone a most enormous amount of denudation—strata of at least 2000 to 3000 feet in thickness having in some places been swept away from the surface; consequently, if there be here a line of conformable overlap, all the beds that dip east (the so-called "upper gneiss," the limestone, and quartzite) must have originally extended much further to the west.

First. The mode of distribution of the rocks is altogether inconsistent with the hypothesis that the eastern gneiss overlies the red sandstone or quartzite. The red sandstone, with a width from east to west of thirty to fifty miles, is seen in innumerable places—at Stornoway, Cape Wrath, Assynt, Gairloch, Skye, resting for miles in all directions on the gneiss. So also the quartzite, with a breadth of ten or twelve miles, is everywhere clearly seen to rest on the red sandstone. Mile after mile, from north to south and east to west, from mountain-top to mountain-top, from valley to valley, this relation may be traced. And thus also it is with the limestone, though this formation is now of such limited dimensions. In every locality where it occurs—Durness, Erriboll, Loch More, Assynt, Ullapool, Loch Maree, Loch Keeshorn, it is seen resting on the quartzite. This relation can be traced round and round isolated masses of the limestone, and across synclinal basins of miles in extent. But how does it stand with the next step in the series, the so-called "upper gneiss" or mica-slate? This gneiss extends for fifty or a hundred miles to the east, and, we are told, conformably overlies the quartzite or the limestone, for a hundred miles from north to south; and for what distance to the east or west of the line of junction has this overlap been observed? Nowhere for more than a few feet, or yards, at one or two widely separated intervals, has this overlap ever been even alledged to occur. We seek in vain for any isolated portion of mica-slate resting on quartzite or limestone, on the west of this line of supposed overlap; and it is as fruitless to ask which of the thousands of lofty gneiss-mountains on the east reposes on a basis of these so-called older rocks. Such a thorough diversity in this step in the series from all those that precede, and from all the known relations of overlying beds in other countries, proves that here no such overlap takes place.

Second. The diversity in the strata brought into contact with the eastern gneiss proves that the line of junction is along a fault, and not one of conformable upward succession. Where a series of beds rest conformably on each other, no amount of denudation can ever alter their order, or cut out one or two members of the series; but along a line of fault the case is just the reverse: always, as denudation proceeds, older and older beds will be brought to the surface, and thus into contact with the gneiss. This will be readily understood from the diagram fig. 1. As drawn, the limestone *d* is shown in contact with the eastern gneiss *a*. A small amount of denudation would bring first the fucoid-beds c^2, then the quartzite c^1, the red sandstone *b*, and even the western gneiss, into contact with the eastern gneiss. On the other hand, in the contrasted section (fig. 2, p. 217) in vol. xvi. of the Journal of the Society, it is evident that no amount of denudation could ever bring the gneissic flagstones d^2 on the east into contact with the lower limestones c^2 or quartzite c^1, and still less with the Cambrian sandstone *b*. But my sections show (and the fact cannot be disputed) that in some places the limestone, in others (and more often) the quartzite, in others the red sandstone, thus come into contact with the gneiss. As a marked instance, I may refer to Loch Maree, where, in less than a couple of miles, all these relations may be seen, as denudation has been more or less extensive. In the hill on one side of the valley it is limestone, in the low ground in the centre the red sandstone, and then, on the other side, the quartzite. How "conformable upward succession" can explain such relations I cannot comprehend.

Third. That there is here a line of fault, and not of conformable overlap, is proved by the nature of the formations. Though along the line of fault, and especially where the disturbance has been most violent, the quartzite is often much hardened and semifused, still it is a decidedly fragmentary, granular rock. The gneiss or mica-slates, said to rest on it, are no less distinctly crystalline in structure. This is true even of the finest-grained of these strata. Now, before we can accept the theory of superposition, this fact must be explained. That a truly crystalline metamorphic rock should rest on deposits, thousands of feet thick, of unaltered sandstones and limestones with fossils, is so improbable, so contrary to all the established principles of geology, that nothing but the most undoubted evidence and the failure of all other methods of explanation would justify us in admitting the fact. In the Alps, where such superposition of crystalline on unaltered strata is seen, the most distinguished and experienced geologists have found it "necessary to admit that the strata had been inverted, not by frequent folds . . . . but in one enormous overthrow, so that over the wide horizontal area, the uppermost strata, which might have been lying in troughs or depressions due to some grand early plication, were covered by the lateral extrusion over them of older and more crystalline masses*."

* Sir R. I. Murchison, "On the Structure of the Alps, &c.," Quart. Geol. Journ. vol. v. p. 248. I need hardly say that no locality is known to me in Scotland where the crystalline strata overlie the limestone or quartzite in the clear manner shown in the section (fig. 28, p. 246) to which the above extract refers. The phenomena in some parts of Sutherland are more closely represented by fig. 4, p. 182, fig. 16, p. 203, and fig. 19, p. 209, of the same valuable and instructive memoir.

A comparatively very small amount of inversion and extrusion of older crystalline masses will suffice to explain any of the Scottish sections, even as drawn and described by the advocates of an overlying "younger gneiss." That such inversion and extrusion of older masses on younger (though not of gneiss on quartzite) do occur in this region of Scotland, and close to this line of fault, is shown in the section of Sailmhore (fig. 13, p. 104); and, until some rational theory is produced of the mode in which an overlying formation, hundreds of square miles in extent and thousands of feet in thickness, can have been metamorphosed, whilst the underlying formation, of equal thickness and scarcely less in extent, has escaped, we shall be justified in admitting inversions and extrusion equal to those in the Alps.

Strike of the beds.—Two general facts have been adduced in proof of the diversity of age of the gneiss on the west coast of Sutherland and that forming the interior of the country—the diversity in strike and in mineral character. Now it is evident that the relative age of the gneiss in these two regions is an entirely different question from the question whether or not the eastern gneiss overlies the quartzite. I have more than once stated that the gneiss of Scotland probably belongs in part to distinct geological periods, and have specially pointed out "the great tract of gneiss with associated quartzite and limestone, stretching from Aberdeenshire through Perthshire to the Breadalbane Highlands of Argyleshire, as a newer formation*." And such newer beds might also occur in Sutherland and yet not overlie the quartzite. In regard to the strike of the gneiss, I mentioned in my former paper that in the western region "its general direction was to the N.W.," whereas, as Macculloch had long before stated, in the centre of the country it was more commonly "to the south-eastward †." But this distinction is not universal. The mica-slate of Far-out Head dips to the S.E.; and, as Mr. Cunningham shows, the gneiss round Canisp and Suilven has also a N.E. strike, and a similar strike with S.E. dip is common in the south of the Lewis. On the other hand, a N.W. strike prevails in Strath Oykill and the lower part of Loch Shin, and in Ross-shire similar diversity occurs. This sudden and entire change in the strike of the rocks in different parts of the Highlands is, however, a very marked feature, and is clearly connected with that peculiarity of structure exhibited by the previous sections. The country does not consist of one large mass of strata, but of fragments, irregular in form and of more or less extent, and each subject to its own laws of position. They may be well compared to the shoals of ice seen on a river-bank in spring, each turned in its own direction, with little reference to the fragments beside it.

There can be no doubt, however, that the country has undergone a very general disturbance subsequent to the deposition of the

* Note explanatory of the Geol. Map of Scotland, pp. 2, 3; and the Section engraved on the Map. See also "On the Slate Rocks of Easdale, &c.," Quart. Journ. Geol. Soc. vol. xv. p. 110.

† Quart. Journ. Geol. Soc. vol. xiii. pp. 35, 37.

quartzite, throwing it over in large fragments to the S.E., independent altogether of the present strike or dip of the beds. This is clearly shown on the west side of Loch Erriboll, where the quartzite, with the inferior gneiss-plateau on which it rests, have both a dip to the S.E. This is also true of the great plateau of gneiss on which we must suppose the quartzite of Foinaven and Arkle, now dipping at 20° to the S.E., to have been laid down in nearly horizontal masses. So also on Loch Maree and Loch Carron, there is evidence of the upturn of the formations in enormous fragments. Further east, the same overthrow of the masses from the N.W. is evident in the form of the hills and in the position of the newer formations of the east coast. The cause of this most remarkable convulsion must be sought in some more powerful agent than any of the masses of igneous rocks now visible on the surface in this part of Scotland.

Mineral character.—The diversity in the mineralogical character of the rocks has also been often alleged in proof of the overlap of the eastern gneiss. Now it must be stated that, though Dr. Macculloch coloured the whole of central Sutherland as gneiss, yet Mr. Cunningham recognized that some portions of it were mica-slate; and the same distinction appears in subsequent maps. In comparing the gneiss of the east with that of the west, such mica- and chlorite-slates must of course be set aside, though it is undoubtedly true that they are quite as crystalline in texture, and as distinctly separated from the true sedimentary formations, as the gneiss. In regard to the gneiss itself, Mr. Cunningham, undoubtedly both a competent and an unprejudiced observer, states that "the mineral characters of both" (the eastern gneiss, which he believed to overlie the quartzite, and the western, which underlies it) "are essentially the same*," and expressly affirms that "he has never found any indications of mechanical action on its individual constituent minerals†." It is no doubt true that "hornblendic varieties of gneiss are very characteristic of this formation in the west of Sutherland‡;" but the more usual kinds also occur, and in the Gairloch district its general aspect "is a light or dark grey, finely granular rock, interstratified with beds of mica-slate§." In Far-out Head, again, it is a true mica-slate, identical in mineral character (as it is also in dip and direction) with that on Loch Hope and the Kyle of Tongue. On the other hand, rocks quite as hornblendic and as thoroughly granitic in character are common in the eastern gneiss-district. Such rocks may be seen near Strath Naver, Strathie Point, and on the borders of Caithness in Sutherland; at Auch-na-Sheen and Loch Carron in Ross-shire, and at Glen Elg and Isle Oronsay in Skye in Inverness. Further east, in Banff-, Aberdeen-, and Kincardine-shires, they are perhaps the more common varieties. In truth, this peculiar character of the rock has no relation whatever to its age or locality, but only, it would appear, to its proximity to the

* "Geog. of Sutherland," Trans. of Highland Society, vol. xiii. (1839) p. 101.
† *Ib.* p. 78.
‡ Nicol, "Quartzites of N.W. Scotland," Quart. Journ. Geol. Soc. vol. xiii. (1857) p. 24. § *Ib.* p. 28.

great foci of igneous action. Wherever we find granitic and syenitic eruptions, there the gneiss appears in these more coarsely crystalline and hornblendic forms. Any person who examines the western gneiss carefully will find these varieties prevailing only in places where intrusive granite and syenite rocks abound, as, for instance, near Scourie and Loch Inver, in parts of Lewis and Harris, and on Loch Greinord. And it is these intrusive igneous rocks, or rather the interior masses, of which these veins are the mere external indications, which have expanded, and tilted up the western gneiss, and thus produced that line of fault and compression which I have pointed out in the sections above described. So far, therefore, from furnishing any objection to the theory maintained in this paper, the fact that the western gneiss has been thus powerfully interlaced, swollen out, and modified, by veins and beds of red granite, syenite, and other hornblende-rocks, by furnishing a veritable and sufficient cause for the fracture and disturbance observed along the line of junction, adds one more proof of its truth.

It is often assumed that the fine-grained gneiss, mica-slate, and clay-slate are younger than the coarse-grained gneiss and hornblende-rocks; but on what grounds I have nowhere seen stated. In the Southern Grampians I have shown that the very reverse relation prevails, and that the clay-slates and mica-slates may be seen troughing the central gneiss both on the south-east and north-west. We see this along the great line of fracture intersecting the primary formations, from the Murray Firth to the Linnhe Loch, and still more on the southern margin of the Grampians. This remarkable line of fracture, dividing the Old Red Sandstone from the primary formations, is the exact counterpart of the great line of fracture now shown to exist in the north-west. As in the south, we find it bringing up fine-grained gneiss, mica- or talc-slate, and even clay-slate, succeeded further to the east by coarse-grained and hornblendic gneiss.

Conclusion.

Before concluding, I must state that, even had it been proved that the mica-slate or fine-grained gneiss of Sutherland truly overlaps the quartzite, and that this overlap is the result of subsequent deposition, the fact would not bear out the conclusions that have been deduced from it, or establish that entire revolution in Scottish geology which has been supposed. Proof would still be wanted that the mica-slate of Loch Erriboll and Loch Hope is inferior to the great masses of granitic gneiss in the centre of Sutherland. We might ask for a continuous section through the interminable moors of the Moin, and for evidence that the Kyle of Tongue and the huge syenite domes of Ben Laoghal and Ben Stomino do not break the series and bring up anew the lower and older gneiss. But such continuous sections have never even been attempted, either there or through the wilds of Assynt and Strath Oykill, still less across the mountain-fastnesses of the Dirry Moor and Fannich Forest, so as to assure us that no older underlying gneiss comes up there. Till this is done, there is no evidence to connect the great mass of crystalline schists stretching from the north coast of Sutherland to the south of Inverness-shire more closely with the mica-slates of Ben Hope than with the gneiss of Scourie, Loch Inver, and the Gairloch, or to justify us in throwing aside mineral characters for some assumed synchronism in the age of the original, but now wholly altered, deposits.

No such revolution in Scottish geology is, however, required. The sections, when carefully examined, are clear and simple, and quite analogous to those of other mountain-regions. Every fact and section alleged in proof of the recent origin of the eastern crystalline strata appears on investigation to lead directly to the reverse conclusion. At Durine, the mica-slate of the Bishop's Castle, stated to overlie the limestone, does not show a single calcareous bed in a thickness of 1000 to 2000 feet of strata; and the same mica-slates are forced up from below the limestone, by igneous action, in the very centre of the field. At Whiten Head and Loch Erriboll, the quartzites and limestone, alleged to dip under the gneiss, are in part separated from it by intrusive rocks, or meet it in wholly discordant position, often so inverted and denuded that the upper limestone is entirely cut out before reaching the line of supposed overlap. So too it is on Loch More and Loch Glen Coul, where mere fragments of the quartzite series are left abutting against, not dipping under, the old gneiss, or separated from it by intrusive igneous rocks. In Assynt the so-called "upper quartz-rock" is proved to have no existence, but to be a mere upturn of the old quartzite, which is seen resting on the gneiss for miles along its N.E. margin, and on the S.E. is divided from it by a line of fault with huge intrusive masses of granite and porphyry. Further south, in Cromarty- and Ross-shires, the same phenomena prevail. The newer, overlying strata—whether the limestone, the quartzite, or the Red Sandstone—always overlie or abut against, never dip under, the older eastern gneiss. In Skye, finally, the Red Sandstone, the oldest overlying deposit, dipping N.W., rests on the eastern gneiss dipping S.E., and thus in an entirely discordant position. Such are the facts and sections on which I have no hesitation in asking a verdict in favour of the old, long-established principles of Scottish geology.