XX. *On the Arrangement of the Foliation and Cleavage of the Rocks of the North of Scotland.* *By* Daniel Sharpe, *F.R.S., V.P.G.S.*

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Introduction.

THE mineralogical characters of the rocks to which this memoir relates have been so fully described by Macculloch and other writers, that it is not necessary to enter into any details on that head; my object is to describe the usual arrangement of the layers of foliation which have given an appearance of stratification to Gneiss and Mica Schist, to show the relation of their foliation to the cleavage of the stratified slates, and to sketch out roughly the direction of the foliation and cleavage through the North of Scotland.

The most important remarks yet published upon these subjects will be found in the sixth chapter of Mr. Darwin's "Geological Observations on South America," which, in addition to his own views and observations, contains a summary of what had then been done by others: Mr. Darwin's remarks will be frequently quoted in this paper. I must also refer the reader to two papers on Slaty Cleavage, which I laid before the Geological Society in 1846 and 1848, and which are published in the third and fifth volumes of that Society's Journal.

The terms *cleavage* and *foliation* are here used nearly as they have been defined by Professor Sedgwick* and Mr. Darwin (p. 141); *cleavage* or *lamination* being applied to planes of division along which a rock may be split into thin parallel sheets independent of, and usually transverse to its stratification. *Foliation* describes the division of rocks believed to be of crystalline origin into layers of different mineral substances, whether the rock splits along those layers as in mica schist, forms a solid rock as in the granitic varieties of gneiss, or consists of distinct sheets of different materials, such as quartz, mica, chlorite, &c., which sheets may be of any thickness, from a line up to 1 or 2 feet, as may be seen both in the "laminar gneiss" and "chlorite schist series" of Macculloch. For the sake of clearness, the term *slate* is here confined to laminated rocks with a cleavage independent of their stratification, and *schist* to foliated rocks with only one set of divisional surfaces produced by the foliation. The distinctions between foliation and stratification, which Macculloch and many subsequent authors have confounded, will be easily understood when the various peculiarities of foliation have been described.

Under whatever aspect we regard them, it is difficult to draw any clear line of

* Transactions of the Geological Society, Second Series, vol. iii. p. 480.

distinction between gneiss and mica schist; considered mineralogically, they are the two extremes of a series of foliated crystalline rocks, between which every shade of variation may be found; their geological relations are the same, and the foliation of the two rocks follows exactly the same laws. Their geographical separation through Scotland has been drawn most arbitrarily; the lines which divide them on Macculloch's map have very little meaning, and there are many large tracts where the colouring might be reversed without any impropriety. The same may be said of the *chlorite schist* series of Macculloch, which, where I have seen it, is a variety belonging to the same class of rocks, but more nearly related to gneiss than to schist, in which the mineral ingredients are more numerous, and more completely separated from each other in parallel layers than is usual in gneiss or mica schist; yet there are many districts in which the separation of the ingredients of gneiss into layers is as complete as in the chlorite schist described by Macculloch*, and in which the quartz forms layers between one and two feet thick, alternating with layers of micaceous schist, or with beds of a crystalline rock without foliation or cleavage. The other varieties of schist described by Macculloch belong to the same series of rocks, and agree with gneiss or mica schist in everything but mineral composition. The difference of their constituent parts appears to have produced no alteration in the foliation of these rocks, which follows the same laws in them all; the only variation in that respect consists in the greater or less completeness of the separation of the different minerals into parallel layers; and these are but different stages of one process. For the sake of brevity, therefore, I shall use the terms gneiss and mica schist to include all the varieties of foliated rocks.

Under the name of *quartz rock*, Macculloch has classed in connection with gneiss and the various schists, two sets of rocks belonging geologically to two most distinct classes, and only resembling each other mineralogically.

The *quartz rocks* of Glenorchy and Tyndrum†, with most of the varieties composed of quartz and felspar, or quartz and mica, enumerated in Macculloch's classification of rocks, belong to gneiss, from which they differ only in simplicity of composition, and with which they are usually found; these are foliated rocks, and are here regarded as so completely part of the gneiss as to require no separate mention. But the greater part of the quartz rock which figures on the map of Scotland is an altered sandstone, of which the mineral character has been changed by plutonic action; it is a sedimentary deposit in which the stratification is usually distinctly visible. The difference between these two quartz rocks is so obvious, that they may be distinguished even in reading Macculloch's descriptions. The latter forms no part of the subject of this paper, being a stratified, and not a foliated rock; but it was necessary to mention it, lest any of the following remarks on the subject of foliation should have been supposed to apply to it‡.

* Western Isles, vol. ii. p. 284. † Macculloch, Transactions of the Geological Society, vol. ii. p. 478.

‡ I have entered more fully into this subject in a paper laid before the Geological Society.

Contortions of the Foliation.

When an observer enters any district of gneiss or schist in search of order in the arrangement of their folia, his first impression will be that of despair; so numerous are the convolutions of both rocks, varying in importance from curves which have determined the outline of mountain ridges to folds no larger than those in the drapery of a curtain, and so complicated and involved do they appear, that it seems hopeless to seek for any general plan among them. These contortions have often been figured*, but no representation has ever shown a tithe of their complication; they are the most numerous along the dip of the foliation, but they often occur on the line of strike also; and in spots where the rock is only exposed to a small extent, it is often impossible to judge of the prevalent direction of the foliation.

But where large sections are well seen, a more extended observation will show that even where the gneiss is most convoluted, there is still a general direction of the folia or layers of which it is composed, which may be caught by disregarding the minor folds, and fixing the attention only on the larger curves formed by a combination of many of the smaller flexures. This will sometimes be more readily seen from a distance, at which the minuter complications are lost sight of. The simpler lines of curve thus obtained may perhaps still be in themselves complicated; but by repeating the process of simplification and disregarding the secondary flexures, a series of lines of dip are at last obtained, sufficiently simple to admit of classification and of representation in a reduced drawing.

The observations of the direction of the strike must be corrected by repetition; and where the lines of strike are most curved, the gneiss will often be found rising into elliptical bosses, the longer axes of which are all parallel and give the general direction of the strike of the district.

Gneiss and mica schists are not equally contorted throughout; the convolutions are usually most complicated where the inclination of the folia is slightest; where their dip is steeper the rock is usually less contorted, and where the foliation is perpendicular it usually follows true planes without any distortion either on the dip or strike. The granitic varieties of gneiss, in which the foliation is slightly marked, are, I believe, more common where the angle of inclination is slight; and the separation of the minerals is usually well marked where the gneiss is either perpendicular or highly inclined. Thus observations taken where the foliation is perpendicular, admit of much greater accuracy than can be obtained where it is slightly inclined.

Arrangement of the Foliation in Arches.

If any extensive region of gneiss or schist is crossed in a direction transverse to the strike, and the larger and bolder curves noted to the exclusion of the minor con-

* Macculloch, Western Isles, Plate 12, and frontispiece; also Geological Transactions, vol. ii. Plate 31 and 32.

volutions, the foliation will usually be found to be arranged in great arches, in which the inclination of the folia increases as they are more distant from the centre until they reach the perpendicular; the whole thus forming parts of a flat arch bounded by two perpendiculars, a theoretical restitution of which is shown in figure 2.

Beyond the perpendiculars which form the boundaries of the arch there are usually comparatively narrow bands, in which the dip of the folia is irregular; these are succeeded by other perpendicular planes, usually parallel to the first, which form the boundaries of other arches standing on each side of the first, but which are often incomplete. As the planes and curved surfaces are extended in the direction of the strike, each arch here represented is the section of a semi-cylinder, which is often of great length.

The perpendicular planes of foliation frequently run along important ridges of hills, which has brought them into notice; while the lower and flatter central portions, in which the general arrangement is disguised by the contortions, have attracted less attention. Hence several geologists have mentioned "the fan-like or radiating structure in the metamorphic schists of the Alps, in which the folia in the central crests are vertical, and on the two flanks inclined inwards*;" but it has been overlooked, that the fan-like form is produced by combining portions of two adjoining arches: an inspection of the sections, fig. 1 to 5, will convince every one that the arch is the figure of real importance in the arrangement, and the *fan-shaped* form only catches the eye when seen without the rest of the figure.

Analogy between Foliation and Cleavage.

If the arrangement of the foliation which has been just described be compared with that of the cleavage planes of the true slates which I have explained elsewhere†, the two phenomena will be found to correspond in all their main features; both forming great arches bounded by vertical planes, with the peculiarity that in both the dip of the divisional surfaces is least at the central axis, and gradually increases towards the boundaries till it becomes perpendicular. The difference between the two lies in the convolution of the layers of gneiss and schist, which contrasts strongly with the regularity of the flat parallel surfaces produced in slate by the cleavage; yet the difference is rather of degree than of principle; for in Devonshire, where the cleavage forms an unbroken arch with a diameter of sixty miles, and where we can judge of its real characters better than in more disturbed districts, the central part undulates in low curves‡, which are evidently analogous to the convolutions of the central portions of the arches of foliation.

Mr. Darwin has stated, that when in various parts of South America he met with laminated and foliated rocks either alternating with or near to one another, the cleavage and foliation were generally parallel; and from this circumstance, and an

* Darwin, South America, p. 164, where Von Buch and Studer are quoted.

† Journal of the Geological Society, vol. iii. p. 92. ‡ Journal of the Geological Society, vol. iii. p. 95.

occasional tendency in stratified slates to exhibit an incipient mineralogical change along the planes of their cleavage, he infers "that foliation and cleavage are parts of the same process: in cleavage, there being only an incipient separation of the constituent minerals; in foliation, a much more complete separation and crystallization*."

Along the southern border of the Highlands, a band of slate, in which the stratification and cleavage planes are equally visible, rests on foliated mica schist, affording an excellent opportunity of testing these views. The result of an examination of that district, fully bears out Mr. Darwin's opinion: where the two formations come together, the cleavage and foliation are not only conformable at the junction, but combine to form an arch in common. I have selected four sections to illustrate this conformity under different circumstances: at Dunkeld, and on the east side of Loch Lomond, fig. 1 and 3, an arch formed principally of the foliation of the mica schist, is completed by the addition of the cleavage of part of the slate on its southern flank. In Strath Earn and the lower part of Glen Shee, fig. 4 and 5, the foliation of the mica schist, besides forming a complete arch, supplies part of the imperfect portion of another arch to the south, in which it is combined conformably with the cleavage planes of the slates: a similar conformity between the foliation and cleavage is found throughout; but the stratification of the slate, indicated in the sections by the dotted lines, is unconformable to the foliation of the mica schist, and is of no account in the question under consideration†.

An additional proof that one cause has produced both the foliation and cleavage, is found in the continuation of the same divisional planes through clay slate and mica schist from Loch Katterin to Glen Shee; these are alternately planes of cleavage in the slate and of foliation in the schist; the boundary line between the formations being deflected, while the divisional planes keep a direct course and pass from one rock to the other several times without changing their direction or their inclination. When Professor Sedgwick announced the persistence of cleavage planes through beds of different mineral character, it was at once admitted that the uniform cleavage of the various beds must be regarded as one process. There is the same reason for connecting together foliation and cleavage, now that the foliation of the schist is shown to be continuous with the cleavage of the slates. For these reasons the two phenomena will now be described together.

Geographical Arrangement of the Foliation and Cleavage.

It is obvious, from what has been stated of the greater distinctness and freedom from contortion of the foliation when vertical, that in studying its arrangements over any district, it will be best to begin by determining the boundary lines of the

* Geological Observations on South America, p. 155 and 165.

† Not to encumber this paper with details foreign to its principal object, I reserve an account of the stratified rocks of the Highland border for a communication to the Geological Society.

arches along which the foliation is perpendicular. In fact it is not always possible to distinguish the central axis of the arches, as the slight inclination and numerous waves of the foliation are most confusing to the observer near the crown of the arch. In some places the correspondence between the central axis of the foliation and the watershed of the district will be an assistance, but in many cases the axis of the arch of foliation will be most easily ascertained by dividing the distance between the two vertical boundaries. For these reasons, in describing the geographical arrangement of the foliation and cleavage through the Highlands, I shall point out in most detail the lines on which their planes are perpendicular.

On the Map which accompanies this paper, the direction of the vertical planes is marked by double lines as far as I observed them or find them recorded; these are continued in double lines of dots to show the supposed continuation of the observed portions: the central axes are indicated by a single thick line, continued by dots in the same manner over the unobserved portions of country: the fainter single lines represent the strike of the foliation over the intervening spaces, the lines being closest where the dip is the steepest. Similar lines are used both for the foliation of the gneiss and schist, and for the cleavage of the slates, the colours on the Map indicating the rock being a sufficient distinction. It must be understood that this map is but a first rough attempt to lay down in a geographical form a set of phenomena which few observers have thought worth recording*, and which require long and patient examination before it can be completed.

Commencing on the south of the Highlands, the first perpendicular line will be found about four miles north of the Highland border, following a direction not quite uniform, but on the whole about N. 60° E., and running partly through clay slate and partly through mica schist, as follows; on the east side of Loch Lomond the cleavage of the slate is perpendicular at the farm of Cashel, half-way between Rowardennan and Balmaha, striking N. 30° E. I did not trace the course of this line to the west coast, but proceeding eastward, I observed it between Loch Chon and Loch Ard striking N. 65° E., and again a few hundred yards above the foot of Loch Ketterin striking N. 45° E., in both cases through slate. There are obviously some faults in this district which have broken the line and thrown its eastern end to the southward. In Strath Earn the boundary of the slate trends somewhat southward of its previous course; but this has not altered the direction of the perpendicular plane, which runs N. 60° E. through the mica schist one and a half mile south of St. Fillan's. The line follows nearly the same direction through Perthshire without further disturbance, running N. 45° E. through the clay slate on the north side of

* Macculloch often mentions the strike of the gneiss in his "Western Isles," but rarely gives the dip. A few observations on the point occur in Nicol's useful Guide to the Geology of Scotland. The only consecutive series of observations which I have met with, are laid down on the geological maps of Sutherland and Banffshire by the late Mr. Cunningham, published in the forty-sixth and fifty-seventh numbers of the Journal of the Highland Society for September 1839 and June 1842: these have been of great service to me.

Dunkeld; through mica schist at the Brig-o-Cally with a strike of N. 50° E., beyond which spot I did not follow it. Thus along the Highland border the foliation of the mica schist and the cleavage of the slate are both vertical, along lines so closely corresponding, that they may be considered as continuous, which is perhaps the strongest evidence that can be adduced to show the identity of the causes which produced the two phenomena.

To the south of the perpendicular which has been traced above, the cleavage hangs over to the south, with a steep dip of about N.N.W., thus forming the commencement of another arch, which is broken off abruptly along the line of junction of the clay slate and Old Red Sandstone, in the manner shown at the southern extremity of the sections, fig. 1 to 5. But on the north side, the cleavage, and then the foliation dip about S.S.E. towards the perpendicular for a space of five or six miles, first at a high angle, and then at a lower inclination accompanied with many waving contortions; the dip then changes to about N.N.W. for a similar space of five or six miles, and again increases till it reaches the perpendicular on a line nearly parallel to the first, the whole forming an arch varying from ten to twelve miles in width, composed partly of cleavage and partly of foliation: the central axis of this arch runs along the high ridge of hills on the south side of Loch Tay.

The perpendicular plane which forms the northern boundary of the arch just described is broken and often irregular in its direction, and entirely confined to the gneiss or mica schist, but as I crossed it at distant intervals I can only map its course approximatively. The first point observed on the west was in Strath Fillan, about one and a half mile south of Tyndrum, where a vertical foliation runs about N. 50° E. through a hard and very quartzose gneiss: the same perpendicular plane runs N. 45° E. through Ben Lawers; N. 60° E. at the ridge between Strath Tay and Glen Tummel, a little to the east of Schehallion; crosses the pass of Killicrankie in a direction very little north of east, and runs N. 35° E. across Glen Shee, about a mile below the Spittal;—a line drawn N. 50° E. from the western point observed in Strath Fillan to Killicrankie passes through the intermediate spots named, and gives N. 50° E. as the general bearing of this vertical plane of foliation, leaving out of account the observation in Glen Shee, where the plane seems to have been thrown to the south by some local disturbance.

If this line were continued westward from Tyndrum, it would pass near Inverary, but some eruptive masses of porphyry on the west side of Loch Fyne have destroyed the regularity of the foliation in that neighbourhood; the vertical line, however, reappears further west and crosses Knapdale, where it attracted Macculloch's attention: the same author also describes the foliation of the schists meeting in a roof-like form down the middle of Cantyre. Thus he has pointed out both the central axis of the arch just described, as well as its northern border, without observing the arched arrangement of the foliation*.

* Western Isles, vol. ii. p. 287.

The next arch which crosses the Highlands, with a diameter of between twenty-five and thirty miles, runs for the most part through gneiss: its southern boundary coincides with the northern boundary of the arch just described; I only observed on two points the perpendicular foliation which forms its northern limit: two perpendicular planes, about a mile apart bearing N. 40° E., cross the valley of the Spey, near the junction of the road from Loch Laggan with that which runs down Strath Spey, from which spot they run on through Corbuie into the line of the Monaglea mountains; I observed the perpendicular again in those mountains four miles N.W. of Kingussie, where the regularity of its course was destroyed by the intrusion of a neighbouring boss of granite, and the direction of the foliation varied; but as this spot bears N. 40° E. from that at which the perpendicular crossed the Spey, we may conclude that to be the direction of the line sought for. The axis of this great arch runs for some distance along the central ridge of the Grampians. The great granitic masses of Ben Cruachan and Ben Muick Dhui, with several minor bosses of granite, have broken through the middle of the arch, in each instance disturbing the regularity of the foliation for some distance around; thus in Glen Feshie, on the western side of the Ben Muick Dhui range, the foliation strikes for some distance nearly north, yet the general features of an arch are preserved, of which the crown coincides with the ridge separating the waters of the Feshie and Geauley.

I have not examined the district to the west of the Ben Muick Dhui range, but this deficiency is partly supplied by a paper of Mr. CUNNINGHAM's on Banffshire*. In the map which accompanies that memoir, the cleavage is marked as vertical with a direction of N. 45° E. in the slates on the south of the town of Banff, and again with the same direction at Kinairdy, south of Aberchirder, while throughout nearly all the rest of the county the dip is represented as inclining to the S.E. at various angles. It appears from these data that though the direction of the foliation and cleavage is nearly the same on the east and west of the granite of Ben Muick Dhui, the whole arch on the eastern side is thrown much to the north of that on the western side of the granite; for the perpendicular boundary of the arch near Banff is about on the line of the centre of the arch at the Grampians: as this is the greatest irregularity met with in these phenomena, I regret that I had not time to work out the details connected with it; but having everywhere found that the regularity of the foliation and cleavage is disturbed in the neighbourhood of granite, I cannot hesitate in ascribing this deflection to the influence of the granite which occupies so large a part of Aberdeenshire, and of which the northerly direction of the foliation in Glen Feshie is the commencement.

I can give but a meagre account of the next line of perpendicular foliation, which runs nearly parallel to that last described at a distance of ten miles farther north, forming the northern boundary of an arch of the usual character, and of that diameter. The perpendicular in question runs N. 35° E. through Coryaraick, cross-

* Journal of the Highland Society, No. 57, p. 447.

ing the top of the pass taken by the old military road from Fort Augustus: this line is nearly parallel to the line of Lochs through the Great Glen, and about six miles south of them. I observed the cleavage of the clay slate vertical on two lines on the south bank of Loch Leven, one less than a mile east of the inn at Ballahulish, striking N. 30° E., the other, three and a half miles west of the same inn, striking N. 40° E.: though these lines are separated from the perpendicular seen at Coryaraick by the granite of Ben Nevis, they obviously belong to the same boundary.

The perpendicular line just mentioned forms the southern edge of a larger arch of gneiss, of which the northern boundary running through the centre of Ross-shire consists of several vertical lines separated by tortuous foliation, which together form a band several miles wide. The most southerly spot on which I crossed this band, was on the road from Fort William to Arasaig, on which traverse the gneiss is well exposed in a most instructive section: a line of vertical gneiss runs due north along each of the high ridges of hills between Loch Eil-head and Loch Sheil, and between these the foliation is highly inclined and much contorted, forming with the perpendiculars several of the fan-like arrangements before alluded to. Westward of Glen Finnen also the gneiss is vertical on several lines, gradually changing in direction as we go westward from N. 5° E. to N. 20° E., which last is the prevailing strike in that district. In taking a broad view of the phenomena, we must regard these lines of vertical foliation as constituting one band.

The next traverse made was from Fort Augustus to Glenelg along Glen Morrison and Glen Shiel: several lines of perpendicular gneiss cross this road in the high region which separates the waters of the Shiel and the Clunie, viz. one at the head of Loch Clunie, striking N. 30° E.; again at the Clunie inn on the top of the pass with the same strike, and another a mile down Glen Shiel, striking north: the prevailing direction is here N. 30° E.

On Loch Linchart the gneiss is vertical, both at the head of the Loch and at the village of Garve, with a direction of N. 45° E., which would carry the latter line through Ben Wyvis. I did not visit the country north of this place, but in Mr. Cunningham's map of Sutherland the gneiss is laid down as vertical, with a strike of N. 45° E. at two places on the north of the Kyle of Sutherland, beyond which I can only carry the line on conjecturally.

A band drawn N. 30° E. would pass through all the above-mentioned spots in Ross-shire at which the foliation is vertical; taken in connection with a line drawn from Ballahulish to Coryaraick, and continued eastward in the same direction, it incloses an arch, which at its southern extremity is not fifteen miles across, but which widens to twenty-five miles on the north-east: the Great Glen with its unrivalled chain of Lochs runs nearly parallel to the southern border of this area, halfway between its perpendicular boundary and the central axis of the arch: the granite of Loch Garry has broken through the centre, disturbing the regularity of the foliation for several miles around.

The perpendicular band which has been traced through Ross-shire is the most

northerly line of vertical foliation belonging to the great system of north-easterly strike which occupies so large a part of Scotland; for to the north-west of that band there is only half an arch broken off nearly along its central axis, at a line which may be drawn about N. 25° E. from the head of Loch Maree to Loch Eribol in Sutherland, and which divides the gneiss of Scotland into two districts of very unequal size, distinguished by different directions of their foliation. The gneiss immediately to the eastward of the last-mentioned line dips about E. 15° S. at angles rarely exceeding 15° or 20°: this dip gradually increases as we proceed eastward, till it reaches the perpendicular on the line just traced through the middle of Ross-shire, thus forming half an arch only twenty miles wide at its southern, and nearly thirty miles wide at its northern extremity, of which the western half is entirely wanting. But on the western side of the line between Loch Eribol and Loch Maree-head all the gneiss of the main land and that of the island of Lewis strikes towards the north-west; thus the axes of elevation of the two districts run nearly at right angles to one another. Mr. CUNNINGHAM, who has drawn attention to the line commencing at Loch Eribol as far as it runs through Sutherland, regarded the gneiss to the east of that line as of a more recent formation than that to the westward of it, stating that the eastern gneiss often overlies the stratified quartz rock and limestone, which never occurs to the westward of the line in question*.

Although the superposition of the gneiss to the quartz rock and red sandstone in other parts of the same line has been mentioned by MACCULLOCH†, we may require further evidence before accepting so remarkable a statement; there are so many districts in the Highlands where secondary and truly stratified quartz rock has been confounded with gneiss that a mistake of the kind need create no surprise. It is however worth remarking, that the alteration of the Old Red Sandstone into quartz rock has taken place principally along or to the east of the line which separates the two districts of gneiss, from Loch Eribol to Loch Maree-head and Loch Carron; while the Old Red Sandstone resting on the gneiss to the west of that line is unaltered.

The want of parallelism between the lines of perpendicular foliation and cleavage, forming the boundaries of the great arches of gneiss, schist and slate which traverse Scotland, is an unexpected phenomenon deserving particular attention. The most southerly of these arches, that including Loch Tay, which consists principally of mica schist and clay slate, widens slightly in its course westward; but all the other arches, traversing districts consisting for the most part of gneiss, widen considerably as they proceed eastward with uniform regularity. The line from Loch Eribol to

Loch Maree, along the supposed axis of an arch, runs about . . .	N. 25° E.
The perpendicular through Ross-shire, runs about	N. 30° E.
That through Coryaraick, runs about	N. 35° E.
That through Corbuie and the Monaghlea Mountains, runs about .	N. 40° E.
And that through Ben Lawers, runs about	N. 50° E.

* Geognostical Account of Sutherland, p. 96 to 100. † Western Isles, vol. ii. p. 94, and Plate 31, fig. 2.

If these lines were continued towards the south-west, they would converge between Lough Foyle and Lough Swilly in the middle of the great mica schist district of the North of Ireland.

As we cannot doubt that the lines forming the opposite boundaries of each arch of elevation are to be regarded as of contemporary formation, the divergence above pointed out militates strongly against M. Elie de Beaumont's favourite theory of the parallelism of contemporary mountain chains. Perhaps the explanation of the divergence is, that the area enclosed between each pair of lines is an ellipse of which we only see a portion in Scotland: this is rendered probable by the frequent occurrence on the surface of gneiss of elliptical elevations on a small scale.

The section given on Plate XXIII. fig. 1, is drawn across the Highlands in a direction transverse to the strike of the foliation; it shows at one view, as far as its scale admits, the dip of the divisional surfaces of the foliation and cleavage and the succession of arches which have been pointed out. It commences at Kyle Rhea Ferry in Ross-shire, on the shore opposite to the Isle of Skye, and is traced from there to the east-south-east, in as straight a line as my observations admitted of, through Fort Augustus to the Highland border below Dunkeld, being a length of about ninety miles. This is as long a line as can be drawn through the district of gneiss and schist, and is as free from the disturbing masses of granite and porphyry as any section which could have been chosen. So constant is the direction of the foliation, that any other line across the Highlands parallel to this would exhibit all the same principal features, differing only in the local disturbances. It is impossible on a small scale to represent the contortions of the gneiss, and the lines here given are only intended to represent the larger features of the phenomena, so that the section is hardly more than a diagram expressing general results. I have added below it a more theoretical diagram, fig. 2, in which the forms of the arches are completed, which are indicated by the lines of the true section, and the outline of the country added to show the relation borne by the position of the mountains and principal valleys to the inclination of the foliation and cleavage.

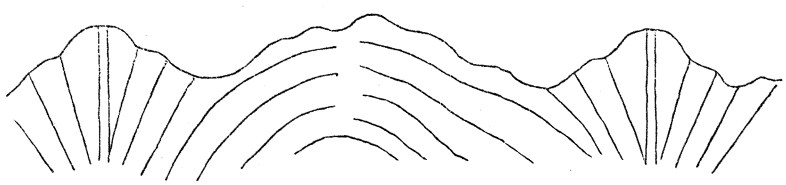
I have but little to add respecting the district of gneiss lying to the west of the line from Loch Eribol to the head of Loch Maree, and which should probably be continued to Loch Carron; throughout which the strike, as far as has been observed, is about north-west. The gneiss is only seen at intervals, between which it is covered up by Old Red Sandstone, so that we cannot see any continuous section, nor obtain a good idea of the relations of the different masses to each other. There seem to be a succession of arches of moderate diameter, of which we see the perpendicular walls standing out in relief, while the central parts between being lower are covered by the sandstone. It will be seen on the Map that the gneiss is vertical, both at Cape Wrath, at Sandwood Bay five miles south of that Cape, again vertical at Loch Inchard, on both sides of Storr Point, and on the north side of Loch Maree; all with a strike between N. 45° W. and N. 25° W. I found the same direction in the

gneiss of the Isle of Lewis as far as I examined it: there is a vertical plane crossing the island N. 45° W. from Broad Bay near Stornaway to Barvas, on the south side of which is a broad arch, which I only followed partially; its central axis is seen at Callernish striking N. 20° W., so that its other boundary may be looked for towards the southern end of Lewis.

Let us now quit these dry details, and turn to the connection between the direction of the foliation of the rocks and the physical features of the country, which will bring out many points of great interest. The most rugged and elevated hills are usually found either along the lines of vertical foliation or where the dip nearly approaches the perpendicular. Thus the southern perpendicular plane crosses Ben Voirlich, and runs close to Ben Ledi and Ben Venue: the next perpendicular described runs through Ben Lawers; the next through the Monaghlea Mountains; another through Coryaraick, and the northern line through Ben Wyvis: and besides crossing these, which are among the highest mountains in Scotland formed of gneiss and mica schist, the perpendiculars run along many high ridges, which will be seen most readily by reference to the Map.

The central axis of each of the great arches described, is also frequently occupied by hills of considerable elevation, but less rugged than those on the boundary lines, of which the hills on the south side of Loch Tay and the Grampians are the most striking examples.

The lowest ground frequently occurs about half-way between the perpendicular walls of the arches and their central axes, and all the great valleys which run parallel to the strike of the foliation occupy this position; as instances may be quoted the line of Loch Tay, Loch Dochart, and the upper reach of Loch Tyne; Strath Spey, from Laggan downwards; the valley of the Findhorn, and the Great Glen; all of which occupy lines intermediate between the centre and the boundary of their respective areas. These great valleys are not cracks analogous to the so-called valleys of elevation of the stratified districts; they seem to be lines of less elevation left at the original upheaval of the areas, and due to some unequal operation of the upheaving force. The annexed diagram shows a frequent form of outline of the country included in each arch of the foliation; but there are also several cases



where there is a valley on only one side of the central axis without any corresponding depression on the other side.

Perhaps the most striking evidence of the connection of the physical geography with the foliation of the rocks, will be found in observing on the Map how many of

the valleys and lakes of the Highlands follow lines which, if produced, would converge on the North of Ireland, near the points of convergence of the perpendiculars already described.

It must not however be supposed that all the great physical features of the Highlands are connected with the foliation of the gneiss and schists; there have been many disturbing forces at work at various later periods, which have broken up the surface into hills and valleys with very different directions. The most important of these are connected with the outbursts of granite, porphyry and similar rocks, far more numerous than are represented on any of our maps, which have broken through the gneiss and schists, and deranged the regularity of their foliation. Many districts also may have been disturbed by agents which have not shown themselves on the surface; of these, the neighbourhood of Loch Lomond is a remarkable instance. But as the gneiss appears to be the most ancient of the formations now visible in Scotland, so also the physical features connected with the foliation of the gneiss must be regarded as the earliest of which we can take cognizance, and we must refer to later periods those which appear to be independent of that phenomenon.

Foliation different from Stratification.

In the chapter already quoted, Mr. Darwin has combated the opinion prevailing among geologists "with respect to the origin of the folia of quartz, mica, felspar and other minerals composing the metamorphic schists, that the constituent parts of each were separately deposited as sediment, and then metamorphosed*." Nevertheless that opinion still appears to hold its ground, and has been lately re-asserted in a publication of high authority†.

The remarks already made on the analogy between foliation and cleavage confirm Mr. Darwin's view, that "foliation and cleavage are parts of the same process;" for on no other supposition can we explain the conformity between the two where seen in contact, and their being combined in the same arch of elevation. Now as cleavage is almost always transverse to the bedding and obviously a change produced in the beds after their deposition, it follows that foliation also is distinct from bedding or sedimentary stratification.

But besides the argument to be drawn from the analogy of cleavage and foliation, a direct comparison of these with the usual disposition of the beds in stratified rocks of sedimentary origin, will equally serve to distinguish true stratification from those phenomena.

We have seen that the arrangement of the foliation of gneiss and schist is in large flattish arches, in which the dip is slight near the central axis, and gradually in-

* Geological Observations on South America, p. 165.

† Sir C. Lyell's Manual of Elementary Geology, London, 1851, where the arguments for the sedimentary origin and subsequent metamorphism of gneiss, mica schist, &c. are produced at great length, and their structure is represented as *stratification* and nowise related to cleavage, pp. 467 to 481.

creases in inclination as we recede from the centre till it becomes vertical at the same distance on each side of the centre; this arrangement is precisely analogous to that of the cleavage of slates which I first described in 1846, and have found in all subsequent observations to be the usual disposition of the planes of cleavage. But this is very rarely the position of the beds of an elevated district; when stratified rocks have been raised into an arch or a dome, the steepest inclination of the beds is usually found near the axis or point of elevation, and the inclination diminishes as the distance from the disturbing force increases. The contrary will undoubtedly be sometimes found; yet it is very seldom that we see the distant beds dip at a higher angle than those nearer to the axis of disturbance. But this, which is a rare exception in planes of stratification, is almost the universal rule with cleavage and foliation.

The contrast just pointed out is so general, that when an observer finds it difficult to distinguish between planes of cleavage and stratification, as sometimes happens where either or both sets of planes are obscure, he will generally be right in referring to bedding those planes whose inclination diminishes in receding from the axis of elevation, and to cleavage those which become steeper at a distance from the axis. And a similar empirical rule will equally assist us to distinguish foliation from stratification.

The contortions of gneiss and mica slate are also far more complex than are ever found in the most disturbed strata, and are such as could only be produced in matter in a state of at least semi-fluidity; for they are not accompanied with any fractures across the layers of rock, such as are found in beds which have been bent after their deposition. The materials of the foliated rocks seem to have been in a state sufficiently fluid to allow the mineral ingredients to separate freely and arrange themselves according to their chemical or crystalline affinities, and while that process was going on to have been subjected to enormous pressure along certain axes of elevation, which has influenced the crystallizing action in so far as to have determined the direction of the parallel layers of different minerals, and has also raised up those layers into the great arches now seen and caused the contortions of certain portions of them.

Finally, not only are the arches of foliation quite different from those of elevated strata, but the general arrangement of those arches is such as has never yet been found in any beds of undoubted sedimentary origin; for it must be recollected that the arches represented in the section, Plate XXIII. fig. 1, run across Scotland side by side, exhibiting traces of a symmetry which was probably perfect before it was disturbed by the eruptions of granite and porphyry.

Gneiss and Mica Schist improperly termed Metamorphic.

The term *Metamorphic Rocks* has been applied to gneiss, mica schist, &c., under the supposition that they still maintained their original bedding, with a crystalline character superadded to it; when that theory is abandoned, there will be no longer

any propriety in retaining the name which implies it. The materials of gneiss and mica schist may have previously existed in some other form; but that alone is not enough to induce us to call them metamorphic; for the name might be applied for the same reason to granite and syenite, or even to lava, all of which have probably undergone various mutations. It would be better to restrict the term *metamorphic* to rocks of a sedimentary origin which have undergone changes affecting only their mineralogical character without losing the evidence of their bedding. It will also add to the clearness of our language if we confine the term *slate* to laminated rocks of stratified origin, and call the fissile foliated rocks *schists*; in which manner the two words have been used in this paper.

Appendix.—Among the attempts made to explain the cause of the lamination of slaty rocks, reference has often been made to the interesting experiments of Mr. R. W. Fox, since repeated by Mr. Hunt, upon the changes produced by long-continued voltaic electricity upon masses of clay, bricks, &c.*. The results produced have a sufficient analogy, both to lamination and foliation, to rouse our attention to the subject, without coming near enough to the great features described in this paper to allow us to regard them as a solution of the problem. In the mass of clay operated on by Mr. Hunt (fig. 12, p. 451), one side has assumed a laminated and the other a foliated structure, the latter being curved and more contorted than the former, as is usually the case in similar structures in the earth; but we do not see the regularity which is so striking in laminated rocks, and the two structures, instead of harmonizing as in nature, appear in a sort of opposition, being produced on opposite sides of the mass in an unconformable position.

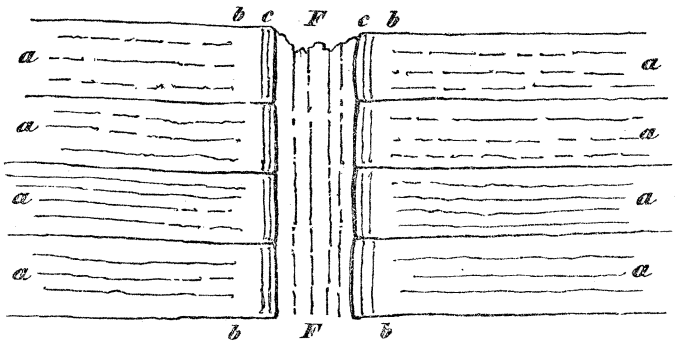
The changes produced in the brick (51) and plaster of Paris (49), p. 453, are more analogous to what may sometimes be seen in rocks traversed by fissures or mineral veins than to slaty cleavage. In these experiments the mass acted upon was found to be laminated on the side nearest the zinc plate of the battery, and considerably indurated on the copper side.

In examining the coast of Portugal near Cascaes, I met with several parallel perpendicular fissures between 10 and 30 feet wide, which run N.W. from the coast about a mile west of Cascaes towards the granite hills of Cintra, through beds of limestone and sandstone of the ages of our lower greensand. Where these fissures cut through the cliff they may be well examined, and the following notes were made respecting one of them. The cliff consists of thick beds of sandstone, in which all the minor traces of the bedding are obliterated for a breadth of 2 or 3 feet on each side of the fissure, only the great divisions remaining visible, and for about 6 inches on each side of the fissure the sandstone is laminated, splitting in perpendicular layers parallel to the walls of the fissure. The crack itself is filled by vertical layers of sandy

* Memoirs of the Geological Survey, vol. i. p. 451 and 453.

clay lining each side, and a mass of calcareous spar down the centre. The annexed diagram, fig. 6, will give an idea of the appearance on the cliff.

Fig. 6.



a a. Beds of sandstone, unaltered.

b b. Hardened portion of the sandstone, deprived of the minor traces of stratification.

c c. Sandstone close to the walls of the fissure vertically laminated.

F F. The fissure filled with calcareous spar and clay.

The changes which have taken place near the fissure are identical with those described by Mr. Hunt (49 and 51), the mass of the rock being laminated on the one part and rendered more solid on the other, which we may safely conclude to have been produced by galvanic currents passing between the mass filling up the fissure and the body of the rock on each side; but it would be too bold a speculation which should attempt to explain the regular cleavage of whole formations of slate by comparing it to the trifling change described above.

Explanation of the Map and Sections, Plates XXIII., XXIV.

As the object of the Map is to represent the direction of the foliation and cleavage, the geological features which have no reference to that subject have been kept as little prominent as possible, and only as many colours employed as were indispensable. The whole of the foliated rocks are painted of one yellow colour, which thus includes gneiss, mica schist, chlorite schist, hornblende schist, and the gneissose quartz rock. The stratified slates are coloured purple. The brown colour includes the Old Red Sandstone, the stratified quartz rock and the limestones associated with them. The more modern formations, which cover a very small space in the Highlands, are omitted. Granite, syenite and the older porphyries are coloured pink, and the more modern trap-rocks red. Thus two colours, the yellow and purple, represent the rocks affected by the foliation and cleavage; the pink includes all the plutonic rocks which have broken through and disturbed the foliation and cleavage; the brown and red represent the rocks which overlie and conceal the rocks affected by those phenomena.

The *strike* or direction of the foliation and cleavage across the surface is indicated by black lines; when these are double the foliation or cleavage is vertical; a single

thicker line represents the central axis of an arch of foliation. The dotted lines show the direction supposed to be followed, in unexamined districts, by the lines just explained. All the lines are laid down on the Map with more continuity and regularity than really exist; this error can only be fully corrected by a minute examination of the whole country.

As the object of the sections (figs. 1, 3, 4 and 5) is to show the direction of the dip of the foliation and cleavage, continuous lines have been used to represent them, while the dotted lines mark the stratification. The contortions of the foliation are indicated conventionally, as is explained at p. 447, since it would not be possible to represent their real complication on so small a scale. In fig. 2 the upper line is an ideal completion of the curves indicated by the dips of the foliation and cleavage seen in fig. 1, and the lower line is a rough sketch of the outline of the country; but it is not intended to be inferred that the rocks ever reached up to the upper line. In all the sections the scale of height considerably exceeds that of length, but the angles of dip are preserved as nearly as the observations taken on a large scale over broad tracts of country admit of.

Note.—The *strike* or direction of the foliation, cleavage and bedding on the plane of the earth's surface was taken with a pocket-compass; the corrections for the variation of the needle being derived from the directions on the Admiralty Charts; viz. for the

Forth	25·30
Aberdeen	26·30
Banff	27
Loch Ryan	27·30
Loch Eil	28·20
Isle of Lewis	30·94

The angles of dip were taken with a pocket-clinometer, which is sufficiently accurate for the object required, as the irregularity of the surfaces to be measured leaves all such observations liable to errors of 2° or 3°.

Fig. 8.

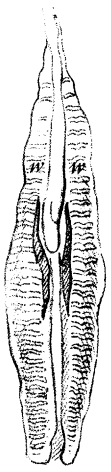


Fig. 9.

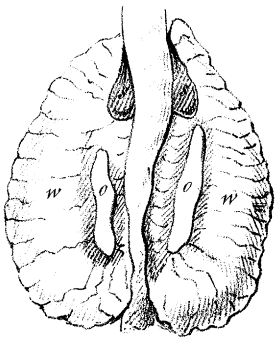


Fig. 10.

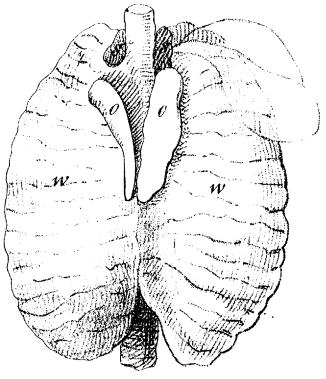


Fig. 11.

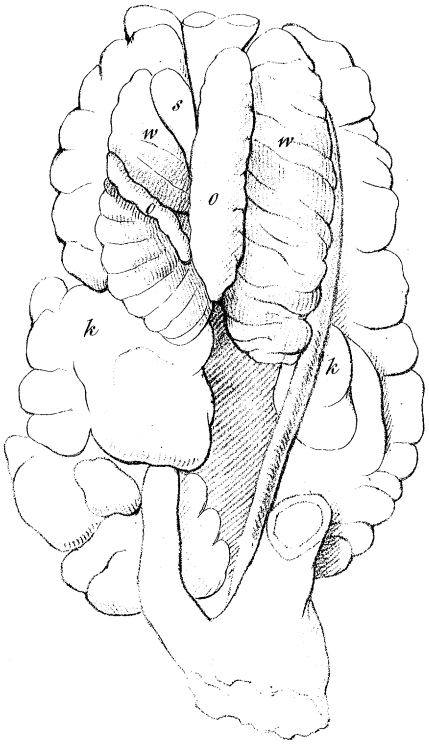


Fig. 12.

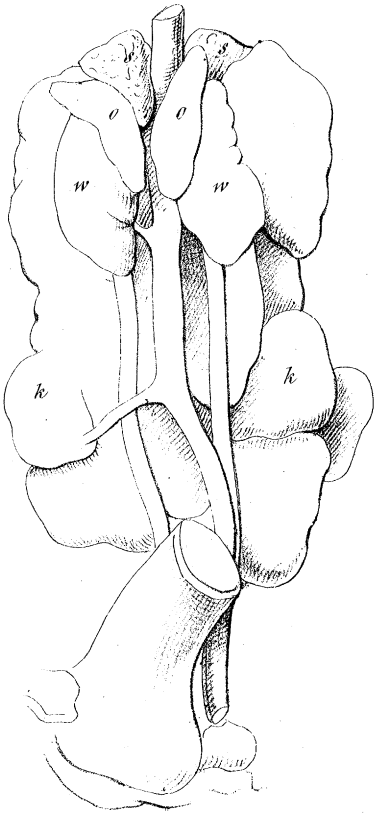


FIG. 1.

From Kyle Rhea to Dunkeld. 90 Miles. Scale 10 Miles to 1 inch.

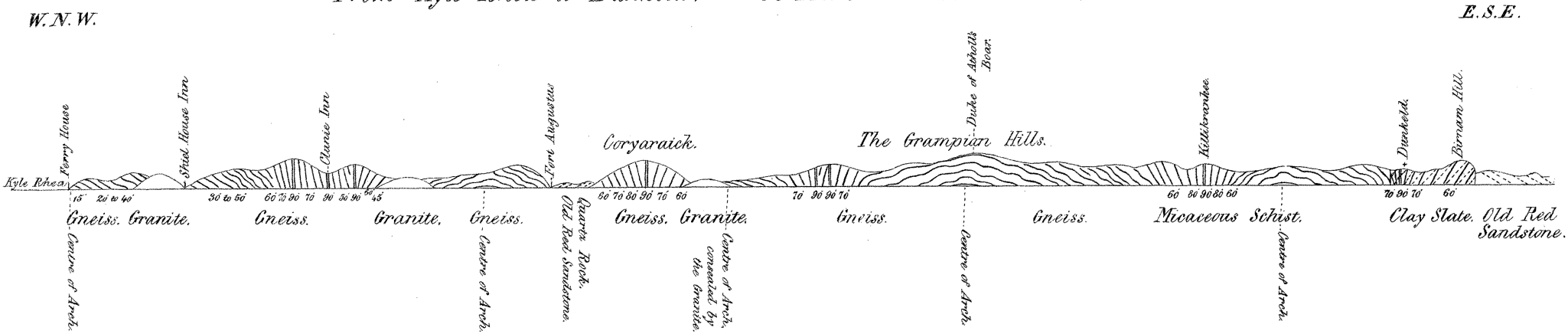


FIG. 2.

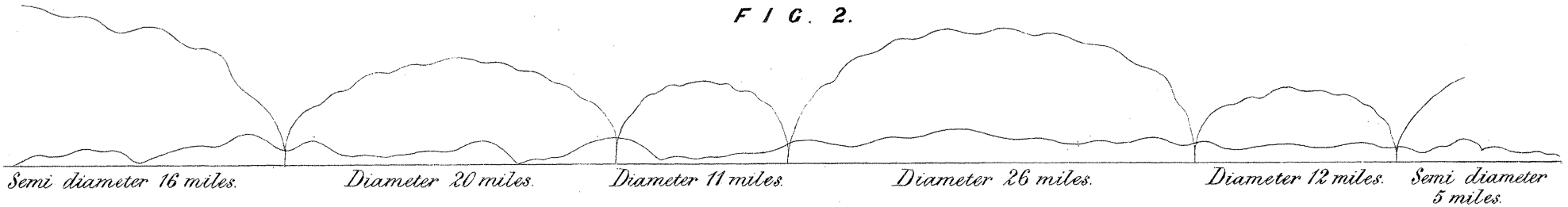


FIG. 3.

East side of Lock Lomond.

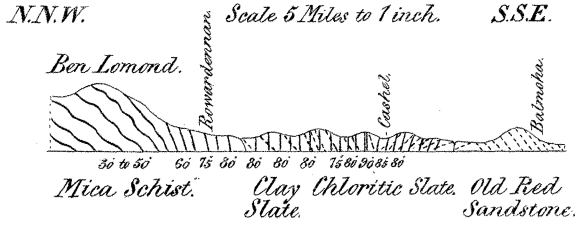


FIG. 4.

Across Lock Tay & St. Fillans.

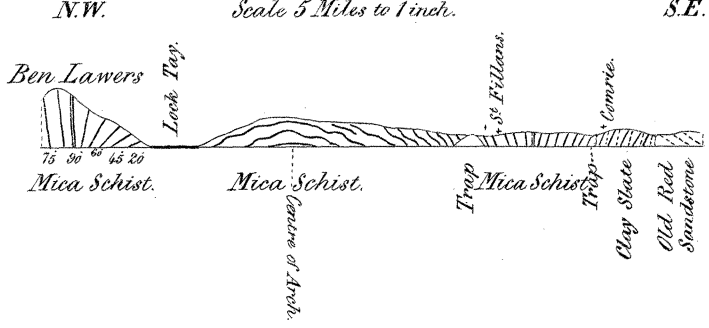
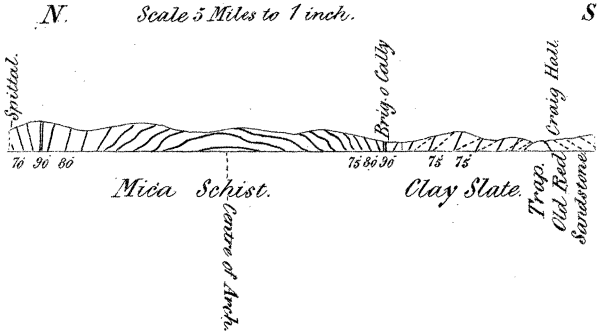


FIG. 5.

Glen Shee.



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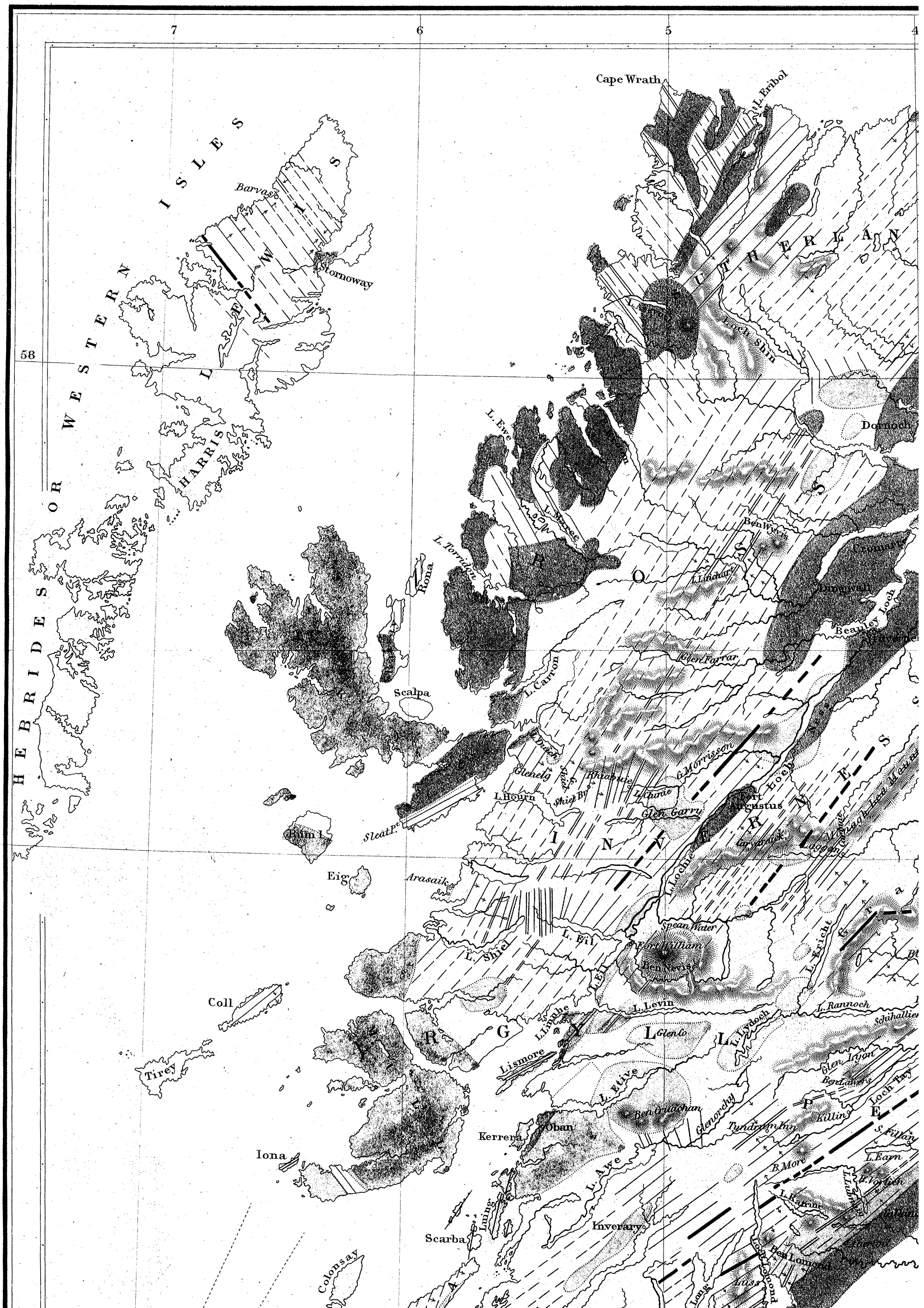

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L. Torridon
Rona
Scalpa
L. Carron
Dornoch
Cromarty
Dingwall
Beauley Loch
Ben Wyvis
R O S S
Glen Farrar
Glenelg
L. Hourn
Sleat Pt.
Rum I.
Eig
Arasaik
I N V E R N E S S
Fort Augustus
Glen Garry
L. Lochie
Spean Water
Fort William
Ben Nevis
L. Shiel
L. Eil
L. Ericht
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L. Linnhe
L. Levin
Glen Co
L. Lydoch
L. Rannoch
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Lismore
L. Etive
Ben Cruachan
Glenorchy
Tyndrum Inn
Glen Lyon
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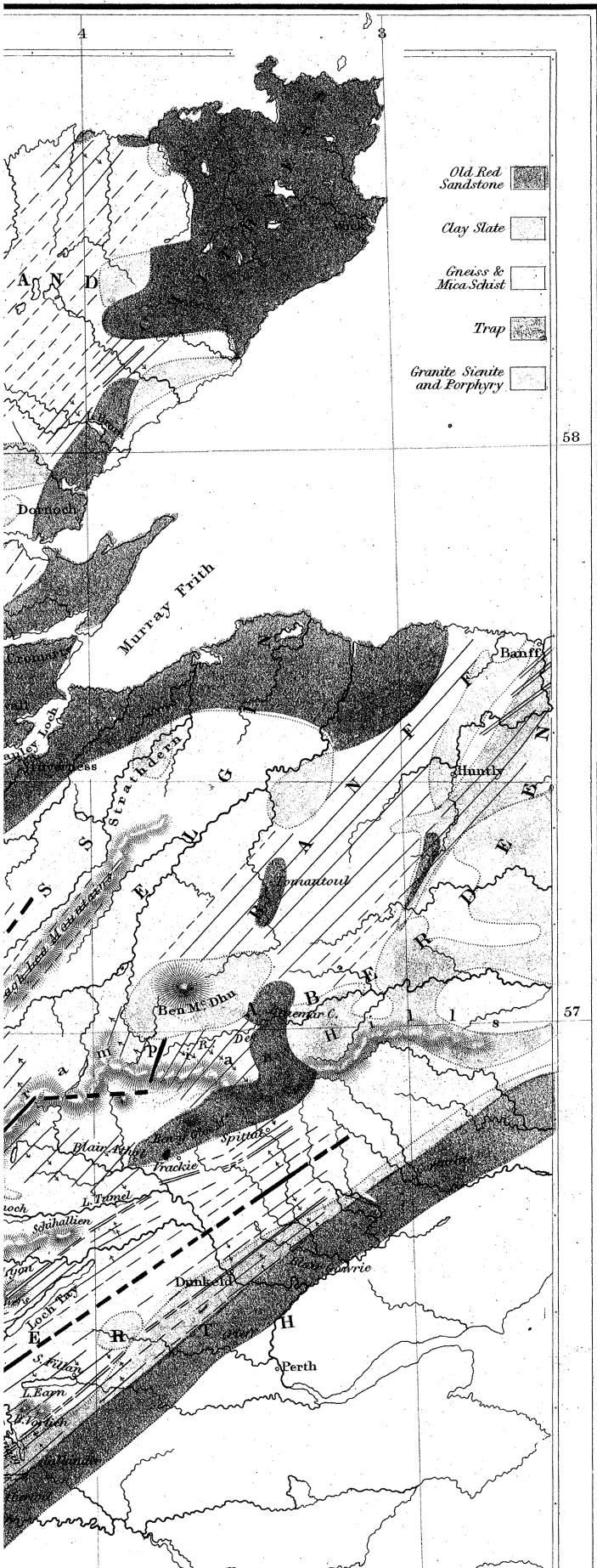
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Inverness
Huntly
Strathdearn
Ben Mc Dhu
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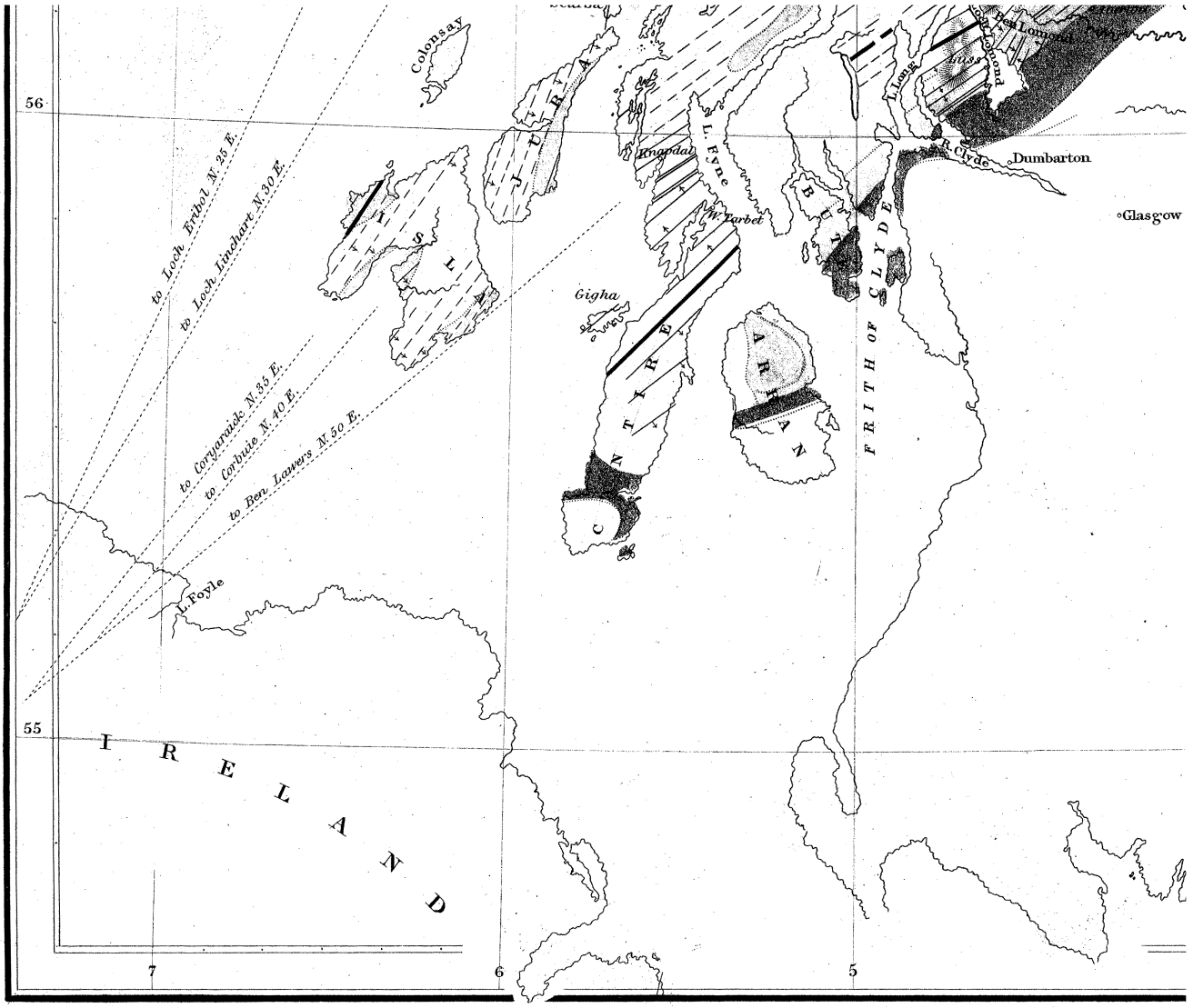
S. Fillan
L. Tromel
Schiehallien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R. Clyde
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Glasgow
Loch Lomond
Inch Lonaig
to Loch Erthol N. 25 E.
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to Corbuie N. 40 E.
to Ben Lauers N. 50 E.
L. Foyle
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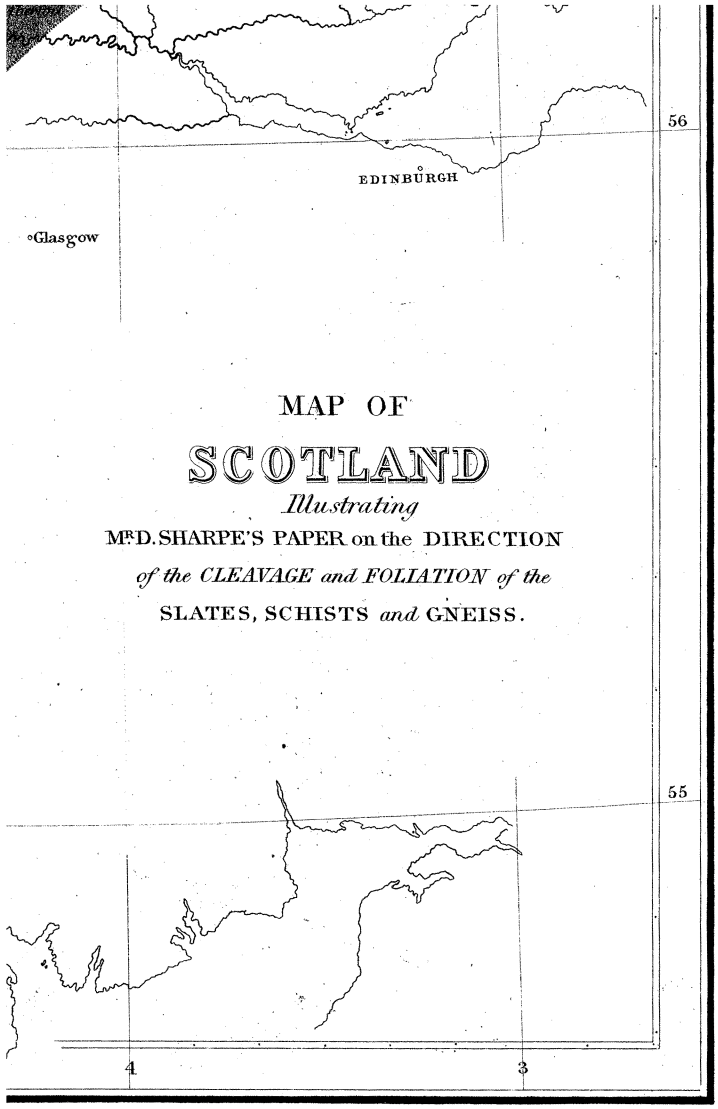
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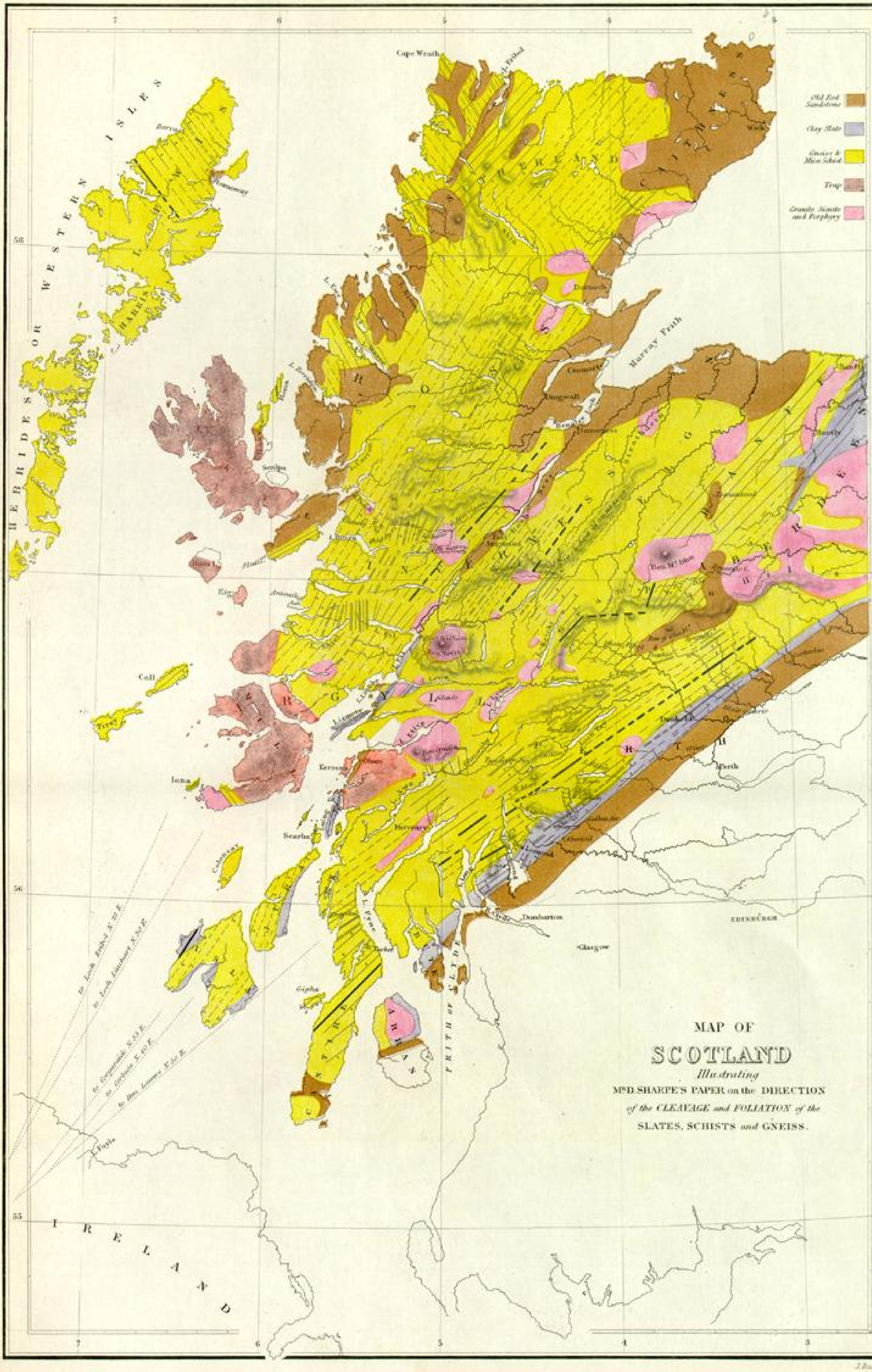
MAP OF
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Dingwall
Inverness
Perth
Dumbarton
Glasgow
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FRITH of CLYDE
Coll
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Kerrera
Oban
Scarba
Colonsay
Gigha
Wick
Banff

J. Basire sc.

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Cape Wrath
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L. Assynt
Loch Shin
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Beauley
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Glen Farrar
L. Carron
Scalpa
Glenelg
Kyle
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L. Duich
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Ness
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L. Cluanie
Glen Garry
Fort Augustus
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Sleat Pt.
Eig
Arasaik
L. Lochie
Spean Water
Fort William
Ben Nevis
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L. Shiel
L. Levin
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Schiehallie
Coll
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Glen Lyon
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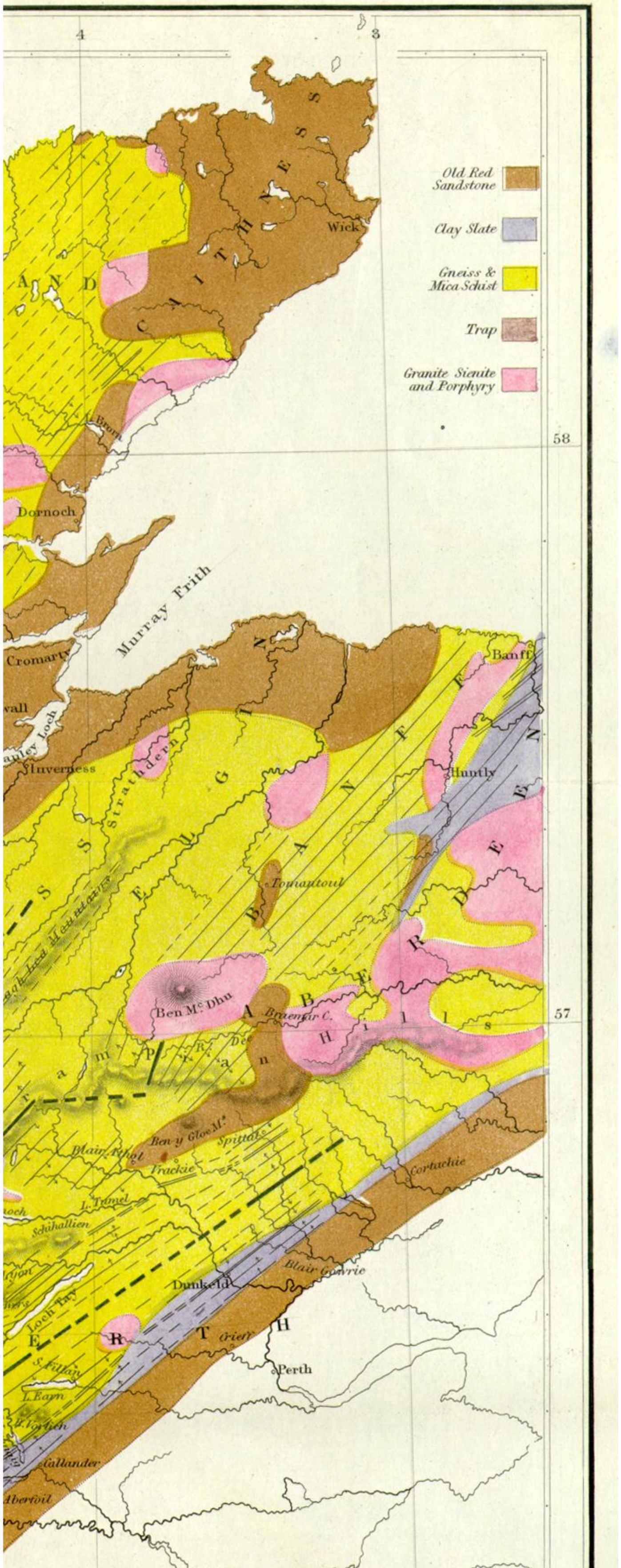
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Spittal
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Ben y Gloe Mt.
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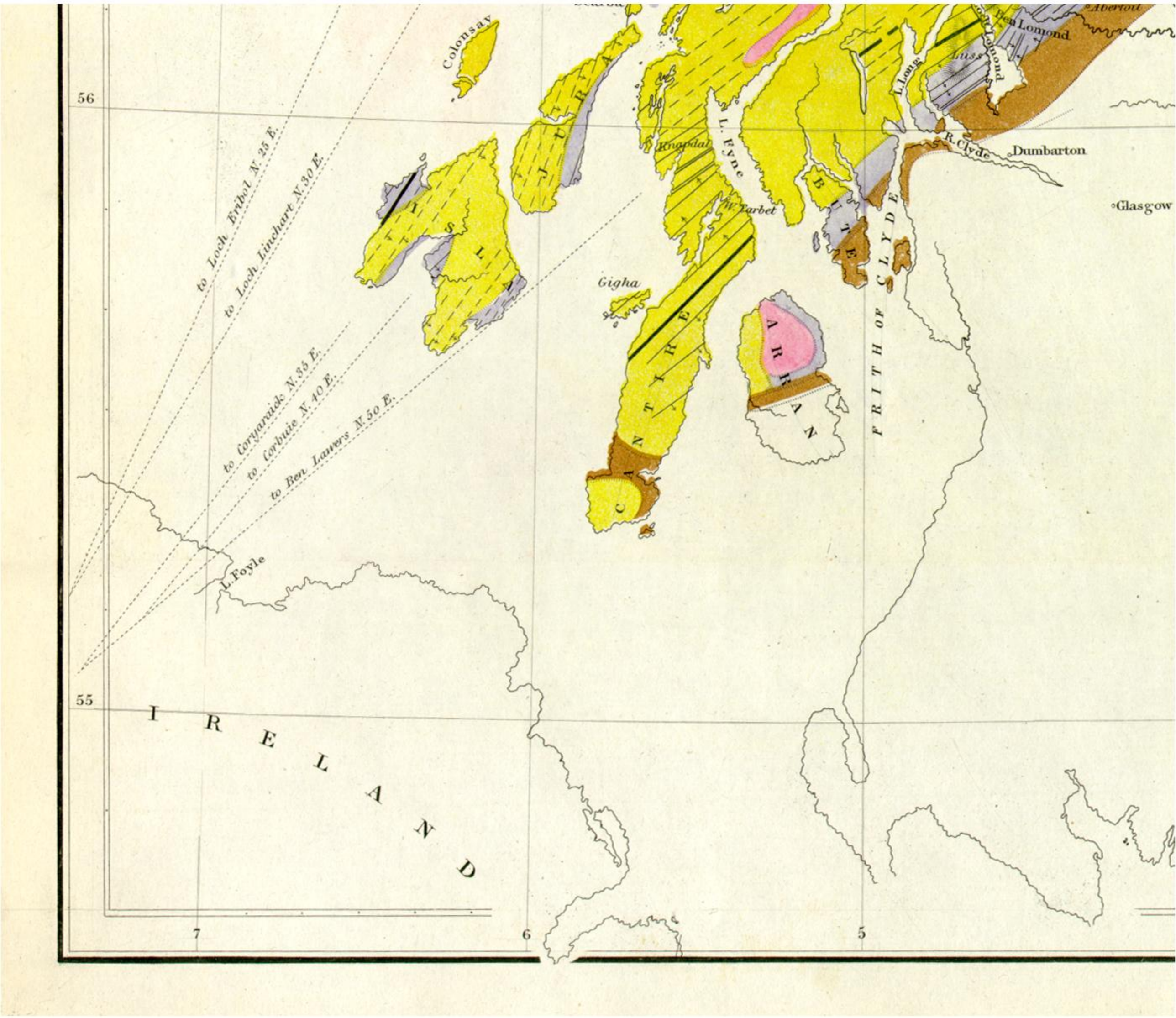
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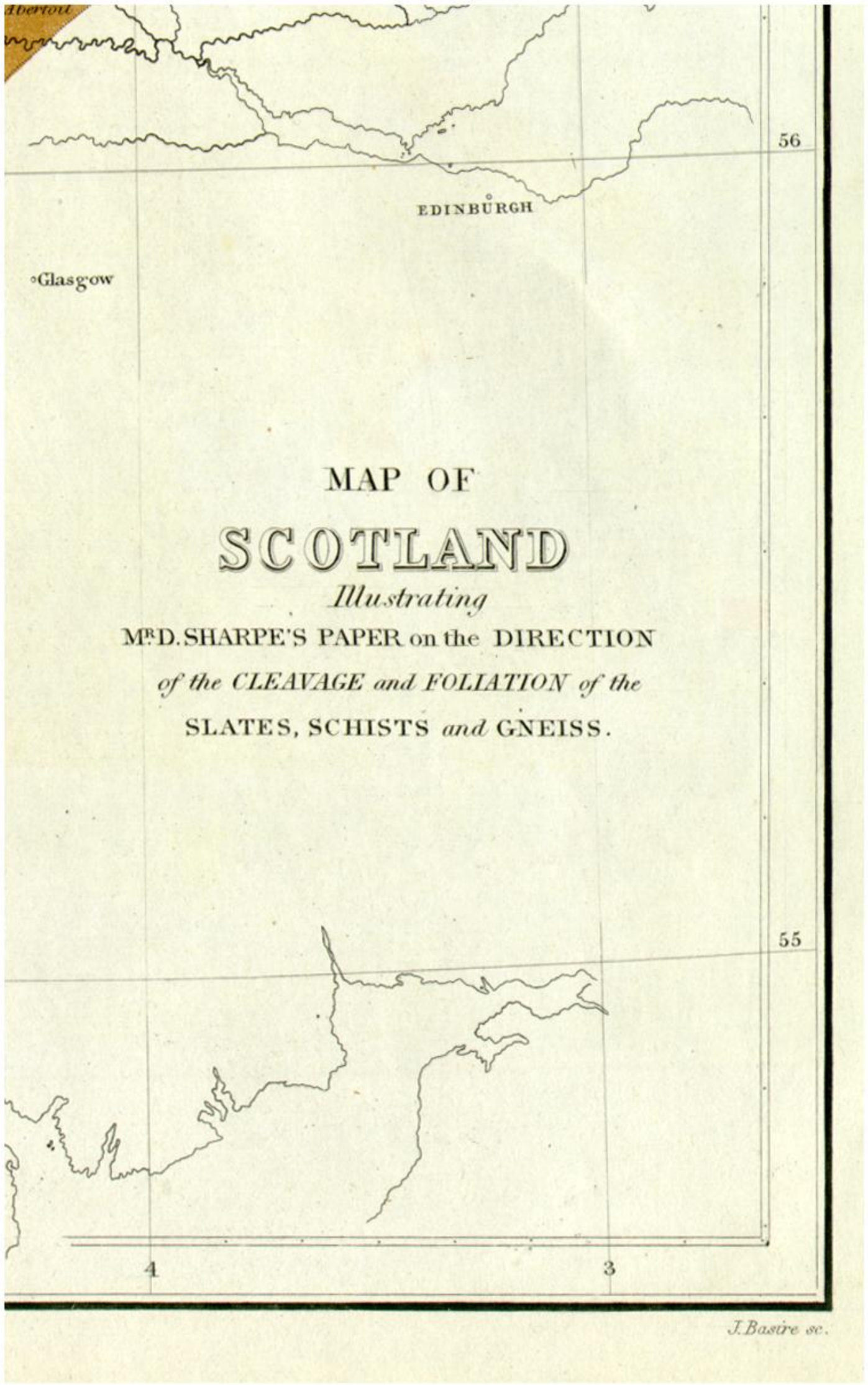
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