Chapter 3 The Manx Slate Series. Historical and introductory

The position of the Manx Slates in the stratigraphy of the Island and their relationship to its physical features have been outlined in a previous chapter, and need little further comment. At some period probably about midway in Palaeozoic times, this great series of slaty, gritty and flaggy strata was ridged up by powerful crustal movements in complex fashion along an axis ranging north-east and south-west, and thus remains as the central framework of the Island.

Before the commencement of the Carboniferous period, erosive influences had cut deeply into this old massif, the rocks of which at that time already possessed the lithological and structural characters that we find in them today. By this early denudation there seems to have been shaped out an isolated hilly tract approximately resembling the present land, which was probably afterwards buried under sediments of Carboniferous and later times, and thus during long ages protected from erosion. By the stripping away of these enfolding strata, probably finally accomplished during Tertiary times, the central portion of the old ridge was once more exposed, and must since have lost considerably in altitude.

The older geologists, Berger, Macculloch and Henslow, in describing the Island, were content to classify the slate-rocks according to their lithological characters as mica-schists, clay-schists, slates, greywackes, etc., without attempting further to distinguish them. Cumming, writing in 1848, seems to have been the first to attempt a closer definition. He remarks: "of the geological age of the schists we have no good criterion, the few undetermined fucoids and corallines in the newer portion being insufficient guides; they are probably, as far as developed, Lower Silurian".<ref>Isle of Man", p. 238.</ref> His later opinion that they were "Cambro-Silurian" has already been quoted (p.19); as also Mr. Taylor's contention in 1864 that they were probably Cambrian (p. 20).

The first definite correlation of the rocks with the Skiddaw Slates of the Lake District appears to have been made by Harkness and Nicholson in a brief paper in 1866,<ref>Quart. Journ. Geol. Soc., vol. sii., p. 488.</ref> though these authors wrote as if the probability of this relationship had been already recognised. They supported the correlation by the mineral characters of the strata; by the presence of *Palaeochorda major, "*a fossil very abundant in the Skiddaw Slates of Cumberland"; and by the correspondence in strike—"the Lower Silurian rocks of this Island being on the exact line of strike of the Skiddaw Slates of the Skiddaw country and of their overlying green rocks". They stated, moreover, that " green slates and porphyries" occurred on the eastern side of the Island which were " equivalents of the ash-beds and porphyries which succeed the Skiddaw Slates of the Lake-country,' though somewhat different "in being more quartzose and in having the ashy rocks better bedded".

This statement as to the presence of Volcanic rocks in the east of the Island comparable to the Borrowdale Volcanic Series was shown, however, by the Rev. J. Clifton Ward in 1880<ref>Geol. Mag. dec. ii.., vol. vii., p. 2.</ref> to be erroneous, since sandy and gritty beds only were contained in the sections indicated.<ref>The existence of "thick sheets of Volcanic Ash" in the series was again stated by Mr. H. Bolton in 1893 (Report British Assoc., Nottingham, 1893, p. 770) but was based on a similar misconception.</ref> The same author, whose intimate knowledge of the Skiddaw rocks of the Lake District gave especial value to his opinion, summed up his investigation of the Manx Series as follows—"The rock occurs in four forms. 1. As a coarse thick-bedded sandstone or grit, slightly conglomeratic in parts. 2. As more or less thickly-bedded flags of a grey colour within but often irony on the outside. 3. As black slate frequently flaggy in character and occasionally cleaved. 4. As soft black shale, not unlike coal-measure shales. All these forms also recur in the Lake District Skiddaw Slate Group It would be unsafe to offer any decided opinion upon the divisions of the Skiddaw Slate in the Island without having made a detailed survey of the whole, and still more so to point to certain parts as the equivalents of Lake District divisions". He also remarks that "on the east side of the Island especially, the beds appear much more sandy than is the general character of the series in the Lake District.'

Mr. J. Horne, in commenting on the supposed Skiddaw age of the series, remarks— "[*If this correlation be correct,*]… they are inferior in position to the Silurian rocks of the south of Scotland. Lithologically, they are totally different from any part of that series".<ref>Trans. Edinburgh Geol. Soc., vol. ii., part iii. (1874), p. 5. </ref>

No further evidence in support of the correlation has been forthcoming, and the reasons adduced in the above extracts are not convincing. Nevertheless it has become the established custom to apply the designation of "Skiddaw Slates" to the Manx rocks, apparently as much from lack of an alternative term as from any other cause. Certainly none of the arguments on which Harkness and Nicholson based the correlation will stand a critical examination. The supposed existence of rocks resembling the Borrowdale Volcanic Series has been disproved. The palaeontological argument, based entirely on the occurrence of *Palaeochorda*, a worm track, already of the weakest, is rendered nugatory by the absence, so far as is known, of any of the Skiddaw graptolites, trilobites, or other fossils. The lithological comparison has somewhat greater strength, but as Clifton Ward has shown, it can onlybe applied in a broad general way and cannot be followed out in detail. In fact the same comparison might be made with any of the monotonous masses of slate and greywacke which occur so commonly in the British Islands among the Older Palaeozoic strata. As for the north-east to south-west strike, this is not a feature peculiar to the Skiddaw Slates, but is common to that wide region surrounding the northern part of the Irish Sea, wherein the Lower Palaeozoic rocks where thrown into folds by the great Mid-Palaeozoic system of earth-movements; and moreover the detailed mapping of the Manx strata has shown that their true line of strike is directed somewhat to the northward of the Skiddaw Slate outcrops in Cumberland, and that it is only in regard to the strike of the cleavage-structures the two areas are linked.

It has also recently been shown<ref>"The Skiddaw Slates", by J. E. Marr, Geol. Mag., dec. iv., vol. i. 1894), p. 122.</ref> that, as long suspected, the rocks known collectively as the "Skiddaw Slates" in the Lake District itself, include deposits ranging in time from the Lower Silurian to an unknown downward limit in the Cambrian, and that the term though useful as an expression of local stratigraphy has no value as a systematic division.

Under these considerations it seems very undesirable that the ill-defined title should be extended beyond its original local application. Hence we propose to cease using the term for the Manx rocks, and to substitute for it the expression "Manx Slate Series" or "Manx Slates". This course has been adopted on the ma 3 which has been issued by the Survey.

After having mapped a considerable area of these rocks in the Isle of Man, the writer spent a few days in the spring of 1895 in examining the Skiddaw Slates of the mainland in the neighbourhood of Keswick for the purpose of comparing the rocks of the two areas. Failing to obtain any definite results, he made in the following year a similar examination of the Black Combo district; and has since visited, for the same purpose, some outcrops in the Cleator district of Cumberland, but still without finding any convincing evidence for the correlation. Along with a certain general similarity in lithological character, one notices many points of difference, which while quite possibly explicable as lateral changes of the original sediments in different parts of the same basin of deposition, or even as partly due to unequal subsequent dynamic or other alteration in these distinct areas, are yet sufficient to destroy confidence in the correlation. Thus, besides the apparent absence from the Manx Slates of the characteristic fossils of the Skiddaw Slates of the Lake District, the greywackes and grits of the Island have usually a different composition and aspect from those of the mainland; and the argillaceous members are much more sericitic, and rarely, if ever, possess the dull muddy character of most of the fossiliferous outcrops of the Skiddaw Slates proper. In both areas the strata have undergone great deformation, but the shearing of the Manx rocks has been exceptionally severe, and the resultant structures are much more strongly marked in them. On the other hand, the Lake District rocks exhibit much greater contact-alteration in the vicinity of igneous intrusions than the Manx rocks, though this of course does not affect the question at issue.

But in spite of this lack of proof, it is nevertheless probable that the actual time-equivalent of some part, at least, of the Manx Slate Series has its place among the lowermost portion of the Skiddaw Slates. This matter will be further discussed on a later page (p. 115).

During the progress of the survey of the Island brief accounts of the steps taken in dividing the Manx Slates were published in the Annual Reports of the Director-General of the Survey for the years 1894–5-6, and in the paper on "Crush Conglomerate" (see p. 55), by W. W. Watts and the writer. The terms adopted for the subdivisions of the Slates on the Geological Map and in the present volume, were first mentioned in the above paper and in the Report for 1895, p. 5.

The contributions of Mr. Bolton to the Palaeontology of the series are discussed under a separate heading (see p. 89).

General description of the Manx Slates

The distinct lithological types comprised in the series may be traced with more or less certainty throughout the Island, but the difficulties in defining their limits and order of superposition have been found almost insuperable. Their meagre palaeontology affords no assistance, so that our only guidance is in the mineral characters of the strata, which unfortunately, besides an original lack of sharpness of definition, have been so greatly complicated by structural changes that it is often impossible to follow them in detail. A much more prolonged investigation than it was found practicable for the present writer to undertake would have been requisite to unravel the effects of unequal and changeable deposition; of folding, crushing and overthrusting; and of subsequent displacements, upon these ancient sediments, so that it cannot be pretended that more has been done than to trace out the broader elements of their stratigraphy.

There is every reason to believe that the different lithological types of which the series is composed have been deposited as a conformable sequence, passing into each other without break. This passage, indeed, in certain areas seems to take place laterally as well as vertically, the rocks of an arenaceous type in one area apparently becoming more argillaceous in another. The whole series thus forms a stratigraphical unit, the base of which is nowhere revealed, while the uppermost portion has been removed by Pre-Carboniferous denudation.

That these sediments were of marine origin there can be no doubt; and from their extent and diversity we may conclude that they were deposited on a subsiding area in a sea of moderate depth at no great distance from land. Since they contain nothing which we can recognise as beach-material, it would appear that the shore-lines of this sea lay always beyond the area rom the character of the grit-fragments in the coarser sediment (see pp. 98–9), some slight evidence may be gleaned as to the composition of the land which was being wasted to supply the material for these rocks; it appears to have comprised older sedimentary strata, both argillaceous and arenaceous, as well as volcanic and massive igneous rocks.

As is usual among the Older Palaeozoic rocks of the British Isles, the Manx Slates are characterised by a paucity in calcareous constituents. A small percentage of lime (see pp. 34–6) is occasionally present in the finer-grained flags or mudstones, either disseminated through the mass or concentrated into slightly calcareous nodules; but usuallythis material is entirely wanting, except for such as is contained in the decomposed basic igneous dykes by which the Slates are traversed.

The slaty and gritty sediments occur both separately andin every stage of admixture. At the one extreme we find dark blue or blackish clay-slate, often altered into phyllite; and at the other, almost pure quartz-grit or quartzite arranged in flaggy bands, with thin argillaceous partings. Between these extremes lies every gradation of sandy slate, mudstone, greywacke and impure grit or flag. The extreme types occur in fairly well-defined belts, but between them are broad tracts in which, either from original variable sedimentation or from the intricacy of the folding and crushing, the different varieties are so closely intermingled as to be practically inseparable. Of course under such conditions the mapping of the boundaries of the divisions must necessarily be more or less approximate and diagrammatic; and the minor features can hardly be deciphered. Indeed, so great has been the displacement and distortion of the rock-masses that, while the main divisions have been traced out, their relative order has not been established with any certainty, and still remains a matter of inference. The chief impediment to more detailed stratigraphical work has been the failure to find bands smaller than these main divisions, with characters distinct enough to be constantly recognisable. On the discovery of such bands any future advance in our knowledge of the district will probably depend, and it should therefore be made the prime object of the next investigator. In different parts of the Island, bands were noticed which at first seemed to promise well for the purpose, but none proved traceable for more than a short distance. These instances will be duly noted in the detailed descriptions of the succeeding chapter; and it may be that among them the requisite more definite clue to the structure of the area will eventually be found.

In mapping the series, the scheme which was adopted as best suited to the circumstances has been to separate out the wider belts of similar lithological composition into divisions to which a nomenclature has been attached, but not to attempt to divide those tracts in which the rocks are ill-defined in character, or in which the different types are closely intermingled. It is indeed highly probable that in some places the " unseparated " rocks may be equivalent to portions of "separated" divisions of other localities; but the former will generally be found to consist either of strata of passage-type which do not fall conveniently into any class, or of rocks m which the original structure has been greatly altered and obscured.

The subdivisions are shown on the map as follows:

Manx Slate Series / Cambrian ?

a■ Barrule Slates.*"Crush Conglomerate".*

a″ Agneash and other Grits.

a′ Lonan Flags and Niarbyl Flags.

The order in which they are written is supposed to be their true downward sequence, for reasons now to be briefly stated, and to be more adequately discussed after the field-evidence has been presented. It must be understood that this supposed succession of the strata is not in accordance with the views hitherto held as to the structure of the Island. By Cumming, Ward and most, if not all, the later observers, the anticlinal axis running north-east and south-west through the interior of the -Island, from which the dominant structural planes of the strata dip away on both sides almost throughout the massif, has been supposed to indicate the true arrangement of the Slate Series; and under this supposition the oldest rocks would lie in the vicinity of the axis, with the newer strata dipping away successively on both sides. Hence the rocks on the outer flanks of the Island would be the newest, instead of, as now suggested, the oldest portion of the Series. My<ref>Throughout this volume the pronoun in the *first person singular* is confined as far as possible to passages discussing hypothetical matters in which the personal factor may have had much influence upon the interpretation. Its use therefore denotes that the statements rest largely upon a basis of personal judgment.</ref>. investigation has shown, however, that the axis is primarily an anticline of the cleavage-structures and not of the bedding, and that the apparent dips are altogether misleading as to the superposition and stratigraphical relations of the strata; and I have concluded from the whole of the field evidence that, instead of forming a stratigraphical anticline, the rocks are probably arranged in a compound syncline or synclinorium, made up of closely packed folds, of varying amplitude, which expand outward from the centre. To such conditions the term "compound fan-structure" has sometimes been applied. In this case the oldest and not the newest beds would occur on the outer flanks of the massif, as illustrated in the diagram, (Figure 32), p. 118.

If this view of the structure be accepted, we must consider the arenaceous flags, which on both sides of the Island occupy the ground adjoining the coast and extend inland toward the central ridge, as older than the grits and slates of the interior which they apparently overlie. Hence in our description of the strata in ascending sequence, we shall commence with these flags.

The flags of the western coast are probably the equivalents of the rocks which resemble them on the eastern margin of the Island; but as their outcrops are separated by nearly the whole breadth of the Island, and as they do not possess characters so definite as to place their identity beyond doubt, it has been considered advisable to describe them separately under distinctive local names. To the flags of the eastern coast, the designation of "Lonan Flags" has been applied, from their wide development in the parish of that name; while for those of the western side, the term "Niarbyl<ref>Pronounce N■-■r-bl</ref> Flags" has been selected, from The Niarbyl, a prominent reef jutting out from the coast at Dalby, in which these flags are typically developed.

The Lonan Flags

On the eastern coast, from Maughold Head [SC 49888 91365] in the north to the margin of the Carboniferous basin in the south, the cliff-sections reveal a predominance of flaggy mudstones and fine-grained grits, usually of bluish-grey or greenish tint, with darker more argillaceous intercalations. In their local modifications, these rocks vary between the extremes of almost pure quartz-grit on the one hand and almost pure clay-slate on the other; but they are characterised throughout by their colour-handing and flaggy stratification, by which the bedding planes are rendered distinguishable even where the superinduced fissile structures are predominant. The old designations, 'greywacke' and 'slaty greywacke', are perhaps still the best descriptive terms to apply to these rocks. The thinly bedded slaty portion of the series might in some places be separable from the more thickly bedded sandy rocks, but they are so intimately related that the task would be full of difficulty. Certain beds of coarsish grit which appear to form part of the series in the vicinity of St. Ann's (Santon) Head, and again between Douglas [SC 38873 74693] and Clay Head [SC 44304 80496] seem however to mark definite horizons, and these have been indicated on the one-inch map.

The prevalent dips of the Lonan Flags are high, ranging usually from 45° to vertical, the direction being generally from the central axis towards S.E. or S.S.E., except in a narrow belt running from Clay Head to Douglas Head, where they are in the opposite direction. Evidences of severe deformation are almost everywhere visible in the deeper sections, and even where not immediately perceptible, closer examination will usually reveal the sharp crests and troughs of folds partially masked by strain-slip planes. In the exceptional cases where the angle of bedding is apparently low, the presence of an overturned recumbent fold may always be suspected; and may indeed sometimes be demonstrated, as in (Figure 2)

The angle of dip frequently brings the bedding into approximate coincidence with the strain-slip cleavage planes, the strata then often assuming a deceptive appearance of undisturbed regularity; so that in the deeper cliff-sections, as in the vicinity of Bulgham Bay [SC 45741 85703], a sequence of beds many hundreds of feet thick seems to be presented. But the detailed investigation of these sections generally reveals indications of repetition, either by folding or by thrust-faults, and it is doubtful whether the natural sequence has been anywhere preserved in more than a comparatively small portion of the mass. No safe estimate of the thickness of the Flags can be based on these sections.

The superinduced structures which the strata ordinarily present are those which usually accompany acute folding. They suggest an intimate fluxion or sliding of the particles throughout the mass of the rock, more or less parallel to and determined by the planes of bedding. These movements have given rise to 'flaser'-structure and strain-slip-cleavage which is often beautifully revealed when thin sections of the rock are examined microscopically, and to various peculiar modifications of the bedding on a larger scale, hereafter to be described (pp. 73–83.)

Hence it is probable that the Lollar' Flags throughout their range constitute a series of closely-packed isoclinal folds. The further inference that they form the lowermost division of the Slates has previously been stated. They seem, for the most part, to have been folded upon themselves, into an irregular platform. The overlying strata were somewhat differently affected by the movement, so that the infolding of the upper series with the lower has been comparatively slight, and confined to rather narrow vertical limits near the junction of the masses. There is scarcelyany safe basis on which to build an estimate, but the original thickness of these flags was probably great. At Laxey [SC 43941 83600] the shafts of the mines, situated in a valley which has been excavated in these flags to a depth of 700 feet or more, descend a further 1,800 feet into them without reaching their base or revealing any marked change, their dip throughout being steadily in one direction at angles of from 40° to 70°. Horizontally their outcrop frequently extends for over two miles, measured at right angles to their strike, with the dips persistently high. These facts seem to postulate a great original thickness for the division, and its wide lithological variability is also favourable to this supposition.

From the acute character of the folding as revealed in the cliff-sections, it is inconceivable that any individual fold in these rocks can have a depth from crest to trough at all commensurable with the proved depth of the whole division. It is therefore tolerably certain that the plications, even within the mass of the flags, have takenplace to some extent independently at several different horizons, and that the thickness of rock crumpled up in any individual fold is not large. This arrangement of folds in superimposed belts must, of course, tend to pile up the strata to an almost indefinitely exaggerated extent vertically as compared with their original thickness. The same structure appears to pervade, in variable degree, all parts of the Manx Slates. It could only occur in a region of intense compression, and thus affords support to my view that these rocks occupy part of a synclinorium. As to the maximum amplitude which the individual folds may attain we have scarcely sufficient evidence, but to judge from the length of unbroken dip-slope in some of the cliff-sections, the hmbs of the folds may occasionally extend for some hundreds of feet, though' usually they are shorter. Regarding this point, it is noteworthy that among the Lonan Flags the folds are generally straighter-limbed and more regularly isoclinal than in other parts of the Island, probably from the more frequent coincidence of the planes of bedding with those of strain-slip movement.

Besides the effect of the folding, there are indications that at a later date these rocks have been displaced in blocks, by faults of various kinds, both normal and reversed; but it is exceedingly difficult, from the general obscurity of the ground, to trace the course of these faults or to recognise the extent of the displacement; and under these circumstances it has not been thought desirable to obscure the map by attempting to show them. They will be separately discussed on a later page (see p. 86).

From the coast-sections in which they are typically developed we may trace the Lonan Flags inland, in the northern portion of the massif, up to the belt of Agneash Grits, into which they appear to merge gradually with every indication of a conformable passage. In the area south of the central valley of the Island, where the Agneash Grits seem to be wanting, the inland margin of the division becomes doubtful, the flaggy character being gradually lost amid the banded slates with occasional gritty intercalations which occupy the interior to the northward and north-westward of the Carboniferous basin. It is not improbable that these banded slates may represent a tract of the more argillaceous type of Lonan Flags in which the distinguishing characters have been modified by some different effect of earth-movement in the vicinity of the structural axis, since the presence in other areas of masses of 'crush-conglomerate', produced by the smashing up of similar flaggy strata by these forces, is sufficient to prove how profoundly the aspect of such rocks may be altered. But as no method has been devised for proving the identity of the Flags where their recognizable characteristics are absent, it has been considered advisable to restrict the division to the area of its typical development, leaving an indefinite boundary where it merges into the banded slates.' The latter rocks constitute the chief portion of the 'unseparated' tracts of the map.

The greenish arenaceous strata of Clay Head and Douglas Head, which, with the numerous greenstone dykes traversing them, were mistaken by Harkness and Nicholson for Volcanic Ashes, form part of the Lonan Flags. Rocks of similar character are exposed on other parts of the eastern coast, as for instance between Port Mooar [SC 48846 90734] and Port Cornah [SC 47286 87802], and between Laxey [SC 44308 83559] and Garwick [SC 43444 81448].

The "worm-tracts" and other obscure markings of like character, which are almost the only organic relics of the Manx Slates, are more plentiful in the Lonan Flags than in any other part of the series. They are best seen at the junction of sandy and slaty layers. Mr. Bolton has shown that they include at least two distinct types (see p. 91).

These Flags are further characterised by the occasional presence of irregular lines of slightly calcareous concretions. The nodules vary in size, the medium being about six inches in diameter. They are of lenticular shape, usually flattened and somewhat drawn out by shearing. They are commonest in the thicker bands of mudstone or fine grit, though not altogether absent from the more laminated argillaceous beds. The amount of lime which they contain is always small, and appears generally to be in the form of dolomite. Occasionally no trace of lime can be detected in them, and those in the more gritty rocks sometimes exhibit in their interior a curious concentration of sand-grains coarser than the sandy matrix of the nodule. In the more argillaceous strata the nodules are frequently pyritous, and not unlike the ordinary clay-ironstone concretions of newer rocks, which they further resemble in sometimes possessing imperfect cone-in-cone structure in their outer crust. Careful search has been made in these nodules for organic remains, for which they seemed to offer promise; but none has been found, though they have been examined in thin sections under the microscope as well as in the field. The microscopic sections revealed, however, some interesting data in respect to the metamorphism of the rocks (p. 96).

These concretions often weather rustily, and at a more rapid rate than their matrix, hence giving rise to shallow depressions on the exposed surfaces of the flags, at more or less regular intervals. The futile discussion which arose from the mistaken supposition that these pittings might represent reptilian foot-prints has been mentioned on a previous page (p. 20).

Further details with regard to the local development of the Lonan Flags will be found in Chapter 4. (pp. 126–155); the curious structures developed in them by earth-movement are more fully discussed on pp. 73–86; and some data regarding their petrographical characters are recorded on pp. 96–99.

The Niarbyl Flags

As already stated, the correlation of this division with the Lonan Flags, though hypothetical, rests on rather strong grounds. Whether the structure of the Manx Slates as a whole be a compound syncline as now suggested, or a simple anticline as previously supposed, a more or less symmetrical arrangement of the strata on the opposite sides of the central axis is implied; though as the axis, for the most part, lies nearer the western than the eastern coast of the Island there is less room for the development of the sequence in the former district than in the latter. Hence, the occurrence of this well-marked flaggy group on the western flank of the massif, agreeing fairly well in most respects with the Lonan

Flags and with differences not greater than is usual in the lateral prolongation of rocks of this character, seems to afford a good basis for their correlation This view is seriously weakened, however, by the apparent absence of the next group of the sequence, the Agneash Grits, which could not be definitely identified in this part of the Island; and there is likewise a difficulty in the relation of the Niarbyl Flags to the adjacent banded slates, which may however be due to overthrust faulting.

The Niarbyl Flags are brought in suddenly at Niarbyl Point [SC 20782 77473], either by an overthrust or by a normal fault; and extend thence in a coastal strip for five miles northward to Peel, where they are cut out by the Post-Carboniferous fault which brings in the Peel Sandstone. The average breadth of this strip is only about ¾ mile, but it has evidently been reduced by the encroachment of the sea, and may be merely the fringe of a broader tract now submerged.

These flags are, on the whole, finer in texture, more thickly bedded, and, paler in colour than the Lonan Flags, and contain fewer of the dark argillaceous partings. Fine slaty mud-stones predominate, usually of a pale bluish-grey colour, weathering brown and developing a smooth hummocky surface under wave-action. Some of the bands contain sufficient disseminated calcareous material to give a brisk effervescence with acid, and one of these on analysis was found to contain 4.4 per cent. of lime.<ref>I am indebted to Mr. Allan Dick, Junr., for this analysis.</ref>

They present greater regularity of lithological type than the Lonan group; but this may be only because of their restricted extent, and it would perhaps be possible to find an equal area of the Lonan Flags which would exhibit corresponding uniformity. The only traces of organisms yet found in them are worm-casts like those of the other division. The strata in the Lonan Group which most nearly resemble the Niarbyl Flags are the rocks which occupy the cliffs between Port Mooar [SC 48846 90734] and Port Cornah [SC 47286 87802].

The prevalent dips in the Niarbyl Flags are high, usually between 45° and 75° in a direction slightly to the westward of north; but the rocks are everywhere buckled and folded, the cliff-sections revealing fine examples of these contortions. (Figure 3.)

The folding appears usually to be shallower and more complex than on the eastern coast, and the stresses which the rocks have undergone have been more intense. The strain-slip cleavage is more strongly developed than in the Lonan Flags, and more frequently traverses and blurs the bedding. The rock-structures due to the rucking up of the planes of stratification in one part of the fold, and their dragging out and planing off by stretching and shearing in another part, are beautifully developed in many places. Some curious examples of these structures are figured and described in the sequel (see pp. 73–86).

The inland boundary of the division is evidently the north-north-eastward prolongation of the overthrust, or fault of low bade, which as already mentioned is seen on the coast at The Niarbyl. Its direction is oblique to the apparent strike of the Flags, but is nearly parallel to the general orientation of the rock-masses of the Slate Series. It brings the flags up sharply against thinly-banded argillaceous rocks of ill-defined character, which are left as 'unseparated' on the map. The junction presents no signs of passage, and there is an absence of that looping together and alternation of the two rock-types along their margin which commonly mark the folded contact of the different divisions. In the coast-section, the slates are seen to be greatly crushed and confused in the vicinity of the junction, and they appear to pass beneath the flags; and the same phenomena are probably continued inland along the line of contact, though the exposures in the interior are inadequate. Supposing the flags to be older than the slates, the apparent superposition of the former upon the latter must have been brought about by overthrust-faulting, and the junction above described would 'represent the thrust-plane. This supposition agrees with the general conditions in the Manx Slate Series, where it is common to find the harder and more massive strata breaking through the softer beds with which they come in contact, so that the thicker bands of grit and quartzite have often an intrusive dyke-like aspect, most extensive displacements of this kind being indicated by the crush-conglomerates' in the centre of the Island. Hence there is much likelihood that the Niarbyl Flags of the west coast represent a block of the lower strata which has been upfolded and driven forward over the beds which once covered them; and the apparent absence of strata which are requisite to complete the sequence in this quarter may be thereby explained.

In the vicinity of Peel [SC 24193 84593], where the boundary is affected by the Post-Carboniferous faulting, the ground in the interior is heavily covered by glacial deposits, so that the exact limits of the flags cannot be defined. They form the ridge known as Peel Hill, but seem to give place to more slaty beds in the lower ground to the eastward, south of the River Neb. Where the Slates reappear in the coast-sections to the northward of the tract of Peel Sandstone, we find among them, in the neighbourhood of Ballanayre Strand [SC 27528 86808], an outlying patch of thickly bedded flags resembling the Niarbyl Flags (too small to show on the one-inch map), bounded by faults and thrust planes, and on two sides in juxtaposition with masses of crush-conglomerate' made up of sheared fragments of similar flags set in a slaty matrix. (See pp. 67–69.)

Still farther northward there is a strip of flaggy grit, shown on the one-inch map, extending for three miles south-westward from Kirk Michael [SC 31277 91364], which may possibly represent the northerly prolongation of the Niarbyl Flags. The stratigraphy of this district is, however, so complicated and uncertain that no confidence can be felt in the identification; and the strip has therefore been indicated on the map simply as a belt of grit, without correlation.

The Niarbyl Flags are traversed at intervals by igneous dykes of diverse age and composition (see pp. 146–9); but these intrusions are not nearly so abundant as on the opposite side of the Island.

Considerable interest attaches to a small patch of andesitic breccia which occurs close to the margin of the Niarbyl Flags at Ballnalargy [SC 22285 79606], about half a mile south of Glen Moay, as it affords the only recognisable example of true volcanic material associated with the Manx Slates which has boon found during the course of the Survey. It is poorly exposed, and its relation to the surrounding rocks is obscure (see p. 163); but from the deformation which the material has undergone, its eruption if not actually contemporaneous with the deposition of the flags must have taken place prior to the great earth-movements which have affected them, and therefore at a period long prior to the Carboniferous period.

Fuller details in regard to the local development of the Niarbyl Flags will be found in the next chapter.

The Agneash Grits

Scarcely any portion of the Manx Slates is wholly free from sandy intercalations. Even where their argillaceous character is most conspicuous, as in the Barrule Slates, it is occasionally broken by streaks of gritty material, while in the flaggy divisions the arenaceous element is always present and sometimes predominant. Hence it is evident that the basin of accumulation was receiving supplies of sandy material in a greater or less degree during every stage in the sedimentation of the series, and it is most probable that the deposition of sand in one part went on contemporaneously with the deposition of mud or clay in an adjacent tract. Under such circumstances the boundaries of the different sediments are not likely ever to have been sharply defined, and moreover their original limits have since been thrown into utter confusion by the folding and crushing together of the strata. The attempted demarcation of the chief masses of grit has therefore proved an extremely difficult task, especially where the flaggy grits of the divisions above described lay adjacent to the gritty flags now to be considered, or where thin-bedded grits gave place gradually to slates, through the thickening of the argillaceous partings with a correlative thinning of the sandy layers. The boundary lines of the grits, as shown on the map, are therefore necessarily to some extent arbitrary and diagrammatic.

With this warning as to the uncertain value of the boundaries adopted, we will commence with the study of the largest and most readily distinguishable of these grit masses, viz., that to which we have applied the term 'Agneash Grits'.

These grits are developed between Maughold Head [SC 49805 91417] and the central valley, along the north-western edge of the Lonan Flags, and might indeed be considered as a gritty phase of that division. The name adopted for them is taken from the Agneash Crags (Creg Agneash) overlooking the Laxey valley, in which they are typically exhibited. They consist of greyish splintery grits or imperfect quartzites, occurring in flaggy layers of a few inches to a foot or two in thickness, usually separated by thin argillaceous partings. The sandy component is mostly of fine texture, though occasionally there are bands in which the larger grains attain a diameter of 3 to 5 millimetres. A conspicuous characteristic of these rocks is the manner in which narrow strings of vein-quartz, ranging up to about half an inch in thickness, traverse the grit-bands in every direction, filling an irregular system of crevices by which the grit-bands have been cut up into cubes of variable size and shape. Quartz-segregations are abundant in every division of the Manx

Series, usually occurring in irregular reefs or gashes of more or less lenticular outline, or in long dyke-like veins; but this kind of criss-cross streaking of the rock with innumerable little strings of quartz is confined to the purer grits. The superior hardness of these beds has caused them to shatter during acute folding in places where the more plastic flags and slates amid which they lie have been squeezed and deformed with scarcely any actual rupture; and quartz has then gradually infiltrated the crevices, and re-cemented the bands.

This shattering and veining appears to be a common feature in regions where quartzites or highly indurated grits have been subjected to severe pressure and movement.<ref>See "Some Dynamic Phenomena shown by the Baraboo Quartzite Ranges of Central Wisconsin", by C. R. Van Hise.—Journ. of Geol. of Chicago, vol. i. (1893), pp. 347–355.</ref> It is the first stage in the production of 'crush-conglomerate'.

The stresses which these grits have undergone are beautifully illustrated by the crumpled and buckled condition of the bedding wherever sections are revealed. Their complicated flexures are apparently the result of folding and refolding, and the simpler isoclinal type of plication found in the flags and banded slates is rarely displayed.

The strain-slip cleavages are far less evident in the grits than in the softer rocks adjacent to them, and are often only indicated by a slight tendency to fracture in a definite direction. Nevertheless the microscopic examination of the rock in thin slices usually demonstrates that dynamic action has affected every particle of it (see pp. 97–9).

The most northerly exposure of the Agneash Grits lies in the upper portion of the cliffs at Maughold Head [SC 49805 91417] between Traie Curn [SC 49763 91578] and Traie ny Foillan [SC 49779 91302], where highly-plicated quartz-veined gritty flags with rather thick intercalations of more argillaceous material are revealed. The inland extension of these grits is hidden by the drift which fills the Port Mooar valley [SC 48698 91042]; and they are probably displaced by faults which range through this depression. About a mile to the westward, the rocky ground near Magher-e-breck [SC 465 905] exhibits an outcrop of much-disturbed grit, including, among flaggy beds, a massive band of coarser grain which was not recognised in the cliff-section. The same beds may be traced thence, at intervals, into the Cornah valley, where they are well displayed in the crags to the south-westward of the hamlet of Corrany [SC 45348 89691]. From this place they extend westward along the steep valley-slopes nearly to the old Glencherry Lead Mine, and expand into a broad belt, broken by slaty arid flaggy intercalations or infolds, on the moorland ridge to the southward. In climbing southward out of the valley near the old mine we cross repeated outcrops of a massive coarse-grained grit-band like that seen near Magher-e-breck. These are almost certainly the repetition of a single bed by folding, though the steep and sometimes nearly vertical west-north-westerly dip gives the impression of a thick sequence of coarse-grained grits. The band seems to ascend the hill-slope in a succession of sharp shallow folds.

The grits range nearly to the summit of Slieau Ouyr [SC 43501 87952], 1,483 feet above sea-level, and form the flanks of Slieau Lhean [SC 42836 87793], 1,506 feet, an adjoining summit of the same ridge, but do not reach quite to its crest. Thence they are continued southwards into the bold Agneash Crags [SC 41936 86659] overlooking the Laxey valley. They probably extend into the bottom of this valley, but here as elsewhere when smoothed down in stream-beds by fluviatile erosion, they are not easy to distinguish from the Lonan Flags by which they are bounded. On the southern side of the valley they are readily recognisable in the rocky slopes of Cronk y Vaare [SC 40973 86466], mud, on the moorlands beyond, their outcrop expands to a width of nearly two miles, reaching from near Baljean [SC 42625 84908] on the east to the westward of the summits of Mullagh Ouyr [SC 39814 86151] and Carn Gerjoil [SC 39281 84076] (1,457 feet). In this space, however, the grits are interspersed with numerous belts of more argillaceous composition, probably representing infolds of the overlying strata, the field-evidence suggesting that an irregular zone made up of the folded grits approximates in this neighbourhood to the plane of the present surface of the moorland, and that this zone is almost cut through by the deeper valleys, and slightly overtopped by the higher hills. The same structure is suggested by the behaviour of the grits in other districts of the Island; but these zones of buckled grit appear themselves to have been thrown into folds, and further complicated by shear-planes and faults, so that they rarely extend far in the same plane.

Southward from Carn Gerjoil [SC 39281 84076] the quartz-veined grits continue to predominate on the gradually descending plateau lying to the eastward of the Baldwin valley, but with a contracting outcrop as the lower levels are reached, so that where they cross the valley at the junction of the Baldwin and Glass [SC 36055 80013] their width seems to be less than half a mile. They are well exposed on the southern ascent from this valley, but on reaching the crest they disappear beneath the drifts which cloak the gentler slopes descending to the Dhoo, and are no more seen in an identifiable form. If prolonged without change of strike into the central valley of the Island and to the southward beyond it, they would traverse comparatively low ground which is mostly cultivated and almost continuously drift-covered, wherein, therefore, rock exposures are infrequent and of small extent. So far as the evidence goes however, the rocks within this area are chiefly banded slates alternating with slaty flags, somewhat resembling the Lonan Flags, but not to be correlated with certainty with any division, and therefore left 'unseparated' on the map. Gritty intercalations do occur here and there among these rocks (see p. 169), but seem always to be of very limited extent, and show no features by which they might be identified with the Agneash Grits.

These obscure conditions continue to the southward of the central valley for six or eight miles, after which, masses of quartz-veined grit and quartzite, comparable in appearance and stratigraphical position to the Agneash Grits, are again encountered, and may be followed thence, with some interruptions, to the south-western extremity of the Island. The correlation of these southern grits with the Agneash Grits, though highly probable, cannot be established with any certainty, in view of the possibility, already discussed, of the development of arenaceous rocks at different horizons in the series. The use of the same symbol and the same colour for separate grit-masses on the published map must not, therefore, be taken to imply that they have all been proved to occur at the same horizon. The indication of separate tracts in this manner has reference primarily to their lithological character, and not necessarily to their stratigraphical position.

The nearest equivalent of the Agneash Grits in position and general character in the south of the Island seems to be the strip which occurs at the northern margin of the Carboniferous basin, north of Ballasalla [SC 28159 70173], in a ravine of Awin Ruy [SC 28361 71299], the tributary of the Silverburn which flows southward from St. Marks. Attention has been called to this outcrop by Prof. Boyd Dawkins<ref>Trans. Manchester Geol. Soc., vol. xx., p. 54. Prof. Dawkins states the thickness of the quartzites in this section to be 632 feet, but this is evidently only an estimate based on the angle of dip and breadth of outcrop, and on the supposition that there was no structural complication in this locality.</ref> in discussing the origin of the quartzite pebbles in the Carboniferous Conglomerate. The beds of flaggy grit or quartzite: which are stained red for some distance from their junction with the Carboniferous rocks, have a general dip southward, but are evidently much disturbed. They may with difficulty be traced northeastward from the principal exposure for about a mile, and then seem to wedge out among softer flags and striped slates.

Belts of similar grit crop out on the opposite side of the Carboniferous basin, to the westward of the boundary fault. One of these forms the Cronnag [SC 22542 68326], a low-water reef off the shore at Kentraugh, and reappears on the other side of Bay ny Carrickey [SC 21503 68229], at Gansey Point and Port St. Mary [SC 21058 67620] harbour; and again in Perwick Bay [SC 20437 67217]. These are probably enfolded spurs from a larger mass which occupies the high ground to the westward of Port St. Mary, extending into Mull Hill [SC 19007 67615]. Ins this locality, again, the lithological and structural characters of the strata — pale greyish grits or imperfect quartzites in flaggy bands of varying thickness, streaked in every direction by thin veins of quartz, and ridged up into irregular folds—bear every resemblance to those of the Agneash Grits. The prevalent dip is towards south-south-east, at angles usually between 30° and 50°.

Rocks of more argillaceous type bound these Mull Hill grits on the south, but only occupy a breadth of ■ of a mile, after which quartz-veined flaggy grits again appear, a few hundred yards before the coast is reached, and extend into the cliff-sections of Kioney Ghoggan [SC 19951 66426]. This is evidently a repetition of the former mass, either by folding or faulting. In the cliffs the dip is low, rarely reaching 20°, and in one portion of the section in Bay Stacka [SC 19002 66335] the grits appear to rest conformably on strongly striped slates possessing a similarly low dip. The apparent stratigraphical simplicity of this section, commented on by Cumming and others, is, however, probably delusive, since the beds turn up sharply on edge a short distance inland, and the presence of an extensive recumbent fold, partly removed by denudation, like that on a smaller scale revealed in the cliff at Maughold Head [SC 49853 91369] ((Figure 2), p. 32), may be suspected, in which case the present superposition of the beds reverses the true order (see p. 174).

The moderate seaward dip of the strata in this section has facilitated the slipping forward of the grits over the slates in the vicinity of the cliff, thus opening the joints of the former into into deep gaping fissures, known as The Chasms [SC 19264 66395], which attract many visitors to this part of the coast.

These grits, along with those of Mull Hill, end off rather abruptly westward, perhaps truncated by a fault which strikes across from Bay Fine [SC 18240 67969] in the direction of Bay Stacka. The sections do not, however, serve to demonstrate the extent of the fault, and the disappearance of the grits might as readily be ascribed to the plunging or pitching of the folds (see p. 47).

North of Mull Hill there is an interval of about a mile mostly drift-covered, in which thin-bedded argillaceous rocks appear to prevail, after, which, at the northern side of Port Erin [SC 18835 69615], strips of quartz-veined grit are again in evidence, and recur several times between this place and Fleshwick [SC 20134 71446]. The magnificent cliff-sections of Bradda Head [SC 18352 69942] reveal most clearly the extraordinary complications of these gritty zones among the more or less slaty beds which surround them Differential movement around the borders of these hard bands on the westward side of Fleshwick has broken up a portion of the grit, and dispersed the fragments through a matrix of sheared slate, thus forming patches of crush-conglomerate' (see p. 171).

On the higher moorland ridge north of Fleshwick, extending from Carnanes [SC 20845 71557] to Lhiattee ny Beinnee [SC 21184 72804], there are excellent rock-exposures, revealing several broad belts of highly sheared grits or quartzites of the Agneash type, with intervening tracts of thinly bedded slates. This locality is very favourable for the study of the stratigraphical relations of these grits and slates as their outcrops may be traced across the plateau into the craggy precipitous slopes, 800 feet or more in height, that form its seaward termination. It is then seen that these belts of rather steeply dipping strata, 200 or 300 yards in width on the plateau, contract when traced in the cliffs into narrow plicated bands which may not have been more than say 50 or 60 feet in original thickness. The breadth of the outcrop on the flat ground depends entirely upon the relation of the plane of the surface to the plane of the crumpled sheet of rock, and gives no indication whatever of its thickness. In the cliffs these plicated sheets are seen to describe great curves, sweeping down to sea-level and then rising again to the surface of the plateau, as shown in the annexed ground-plan, (Figure 4), slightly reduced from the six-inch map. Their continuity is, however, broken in places by faults or thrust planes.

From the summit of the ridge the grits appear to strike inland north-eastward, in long tongues which cross a wide drift-covered depression and then traverse the parallel ridge of Slieau Earystane [SC 23646 73529], where some of the strips seem to die out; but one or two are continued into the southern slopes of South Barrule [SC 26124 75171], the last traces of them being lost in a region of severe crushing and partial brecciation (see p. 169).

It is reasonable to suppose that the whole of these southern grits are portions of one and the same plicated and faulted sheet, corresponding in structural arrangement to, and perhaps once actually conterminous with, the Agneash Grits of the northern area. The difficulty found in each case in tracing the grits towards the centre of the Island may be due to some structural peculiarity affecting the rocks in the vicinity of the central valley which has not yet been unravelled, since there are complications in the arrangement of the Barrule Slates equally with the grits towards this quarter, that division also here showing a narrowing of outcrop both from the northward and southward. The complication may be in some way connected with the intrusion of the Foxdale Granite (see p. 168); or may be the result of transverse folds crossing the axes of the earlier folds. On the other hand the difficulties in question may arise simply from lateral changes in the character of the sediments.

There is a curious point in relation to the general direction of dip in the grits and thicker flags as compared with that in the more argillaceous rocks of the series which deserves careful attention. It is that the prevalent dips of the harder and more thickly bedded strata are almost invariably many degrees farther from the north and south line than are those of the more slaty rocks, even where the different types are in close proximity. In the slates the dominant dips are, respectively, about N.N.W. and S.S.E., from the opposite sides of the central axis, agreeing closely with the dominant cleavage-dips, and rarely diverging sufficiently to attain a N.W. or S.E. direction. In the grits, on the other hand, especially in the interior of the Island, north-westerly and even west-north-westerly dips are common. We also find that the orientation of the rock-masses, whether of slate or grit, as brought out by the mapping, is rarely at right angles to their general dip, but is almost always more nearly north and south than would have been inferred: that is to say, the true strike cannot be deduced from the dips alone. This peculiarity, again, is more strongly exhibited in the grits than in the slates, hence causing an appearance of unconformability between the different divisions when represented on the map, which the field-evidence shows to be misleading. This point will be further discussed when the 'Crush-conglomerates' are described.

Other eastern Grits

On the eastern side of the Island, besides the grits already described there are some strips of similar composition lying within the boundary adopted for the Lonan Flags and apparently forming part and parcel of that division, though, as they possessed distinguishable characters, they have been separated out on the map and indicated by the gnt -colour and symbol. That these may represent deep isolated enfolds of the Agneash Grits is not impossible, but it is more probable that they occupy a different and lower horizon, and may indeed be the oldest rocks exhibited in the Manx Slate Series. In general lithological character they for the most part resemble the Agneash Grits, but are sometimes rather darker in colour and coarser in texture.

One narrow belt of this kind is exposed among the Lonan Flags on the north side of Clay Head [SC 44184 80948] and may be prolonged inland, parallel to the coast, until it is again intercepted by the northern shore of Douglas Bay; and at the Nunnery [SC 36668 74677] on the south-western outskirts of Douglas, and again still farther to the south, similar grit-bands are found on approximately the same line of strike.

A much larger and more interesting tract of gritty rocks occurs in the cliffs and vicinity of the coast around St. Ann's (Santon) Head [SC 33310 71047]. Some of these grits are coarser than any other in the Manx Slate Series, being occasionally almost conglomeratic in texture. They are interbedded in thick massive bands among flaggy strata of the Lonan type. In some places, from their unyielding character, these bands when folded have burst across the bedding planes of the softer strata with which they are associated, so that the junction presents a misleading aspect of unconformity or intrusion, but in other sections it is seen that they are folded conformably with the flags. The larger particles of these grits attain to about ¼ inch (5 to 8 mm.) in diameter, and consist chiefly of bits of fine-grained arenaceous rocks, vein-quartz, felspar, etc., with a few fragments of andesitic rock. These particles are frequently drawn out into lenticles by the pressure which the rock has undergone, while little wisps of slate, sometimes an inch or two in length but only a few lines thick, scattered through the mass, seem to represent the shredding up of thin shaly partings by the same agency. These features are admirably displayed in microscopical sections of the rock, as described on a later page (98).

These coarse grits are well exposed in the rugged cliffs on the southern side of St. Ann's Head, and extend inland for 300 or 400 yards. When traced round the headland northward, they are seen to nose out' at the foot of the cliff in a succession of sloping anticlines, in shape like the rounded bows of upturned canoes, an appearance due to the eastward 'pitching' of the ridges of the folds, in this place at an angle of about 20°, but varying in different parts of the outcrop. Whenever tilting or pitching' of the folds of this kind occurs, the structure must have an important effect upon the stratigraphy and may often be held accountable for the disappearance of beds along the line of their apparent strike. In the present example the strike of the grits at the top of the cliff would lead one to infer that they would reappear on the opposite side of the little bay, but they are carried down below sea-level in the interval by the easterly pitch of the folds.

Similar massive bands of coarse grit and quartzite, probably representing the same horizon, make their appearance in the cliffs here and there, in short disjointed segments as if cut up by faults, both to the southward of St. Ann's Head as far as the edge of the Carboniferous basin at Cass-ny-hawin [SC 30291 70347], and to the northward, at Coolebegad [SC 35415 72950] beyond Port Soderick.

Grits west of the main axis

The difficulty in correlating the strata on the western side of the Island with those on the eastern has been already discussed. In regard to the grits, it remains altogether doubtful whether there be any equivalent of the Agneash Grits to the westward of the central axis, for though in this region there are some narrow belts of gritty character, these are always of limited extent as compared with the eastern tracts, and cannot be proved to occupy the same horizon.

In the north of the Island, strips of flaggy grit, with one rather massive band of quartzite which has been shown on the one-inch map, occur among the 'unseparated' rocks of the eastern coast to the northward of Maughold Head [SC 49881 91348]. Another wedge is seen near the margin of the 'crush conglomerate' at Claghbane [SC 44827 93496], in the steep brow overlooking Ramsey. These and another strip at the headwaters of Glen Auldyn [SC 43453 93016] are almost certainly distinct from the Agneash Grits. But on the moorland to the westward of Glen Auldyn there is a larger patch of grey flaggy quartz-veined grit or quartzite, set in a rim of 'crush-conglomerate', which is decidedly of the Agneash type: while in Sulby Glen [SC 38083 91484], two miles farther westward, a still larger mass of similar grits is revealed in the high crags which border the valley on both sides.

On the western slope of the Sulby valley the last-mentioned grits ascend to the summit of Mt. Karrim [SC 37740 91933] (1,084 feet), flanked on the east by the main mass of 'crush-conglomerate', and on the west by 'unseparated' slates and flags. The violent contortions into which the strata have been thrown in this district are admirably displayed in the craggy walls of the valley (see p. 61, (Figure 7)).

Another strip of grit, probably a repetition of that last described, occurs two miles farther up the same glen, between Craigmooar and Druidale [SC 36432 88346]; this also is fringed in places on the east by crush-conglomerate.'

Near the head of Glen Dhoo [SC 35073 90518], the next valley to the westward of Sulby Glen, an ill-defined belt of gritty rock, shown on the map, is revealed, which is of different character from the above, more closely resembling the arenaceous part of the Lonan Flags than the Agneash Grits; but it has been much altered from its original aspect by shearing (see (Figure 26), p. 81). There are other smaller patches of similar composition among the 'unseparated' rocks of this part of the Island, which could not be shown on the map. Still farther west, on the outer slope of the mountains, a gritty zone may be traced, with many interruptions and intercalations, from the western flank of Slieau Curn [SC 33943 90677] south of Ballaugh, to Kirk Michael, and thence along the edge of the hills to Ballakaigen [SC 29500 85801]. Its constituent strata are, however, often of the muddy greywacke type and not pure grits; and, as mentioned on a former page, these may represent the Niarbyl Flags of the country further south.

About a mile to the southward of Ballakaigen another wedge of grit sets in, nearly on the same line of strike as the previous belt but of different lithological character, and is prolonged from from Knocksharry to Poortown [SC 26837 83165] along the crest of the ridge that borders the Peel Sandstones. It includes some massive quartz-veined bands, and also, near its northerly termination at Creggan Mooar [SC 21925 77082], a highly sheared coarse grit somewhat resembling the St. Ann's Head rock, with particles three or four mm. in diameter, among which are bits of andesite. In hand-specimens this bed has somewhat the aspect of an ash, but it appears to be a true grit. (See petrographical description p. 99.)

Flaggy grits are visible in many places in the interior of the Island between the two belts of Barrule Slate, especially at the lower levels, but are not often well-exposed, or sufficiently traceable to be shown on the one-inch map. They are often associated with arenaceous mudstones, scarcely to be distinguished from the grits but without the criss-cross quartz-veining and possessing in other respects the characters of the flaggy divisions. The gritty belt shown on the map at Dreembeary [SC 31815 83547], a mile to the eastward of Glen Helen, is of this nature; and likewise the strip occurring south of the central valley, in Glen Rushen, and striking thence to the western coast south of Niarbyl Bay. It is doubtful whether these rocks should be classed with the Grits or with the Flags.

The narrow belt seen on both sides of the central valley about a mile to the eastward and south-eastward of St. John's, in quarries where it has been worked for road-metal, is of different character. Its chief constituent is a hard splintery dark blue rock, somewhat pyritous, composed of an admixture of coarsish sand and fine argillaceous material, occurring in layers one to two feet thick, with slaty partings. (See p. 164.)

The relations of these grits to the other divisions will be further discussed on a subsequent page.

The Barrule Slates

This division where developed in force is lithologically the most distinct and stratigraphically the most persistent member of the Manx Slates, and has therefore an especial value for the student of the series. It consists of dark blue, somewhat altered clay-slate, and is traceable, with scarcely an interruption, through the main hill-chain of the Island from coast to coast. From its homogeneous composition, and from the shearing which it has undergone, its original bedding planes are rarely distinguishable excepting where the rock is polished by wave or stream action, and even then are sparingly revealed. Its weathering and fracture are determined by the secondary planes of strain-slip which have been imparted in it by earth-movement. These planes are frequently glossy from the sericite which has been developed upon them, and the rock then deserves the term "phyllite", which has been applied to it by Prof. Dawkins.<ref>Trans. Manchester Geol. Soc., vol. xx., p. 53.</ref>

This shear-structure is so predominant in the rock that its apparently homogeneous character may be partly due to its argillaceous strata having been kneaded and squeezed together so that the original lamination has been lost. Under such conditions it is even possible that a mass resembling the Barrule Slates might be produced from some of the striped slates of the 'unseparated' areas. But while it is clear that patches of these banded strata have been drawn out and mingled inseparably with the margins of the Barrule Slates, the general tenor of the field-evidence is fairly convincing for the original identity of the division as a separate member of series, of which the limits can be delineated on the map, though somewhat diagrammatically.

Where bounded by 'crush-conglomerate' the margin of the Barrule Slates is fairly well-defined, but elsewhere it usually fades off, by imperceptible degrees or by alternations, into the paler colour-banded 'unseparated' beds. There are two distinct and more or less parallel belts of rock of the Barrule Slate type, of which the more easterly, in the principal hill-range, is the more continuous and better defined. These, along with other smaller subsidiary strips, are probably portions of a once-continuous mass.

With the exception of obscure worm-like markings, which may or may not be organic, no fossils have hitherto been found in the Barrule Slates, unless we consider the outlier of slate on Cronk Sumark [SC 39210 94160] near Sulby to belong to this division, where Mr. Bolton obtained the remains described on p. 93. Some dark iron-stained bands in the series have been searched without success for graptolites (see p. 94).

The microscopical structure of these Slates, and the changes effected in them in many places by metamorphic agencies will be discussed under a subsequent heading (see pp. 99 & 110).

The homogeneous aspect and fissile structure of the rock has encouraged many futile attempts in the past to develop quarries of roofing slate in it. Enterprises of this kind were especially numerous about 35 years ago, when large sums were expended in making openings into the Barrule Slates in every part of the Island. But these enterprises all proved failures and were sooner or later abandoned with heavy loss, the saleable slate obtained being very limited in quantity and poor in quality (p. 559). Indeed if the uncertain character of the cleavage and its close dependence upon the planes of shear-movement had been understood, no other result than failure could have been anticipated, especially in a rock so frequently traversed by quartz veins and zones of crushing.

Main Belt of Barrule Slates

From the coast near Ramsey at the north-eastern corner of the massif, we may trace this belt into the steep mountain-ridge which commences in North Barrule [SC 44250 90972] and continues to Snaefell [SC 39761 88116], a distance of four miles. The physical characters of this ridge correspond with the structural features of the slates, the steep craggy south-eastern side being due to the outcrop of the schistose planes, perhaps in part coinciding with the original bedding, while the grassy north-western slope marks the direction of dip of these planes.

The slate is traversed at frequent intervals by segregation-veins of quartz, of all sizes up to 5 or 6 feet in breadth. These are usually more or less lenticular, and have generally been crushed and drawn out with the country-rock. They often include small quantities of yellow mica, chlorite and other minerals; and the crushed slate around their margins sometimes contains garnets and other alteration products, apparently developed by the differential movement (see p. 111).

While the Slates form the whole of the high ground of this hill-chain, they do not reach down into the valleys on either side, and where a partial transverse section of the ridge is presented we find that the outcrop of the slate is contracted as it descends to lower levels. The same relation between breadth of outcrop and altitude of ground holds good through the whole extent of this belt of slate, and tells strongly in favour of the view that in spite of the apparently persistent north-westerly dip, the slates occupy a synclinal trough.

A good illustration of this structure is found in the southwestward prolongation of the belt between Snaefell and Beinn y Phott [SC 38085 86059] the next summit of the range, where its outcrop descends to below 900 feet in crossing the deep intervening glen, and is there contracted to a breadth of 200 or 300 yards, expanding again to over half a mile on Beinn y Phott and its continuation Garraghan [SC 36811 84923], once more to shrink to less than its breadth in the former glen in crossing the valley of the Glass near Injebreck [SC 35559 84798] at an altitude of about 500 feet. When it ascends from the last-mentioned valley into The Creg [SC 34603 83296] (Creg y Whuallian,<ref>The ridge so named on the six-inch Ordnance map should probably be written 'Grey Awhallan', after a farmstead of that name at its foot. It must not be confused with the 'Creg y Whualliam' south cif the central valley at Greeba, nor with 'Slieau Whuallian' south of St. John's.</ref> 1,344 feet), a spur of Colden Mountain [SC 34353 84358], its expansion at the higher level is not so well marked, which may be partly explained by the almost precipitous steepness of its outcrop in this ground but is also in keeping with that general contraction which the belt undergoes in approaching the central part of the Island, a structure already mentioned as being there equally visible in the Grits. On the eastern slopes of Slieau Ruy [SC 32846 82394], and in Greeba Crags [SC 31939 81766] overlooking the central valley, the belt dwindles to an irregular contorted strip, scarcely recognisable among the partly brecciated colour-banded slates and thin grits which appear to constitute the greater part of these exposures; but the whole of the rocks have been crushed in this quarter into an almost inseparable mass.

Half a mile to the westward of this outcrop, on the opposite or western slope of Greeba Mountain, another strip of dark slate of the Barrule type is found, which wedges out rapidly northward, but expands southwards. This is interrupted by the central valley, but seems to reappear on the southern side, where it has a width of over half a mile, and is prolonged thence southwestward, across Kerrowgarroo, for two miles farther. It then descends into the Foxdale Valley much contracted in width, and wedges out on the western side of the depression. The position of this strip in regard to the former belt may be interpreted to indicate a subsidiary trough of the synclinorium.

The prolongation of the main belt across the central valley is not so readily followed, there being great confusion and irregularity of structure on the southern hill-slope opposite to Creg ny Greeba [SC 31475 80670]. There does, indeed, exist a patch of altered dark-blue slate of the Barrule type on the crest of that slope, but it appears to be discontinuous, wedging out in both directions; and moreover, instead of its dominant structural planes presenting the usual dip towards N.W. or N.N.W., they possess for the most part the unusual direction of, approximately, N.E. This divergence of dip and strike is accompanied by a marked augmentation of the schistosity and mineral alteration of the rock, a matter to be subsequently discussed (see p. 111).

Hence in trying to trace the main belt southward from the central valley, it is not until we have followed its previous direction of strike for two miles, and have begun to ascend the eastern slope of South Barrule [SC 25788 75938] beyond Foxdale village, that we can confidently again identify the Barrule Slates. Their reappearance in recognizable form is coincident with the sharp increase of altitude, the mountain rising 700 or 800 feet above the country to the eastward, to a total height of 1,585 feet. In this hill the Barrule Slates regain all their characteristic features, and their expanded outcrop, nearly a mile in width, occupies the summit and most of the western slope. Thence they may be followed along the same ridge through Cronk Fedjag [SC 23969 75026] to Cronk ny Arrey Lhaa, [SC 22426 74714] 1,449 feet, maintaining their width of outcrop at the high levels but contracting to at least one half as they plunge down to sea-level in the terminal precipices of the ridge on the western coast. These precipices afford the grandest transverse section of the division to be found in the Island, but unfortunately, from their inaccessibility, only a very small portion of the section can be studied.

Barrule Slates north-westward of the main belt

We now return to the northern part of the massif, to examine the areas to the north-westward of the belt above described in which dark slates of the Barrule type prevail.

Nearest to the northern part of the main ridge, we find an isolated patch of irregular outline, out of which the middle portion of Glen Auldyn [SC 42451 92197] is carved. This tract of dark blue slate is rimmed on the west, north and north-east by 'crush-conglomerate', and on the south-east by 'unseparated' flaggy strata. A little farther westward a larger tract of similar composition, also bounded in the same quarters as the last by 'crush-conglomerate', occupies the high moorland of Slieau Monagh [SC 39604 90997] (or Meanagh; 1,257 feet), and extends in long tongues, north-north-eastward and south-south-westward, from the head of Glentrammon [SC 41479 93153] to Sulby Glen.

Among the rocks left as 'unseparated' in the broad area to the westward of Sulby Glen, there are some narrow strips which may belong to the Barrule Slates, but scarcely sufficiently characterized for definite recognition. When, however, we cross the bold outer ridge of the Island which forms the western rim of the Sulby basin, we reach a more extended development of the slates. Commencing in a tapering belt on the western side of Slieau Freoaghane [SC 34064 88392], and expanding rapidly southward to a width of three-quarters of a mile or more on Sartfell [SC 33356 87183] the next summit of the ridge, the band apparently continues of about the same width across the lower drift-encumbered ground to Glen Helen [SC 30423 84540], and thence, occupying both sides of the Neb valley [SC 29141 83945], to the central depression in the vicinity of St. John's [SC 27867 81866], a distance in all of six miles. Though interrupted by the central valley, the same belt of dark blue slate seems to be prolonged on the opposite side, as noted by Clifton Ward,<ref>Geol. Mag., dec. ii., vol vii., p. 2.</ref> rising again abruptly in the steep gable-end of Slieau Whuallian [SC 26529 80525] (alt. 1,094 feet), and rapidly attaining the same breadth of outcrop as before.

It may then be followed south-westward along the ridge and across the transverse gash of Glen Rushen [SC 24185 76934], into the moorlands of Dalby Mountain [SC 24065 77959], where it is about a mile wide, and thence to the western coast. It narrows suddenly in descending from the high land, and before reaching the shore at Fheustal [SC 21748 76555], on the south side of Niarbyl Bay, splits into a series of obscurely defined strips a few hundred feet in breadth, again illustrating the general tendency of the division to wedge out downwards. Throughout this belt the dominant structural dips are, like those of the former bands, towards N.N.W.

It is to be noted that., while in the northern part of its course there is a space of over four miles between this belt and that of the Snaefell chain, the two gradually converse southward until only three-quarters of a mile apart in the vicinity of the western coast. It will be observed, too, that the isolated strips in the centre and with of the Island are set *en échelon* to each other and to the principal belts, and again, that the incoming and rapid expansion of the north-western belt is concurrent with the contraction of the main belt in the central district of the Island. Like the downward narrowing of the outcrops, these phenomena seem to imply that the slates occupy a succession of irregular troughs.

In any case, the arrangement of these belts of slate is proof that the structural axis which divides the dominant south-south-easterly from the dominant north-north-westerly dips cannot mark a simple stratigraphical anticline as hitherto supposed, since they all lie on one — the north-western — side of this axis, with their planes of fissility throughout dipping in the general N.N.W. direction. If the axis had been a true anticline, the Barrule Slates must, of course, have been repeated on its south-eastward flank, in the district where only grits and flags are to be found.

It is, however, possible that the arrangement of the Barrule Slates in the different belts may be due in part to normal faults, or to planes of overthrust, since we know, from their faulted junctions with the Carboniferous rocks and from other evidence in connection with the mineral lodes, that many unrecognised normal faults must traverse the series, and that indications of overthrusting on a more or less extensive scale are prevalent throughout. But while it must be acknowledged that both these factors are likely to have produced greater effects than is here assigned to them, the constant association of the margin of the slates with the striped or banded beds which apparently mark a passage into the flaggy or gritty deposits, seems to show that the junctions are for the most part simple; and it has been considered desirable, therefore, to avoid further complicating the subject by introducing faults where definite proof was lacking.

Strata of the 'Unseparated' Tracts

Brief mention will suffice for these tracts, since the general characters of the rocks of which they are composed have been incidentally stated more than once in the foregoing pages, and fuller local information will be given hereafter in the chapter of topographical details.

The predominant strata are intermediate in character between the slates and the flags, being usually composed of alternating laminae of impure argillaceous and fine-grained arenaceous material, often in vividly contrasting blue-black and pale grey tints, while thin bands of grit or quartzite, both isolated and in groups, recur at frequent intervals.

These rocks pass gradually on the one hand into the grits and flaggy greywackes, and on the other into the smooth argillaceous slates; and in their original position they have no doubt marked the vertical upward passage from the sandy to the slaty divisions. In these strata, so long as any vestige of their original bedding remains, every-plication and fracture which has affected them is brought out with the greatest distinctness, and they consequently afford admirable material for the study of the movements by which the rocks have been affected (see p. 73).

Here and there in these tracts occur thin lenticular belts of more peculiar type, which have been referred to on a previous page. Among these, the handsome banded pale-and dark-green slate exposed on the foreshore in Niarbyl Bay [SC 21438 77089] and at Port Lewaigue [SC 46830 93047], and the strongly striped light-grey laminated strata of the upper basins of the Sulby and the Neb, best deserve mention as likely to prove traceable, though the present investigation failed to follow them for more than a short distance (see pp. 123, 149).

The "Crush-Conglomerates".

<ref>The presence of this structure in the Isle of Man was first recorded by W. W. Watts and the author in a paper on "The Crush-Conglomerates of the Isle of Man". Quart. Journ. Geol. Soc., vol. li. (1895), pp. 563–597. Passages in the following pages taken verbatim, or *nearly so,* from that paper are marked by single inverted commas.</ref>

Though as essentially the result of earth-movement as the strain-slip cleavage and other secondary rock-structures subsequently to be discussed, the 'crush-conglomerate' requires distinctive consideration by reason of its having been developed in such a manner and on such a scale in some parts of the Island as to form a separable zone among the rocks (see Map, (Figure 29)). In the areas referred to, its boundaries have been independently traced out, and are shown on the one-inch map.

Previous to the present Survey, the true character of the structure had not been recognised, and it was supposed to represent either a true slate-conglomerate or a volcanic breccia. References to it are, however, curiously rare in the previous literature. Henslow in 1820 gave a faithful description of one of the sections in the following terms: "Near Balla Neah [Ballanayre [SC 27606 86783] of the Ordnance Map, on the west coast north of Peel], I observed the cliffs to consist of angular fragments of clay-slate embedded in a clay-slate paste, and what is curious, these fragments are scarcely to be distinguished from the base excepting on the surface of the rock which has been exposed to the action of the waves, where they become sufficiently apparent by the fragments assuming different tinges of colour, giving the specimen a mottled appearance<ref>Trans. Geol. Soc., ser. i., vol. v., p. 490.</ref>. Among the later literature we find one or two obscure references to 'volcanic breccias' in the series, with which these rocks seem to have been included; and in 1893 Mr. H. Bolton<ref>Report Brit. Assoc. for 1893, p. 771.</ref> described a portion of them in the following passages: "In the neighbourhood of Ballure Glen [SC 45638 93326] and Ballastowel Hill [SC 45159 93146] [near Ramsey], the slates are badly bedded, and full of irregular pebble-lik.e inclusions, which give to the rock a brecciated appearance. These have yielded the cast of a trilobite much resembling *Asaphus* or *Aeglina*, and also certain other structures which may possibly prove organic. North and north-west from Ballastowel, the Skiddaw Slates consist of irregularly bedded iron-stained slates with interbedded volcanic ash, the latter often of considerable thickness.<ref>The "interbedded volcanic ash" of this description is part of the crush-conglometate. Compare also Mr. Bolton's paper "On a trilobite from the Skiddaw Slate of the Isle of Man". Geol. Mag., dec. iii., vol. x., p. 29. (Jan. 1893.)</ref>

It is now recognized that conglomeratic rocks of this character, due to the breaking up of the strata under shearing pressure, are of common occurrence in all parts of the world where strata of variable lithological characters have undergone severe movement, and the term "autoclastic" has recently been applied to them.<ref>See "Structural Geology of Steep Rock Lake, Ontario", by H. L. Smyth (Am. Jour. Sci., 3rd ser., vol. xlii., p. 331). In this paper the author defines " autoclastic schists " as " schists formed in place from massive rocks by crushing and squeezing without intervening processes of disintegration or erosion, removal and deposition".</ref> The following is the definition of the structure given by Prof. C. R. Van Hise in his "Principles of North American Pre-Cambrian Geology".<ref>Sixteenth Annual Bcport of U.S. Survey, pt. 1, p. 679. (Washington, 1896.)</ref>

"When rocks are folded by strong orogenic forces, and they are not so heavily loaded as to render them plastic, they are frequently broken into fragments, and "autoclastic" rocks areproduced. The autoclastic rocks which readily show their origin may be called *dynamic breccias,* and those which resemble ordinary conglomerates may be called pseudo-conglomerates. Brittle rocks are the most likely to become autoclastic; hence it is that cherts, quartzites, cherty limestones, graywackes, and rather siliceous slates are some of the kinds which most frequently present the phenomena described. The movements of the broken fragments over one another in many cases so thoroughly round them that they have the appearance of being waterworn, and the matrix between the larger fragments may consist almost wholly of well-rounded fragments of a similar character. For instance, in a semi-indurated quartzite the larger complex fragments may be well rounded by their mutual friction while the matrix may consist of the simple original waterworn grains which are rent apart. In another ease the original rock may have consisted of beds of mud interlaminated with thin beds of grit.

"By consolidation and cementation these beds may have been transformed to alternating shale and graywacke. The shale is plastic under light load; under the same load the graywacke is brittle. When such a set of beds is deformed the shale yields largely by flow and the graywacke by fracture. The beds of graywacke are broken into fragments of varying sizes, which are ground over one another, and thus are rounded. At the same time the shale flows and fills the space between the fragments.Also slaty cleavage may be developed. As a result, a pseudo-slate-conglomerate is produced, having a slate matrix and pebbles of graywacke, which, so far as its own characters are concerned, could not be discriminated by any one from a true conglomerate. Fortunately, in most eases it is possible to find transition phases between such a rock and one in which the process has not gone so far, and thus one is enabled to determine that the rock is autoclastic".

This description of the structure as it occurs among the Pre-Cambrian rocks of the Lake Superior region in North America, which had not been published at the time of our investigation of the Manx examples, applies in every particular to the 'autoclastic' or 'dynamic' conglomerates of the Isle of Man.

Where typically developed, in the north and north-west of the Island, the breccias form thick masses of imperfect conglomerate, made up of irregular scattered fragments set in a slaty matrix. The fragments vary in composition, but most frequently are of fine-grained grit or sandstone and of sandy slate, with less abundant pieces of coarsish grit, of banded flaggy slate, and of purely argillaceous smooth blue slate or shale. These fragments are usually phacoidal or lenticular in outline (hence appearing rounder in transverse section than they really are), but the shape varies with the size, and also differs in different places. In some localities many of the smaller inclusions are well-rounded, while in others they take the form of subangular or spindle-shaped strips (see (Figure 6), (Figure 9), (Figure 12), (Figure 23)). The fragments are of all sizes, from blocks several feet in diameter to particles of microscopic dimensions. They are, as a rule, indiscriminately mingled, large and small, in a highly sheared slaty matrix; but the average size of the inclusions varies greatly in different localities, and there is sometimes a total absence of the larger fragments.'

These characters are well illustrated in the weathered exposures on Cronk Sumark [SC 39182 94146], near Sulby Bridge Station, from which the figure on p. 57 is taken.

'A glossy sericitic face, due to shearing, coats the harder inclusions, and planes of similar character are abundant throughout the matrix, and sometimes cut the fragments. These schistose planes determine the weathering and the fracture of the rock, and when, as frequently happens, they lie very close together and the inclusions are all of small size, the fragmental character of the mass is not evident in ordinary exposures, and needs a fresh cross-fracture to reveal it. There is usually an abundant development of iron pyrites in the rock, sometimes finely disseminated, and sometimes, as in the quarry-section on the eastern side of Cronk Sumark, in cubical crystals from one-eighth to one-quarter inch in diameter, which have been affected by a later movement than that which formed the conglomerate. Such is the composition of the rock over large areas.'

Distribution of the Crush-conglomerates

As stated in the earlier part of this chapter, indications of shear-fluxion and partial brecciation are exhibited by the Slate Series in every part of the Island; but these become greatly intensified on the north-western side of the structural axis, particularly where, in this quarter, the more thinly-banded rocks — lie in the proximity of masses of grit. We also find that the disturbance of the bedding increases in severity as we follow the strike of the rocks from south-west to north-east.

In the southern part of the Island, the occurrence of actual crush-conglomerate is confined to a few isolated strips bordering detached portions of grit, as in the instance already described on the western side of Fleshwick (see p, 43), and in similar examples on the foreshore near Gob yn Ushtey [SC 21516 75684] north of Cronk ny Arrey Lhaa, and on the eastern slope of South Barrule.

Northward of the central valley the structure is first developed slightly near the southern termination of Creg ny Greeba [SC 31472 80663]. Then, two miles farther north, it is next found in strong force in the depression on the northern side of Lhargee Ruy [SC 33175 83225], and here first begins to from a definite belt. The exposure just mentioned occurs in the bed of a feeder of the River Neb near its source on the western side of Colden Mountain [SC 33649 84237], and exhibits slaty breccia, crowded with subangular and lenticular fragments of fine grit and pale slate up to 6 inches in length, in a zone of about 100 yards in breadth.

The persistent drift-covering of the surrounding moorlands hides the prolongation of the belt, but some traces of it are visible on Slieau Maggie [SC 34691 86048] (the hill nameless on the one-inch map, next west of Injebreck Hill) and its line of strike points exactly for the most southerly exposure of the great belt of Sulby Glen, which occurs three miles north-north-eastward, in the bed of a rivulet draining into the Druidale branch of the Sulby River, west of the ruined farmstead of Close, where the conglomerate is 150 yards in breadth. The outcrops of the structure expand rapidly in width in Sulby Glen, and are practically continuous from the above mentioned exposure to the mouth of the valley, a distance of five miles. As the most typical sections occur in the northern portion of the belt, we will pass at once to the mouth of Sulby Glen, and thence trace the belt back southward, and also eastward.

The structure is well exposed on the eastern side of the entrance to the Glen, in the prominent hummock of the Slate Series known as Cronk Sumark [SC 39187 94110] or Primrose Hill, which rises steeply above the drift plain. Some low crags near the north-western baseof this hill reveal a highly contorted strip of rather coarse-grained massively-bedded grit, and 40 or 50 feet higher on the same slope a large quarry has been excavated, in obscurely-cleaved dark blue slates welded into a mass, in which indistinct traces of folded bedding alone remain in the upper part of the section, while the lower.part gradually changes into a slaty breccia. In crags outside the quarry, below the level of its floor, the breccia is continued downward towards the strip of grit, and there contains many gritty inclusions. It is from the talus of this quarry that Mr. Bolton, obtained the specimens described on p. 93. The 'crush conglomerate', full of grit fragments, some of large size as shown in Figure 6, p. 57, extends from this place to the eastern edge of the hill, where, behind the farm-yard of Grangee [SC 39397 94099], it has been quarried for building-stone, the later shear-planes being sufficiently developed to give a rudely flaggy character to the rock. From Cronk Sumark, so far as we can judge from the exposures, the autoclastic structure extends in a more or-less continuous sheet southward and eastward for more than a mile though the brecciation is sometimes imperfect and there are a few strips in which the bedding has not quite disappeared. In the quarried crag at Kerroomoar [SC 39875 94432], half mile to the east-north-east of Crank Sumark, the conglomerate is traversed and altered by two igneous dykes of widely different ages; the older, a dioritic rock probably belonging to the Pre-Carboniferous 'greenstone' group, is intersected by the newer dyke, one of supposed Tertiary olivine-dolerites (see p. 105). To the southward of this place the breccia can be traced in exposures here and there in the roads, and in small bosses in the fields, until it enters Narradale [SC 39783 93752], where it occupies the stream-bed for nearly a mile, traversed by -several 'greenstone' dykes and interrupted by occasional intercalations of bedded slate. In the right bank of this stream, southwest of the only farmstead in the upper part of the glen, there occurs a boulder-like mass of coarsish grit or quartzite, apparently embedded in the crush-conglomerate, which measures, in its exposed portion, 14 by 8 by 6 feet. Its partially rounded surface has a thin smooth sericitic coat, with little patches of the breccia adhering to it, but the shearing seems to have been confined to this crust, since petrological examination of the layer immediately beneath gave no indications of movement (see p. 104). This is the largest single boulder which has been observed in the crush-conglomerate of the Island, though the structure often isolates and surrounds irregular patches of disturbed but still continuous strata of very much larger dimensions.

On the high-lying land to the eastward, between Narradale [SC 39954 93495] and Glentramman, which rises from about 300 feet to nearly 800 feet above sea-level, the autoclastic structure is exhibited in scanty exposures, but seems to split upinto narrow strips and end off before reaching the latter glen, in which, however, the stream-sections are extremely difficult of access and have been only partly examined.

In the opposite direction, the conglomerate may be traced westward from Narradale into the bed of the stream of the next glen, where it is often very coarse in texture; but it is less distinctly represented in the short valley draining to Ballamanaugh, one-third of a mile farther west, which seems to lie somewhat to the northward of the zone of brecciation. The southerly margin of the belt is reached in the streams near Cronkgarroo [SC 40073 92746], (the more northerly of the two places of that name on the one-inch map) and then, following the line of south-westerly strike for 400 or 500 yards across grassy moorland, we descend at Ballaneary [SC 39655 92112] into the valley of a tributary of the Sulby River, where a deep gully has been cut in compact dark slate of the Barrule type, from which the stream falls into Sulby Glen in a picturesque cascade known as the Cluggid. [SC 38570 92392] <ref>This name is not recorded on the Ordnance maps. It is said to signify "a throat", and to apply particularly to a natural perforation in the rock through which the stream drops in one part of its fall.</ref> Below the cascade, paler banded slates with a partially brecciated structure are revealed, and less than 100 yards lower down these pass into pebbly crush-conglomerate which forms the bed of the stream. The same phenomena are beautifully exhibited in the craggy walls of the great glen, which rise 500 or 600 feet high on the northern side of the water-course, furnishing a continuous section across the strike of the brecciated zone, as indicated in the opposite figure.

Nowhere can the development of the structure and its relation to the accompanying strata be more satisfactorily studied than in these crags. The width of outcrop of the crush-conglomerate is slightly over 400 yards, and its vertical depth exceeds 500 feet, the top being lost in the grassy ground above the valley. South-eastward, it passes gradually into the dark Barrule Slate of Ballaneary; and northwestward, into highly contorted banded slaty and gritty flags and quartz-veined grits which constitute the northerly termination of the section and are excellently displayed in the opposite or western wall of the Sulby valley.

Every stage in the breaking up of these sandy slates and grits can be distinctly traced. Amid the mass of the breccia there are isolated patches of unbroken or only partly broken strata, from a few feet to a few yards in diameter; while at its margin narrow strips of disrupted rock are interbedded with comparatively unbroken bands, as though the structure had pushed its invasion more readily along some beds than others. In a few instances, well-defined included fragments are themselves composed of breccia differing in texture and tint from that in which they are embedded, as though portions already in the state of crush-conglomerate had been broken up a second time. Occasionally, also, there is a distinct U or V-shaped arrangement of the longer axes of the fragments, as shown in (Figure 8), suggestive of sharp folding of material already crushed.

Movement subsequent to the primary brecciation is also proved by the strain-slip or 'shear-cleavage' which frequently affects the crush-conglomerate equally with the neighbouring unbrecciated rocks, and with the same direction and dip. The fissile planes of this cleavage traverse matrix and inclusions alike, except that when the latter are of hard grit the planes sometimes swerve around their edges in a fashion which demonstrates that the fragments held their present position before the fissility was imparted to the rock.. These phenomena are perhaps best displayed in sections two miles higher up the valley, whence the following illustrations, (Figure 9) and (Figure 10), are taken.

Where the conglomerate is chiefly made up of slate with few hard inclusions, this fissile structure is as strongly developed as in the Barrule Slates and renders the fragmental character of the 'rock almost invisible.

In the crags east of the Cluggid, an intrusive dyke of diabase (see (Figure 7); also p. 133), from 10 to 20 feet thick, crosses the brecciated belt and is prolonged among the unbroken flags to the northward. This dyke, though not so much affected by shearing as those in Narradale, affords further evidence of post-brecciation movement.

In the country to the eastward of Sulby the belt of crush-conglomerate appears to lie approximately flat or only gently inclined, and its outcrop is therefore broad; but in Sulby Glen it seems to have a steepish north-westward dip or pitch, and therefore, though its thickness may not be diminished, its outcrop is narrower. Its limits are not, however, so regular that the mode of occurrence of the zone in this respect can be determined with certainty; but whatever its position may be, it is evident that its thickness must be considerable, since its outcrop in this part of Sulby Glen measures from 200 to 400 yards in horizontal extent and has a vertical range of 200 to 500 feet in the precipitous slopes.

Southward from the Cluggid, in the portion of the Sulby valley named Glen Mooar [SC 38398 92143] on the Ordnance map, the 'crush-conglomerate' occupies the lower slopes on both sides. But where the river makes a sharp elbow eastward, under the upland farmstead of Killabraggah [SC 37869 90795], the belt of breccia strikes across into the western bank, so that both its upper and lower limits are contained in a single range of precipitous crags, showing its vertical depth to be between 250 and 350 feet.

The above section (Figure 11), on the margin of the zone where it crosses the river, exhibits the transition from bedded rocks into breccia.

Thence the belt can be traced across the rocky shoulder of Craigmooar, and comes down into the valley again at the school-house of Tholt-e-Will [SC 37814 89616] (adjacent to "Chapel" of Ordnance map), still flanked on the west by grits and on the east by Barrule Slates. Meanwhile a subsidiary strip of the conglomerate, apparently wedging out both northward and southward, occupies the eastern slope of the Sulby valley around Ballaskella [SC 38324 90014], possibly representing the emerging crest of a sharp fold in the brecciated zone.

Half a mile south of Tholt-e-Will the structure in all its phases is admirably displayed in the bed of the Sulby, under Druidale farm [SC 37164 88774], and in the adjacent craggy ground around the confluence of tributary streams from both sides. It here occupies a zone fully 500 yards in breadth, but this includes certain bands in which the bedding-planes are only partially disrupted, and the belt is also complicated by faulting. Its component materials are chiefly slaty flags, broken and drawn out into irregular lenticles which often still preserve traces of the original bedding. The shear-cleavage, as already noted, is strongly developed throughout the mass.

The higher or Druidale portion of the main valley above this place swings to the westward of the conglomeratic belt which however is displayed for 300 yards in the bed of the side-stream, Glen Crammag [SC 36951 88009], whence its south-westerly strike probably carries it under the drift-covered moorland, for 600 yards, to its final exposure in the Sulby basin, in the bed of the rivulet west of Close, as already described.

These Sulby Glen sections thus afford satisfactory evidence that the autoclastic structures are continuous for a distance of at least six miles. Moreover, there is no reason to doubt that, before the truncation of the Manx Slate massif by denudation, the belt has once extended farther northward, —probably much farther, since the maximum development of the conglomerate is attained at the extreme northerly border of the hills.

There are further developments of the structure to the eastward of the great Sulby belt, apparently on the same strati-graphical horizon, and once perhaps continuous with it, but now reduced by denudation to a series of isolated wedges set *en échelon.* The western border of the most westerly of these wedges, on the slope south of Lezayre Church, approaches within half a mile of the eastern termination of the Sulby belt at Glentramman [SC 43173 93952], and extends thence into the summit of Skyhill [SC 43173 93952] between Lezayre [SC 42325 94119] and Ramsey. The weathered crags on the northern crest of this hill show very clearly the gradual disruption of grit-bands; while farther south oil the ridge three, or possibly four, separate strips of crush-conglomerate, each narrower than the last, may with some difficulty be traced, with intervening wedges of more or less unbroken strata. On the hypothesis of a once-continuous sheet of crush-conglomerate covering the area, these exposures may represent the infolded remnants of its plicated lower margin.

About a mile farther south a rim of breccia, as mentioned on a previous page (p. 48), borders the mass of grit on the moorland west of Glen Auldyn, and is prolonged north-eastward into the side-ravine south of Skyhill Farm [SC 42455 92923], where it is traversed by several 'greenstone' dykes. Its course then becomes obscure through lack of exposures, but it probably reaches into the main glen a little farther northward.

On the eastern side of Glen Auldyn the autoclastic condition is imperfectly developed in the low crag overlooking Balleigheragh; and occurs, in a series of streaks a few feet wide, in the stream-bed of the deep glen falling into Glen Auldyn on the east, near the old lead mine marked on the Ordnance map. These streaks probably represent the westerly point of a wedge expanding rapidly north-eastward in the direction of Ramsey, but for three-quarters of a mile cultivated ground intervenes, and there are no outcrops. A belt of breccia having a breadth of about 300 feet is then revealed in

Ballacowle or "Elfin" Glen [SC 44912 93265] (unnamed on the map) on the southern outskirts of Ramsey, and is prolonged thence towards the sea in the broad ridge of Ballastowell. Its major portion is then lost, within 150 yards of the coast line, under a low terrace of drift; but its southern margin reaches into Ballure Glen [SC 45581 93236], and may possibly be continuous with a narrow strip, twenty or thirty feet wide, which is visible in a little headland of the adjacent coast, 150 yards east of the first cliff of the solid rocks. This strip appears to be wedged in between parallel faults.

In the eastern portion of the Ballastowell ridge the conglomeratic belt is over 200 yards wide, and its depth, between the lowest and highest visible points, about 300 feet. Where cut by the new mountain-road in the craggy slope overlooking Ramsey, its northern margin appears to be faulted; but the same margin to the westward of the Albert Tower [SC 45292 93429], 250 yards farther west, shows a gradual passage from a coarse breccia of grit- and flag- fragments in a slaty matrix, to sandy and slaty flags in which the bedding, though much shattered, is more or less continuous.

In two places on the ridge, the breccia has been quarried for building; the more extensive excavation is at the eastern base of the hill, behind Ballure House [SC 45314 92986]; and the smaller, near the summit at the western end, close to the farmstead of Ballastowell. From the talus of the latter quarry Mr. Bolton, as already mentioned, obtained the supposed impression of a trilobite. The specimen is discussed on a subsequent page (see p. 93).

The district to the westward of Sulby Glen now remains to be described. While partial brecciation is of frequent occurrence in this area, the complete disruption of the bedding is, with certain notable exceptions, rarely attained. A few limited strips of crush-conglomerate have been recognized in the 'unseparated' tract to the westward of the outer belt of Barrule Slate, but it is uncertain whether they occur independently, or represent a definite plane. Thus, on the hill-slope east of Kirk Michael the structure, in a slaty form, is scantily exposed near the margin of the gritty flags of that district. Sunilar material is seen again near Chester [SC 30940 88056], two miles S.S.W. of the former locality, in a low outcrop between the forks of the small streams which unite at this place. At Corvalley [SC 29098 87101] rather over a mile farther along the same line of strike, a better exposure of highly sheared slaty conglomerate was observed in a small field-quarry 200 yards west of the high road and 500 yards S.W. of the ancient chapel ruins (Keeill Pharick) [SC 29585 86415].

It is on the coast, however, about a mile to the westward of these places that we find the best of the western outcrops, in the cliff-section noticed by Henslow (see p. 55). This is, indeed, the only large-scale exposure of the structure to be found on the shores of the Island, and though somewhat inaccessible, it is fortunately in other respects excellent. From the northern end of the section at Gob ny Creggan Glassey [SC 29700 88868] near where the solid rocks first rise into the cliff, we may find here and there for a mile to the southward, thin streaks of breccia upon definiteshear-planes bordering the thin grit bands which occur among confused and crumpled banded slates; (see (Figure 33), p. 122). But when we pass beyond Gob y Deigan [SC 28368 87486], to the point where the buttresses of the cliff are perforated by a series of picturesque sea-worn caves and arches <ref>This charming spot is now locally known as Gob y Deigan (Devil's. Gob), but the Gob y Deigan of the Ordnance map is the little headland 500 yards farther north.</ref> (probably betokening lines of fault), we suddenly find that the whole section, from low water mark on the foreshore to the crest of the solid cliff 60 to 80 feet high, is composed of autoclastic breccia in various stages of disruption. From this spot up to the northern edge of the supposed outlier of the Niarbyl Flags (p. 38) at Ballanayre Strand [SC 27612 86779], 350 yards distant, we have a succession of similar exposures, diflbring only in the degree of the brecciation and the size of the unbroken intercalations. Access to the section is somewhat difficult, not only from the ruggedness of the cliff and shore, but also because the exposures can only be reached at low water of spring tides and the time during which they can be studied is therefore limited. The difference between the aspect of the breccia in surfaces subaerially weathered and in those sea-worn, as noted by Henslow, is very striking; in the former the fragmental character is blurred by the slaty cleavage and can scarcely be detected; while in the latter every feature is brought out beautifully, and every stage in the bursting asunder and dispersal of the harder fragments in the slaty matrix can be followed (see (Figure 12)). Some of the more argillaceous fragments seem to have possessed a slaty cleavage before they were incorporated in the breccia.

In the southern part of the section the conglomerate is traversed, as shown in (Figure 14), by several 'greenstone' dykes, some of which have been folded, frayed at the edges, and dislocated into long tapering segments by post-brecciation shearing, so that in the thinner examples their igneous structure has been almost obliterated. In spite of the number and variety of the Pre-Carboniferous intrusions of the Manx Slates, all seem to be of later date than the brecciation. Careful search was made in many different exposures of crush-conglomerate for fragments of igneous rock among the other inclusions, but none was found, either in the field or by microscopic investigation (see p. 100). It is therefore clear that the movements by which these dykes were sheared and distorted, like those which produced the fissile cleavage in the breccia, were distinct from and later than the movements which produced the autoclastic structure. The quartz veins, also, with which the crush-conglomerate is frequently penetrated, present in this respect exactly analogous phenomena to the dykes. They have been stretched and broken, and the rock around them has been bruised and crushed, but they have not contributed fragments to the breccia.

The hard flags at Ballanayre Strand [SC 27625 86787] probably represent part of the nether millstone upon which the brecciation was accomplished, while at the same time their margin has not entirely escaped the process of disruption. The cliff-section in these Haas (Figure 13) exhibits a good example of an overturned closed fold partly removed by erosion.

On the southern side of the same little bay the crush-breccia is again seen, in the form of a wedge, sharply bounded by unbroken beds, as if faulted in. Three hundred yards farther southward, near Gob y Skeddan [SC 27360 86464] <ref>This place is named on the six-inch Ordnance map, but not on the one-inch map.</ref>, both the foreshore and cliff are occupied by similar breccia, traversed by several much-disturbed dykes and confused by thrust-planes and faults, affording exposures scarcely inferior in interest to these previously described.

Throughout the sections to the southward of the above, up to the incoming of the Peel Sandstone, the Slate Series with its accompanying dykes and bosses of greenstone is chopped up in every direction by thrust-planes and faults. Some of these may indicate displacements of large amount, like the boundary-fault of the Sandstone, but as their value could not be ascertained they have not been shown on the one-inch map.

In concluding these descriptions it is essential to point out that in almost every case the autoclastic structure occurs where strata of different characters are in juxtaposition, and that the disruption has taken place chiefly among the *passage* beds between these dissimilar masses.<ref>cf Quart. Journ. Geol. Soc, vol. li., pp. 582–3.</ref> It has already been shown that the most probable interpretation of the stratigraphy of the Manx Slate Series as a whole is, that there has originally been an underlying platform of flags and grits (Lonan and Niarbyl Flags and Agneash Grits) passing up gradually, through rocks of intermediate type, into an overlying argillaceous mass (Barrule Slates), and that the whole group has undergone intense deformation. Under these conditions, differential movement on a large scale was most likely to occur in the intermediate zone, as the result of the difference between the compressibility of the underlying and overlying rocks. Under powerful lateral thrusting, if the slates were driven into narrower bounds than the grits a local rending asunder and shearing of the interlocked masses one over the other would be produced. If the limits of the different rock-types had been sharply defined, the readjustment might have taken the form of a simple thrust-plane, but since the change of character was gradual, the disruptive effect, having no guiding plane, appears to have spread throughout the belt of passage-beds, shattering and milling many parts of them into dynamic breccia. Hence we find the crush-conglomerate to be fairly well restricted to a definite zone in the series, below the Barrule Slates and above the Flags and Grits. The diagram on the opposite page illustrates the production of the brecciated structure under the above-supposed conditions.

The results of the petrographical examination of the crush-conglomerate by Prof. Watts are given on pp. 100–106. They support and extend the conclusions drawn from the study of the rocks in the field, and furthermore show that the brecciation has not been accompanied by any increase in the degree of mineral alteration, the sediments possessing the autoclastic structure being not more altered than those in which the bedding is preserved. In an irregular belt along the structural axis of the massif, slates similar in composition to those involved in the brecciation have undergone a considerably higher degree of metamorphism, apparently from dynamic action, without disruption of their bedding (see p. 108).

Succession of movements in the Manx Slates

The earth-movements, as we have already seen, have affected the rocks at more than one period, and there seems to be strong grounds for believing that intervals of quiescence or comparative quiescence, perhaps of long duration, have separated the successive periods of movement. But as the effects of the different epochs have been superimposed one upon the other, the task of tracing out the successive stages is extremely difficult. In investigating the phenomena it has seemed to me that I could recognise the following phases; and this, though stated without much confidence, may serve, at any rate, as a provisional classification.

1. Consolidation of the sediments, accompanied by feeble disturbance of the bedding.
2. Acute folding, leading to fluxion-movement along the bedding planes, and in its later stages to extensive displacement in every part of the series, with the development of strain-slip and brecciation in certain areas.
3. Relief from extreme strain, and intrusion of the older basic dykes, and segregation of the older quartz veins.
4. Renewed pressure on the folded mass, causing the local development of close-set planes of fissility or shear-cleavage through the further compression of the rock-material. Sericitic mica frequently developed on the planes of movement, along with other and more considerable metamorphic effects in certain tracts. The intrusion of the granitic rocks seems to have taken place at about the close of this stage.
5. After short interval of comparative quiescence, the stresses again renewed, especially on the flanks of the Island, acting in the same direction as before, but with less intensity, producing incipient cleavage in the finer grained strata, but with little shearing except along definite planes of weakness. The granitic dyke-rocks suffered deformation during this stage.The above stages of movement seem all to have been Pre-Carboniferous.
6. Post-Lower-Carboniferous disturbances, producing much local complication in the Carboniferous rocks (see Chapter 5.), but with no recognisable effect except normal faulting m the older strata.

Of these stages the second and fourth are those which principally concern us in considering, the rock-structures, the former being especially the period of intense deformation and the latter of mineral alteration.

Other effects of movement in the Manx Slates

While the crush-conglomerate represents an extreme phase in the effect of the orogenic forces, many other structures, falling short of this extreme but equally deserving our attention, have been produced by the same cause, and these will now be considered.

The flow of the rock-particles during the folding, in a direction more or less parallel to the bedding planes, has given rise to certain features which are best illustrated in the banded slates of the 'unseparated' type and in the finer-grained greywackes or mudstones of the Lonan and Niarbyl Flags. The dominant parallel planes in these rocks correspond generally to the original bedding, but here and there between these planes we may discern irregularities of the stratification, revealed by the colour-stripe, in the form of minute puckering and thickening of certain laminae, counter-balanced by the cutting out or tapering away of others, the structure sometimes simulating cross-bedding (see (Figure 16)) and ripple-marking. It is by this kind of re-adjustment that the band as a whole has adapted itself to its position in the fold, thickening or thinning to a remarkable extent within the distance of a few feet.

Where the separate strata are thick, flaggy and nearly homogeneous, the intramural movement may implicate every particle of the individual band without disturbing the surface of the layers or destroying the general parallelism of the bedding. Where, however, the rock is thinly bedded, and especially where there are alternating layers of different composition, the same process has caused more or less disturbance of the bedding planes, producing in one place crumpling through compression and in another disruption through stretching, with many curious modifications of form. These structures are frequently conspicuous on the surfaces of the flaggy beds, and, in the Isle of Man as well as in many other places,' have been mistaken for original characters of the sediments, The misapprehension has been particularly prevalent in regard to the minor plications of the bedding-planes, which have beenmany times described as ripple-markings and held to indicate the shallow-water origin of the deposits. In every instance which I have examined, these supposed ripple-marks have proved to be secondary structures, due either to the emergence of parallel series of small step-faults akin to strain-slip (as in (Figure 17)), or to the rucking up of the bedding plane in little folds which have sometimes been overthrown and broken in the under limb (as in (Figure 18)).

As for example, in the Cambrian Flags of Bray Head in Ireland, where, in all the cases I have examined, the so-called ripple-marks are identical in origin with those of the Isle of Man.

This pseudo-ripple-marking is commonly developed in the thin sandy bands among the striped slates, but may occur in any hard seam traversing softer beds. Thus, the example represented in (Figure 19) shows the structure, on a small scale, in a thin segregation-vein of quartz.

Hence, although the rocks are in many places of a character in which ripple-marking may once have existed,it is doubtful whetherthe true structure anywhere now remains in them; if originally present, it has been masked by the secondary deformation. Analogous to the pseudo-rippling, but of rarer occurrence, is another curious structure which is probably confined to the interior portion of the crests and troughs of closed folds. In such situations the harder rock-bands have sometimes been crumpled and thickened so that their surfaces have risen up into the more plastic material overlying them in small lenticular swellings or bosses, more or less regular in size and so arranged between two intersecting sets of strain-slip faults or joint planes that the rock-surface presents a rude embossed pattern.

This structure seems to have been noticed by Berger<ref>Berger *op. cit.* p. 38. This structure also is beautifully developed at Bray Head.</ref>, who remarked that it was called by the quarry-men " knobby-side". An unusual example from the neighbourhood of Perwick [SC 20314 67224] near Port St. Mary, in which the protuberances have been elongated, perhaps by a later movement than that which originated them is illustrated, though somewhat crudely, in (Figure 20) on the next page, taken from my note-book.

Somewhat analogous to this structure and to a certain extent its reverse, produced probably under conditions of stretching instead of compression, is the singular tesselation sometimes exhibited by surfaces of thin beds in the flags due to a slight ridging up of the material along intersecting lines of jointing or strain-slip. These ridges, one-tenth to one-quarter of an inch high, form sets of fairly regular parallel lines, from one to three inches apart, crossing each other at uniform angles. Usually there are two sets of the ridges, as in (Figure 21), but occasionally three or more sets occur, resulting in a somewhat irregular meshwork of intersecting lines, as in (Figure 22) These structures evidently belong to the period of acute folding (No. 2 of the above classification), and they are crossed by the faint striae of the later shear-cleavage (No. 4 and possibly in part No. 5 of classification).

Another interesting structure due to the differential movement of one bed over another during the folding takes the form of brightly burnished planes of stratification, which occur, though somewhat rarely, among the fine-grained Niarbyl Flags. Similar polished planes are well known in the folded limestones of the Jura.

It is evident that all these structures are early phases of the process which produced the brecciation, the difference being one of degree only. On theoretical grounds it has been stated that the 'zone of flowage' of rocks in the earth's crust lies below the 'zone of brecciation', and that at a depth exceeding 10,000 metres no fracturing such as that indicated in the 'autoclastic' rocks can take place<ref>See Van Hise, op. cit., p. 592.</ref>. But while great depth may be requisite to bring the whole of a consolidated rock-mass into the state of flow, it is certain that very considerable transference of material by gradual "creep" from one part of the fold to another, can take place comparatively near the surface, even in rocks of extreme hardness. In the Isle of Man the brecciation does seem to have taken place at a slightly higher horizon than that occupied by the unbroken grits and flags, but I think it is by the dissimilarity in lithological composition of the rocks, and not by the relatively small difference in depth that the variation in the character of the secondary rock-structures can be most readily explained. During the production of a fold under a certain thickness of super-incumbent material, the stresses in one and the same place must vary greatly from time to time, according to the position which the moving strata assume in regard to the direction of the pressure, so that any particular segment during one part of the process might be placed under conditions producing 'flowage', and at another under those producing fracture. In this connection the element of time, as it is acknowledged,<ref>See Van Elise, *op. cit.,* p. 594.</ref> may be of prime importance, since extensive deformation by flow might take place under comparatively slight stress, if this be sustained sufficiently long. All the various above-described effects of movement in the Manx rocks may be explained by supposing that in some cases the compressive forces were so slow in their action as to permit gradual re-adjustment of the material in the growing fold by "creep", while in other instances the natural plasticity' of the rock — if we may use this term — could not keep pace with the rate of growth of the fold, and more rapid methods of deformation were then called into play. Under the latter conditions the intersecting systems of strain-slip-planes with their concomitant phenomena have been produced, and these may be traced step by step, with increasing severity of displacement (see (Figure 23) and (Figure 24)), until we reach the extreme state of complete disruption of the strata and their reconstruction as an autoclastic conglomerate.

At a somewhat later date than the major folding, the structure which I have described as 'shear-cleavage' <ref>Quart. Journ. Geol. Soc., vol. li., p. 567. My reason for applying a separate term to this structure is, that it is frequently present along with a much more widely spaced and better-defined system of strain-slip planes independent in direction and apparently of older date, probably connected with the brecciation-stage of movement. See Figs. 17 and 24.</ref>- was extensively developed in the area. This structure, agreeing in most respects with that termed fissility' by some authors,<ref>See Van Hise, op. cit., p. 633.</ref> and 'ausweichungs-cleavage' or 'strain-slip cleavage' by others, consists in the development of close-set, more or less parallel planes of shearing, along which the opposing surfaces have been slightly shifted relatively to each other. A distinction is usually drawn on theoretical grounds between this structure and the 'true' or 'ultimate' slaty cleavage, in which the mineral particles of the cleaved rock are supposed to have been forced by pressure into such a position that their longer axes possess a parallel arrangement throughout the mass, so that the tendency of the rock to split in a definite direction is not confined to particular planes, but affects equally every portion of the material. It is doubtful, however, whether this distinction can be made in the field in any area where extensive shearing has taken place, and where both structures may be present in the same rock. In the Manx Slates, though the 'shear-cleavage' is nearly always predominant, the two structures appear to merge inseparably into each other, so that the interior portion of a block of slate surrounded by shear-planes may possess a structure indistinguishable from ultimate cleavage,' but passing insensibly at the margins into well-marked 'shear-cleavage' or 'fissility', without change of direction.

The period at which this shear-cleavage was developed in the Manx rocks must have been later than their brecciation, since it has affected the crush-conglomerates equally with the surrounding unbrecciated rocks (see p. 62, Figs. 9, 10), and also the greenstone dykes, which, as we have seen (p. 68), were injected among the slates after the brecciation. These dykes in many places have been shredded down into chloritic schists by the later shearing. During their intrusion the earth-movements seem to have relaxed in severity, or were even temporarily in abeyance, (Stage 3 of classification). Afterwards there came a renewal of the forces, acting in the same direction as before, still further compressing the already packed and folded massif, and producing a fissile structure both in the sediments and the dyke-rocks (Stage 4). Later followed the intrusion of the granite masses, with their associated micro-granite dykes, which are seen in many places (see pp. 128, 150) to intersect the older greenstones and to alter them at the contact in such a manner as to suggest that the basic dykes had previously received their shear-cleavage.' Whether there was any relaxation of the pressure during the irruption of the granites is not clear, but it is certain that the strain *was* renewed (Stage 5) after the consolidation of those rocks, since shear-structure has been imparted to their margins and to their elvans, though in a less degree than to the older basic dykes.

The quartz veins stand in the same relation to the different stages of movement as the dykes; they are all posterior to the primary folding and brecciation, but have been formed during more than one of the later stages, and some have therefore been implicated to a greater extent than others in the movements. A few of the veins seem to be of later date than the disturbances and are probably Post-Carboniferous, but these are comparatively rare.

In the strongly banded slates bordering the Barrule Slates, and in the argillaceous intercalations among the flaggy rocks of the 'unseparated' central area, the shear-cleavage is especially well developed and frequently in more than one direction. On the flanks of the island it is not so well seen, except occasionally in the slaty intercalations of the Lonan and Niarbyl Flags.

The more or less oblique emergence of the shear-planes upon a rock-surface frequentlyproduces a peculiar and characteristic minute frill-structure in beds of fine texture. This structure is most apparent in the argillacecrus layers, and sometimes strips out thin slaty partings among the harder flags transversely along the strain-slip planes, so that each lamina presents a saw-like cross section bearing some resemblance to a sheared graptolite, as shown in (Figure 25)

The frilling reaches its greatest intensity on the crests of folds, where it sometimes nearly obliterates even the most pronounced bedding (see (Figure 26)), while in the more homogeneous strata like the Barrule Slates the structure completely overpowers the original stratification.

Frequently the parallel planes of fissility, when transverse to the bedding, are thickly clustered in bands of ¼ to inch to ½ in breadth, separated by intervening unaffected spaces of an inch or two; and in such cases the alternation of the sheared zones showing the sericitic shimmer with those in which the fissile structure is absent, gives an appearance very closely simulating true bedding, though of course in no way connected with it as in (Figure 27) When sheared dyke-rocks are affected by this false stripe it is impossible to distinguish them from the slates, unless independent evidence can be obtained of their intrusive character.

The difficulty in distinguishing between the bedding and the 'fissile tendency' in such cases was commented on at considerable length by Macculloch, who failed to recognise the true character of the sheared 'greenstone' dykes, and was thereby led to the conclusion that these dykes in a section near Douglas were greywacke bands and indicated the true bedding planes.<ref>The Western Islands, etc"., pp. 542–644 and pl. xxviii. fig. 1.</ref> Henslow was similarly misled by the resemblance of the dykes to greywackes<ref>Trans. Journ. Western Soc., vol. v., p. 490, and Pl. 35, figs. 1, 2 and 3.</ref>; as also, at much later dates, Harkness and Nicholson, by an altered trap at Laurel Mount near Ramsey,<ref>Quart. Journ. Geol. Soc., vol. xxu., p. 489. </ref> and Clifton Ward by the sheared micro-granite at Crosby<ref>Geol. Mag., dec. ii., vol. vii., p. 3.</ref> (see pp. 135, 168).

In some localities, especially in the belt of laminated slates between the Agneash Grits and the Barrule Slates, the rocks possess two or even three distinct systems of cleavage-planes, striking in different directions and intersecting each other at definite angles, as shown in the annexed example, (Figure 28)

In such cases it is difficult to decide whether /we are dealing with the effects of separate stages of movement superimposed upon each other; or with the complex results brought about during a single stage by the gradual change of position of the strata during the formation of the fold; or with instances of uncomplicated cross-fissility; a structure thus described by the American geologists<ref>See Hopkins and Van Hise, op. cit., pp. 64 et seq. and 845 *et seq.*</ref>: "In the zone of fracture where the differential stress surpasses the ultimate strength of the rock, there may be produced a fissility in two sets of intersecting planes equally inclined to the greatest pressure".

If we accept the last explanation as the most probable, then we shall recognize in the specimen figured above, (1) Flow-structure parallel to the bedding-planes, assignable to Stage 2 of our classification, and (2) 'cross fissility' of later date (Stage 4), in this case meeting at an angle of 80°, but in other places making angles varying from 35° to a right angle. In the central part of the massif, where the 'cross-fissility' is chiefly developed, these are perhaps the only stages of movement definitely recognizable in the sedimentary rocks, and evidence for the later stage (5 of classification) is presented only by the intrusive microgranites. On the flanks of the Island, however, the last-mentioned stage appears to have given rise to a 'later cleavage' in the slates, though as hinted above the distinction between it and the earlier structures is often far from satisfactory. This latest cleavage affects the greenstones and micrograṇites equally with the stratified rocks. With few exceptions, it preserves a regular strike in every part of the Island where it can be recognized, and dips generally from the central anticlinal axis, as shown on the sketch map, (Figure 29) This regularity indicates that the strata had been folded and packed before 'this cleavage was developed in them and that they have not since been much disturbed. Even at this stage, some minor degree of shearing has taken place among the rocks, since the cleavage-structure only now and again approximates to 'true slaty cleavage,' and more often has the character of slight strain-slip. Its direction frequently coincides with that of the earlier structures, and where the angle of dip is also the same it is indistinguishable from them.

There is frequently a close relationship between the folding of the strata and the cleavage-structures, as shown in the following section, (Figure 30), where the inclined axial planes of the minor folds are parallel to the planes of the cleavage.

It is also common to find the cleavage in agreement with the bedding planes of the strata both in strike and clip, in which case the secondary structure is only visible in weathered outcrops, where it will often cause the thicker rock-bands to shiver into slaty fragments. It is in the crests and troughs of folds, where the bedding diverges from the dominant direction, that the structure is most distinctly visible (see (Figure 3) & (Figure 26)).

On the flanks of the Island, and in the flaggy rocks generally the most frequent relationship is that while the bedding and cleavage have approximately a common strike, they diverge widely in degree of dip, that of the cleavage remaining steady over wide areas, while that of the folded bedding varies from point to point. Even in the larger folds like the great syncline skirting the east coast from Clay Head [SC 44287 80466] southward to beyond Douglas Head [SC 39032 74807], the cleavage is unaffected by the reversal of the bedding and maintains its dominant direction and angle across the strata.

This cleavage has an unfavourable effect upon the rock as a building-stone, its oblique emergence on the bedding-planes producing a wedge-shaped edge in the quarried flags which can be only partially removed by dressing.

The granitic bosses of Foxdale and the Dhoon appear to cause a displacement of the anticlinal axis of cleavage in their vicinity, as elsewhere described (p. 168), as well as some minor local modifications (see Map. (Figure 29)). But the intrusions occur in the belt in which the different structures are more or less inseparable; and while the evidence suggests that a fissile structure was in existence in the strata before the irruption of the igneous rocks, and that other structures have been imparted since the consolidation of the granite, it is not sufficient to enable us clearly to distinguish them where both are present.

Faults

As already mentioned, the value and effect of overthrusts and faults upon the Manx Slate Series can rarely be estimated although we know that extensive displacements have occurred both in Pre-Carboniferous and in Post-Carboniferous times. Even the faults which bring down the newer Palaeozoic strata into the flanks of the massif can rarely be traced beyond the borders of the Carboniferous rocks, from the difficulty in identifying them amid the general confusion and deformation of the older strata and from the prevalence of fault-like effects produced by other causes. For example, the disappearance of members of the Slate Series on their line of strike may be either the result of faulting or of the pitch of the folds; and a sudden change of rock-character at the surface transverse to the strike, when the strata are so often almost vertical, may denote a strike-fault or simply the upturned normal succession of beds of different composition. For these reasons the tracing of fault-lines within the Manx Slate area must necessarily be more or less hypothetical; and it was thought unadvisable, so long as the difficulties of the ground could be otherwise explained, to introduce such lines on the published map.

Nevertheless, the cliff-sections all round the shores of the Island reveal planes of crushing and probable dislocation at frequent intervals, and similar appearances are numerous in the stream-beds of the interior, giving rise to deep narrow rock-gullies where they coincide with the water-courses, and to cascades where they cross them.<ref>Many of these fractures of unknown value hay e been recorded on the MS. clean copies of the six-inch sheets which have been deposited in the London office of the Survey.</ref> Most of these fractures fall into one or the other of two sets, going either about E.N.E. to W.S.W.; *i.e.,* approximately with the strike of the rocks; or in a direction more or less nearly at right angles to this, namely, N. or N.W. to S. or S.E., *i.e.,* across the strike.

The planes of the strike-faults are sometimes of low hade and accompanied by crushed stringers of vein-quartz and brecciated rock, with other indications of reversed faulting or overthrusting (see (Figure 44), p. 178); while the north and south fractures are generally steep, sharply defined, with a newer aspect, and like normal faults. On this evidence it was at first thought that all of the former set were older than all of the latter; but an examination of the north and south lodes of the lead mines at Cornah, Laxey and Ballacorkish (see p. 487), which seemingly represent faults of this direction, revealed the fact that these are intersected and displaced by slides' or faults having the east and west direction. Hence it appears likely that each set may include fractures of different epochs.

That some of the faults may be of Post-Triassic age is indicated by the presence of a dislocation in one of the deep borings in the north of the Island, which apparently brought down the Triassic rocks against Carboniferous Limestone (see p. 283). In Cumberland, in the district adjacent to the coast, where the geological structure is closely related to that of the northern part of the Isle of Man, there are, besides the Pre-Carboniferous fault-systems about which little is known, at least two later systems, one Pre- and the other Post- Triassic, the older set, striking N.E. to S.W., affecting only the Carboniferous rocks, and the newer set, striking N.W. to S.E., dislocating the Trias and Permian along with the Carboniferous.<ref>These two systems are brought out clearly by the mapping (see one-inch map, Sheet 101 S.W.)</ref> It is very probable that the same conditions extend to the Island, where, however, as the Triassic rocks are concealed by drift we are unable to establish the point.

The high angle at which the Manx Slates are usually inclined would allow considerable vertical displacem ent of the opposite sides of a fracture without much apparent effect on the outcrop; and it is possible that the contract ion and expansion exhibited by rock-belts in some parts of the massif, as shown on the map, may be due to systems of faul ting transverse to the folds. At the same time, the general persistence of these belts seems to imply that no individual fault can be very great. Excepting in the case of the Niarbyl overthrust (p. 148), the boundaries of the different divisions of the Series, where exposed in the cliffs, do riot definitely indicate faulting; and the changes of rock-character which are sometimes visible on the opposite sides of fractures are usually such as to imply that the beds brought into contact were originally not very far apart.

It appears probable that the master-faults of the Island are those on the edges of the old massif, and that, indeed, their occurrence has determined its position. Thus the downthrowing of the Carboniferous Limestones on the south-eastern flank of the Island; of the Peel Sandstone on the west; and probably of the Permo-Triassic and Carboniferous rocks on the north has defined the extent of the higher central mass of the Slates. Even these displacements need not be of more than moderate magnitude; that which bounds the Carboniferous basin of the south is not large, in spite of its important effect upon the stratigraphy (see p. 196), while those which bring in the Peel Sandstones, though of higher value, can only doubtfully be traced into the interior, and certainly do not seriously break the westerly belt of Barrule Slate.

The peculiar dislocation and displacement in short segments of the quartzite-bands and many of the dyke-rocks, especially the microgranites, described in other parts of this work (pp. 137, 182 and pp. 128, 167), are probably due to the development of step-faulting in a manner not yet understood. This structure is admirably displayed by the microgranite dykes which pass from the south-western coast near Fleshwick inland towards the Foxdale Granite; and again by those of the northeastern coast around Maughold Head which are connected with the Dhoon Granite. These are apparently cut into segments and displaced along more or less vertical planes which have a general, though not universal, tendency to shift the separated portions, bit by bit, in one direction, the Foxdale dykes being dragged to the northward of their easterly course and the Dhoon dykes to the southward of their westerly course (see map, (Figure 29), p 84). Similar peculiarities may be observed in the thicker bands of quartzite, in the coast-sections between Cass ny Hawin and St. Anne's Head, as well as in other places.

It is very probable that the same structure may be accountable for that divergence from the apparent strike already mentioned as characteristic of the general arrangement of the Manx Slates, and especially of their flaggy and gritty divisions. It seems to imply some system of step-faulting by which the massif has been cut up into strips which have been laterally displaced, in a definite direction relatively to each other, as in (Figure 31) The subject is one which might well repay further investigation.

These features and others in regard to the position and relations, of the larger igneous intrusions seem to indicate the presence of a multitude of small overthrust and normal faults, which, in the aggregate, may have had considerable effect. It is more than probable that I have myself failed to make sufficient allowance for both kinds of faulting; it must be left to the future worker to discriminate more closely between the relative values of folding and faulting in the production of the intricate structure of the Manx Slates.

Palaeontology of the Manx Slates

Almost the only traces of organisms in the Manx Slate Series are the tubular 'worm-casts', which are fairly abundant in some localities on the surfaces of the flaggy beds, especially where the rocks consist of thin alternations of argillaceous and fine arenaceous material. The presence of these markings in the slates was first mentioned by Cumming and afterwards by Harkness and Nicholson, Binney and others. Recently the whole subject has been reinvestigated by Mr. H. Bolton, whose descriptions are quoted below. Mr. Bolton's personal researches have also brought to light specimens which he believes to represent the cast of a trilobite and two examples of graptolites. But the conditions under which these specimens occurred seem to justify some doubt as to their character, especially since some examples of markings collected during the course of the survey, which were thought to indicate organic remains of the same kind, have proved under microscopic examination to be of inorganic origin. This subject will be further referred to after the descriptions of the specimens have been quoted.

In his recent paper<ref>"Paleontology of the Manx Slates", Manchester Memoirs, vol. xliii. (1899) no. 1., pp. 1–15, with a plate.</ref> Mr. Bolton has critically discussed the previous palaeontological literature, and in the following passages he sums up the work of his predecessors and the result of his own researches.

"In 1862 Mr. J. [E.] Taylor<ref>Supposed Imprints in the Lower Cambrian Beds of the Isle of Man". *Geologist, vol. V.* 1862, p. 321.</ref> described certain supposed imprints in the slates of Dalby. These imprints were said to resemble the dotted outline of the *Protichnites* figured in Owen's *Paleontology.*

"Mr. Mackie, Editor of the *Geologist,* thought that the impressions looked more like portions of gigantic *Lingulce* or some fibrous shell. Mr. Salter denied their organic origin altogether, and Mr. Lamplugh informs me that the impressions were probably the hollows left by the decay of the slightly calcareous nodules, which occur rather abundantly in some localities

"In 1863, a paper was read by Mr. Taylor<ref> "Cambrian Strata of the Isle of Man". *Trans. Manch. Geol. Soc.,* vol. iv., 1863, p285.</ref> before the Manchester Geological Society, in which he mentioned the discovery by Mr. Thos. Grindley of a fucoid, and also avers that behind the Castle Mona Hotel he himself discovered both fucoids and the tracks and castings of worms.

"At Mount Craig he found the remnant of an *Orthoceras,* the specimen showing the chambers and also the gradual tapering of the body of the shell.

"In the absence of either the specimen or of any figure, neither of which seem to have been exhibited, very little reliance can be placed upon the description.

"It is not unlikely that it refers to some partially weathered-out worm-casting, or to thin intersecting mineral veins, which in these rocks often simulate chambered organisms.

"Profs. Harkness and Nicholson<ref>"The Lower Silurian Rocks of the Isle of Man". *Quart. Journ. Geol. Soc.,* vol. xxii., 1866.</ref> in 1866 recorded the finding of *Palaeochorda major.* Mr. E. W. Binney<ref>"A Notice of some Organic Remains from the. Schists of the Isle of Man". *Proc. Manch. Lit. and Phil. Soc., vol.* xvi., 1878, p. 102.</ref> next took up the work in 1877, and published figures and descriptions of worm-tracks which he named *Nemerites monensis* and *Neretites monensis* respectively. Worm-burrows (*Scolites*) were also mentioned, and certain oval structures which he supposed had some faint resemblance to *Lingulae,* but which Mr. Lamplugh thinks may have been the cross-sections of worm-casts.

"Whatever these latter may have been, one was somewhat doubtfully referred by Binney to *Lingulella davisii.*

"In the succeeding year Binney<ref>"Notice of a Fossil Plant found at Laxey, in the Isle of Man". *Proc. Manch. Lit. and Phil. Soc., vol.* xvii., 1878, p. 85, and *Manch. Memoirs,* 3rd Series, vol. vi., 1879, p. 214.</ref> figured and described the supposed fucoid found in the glacial drift at Laxey, and from a superficial resemblance of the specimen to *Psilophyton cornutwm* of Lesquereux, he was led to name it *Psilophytcra monense.* In a later communication, Binney<ref>"Remarks on a Fossil Plant found at Laxey, in the Isle of Man". *Proc. Munch. Lit. and Phil. Soc., vol.* xviii., 1879, p. 19.</ref> states that Dr. Dawson was of opinion that the supposed plant more nearly re.enibled *Buthotrephis harknessi* of Nicholson; it is well to bear in mind, however, that Dr. Dawson was guided in his determination by the description and figure, and not by an examination of the specimen.

"Prolonged research amongst the slates by many recent workers has revealed no trace of true fucoids, and, as we shall see later, the supposed fucoids were, in all probability, the casts and tracks of *Palaeochorda.* In the absence of descriptions, figures or specimens, we are forced to reject the supposed fucoidal structures of Taylor, Grindley and others.

Psilophyton monense of Binney calls for more attention. It was described as follows: The stem is thick, dichotomous, divisions variable in distance, the terminal ones short, pointed, nearly equal in size and length, surface nearly smooth.

The branches in the lower part are thick comparatively to their length. The surface of the stem appears to be smooth, and affords no evidence of striae or scales.' A woodcut accompanies the description, but is too coarsely drawn to illustrate anything except that there is no dichotomy.

"The specimen was said to run nearly at right angles to the bedding (?cleavage), and that it lay upon the surface of a boulder taken from the glacial drift.

"In this case, as with previous writers, there is a lack of positive evidence, hut an attempt has at least been made to describe the supposed fucoid intelligently. It is most unfortunate that the woodcut does not increase, but rather nullifies, the value of the description.

"The species cannot be accepted as a good one, nor is there evidence to show that the boulder was derived from the slates of the island. There is no certain knowledge of plant remains.

"Animal remains are of a less uncertain character than the fucoids, but are few in number and species, and far from satisfactory.

"Worm-castings, tracks and burrows.

"Under this head must be placed the *Palaeochorda major* and *P. minor,* McCoy, once regarded as fucoids.

"Palaeochorda majorwas recognised in the Manx slates by Profs. Harkness and Nicholson, and considered by them of considerable value in correlating the latter with the Skiddaw slates of the Lake district.

"Worm-castings, tracks and burrows are fairly common in many of the Manx slates, and certain grits are almost composed of them. Especially is this the case in the cliffs south of Port[h] Mooar [SC 48807 90752].

"Palaeochorda minor, **McCoy.**

"The smallest worm-castings the writer has seen are a series collected by Mr. G. W. Lamplugh…

"The castings are usually in the form of long straight semi-cylindrical rods, rarely occurring in clusters, or showing much trace of coiling. They consist of grains of sand hardened into a fine grit.

"To this species we would also refer Mr. Binney's *Nemerites monensis.* The latter was stated to occur in blue laminated slate at Oakhill [SC 35452 73984], Braddan, and was found during the cutting of the railway from Douglas to Castletown. It was described as occurring in the form of a simple loop, twelve inches long and one-eighth of an inch in diameter. Mr. Binney's figure agrees very closely with that of *P. minor* figured by McCoy.

"Palaeochorda major, **McCoy.**

"Worm-castings, larger than those of *P. minor,* occur abundantly in many of the slaty grits; they vary somewhat in diameter, from three to four lines being a fair average. Not infrequently the castings lie in clusters, but show few traces of coiling.

"The fine cleaved slates have yielded few castings, but faint shallow tracks are not rare. They are usually very long, and average two lines in diameter.

"Neretites monensis of Binney was a worm-track found in a blue slate. The dimensions are not given, but the worm-track was described as meandering and consisting of about one hundred segments with traces of feet and cirri, and terminating in an oval-shaped head.

"An examination of Binney's figure shows that the segments cross the worm-casting obliquely, and that they are in line with a shear structure developed in the slate. Indeed, the shearing is shown by the artist to join with the segments, so that the latter appear as slight dislocations of the casting. The segments are clearly no part of the worm-track, but have been induced by shearing, a fact still further brought out in the figure by the dragging out of one side of the casting along its upper loop.

"The 'oval-shaped head' is figured as a depression against which the cast abruptly stops. It looks like, and probably is, a worm-burrow.

***"Chondrites informis,* McCoy.**

"Among the worm-casts collected by Mr. Lamplugh in the course of his examination of the slates there is a series differing from any hitherto described, and of larger size….

"The castings vary in size from a diameter of three to seven lines. They are composed of rather coarse grains of sand, which are partially compacted together. The matrix upon which they lie, often in high relief, is a slaty grit. A few of the castings are solitary, and when well preserved show a gradual reduction in diameter towards one extremity. More often they occur in clusters, lying parallel to or overlapping one another. Where they overlap, subsequent crushing has obliterated, to some extent, the lines of apposition between contiguous castings, so that they appear at first sight as branching or forked structures.

"Their resemblance to *Chondrites informis,* McCoy, is so very close, that we include them in this species.

"Brachiopods are not known with certainty, for though the oval depressions described as footprints by Grindley and Taylor were afterwards doubtfully referred to as the casts and trails of bivalves and the impressions of *Lingula,* neither figures, specimens, nor facts which can be verified, are available to justify their retention.

"The figures and descriptions of the supposed *Lingulella davisii* published by Binney might serve equally well as figures and descriptions of nodule masses still *in situ in* the slates, and wholly inorganic in origin.

"The casts and trails of Grindley and Taylor can be similarly duplicated by hollows left by the weathering out of nodules, and by worm-tracks".

The writer of the present memoir fully agrees with Mr. Bolton that the supposed foot-prints, fucoids, *Lingulae,* and *Orthoceras* previously described were probably all nothing more than the impressions of nodules or worm-casts, and the fauna of the slates is therefore reduced to the three species of the latter: — *Palaeochorda minor,* McCoy, *Pal. major,* McCoy, and *Chondrites informis,* McCoy. To those Mr. Bolton adds Aeglina or *Asaphus; Dictyonema (Dictyograptus) sociale,* Salter; and *Dendrograptus flexuosus,* Hall; which he describes as follows<ref>While the following descriptions are quoted verbatim from Mr. Bolton's paper, the order of the sentences has been slightly changed, and a few passages of which the sense has been previously given are omitted.</ref>:

"In 1892 the intaglio cast of a trilobite was found by the writer<ref>"On the Occurrence of a Trilobite in the Skiddaw Slate of the Isle of Man". *Geol. May.,* dec. 3, vol. x., 1893, p. 29.</ref> in a crush-conglomerate at Ballastowell, near Ramsey, and in 1893<ref>"Observations on the Skiddaw Slates of the Isle of Man". *Brit. Assoc. Rep., Notts,* 1893.</ref> a few other fossils (*Dictyonema* and *Dendrograptus)* were added from the slates of Cronk Sumark [SC 39196 94105], near Sulby Glen station…. A diagnosis, already published in the *Geological Magazine* [of the first-mentioned is as follows:

"Aeglina or *Asaphus.*

Impression of body and pygidium

"Thorax of six rings; axis convex and of uniform width; body rings narrow and well marked off from one another. Pleurae very broad, twice the width of the axis; grooves deep, broadening towards the extremities, and disappearing a short distance from the axis; extremities directed backwards pygidium a little more than half the length of the thorax width double the length; axis flattened, convex, and ending bluntly in the middle of the pygidium.

"Observations.—*From* the presence of six thoracic rings, grooved pleurae, and semi-circular smooth pygidium with feeble axis the writer was inclined to class the specimen as an *Aeglina*, but Dr. Henry Woodward has kindly pointed out that it differs from *Aeglina*in the sides of the axis being parallel along their whole length, and in being convex whereas in the former the axis diminishes in breadth from before backwards, and is flattened.

"From a careful comparison of the specimen with others from the Cambrian of North Wales1 Dr. Woodward is of opinion that it might with equal propriety be placed in the genus *Asaphus as Aeglina.* Unfortunately the specimen is too distorted and fragmentary to settle the point".

[With regard to the other fossils], " prolonged search resulted in the discovery of two small splintery masses of slate, each bearing *Dictyonema* and *Dendrograptus* in association. The former genus was most numerous, fragments of nearly a dozen individuals being present; of the latter genus only two specimens were clearly distinguishable.

"In the north quarry [at Cronk Sumark], from which the specimens were obtained, the slates are strongly cleaved and break up readily into irregular shuttle-like masses. The cleavage planes form an acute angle with the bedding, which is frequently indicated by bands of colour. The slates are much iron-stained, and in close association with grits and the remarkable crush-conglomerate' described by Mr. Lamplugh.

***"Diceyonema (Dictyograptus) sociale.* Salter.**

"Remains of not less than eight individuals were found lying in close apposition upon the surfaces of two narrow splintery slabs of slate. Two individuals are fairly well defined, and show clearly the bifurcation of the branches. Each consists of about six main branches which bifurcate twice, and are arranged parallel to one another in the close radiate order so characteristic of the species.

"Transverse filaments, or dissepiments, are not well defined, except in the case of the tertiary branchings where they are very oblique.

"On one slab, the individuals lie without any order as if drifted there; on the other, three individuals lie at equal distances apart and pointing in the same direction, and are at right angles to a specimen of *Dendrograptus flexuosus.*

"A direct comparison of the Isle of Man specimens with well-defined forms of *D. sociale* obtained from Borth, Tremadoc, Wales, shows a close similarity, extending even to the character of the rock, and the abundant presence of iron-staining in both.

***Dendrograptua flexuosus,* Hall.**

"Fragments of three individuals of this species are associated with those of *Dictyonema sociale* already described. The frond expands rapidly and consists of short flexuous branches which bifurcate regularly and at equal distances. As in the type, the first branchings are placed at an acute angle with each other, the last ones being fairly parallel. The agreement of these specimens with the description given of the species by Hopkinson and Lapworth is very close. They are too badly preserved to show the hydrothecte, but the regular bifurcation, the flexuous character of the branches, and the close correspondence of size are distinctive".

In spite of Mr. Bolton's confidence in his specimens as expressed in the foregoing descriptions, the writer, after having been permitted, by Mr. Bolton's courtesy, to examine them, still feels much hesitation in accepting the conclusions based upon them, and prefers to await further evidence before using them as stratigraphical guides. The supposed cast of trilobite, of which the somewhat too favourable figure in Mr. Bolton's paper has been taken from an impression in modelling wax enlarged four diameters, appears to have been found in the midst of highly sheared crush-conglomerate (see p. 66). Now, though instances are known, *e.g.,* in the Silurian rocks of Ireland and in the Carboniferous rocks of West Yorkshire, in which fossils have survived the disruption of the strata containing them, such instances have hitherto only been discovered where the parent rock is highly fossiliferous, while in the present case careful search in the unbroken strata which go to make up the crush-conglomerate' has failed to reveal any trace of organisms other than worm-casts '; and, on the other hand, the surfaces of lenticles of grit in the breccia are often marked and striated by shearing and strain-slip in a manner simulating organic structure. Hence it seems possible that the cast in question may be that of an exceptionally striated grit-fragment in the conglomerate.

The doubt as to the supposed graptolites, though not so strong, has still some weight. Mr. Bolton discovered his two specimens in the screes of a quarry which lies exactly upon the margin of the crush-conglomerate (see p. 59), where the pressures must have been intense, and where, though traces of contorted bedding still persist in the upper part of the quarry, the slate in the lower part of the section has been reconstructed, and mingled with fragments of broken grit-bands. On Mr. Bolton's two small specimens the graptolite-like markings are thickly spread, as if the fossils were abundant; but later searches in the same quarry by Mr. Bolton, as well as by the writer and others, have failed to reveal any further examples; and markings found by the writer on slate-fragments at this locality and at Gob y Volley [SC 37024 93829], a mile to the westward, which were at first thought by Mr. Bolton to begraptolites, have, as already mentioned, proved to be of inorganic origin when sliced and examined under the microscope. Search has also been made in several other localities where black carbonaceous or graphitic slate, such as often forms the matrix for graptolites, was observed — e.g., in the stream east of Slieau Monagh [SC 39632 90966]; on the coast at Gob ny Creggan Glassey [SC 29709 88878]; on the western slope of Greeba Mountain [SC 31848 81837]; on Dalby Mountain [SC 24065 77959], etc.; but up to the present with negative results. With regard to the supposed *Dictyonema,* it may be noted that this genus has not been recorded from the Skiddaw Slates of the Lake District, the lower part of which offer a probable correlation with the Manx Slates (see seq., p. 114–6). On the whole, therefore, it has been thought preferable to await further evidence before including either *Trilobites* or *Graptolites* in the fauna of the Manx Slates.

Petrography of the Manx Slates and of the Crush-Conglomerate

The following account of the petrographical characters of the Manx Slates, and the corresponding account of the igneous rocks given in Chapter 8., p. 296, are mainly based upon the work of Professor W. W. Watts. Before relinquishing his post on the Geological Survey to undertake his present duties at Birmingham, Professor Watts had made considerable progress in the petrographical examination of the Manx rocks collected during the course of the survey, and had also visited the Island to study their mode of occurrence in the field, with the intention of contributing a full account of the subject to the present memoir. Unfortunately, owing to the pressure of other work, Professor Watts has found himself unable to complete his labours, but has handed over to me his notes and descriptions c f a large number of slides, which have enabled me to prepare the following general account of the petrology of the rocks. Unless otherwise stated, the descriptions of slides given in the following pages are taken nearly verbatim from Professor Watts's notes.

General petrographical characters of the Slate series

As their field-structures would lead us to expect, the chief petrographical characteristic of the Manx Slates when microscopically examined is the extreme and intimate deformation which they have generally undergone, giving rise to structures on a minute scale in the 'grain' of the rock that are visible to the unaided eye in mass. Among these are the flaser or drag-structure, and the strain-slip or *ausweichungs* cleavage, which are often beautifully exhibited in slides prepared from the slate-rocks. In intimate association with these structures and apparently due to the same cause, there is usually some mineral alteration of the constituents of the rock, this being most marked in the finer sediments and least marked in the coarser. The predominant feature of this alteration is the more or less abundant production of sericite along the planes of movement, and the development of strain-shadows in the quartz, or sometimes its complete granulitization.

Besides these general effects, there is in certain districts a much greater degree of mineral alteration by which other new minerals make their appearance in the slates, sometimes in such abundance as completely to alter the original character of the rock, transforming it into a true mica-schist, occasionally garnetiferous.

This more severe metamorphism is of the type which petrologists usually regard as denoting thermal alteration by igneous rocks; but the field-evidence points to a very close relationship between the dynamic movements and the alteration of the rock; and, moreover, where local metamorphic effects of igneous intrusions are exposed to examination they appear to be independent of and separable from the wider regional effects.

This question as to the relative values of contact-alteration and of dynamo-metamorphism in the Manx Slates was one to which much attention was devoted during our survey, and a large quantity of material was collected for petrographical investigation, so that we hope eventually to be able further to elucidate the matter. Meanwhile a general outline of the problem with a few illustrative descriptions will be given in subsequent pages.

The usual petrographical character of the sedimentary rocks of the series may be gathered from the following descriptions of slides at the Geological Survey Office. The prefixed numerals are in all cases the reference-numbers attached to the slide in this collection.

Flags and Banded Slates

The first slide is from a fresh unweathered specimen of the Lonan Flags obtained in the Laxey Mine.

(E2521) [SC 43176 86367] Lonan Flags: From the 255 fathoms level of Dumbells Shaft, Laxey Mine.

Macro. Gritty phyllite, contorted and with strain-slip.

Micro. A finely-banded, slightly gritty slate, the elastic structure almost solely visible in the coarser bands, the finer being concealed in calc-mica-schist, or a phyllite almost solely made up of contorted sericite with little lenticles of quartz (original grains) and calcite. In these layers strain-slip occurs and is beautifully brought out by polarized light, when the sheeny structure is visible. The coarser rock consists of granules of quartz amongst mica flakes and small granules of calcite.

A few slides were cut from specimens of the slightly calcareous nodules of the Lonan Flags, in the hope that they might reveal traces of organisms, but none were found. The two following slides represent the average character of the nodules.

(E2811) [SC 39063 74736] and (E2810) [SC 39056 74732] Nodules in Lonan Flags, Douglas Head.

(E2811) [SC 39063 74736] *Micro.* A very fine angular quartz-grit with a calcareous cement; a little detrital mica is present and a good deal of fine secondary sericite decomposed felspar grains seem about as abundant as those of quartz.

(E2810) [SC 39056 74732] *Micro.* Decidedly coarser than above, with a larger proportion of calcite matrix; tourmaline, epidote, felspar in abundance, chlorite, slate fragments and quartz-granulite fragments.

An interesting point in connection with these nodules is that they sometimes appear to show 'selective' metamorphism, being altered to a greater extent than their gritty matrix, probably on account of the original difference of composition. This was especially noticed in a nodule from the flags at *Gob ny Ow,*<ref>Place names in italics are those not given on the one-inch map </ref>Port Cornah, the slide (E2510) [SC 47537 87974] showing a development of garnet with epidote, sphene and zoisite. The matter will, however, require further investigation.

The next slide is from a hard band in the crushed slate bordering the crush-conglomerate of Sulby Glen. It is a good example of modification by movement, with comparatively unimportant mineral alteration.

(E2422) [SC 37837 89387] Hard slate: *Tholt-e-Will* glen, 200 to 300 yards above hotel.

Micro. Very much crushed phyllite; all the particles of lenticular shape, with good strain-slip and shearing-structure and free development of satiny sericite. The coarser portion is not traceable as a band, but is a good example of phacoidal structure. The twisting of the lenticles is along the foliation, the contortion of which produces the strain-slip, so that except the discontinuity of the coarse portion there is no other evidence of more than one movement, which must have been an intense one.

Fine and coarse grits

Of the four following slides, given as examples of the finer grits, the first (E1812) [SC 28610 66794] is from an unweathered thin sandy band in the slates of Langness (probably Lonan Flags, see p. 178), obtained from a mining shaft; the second (E2514) [SC 43307 85790] is from a much thicker band at the margin of the Agneash Grits, obtained from a deep mine in the Cornah valley; the third (E2814) [SC 31678 81541] is from an isolated gritty band in the slates of the middle of the Island; and the fourth (E2387) [SC 47214 90795] from the thick band of Magher-e-breck, in the N.E. of the Island, described at p. 140, which is included with the Agneash Grits.

(E1812) [SC 28610 66794] Grit from mining shaft at Langness Point.

Micro. A medium quartz-felspar grit with some slate fragments; somewhat crushed, but without much new mineral development; grains fitting together and not much ground-mass except calcite.

(E2514) [SC 43307 85790] Grit, 3 ft. band; from bottom of shaft, 174 fathoms, North Laxey Mine.

Micro. A fine, even, angular, quartzose grit with a cement of carbonate of lime (ophitic).

(E2814) [SC 31678 81541] Slaty grit: Greeba Mtn., 100 yards S.E. of slate-trial.

Micro. A very interesting slide of a much crushed quartz-grit, in which the fragments have a marked linear arrangement; at right angles to this is a slightly irregular strain-slip which, crossing the other structure, makes the fragments phacoidal, and they tail off into fibrous white or pale brown mica; there is a good deal of sericite and some chlorite between the grains which are very close-packed, giving a sort of quincuncial pattern to the slide; very few rock-fragments.

(E2387) [SC 47214 90795] Pale grit; quarry 250 yards N. of Magher-e-breck, Maughold.

Micro. An ordinary quartzose grit with angular grains very close-packed and little matrix in which chlorite and sericite are developed. There is no visible evidence of secondary quartz-growth as in the quartzites. It has been somewhat crushed. Quartz when smaller than 0.03 inch, not rounded; many grains very "dirty"; one grain of zircon; sometimes several adjacent grains behave as an optical unit.

The following is the description of the curious boss or lenticle of quartz-rock in the west of the Island, south of Kirkmichael, described on p. 137.

(E2102) [SC 29434 88190] Quartzite; crag, west side of road 120 yards N.N.E. of branch to Skeristel Beg, Michael.

Micro. Almost the whole of the fragments of this are quartz' but there are a very few of felspar; not much alteration of the ground-mass: some of the grains well rounded, and ground-mass not in great plenty; a little detrital mica, both brown and white.

The next two slides, one from the southern coast and the other from the western interior, afford good examples of the effects of shearing upon grit-bands associated with slaty rocks.

(E1984) [SC 22659 68389] Sheared quartzo-felspathic grit; outer Cronnag Rock, Bay ny Carricky.

Micro. Quartzose grit with some felspar, but no rock-fragments; crushed ground-mass crypto-crystalline with sericite.

(E1969) [SC 25304 78116] Sheared bluish-grey grit; Glen Dhoo in Glen Rushen.

Micro. A quartzose grit with angular fragments, much crushed, and with micro-flaser structure; the grains all "tailing" off into the matrix, with sheaves of mica; the ground-mass intensely crushed, with banded structure in which layers rich in granulitic quartz, sometimes becoming fairly coarse, alternate with layers rich in sericite, which is very freely developed.

We have next to deal with the group of coarse-grained or pebbly grits. These besides exhibiting many instructive crush-phenomena, are especially interesting in sometimes containing small fragments of andesite' referred to on p. 49, along with other rock-detritus derived from land which was undergoing erosion during the deposition of the grits, thereby furnishing our only information respecting that land. The first three are from the south-eastern coast; the fourth (E1967) [SC 21717 75404] from the west coast; the fifth (E2131) [SC 28057 85912] from the western slope north of Kirkmichael; and the sixth (E2425) [SC 44063 92379] from the northern part of the massif.

(E2812) [SC 33302 70250] Pebbly grit: St. Ann's (Santon) Head.

Micro. A coarse grit, mainly quartzose, but with fragments of fine grit and slate in it. The quartz is very much shattered, having undulose extinction, brecciated, with the unseparated portions divided by very fine quartz completely granulitized, and sometimes with a structure resembling a rude microcline twinning developed in it.

(E2813) [SC 35005 72869] Sheared grit: west side of *Keristal* near Port Soderick.

Micro. A finer quartz-grit, not so much crushed as usual; several rock-fragments occur, and, amongst them, several slivers of slate and one or two large angular fragments of it which are squeezed out at their ends into fine shreds. They appear strangers to the rest of the rock and may have been enfolds, though there is nothing visible to prove this. I think it rather more likely they may have been clay-galls, torn up by subsequent rock-movement.

(E1959) [SC 30215 69300] Coarse dark bluish-grey grit: north side of Cass-ny-Hawin Head.

Micro. A coarse grit in which quartz is predominant, all the grains being markedly angular; some of them having certainly been derived from the porphyritic quartz of a quartz-porphyry. They have suffered much from movement since they were embedded in the grit, and they show first undulose extinction, then partial, and finally complete granulitization. Detrital grains of felspar mainly converted Into a micro-aggregate, iron-ores and muscovite are common) besides these, there are large and small grains of slate, granulite, and at least one fragment, and probably more, of a fine-grained (non-porphyritic) felspathic *andesite.* The ground-mass is fine-grained and detrital, and has sericite abundantly developed in it.

(E1967) [SC 21717 75404] Dark bluish-grey grit showing linear stretching: beach under Glion ny Goayr; S. of Niarbyl Bay.

Micro. This grit contains a much larger proportion of rock-fragments and a smaller one of quartz than the others examined. The latter are in most cases strained, crushed, granulitized, and broken, and the whole rock has evidently suffered much from crushing. Slivers of very fine dark slate are conspicuous. They are intensely contorted and dragged into the finest interspaces in the grit. The rock appears to be a variation of the crush-conglomerate in which there was not enough shaly matter to form a flowing matrix, but a preponderance of hard material to make a *crush-grit.*

(E2131) [SC 28057 85912] Crushed coarse ashy-looking grit: small quarry 200 yards E.N.E. of Creggan Mooar, Knocksharry.

Micro. A much-crushed quartzose grit, a few of the grains being rounded; rock-fragments not so common as in (E1967) [SC 21717 75404]. Slivers of slate, contorted, and at least two undoubted fragments of *andesite.* Sericite is the most abundant matrix-mineral. Apparently originally a grit, which is approaching the crush-conglomerate condition.

(E2425) [SC 44063 92379] Coarse quartzose grit: Braid Foss, Glen Auldyn, E. of B.M. 5409.

Micro. This appears to be an advanced condition of the state of things existing in (E1967) [SC 21717 75404] The crushing has been carried so far that the boundary between grains and,aroundmass is not a very definite line when seen under non-polarized light, while with polarized light the edges of the grains are seen to become highly granulitized and to shade off into the 'matrix'. Simple quartz grains, not more than 0.05 inch in diameter; larger grains are granulitic aggregates up to 0.1 inch diameter.

Slates

The two following slides were cut to investigate the supposed organic (graptolite) structures referred to on p. 94; besides showing the inorganic character of the structure in both cases, they will serve to illustrate the general characters of the less altered slate-rocks of the series. The localities are on the northern margin of the massif, respectively west and east of the mouth of Sulby Glen.

(E2846) [SC 37043 93806] Slate with supposed Graptolite (see p. 94). Crag on summit of Gob y Volley.

Micro. This is a cleaved rock with perfect lineated structure, every fragment being elongated with the cleavage and somewhat phacoidal in shape, NI hile it is sheeny throughout with a mat of sericite. Thin contorted layers with rather larger micas wander across the slide, pinched off in places and making a low oblique angle with the cleavage. The supposed fossil is a quartz-vein, on one side of which the cleavage is beautifully frilled and traversed by a strain-slip. The "D*ictyonema"* is undoubtedly the outcrop of this structure.

(E2847) [SC 39108 94112] Slate with supposed Graptolite (see p. 94): west quarry, Cronk Sumark, Sulby.

Micro. The rock is a slightly gritty phyllite with all the minute particles of quartz, etc., phacoidal and with fair strain-slip running about at right angles to the general lineation as indicated by the sheeny development of sericite. The rock has been profoundly affected by movement which has made itself felt pretty well all through the rock about evenly. The rock splits more easily along the lineation than along the strain-slip.

Crush-conglomerate

The following account of the petrographical character of the crush-conglomerate and its incipient stages is reproduced almost *verbatim,* with some omissions and slight alteration of arrangement, from Prof. Watts' notes on the subject in our joint paper, "The Crush-conglomerates of the Isle of Man", published in Quart. Journ. Geol. soc., vol. li. (1895), pp. 588–596. In this paper Prof. Watts' descriptions were illustrated by two plates, containing ten figures of the slides, which should be consulted by the reader.

"It is very rare to find in the Manx Slate series any sedimentary rocks, except those of very coarse grain, which have not been crushed and sheared by earth movements. Outside the principal zone of crush and brecciation the rocks still show their original elastic structure, but they begin to show, by much deformation, shearing, and cleavage, the influence cf those movements which have produced such grand results in the great crush-zone itself. These rocks may be regarded as the raw material out of which the crush-conglomerates have been manufactured.

"The microscopic observations appear to confirm in all essential points the deductions drawn from the field evidence. They even enable us to go a little further on some points: To trace the disintegration of the grit bands; to watch the process of 'pebble-making' on a small scale; to see the breaking up of the 'pebbles' themselves into miniature 'crush-conglomerates'; to follow the erosion of the 'pebbles' into single grit-particles involved in slate; and, finally, to state the amount of secondary change which the rocks have undergone.

"It is not proposed to give a full microscopic description of each specimen, only of those which are of prime importance, merely referring to the principal features which are to be observed in the other specimens.

"The original sediments are best illustrated by the following specimens:

(E2403) [SC 34669 90105] Crushed grit: Glen Dhoo Stream, nearly 2 miles west of Sulby Glen.

Micro. A dark-grey, compact grit, with veins running parallel to the shear planes. Microscopically this grit is seen to be made up chiefly of quartz-grains with a smaller quantity of felspar and a few bits of detrital mica and tourmaline. The largest grains measure 0.02 inch in length, but the average size varies from 0305 to 1:007 inch in length. In part of the slide the grains show the effects of crushing, and have become phacoidal in shape; the shear planes which curve round them are marked by sericite-flakes. The matrix in which the grains are set is a very fine-grained aggregate of quartz-grains, calcite, and very minute scales of sericite the latter mineral from its relation to the fragments, occasionally encroaching on even the larger grains, must be secondary product.

(E2427) [SC 35259 90546] Close-grained grit; same locality as last.

Micro. This is a still finer grit, which is more crushed than that last described, so that all the grains are phacoidal in shape and are set in a plexus of minute flakes of sericite and pale-brown mica. It has evidently undergone some chemical change.

(E2414) [SC 35245 90513] Grit cut into 'pebbles', which are only just being disconnected (see p. 132): eastern side of Glen Dhoo stream, opposite farmstead.

Micro. The two slides cut from this specimen are extremely instructive, as they show fine puckered slate in contact with fine-grained grit, just the kind of junction which one would expect to throw light on the progress of the crushing. The junction is irregular, rounded promontories of the grit projecting into the slate, and fine crushed shreds of slate running into the gulfs and bays between. Occasionally bits of grit are quite isolated from the main mass, and form as it were islands in the slate. Where this (wears the straits of slate are highly puckered, and often have a fine strain-slip cleavage developed in them, which does not, however, penetrate into the grit. These divisional planes vary in direction in different parts of the slide and appear to be here merely a local phenomenon, due to the pinching of the slate in the jaws of the grit. It bears no relation to the incipient separation of the grit promontories into islands, which must be attributed to another and earlier movement.

The dividing of the grit band into fragments can almost be watched in the two slides cut from this specimen. The *disjecta membra* vary in size, from fairly large patches to those which contain only a few grit-particles, and even these are beginning to go to pieces, so that one is compelled to believe that many of the separate grit-particles in the slate, which are evident strangers there, have been floated off from the grit-band, and are the ultimate term of the disintegration.

"The Crush-Conglomerate.The slides from the crush-conglomerate belong to two groups: (a) those which are taken from individual fragments or 'pebbles', generally the larger ones, and (b) those which show the microscopic aspect of the conglomerate itself and its smaller 'pebbles'.

"A remarkable feature about the crush-rocks is, that in spite of the immense amount of mechanical disturbance which they have undoubtedly undergone, they have suffered comparatively little mineralogical change. The slate of other areas presently to be described exhibit locally much more mineral change than has been detected in the zone of crush, so that the amount of change found in particular specimens of the conglomerate, such as (E2412) [SC 36798 88460], need not necessarily be connected with the actual brecciation. A specimen to be subsequently described will show that the conglomerate itself has sometimes suffered from a later thermal metamorphism.

"Two specimens and four slides of the crush conglomerates' have been chosen for description:

(E2413) [SC 38581 92569] Band of pale breccia in darker breccia. Lowest crags on eastern side of the Sulby river, at Cluggid junction.

Macro. This specimen breaks with a slabby fracture, which is seen on the cut surface to correspond to a banding of the specimen, at first resembling bedding. This direction corresponds with a grit-band traversing the fine slaty material in the middle of the specimen. Parallel with this, on each side run one or more bands of conglomerate, generally consisting o light-coloured fragments in a darker matrix; some of the fragments are, however, darker than the matrix. Traversing all these bands at an angle of about 30° or 35° runs a close cleavage, the planes being lead-coloured and marked by a deposit of exceedingly line chloritic matter. This is the " shear-cleavage " previously described (p.78), and its intersection with the slabby structure produces a streaking on the surface of the latter. The slide described is cut at right angles to all three structures.

Micro. In the slide, the fine band is seen to be a grit made up of angular quartz-grains varying from 0.002 to 0.001 inch in length. The coarse bands are conglomeratic, and consist of fragments from 0.100 to 0.125 -inch long, set in a slaty matrix; this frequently contains grit-particles set in a fine-grained fibrous material, which appears to be chiefly chlorite. A fine slaty substance of this description makes up the fine dark laminm which separate the conglomerate-bands from the grit and from each other.

The fragments in the conglomerate-bands are made up chiefly of grit similar to that just described; of still finer grit; and of slaty rock in which mica is rather freely developed. No fragments of igneous rocks, or indeed of any other rock than those just mentioned, have yet been discovered in the crush-conglomerate.

Signs of great crushing are at once observable throughout the slide; faulting, contortion, and cleavage are all present, and the quartz-particles in the grit, and especially in the slate, are nearly all phacoidal in outline.

Turning next to the divisional planes to be seen in the slide the following phenomena are important. Taking the main grit-band as a direction of some significance, and without stopping to inquire exactly whether it represents bedding or what not, we find that it bears no relation to other very important structures of the rock. The "shear cleavage" is well developed throughout the rock, and especially in the finer-grained portion. It is a true contortion-cleavage, and it appears to be the same as *"ausweichungsclivage"* and the "*strain-slip*" cleavage of Bonney. This structure, when best developed in the slaty matrix, is at an angle of 30° to the general direction of the grit-band it runs in the same direction in the slate-fragments. It is noteworthy that it isnly in such fragments as have their laminar at right angles to the strain-slip direction that the structure is at all characteristically shown; these alone show contortion clearly. Those otherwise orientated are merely crushed, and do not display so clearly the reason for the cleavage-planes which traverse them. The difference of 30° in the directions of the lineation of the rock and of its cleavage shows that the latter structure is to some extent independent of the former.

That the "shear-cleavage" has acted on the rock when it was a conglomerate is evidenced by two facts. When an edge of a fragment is at right angles to the shear-cleavage the fragment and the matrix are seen to have been contorted together and even faulted. The shear-cleavage is perfectly developed only in the slaty matrix and slate-fragments and very imperfectly in the gritty fragments and bands. When, however, there has been exceptional movement and crush, the planes travel from the coarser constituents to the finer.

When, however, an attempt is made to assign each structure in the rock to the earlier or later movements very great difficulties crop up, chiefly owing to the tendency there would be for the shear-cleavage to follow the lines of weakness initiated by the first crushing of the rock.

That the "conglomerate" is cataclastic and not epiclastic might have been, I think, predicted from the examination of the slide and specimen. In the first place, the nature of the conglomerate—slate and grit-particles in a slaty matrix—is, to say the least of it, a very unusual one; it is difficult to see how such a conglomerate could result from a deposit in water. In the next place, the absence of extraneous fragments is most suggestive, all the fragments being such as are found bedded in the Manx Slate series. Further, the examination of the shape of the fragments leads to the same conclusion. Working along the slide from right to left, one seems to be following a bed of grit; first it is slightly bent, next it is more sharply folded and almost faulted, then nearly pinched off by a sharp wrench, and at last it is actually torn off, and one realises that one has been tracing a fragment and not a band; or, rather, that one is watching the actual method of forming a fragment out of a band. This may be seen again and again, and in places smaller bits of such fragments will be seen wrenched off and still standing in close proximity to their parent masses (compare p. 67, (Figure 12)).

Few of the fragments in the slides studied are entirely rounded; usually one or two corners are rounded off; while the rest are sharp and angular. A peculiar feature is that some fragments are rounded and 'pebbly' at one end, while at the other they have behaved as matrix and have had other 'pebbles' jammed into them. In one case where this is observable the reason is obvious; the 'pebbly' end is coarse-grained and resisting, the 'matrix' end is made of finer, softer material.

Without going into further minute detail, the appearance of the slide may be thus summed up: Fragments are bent, twisted, broken, faulted, and floated off from one another; one fragment indents another, or has another bent or broken over it; wisps and shreds of matrix are caught up amongst adjacent fragments, torn, faulted, and teased out, or rounded and made into 'pebbles' where there is more space for them to move; the matrix and fragments are in places so inextricably mixed up that it becomes impossible to discriminate between them.

(E2412) [SC 36798 88460] Crush-conglomerate in Druidale stream N. of Close.

Macro. A dark slaty rock or phyllite containing fragments of pale grit. The rock splits into slabs, which are at an angle of about thirty degrees to the minutely puckered foliation; these slabs are defined by the "shear-cleavage". The elongation of the fragments is in the plane of foliation. Owing to the less marked character of the second movement this specimen is very valuable in showing the origin of the conglomeratic structure.

Micro. Three slides have been prepared; two are in the plane of intersection of the slip strain with the contorted foliation, and almost at right angles to the elongation of the fragments; they consequently show only the strike of the divisional planes, which appear as cleavage cracks. The slide has a damascened appearance, owing to the direction in which the mica-folia are cut, and the matrix of the rock is rich in sericite, which is clearly a secondary product. The fragments do not show any decisive orientation in this slide nor do they seem to be in any way related to the foliation planes.

The other slide (E2412C), however, is cut at right angles to the cleavage and foliation, and parallel to the elongation of the fragments, so that it is very instructive. The phyllitic matrix is rich in sericite, and is well foliated. The folia are in wavy bands, with the development here and there of strain-slip cleavage-planes which traverse matrix, or fragments, or both, according to the nature of the material of which they are made; such planes define the slabby surfaces of the hand-specimen. The grit- and slate-fragments are all phacoidal in outline, and are drawn out along the foliation planes, folded, torn, and enwrapped by the folia of the matrix. Fragments are occasionally, but rarely, cut off abruptly, and even when this is the case with one end, the other is frequently drawn out into the matrix. The nature of the fragments and the absence of any extraneous types of rocks must be relied on here to prove that the brecciation has occurred *in situ.*

The whole rock has undergone more mineral change than the specimen (E2413) [SC 38581 92569] last described.

"Pebbles" in the Conglamerate — The fragments exhibit a great uniformity, and nothing has hitherto been found in them but the grits and slates. Now, the field evidence has shown that the location of the brecciation has been settled, in the majority of cases, by the existence of thin grit-bands in slate, forming a transition in the series between the main grits below and the slate above. The fragments found in the crush-conglomerates could all be matched either in this transition series or else in the main grits or slates. Although the importance of looking out for the existence of 'fragments and other strangers was fully recognised and a number of specimens were collected to be tested with this point in view, not a single fragment of any other rock has been up to the present detected. To enforce this point the following four specimens of grit fragments have been selected for description:

(E2409) [SC 40637 93019] From grit-block 14 feet across, in crush-conglomerate: Narradale stream, W. 5° S. of 838 ft. level on Sulby Road.

This is a fragment from the largest individual block hitherto found in the conglomerate. The block, which was 14 feet in diameter, as described at p. 60, had its outer face smoothed and striated. Within the surface-layer the rock has not been affected by crushing, as is shown by the character of a slide taken from beneath the crust of the block.

Microscopically this slide is seen to consist chiefly of quartz-grains, the largest of which are a little over 0.02 inch in diameter. Some of these are rounded and marked off from the matrix by a deposit of dark material. The smaller grains, which are angular, vary from 0.01 to 0.005 inch in diameter. One of the grains contains a felsitic inclusion as though the quartz had been derived from a quartz-porphyry, and a few of the grains answer to the matrix of such a rock. Very few grains of felspar, and one or two of detrital tourmaline, are present. The matrix is quartzose, with a little sericite and much chlorite. The rock shows no signs of crushing or shearing, and there is practically no new mineral development in it.

(E2410) [SC 36934 88466] Grit-inclusion in conglomerate: Sulby Glen under Close.

Micro. The finer grits of this and another similar slide have suffered much more from crushing. The grit contains abundant grains of felspar, as well as of quartz and muscovite, together with particles of iron-ore Many of the quartz grains 'are composite, and have been derived from a granitic or gneissose rock. The grains of felspar are frequently dusty with inclusions and decomposition-products interiorly, but are surrounded by a ring of water-clear felspar in optical continuity with the interior.

The grains average 0.006 inch in longest diameter; the fine matrix is made up of quartz, twinned felspar, and muscovite. The smaller grains are arranged with their long axes parallel to the plane of movement, and the matrix is chiefly occupied by folia of sericite which wrap round the grains and are evidently a secondary product due to the movement that the rock has undergone. 'lie patches of iron-ores are broken to dust, and spaced out in lines parallel to the movement.

(E2411) [SC 37171 88956] Grit-inclusion in crush-conglomerate; 60 yards N. of Druidale junction of Sulby River.

This specimen is of great interest, because, while collected as a single fragment in the conglomerate, it is quite evident that a little further crushing would have converted it into many fragments with 'matrix' material between them, and would have incorporated them in the body of the conglomerate.

Micro. A coarse, dark, quartzose grit, in which some of the quartz-grains axe opalescent. The original sedimentary arrangement of the materials of this rock is entirely lost, and the structures which are left are merely those due to movement. The rock has evidently been a coarse quartz-felspar grit in which quartz predominated, but fragments of slaty and felsitic rocks were also present. The quartz-grains are phacoidal in outline; they often possess undulose extinction, and they have at times an appearance of twinning. They are often made up of one, two, three, or even more inosculating portions, and they can be seen beginning to divide, the separated portions becoming filled with granular quart; and every transition down to complete granulation can be followed up step by step.

Even when a grain as a whole has withstood the crushing force, its edges, and especially its ends, pass into a granular quartz with muscovite. Actually inside the grains granulitic patches occur, which were at first mistaken for felsitic matter, but which are now regarded as the products of crushing anti granulation. Fragments of striated felspar have been treated in similar fashion, and slaty fragments are flattened and dragged out amongst the more resisting fragments.

Metamorphism of the Crush-Conglomerate

(E2418) [SC 40144 94293] Baked crush-conglomerate: Fast side of quarry adjoining dyke, [(E2390) [SC 40135 94279], see p. 305], Kerroo Mooar.

Micro. The fragments in this rock are made of quartzose grit rather coarser than the rest of the rock, which consists of very finely granular quartz, with some felspar, and abundant muscovite flakes not arranged in any definite direction. The fragments have phacoidal outlines and some of them are full ofpyrites. The abundance and size of the mica seem to indicate that contact-alteration has taken place, and its irregular arrangement is quite independent of the shearing of the rock. As might have been expected, mica is much more freely developed in the slaty matrix than in the grit-fragments.

The details of the section from which the above specimen was taken are described at p. 59.

Metamorphism of the Slates

We have next to deal with the mineral structure of the slates in different phases of alteration, but, as previously stated, this branch of the subject will be only tentatively discussed at present.

In the immediate neighbourhood of the granitic masses, the sedimentary rocks are rendered more or less crystalline, by the development of new minerals, but the problem which yet remains to be solved is as to the condition of the rock just before the intrusion of the granites. It is clear that the strata had been folded and crushed at some time previous to the intrusion of the principal igneous masses; and if the regional metamorphism referred to on previous pages (pp. 70, 72) be really the result of dynamic movement, as the field-evidence appears to indicate, it it is probable that the granites were intruded into rocks which were already much altered. The attempt to disentangle the effects of these two supposed periods of alteration by microscopic examination has not hitherto been altogether satisfactory, though it, does not appear to be hopeless. In the field it was thought that an older schistosity could be detected, particularly in the vicinity of the old Cornelly mine (see p. 165), with the newer contact-alteration superimposed upon it, but this point has not yet been made out definitely in the microscope-slides.

Contact-alteration — Beforeseeking to discuss the regional alteration, it will be advisable to give a few notes on the mineral condition of the sedimentary rocks in the immediate proximity of the larger igneous intrusions.

The Dhoon Granite, which comes up, apparently with steep walls, through sandy flags not particularly susceptible to mineral change (see Chapter 8., p. 311), causes, so far as we can judge from the exposures (pp. 142–4), very little alteration of the country-rock until we are within a few yards of the actual junction, and even then the alteration is not excessive, as the two following slides will show.

(E2489) [SC 45954 86713] Lonan Flags, altered: 3 ft. from junction with granite: quarry at Kionehenin, Dhoon.

Micro. This rock is a fine quartzose grit with an abundant development of pale greenish mica, slightly pleochroic; associated with this is a brown mica, which increases in quantity in one part of the slide; iron-ores, and a little zircon. Beyond the nature of the mica there is not much evidence either of dynamic or contact metamorphism.

(E2490) [SC 45924 86663] Lonan Flags, altered: 2 inches from junction with granite; quarry at Kionehenin, Dhoon.

Micro. This slide shows a good deal of contortion, which is especially indicated by the presence of a coarsish grit-band now quite granulitic and a good deal sheared. Along its margin a certain amount of brown mica has been formed, which is set amongst somewhat elongated grains of granulitic quartz; at the corners of the grit-folds, too, there is abundant sericite in the form of ' tails.' The rest of the rock is a very fine grit with abundance of the greenish mica and sericite, muscovite in larger grains, iron-ores, and but little brown mica; a few bands are much contorted and quite sheeny, and in places tourmaline is well-developed. Judging by the appearance at the edges of the coarser bands, the alteration, with the probable exception of the tourmaline, appears to be as much the result of dynamic action as of thermal action. At one spot a few crystals of triclinic felspar occur.

Conditionssimilar to the above obtain in regard to the sedimentary rocks surrounding the Oatland Granitite, which is intrusive upon Lonan Flags of a somewhat more argillaceous type (p. 185).

(E2914) [SC 32612 72454] Baked Flags: N.E. side of Oatland intrusion, near contact.

Micro. This rock is banded, alternately coarser and finer gained; the coarser bands show elastic grains of quartz set in an aggregate of minute mica-flakes which are probably of secondary origin; the fine bands are spotted, the clear spots consisting of white mica with an occasional particle of quartz, the darker network in which the spots are set consisting mainly of chlorite. A banded and spotted hornfels.

The Foxdale Granite, however, which is intruded into rocks of a slaty character (p. 165), and, moreover, is known to shelve gradually downward from its outcrop for some distance (p. 506–7), has a wider halo of alteration, though even this is apparently limited to a few hundred feet at the most, and is insignificant both in extent and in the degree of mineral change when compared, for example, with the halo surrounding the Skiddaw Granite of the Lake District. But there is a large tract of highly-altered slate—indeed, a true garnetiferous mica-schist — lying not far to the northward and north-eastward of the granite. This tract has its centre a little over a mile distant from the visible margin of the granite, and the alteration is believed to be of the regional type, in spite of certain facts which might be taken to indicate a direct relationship with the plutonic intrusion (p. 165). Leaving this point for the present, we give the description of two slides cut from specimens of slate close to the granite outcrop.

(E2889) [SC 29767 77345] Junction of granite with slate: Renshent, w. of Eairy, near Foxdale.

Micro. This is a granitite with altered biotite, in contact with a garnetiferous biotite-schist. The granite bears a little tourmaline and in the slate at the margin there is a mineral like cordierite.

(E2803) [SC 28636 77956] Altered slate, in or near lode, in S. cross-cut of 170 fm. level, Potts Shaft, Foxdale Mines.

Micro. A tine-grained white-mica-phyllite without garnets; there are augen of a mineral with good edges and approximately hexagonal outline made up of an even and very minute aggregate of highly polarizing fibres; this may be an approach to the formation of cordierite.

The majority of the intrusive dykes which traverse the slates are too narrow to have exerted much metamorphic effect; but the broader examples, whether acid, intermediate, or basic, have had more influence in this direction, and are usually margined by a narrow rim of baked and splintery slate. This kind of alteration may be best studied in cliff-sections where the broader dykes are exposed.

The boss of diabase at Poortown (p. 156) has this baking effect in a marked degree, as is well seen in the small quarry at its eastern edge.

Regional Metamorphism — The area affected by the regional type of alteration is roughly indicated on the sketch-map, (Figure 29), p. 84. Its limits cannot be sharply defined, as the metamorphism varies considerably in intensity from place to place, and appears to be essentially only a local enhancement of that slight sericitic alteration which affects the whole mass of the slates. This enhancement takes place, however, mainly within a rude belt running parallel to the central stratigraphical axis of the island, and is chiefly prevalent in the banded strata of transitional type which lie between the Barrule Slates and the Grits on the south-eastern side of that axis. Starting at the N.E. corner of the massif,this belt may be traced south-westward, with the strike of the rocks, from the vicinity of the coast near Maughold Head, into the interior along the line of the upper Cornah Valley and the main ridge of Barrule Slates; past Snaefell and Beinn-y-Phott to the central valley near Greeba; across that valley into the broader and more highly altered schistose tract lying northeast of the Foxdale Granite; and thence to the upper reaches of the Silverburn Valley, beyond which its further prolongation is uncertain. It has already been noticed (p. 70) that the position of the belt on the south-eastern side of the structural axis is in many respects analogous to that of the belt of crush-conglomerates on the opposite or N.W. side, and involves the same set of rocks. This correspondence can scarcely be accidental, and it seems conceivable that the differential movements to which these beds were peculiarly exposed (p. 70) led to the production of the crush-conglomerate on the one side, where the superincumbent load was least, and on the other side to a more intimate change of mineral character, where the compressive force was too great to permit of rock-brecciation (p. 76). Whether from this cause or another, the banded slates of the altered zone nearly everywhere show, under the microscope if not to the naked eye, a new development of small mineral crystals, including brown mica, garnet, tourmaline, chloritoid, ilmenite, etc., in addition to the usual sericite; and not only are the slates thus altered, but also the older igneous dykes, especially those of 'greenstone', traversing the belt (see p. 308). The slide is usually most altered and its new minerals largest and most conspicuous in the immediate vicinity of grit-bands, quartz-veins, or other hard bodies; and the appearances suggest that this increased alteration is due to the increased crushing and friction developed along the junction of soft and hard masses.<ref>The alteration seems to be very similar to that recently described by Miss C. A. Raisin in her paper "On certain altered rocks from near Bastogne (Ardennes) " (Quart. Journ. Geol. Soc. vol. lvii. pp. 55–72), in which it is suggested that the patchy alteration may be ascribed to the action of hot springs. Lenticular grit-bands and quartz-veins would be very likely to imprison a small quantity of water, which, when superheated during the movements, might materially facilitate the alteration of the surrounding rock; but in the Isle of Man no evidence was observed that suggested the flow of hot water through the strata near the garnetiferous patches.</ref>

Within the limits of the zone, the alteration is least marked at the north-eastern extremity of the island, and increases inland. The following slide will show its character in the cliffs south of Maughold Head.

(E2416) [SC 49791 91324] Striped sandy shale; frilled and sheared. Traie ny Fallon, Maughold.

Micro.— The stripe of this specimen is a plane which has been minutely puckered and in the slide is seen to be crossed, at an angle of about sixty degrees, by a strain-slip cleavage in the slate-bands. In places the grit is torn off, and forms lenticles in the slate. Pale brown mica is developed along the planes of stripe in the slate bands, and it runs into the strain-slip planes in wavy surfaces. The amount of mica present here is very great, but there is much less in the grit-bands. A few colourless needles, which I take to be felspar, occur in the slate, and a few needles of tourmaline are also present. A great quantity of ilmenite in fine needle-like crystals occurs scattered quite irregularly all over the slide. It has no definite orientation. The shredding-out of the coarse beds is observable, but the fragments remain along the line of stripe.

Particulars respecting the exposures of similar 'spotted' slates in other places within the altered belt in this part of the island will be found in the chapter of topographical details (Chap 4), wherein also the later discolouration and decomposition of certain portions of the slate in the upper Cornah Valley, possibly by comparatively recent hot-spring action, are also discussed.

The next spot within the belt which needs description is in the vicinity of gnaefell, where the alteration has locally reached a more advanced stage. The peculiar interest of this locality lies in the fact that the altered slates occur on the flanks of the mountain at between 1,000 and 1,800 feet above O.D., and that the slates are not only dissected by deep valleys on all side, but are also penetrated by the shaft of a lead mine (p. 526), to a depth of about 1,000 feet from the bottom of the valley east of the mountain, equivalent to nearly 200 feet below the sea-level, with long drivings northward under the hill, without discovering any buried igneous mass adequate to cause the alteration. The nearest vssible intrusive rock, other than the usual small dykes, is the Dhoon Granite, the western edge of which lies over two miles distant to the eastward. The two following slides represent the altered slate of Snaefell:

(E2413) [SC 38581 92569] Altered Slate: small quarry 150 yds. E.S.E. of Snaefell Hotel; about 1,450ft. above o.d.

Micro. A black contorted fine-grained schist with crystals of gullet, with minute needles of a white mineral (1 ilmenite); the garnets are perfect rhombic dodecahedra. The rock is a *garnetiferaus mica-schist,* with beautiful but irregular strain-slip cleavage; it consists chiefly of the usual pale mica, slightly pleochroic, in wavy folia, separated here and there by lenticles of quartz, varying in size, and generally aggregated. There can, I think, be no doubt that this is secondary and deposited in the opening lenticles. (It is possible some of this may be felspar, but the mineral is much too small for identification there is, however, a tendency for it to assume oblong arid prismatic forms.) The knot-mineral is always garnet, in rhombic dodecahedra giving hexagonal sections, and each garnet is associated with one or more crystals of chlorite. The strain-slip ends up against the garnets. The garnets contain long needles withparallel extinction, the nature of which has not been determined, and the interiors of the crystals are often dusty. The ilmenite needles tend to arrange themselves parallel to the folia as far as possible, but they are longer than the bends and project through them. There is one shredded patch of grit in this specimen.

(E2415) [SC 39746 86926] Striped and puckered slate: roadside, S.E. side of Snaefell, 1350ft. above o.d.

Micro. This specimen shows alternate bands of grit and slate on its outer surface, and the microscopic slide gives an excellent example of the "cleavage-foliation" of Sorby. The strain-slip cleavage runs at right angles to the stripe, and the cleavage-planes are planes of foliation marked by a deposit of pale brown mica. Where the quartz-grains are large enough to be well seen they. have a phacoidal shape, but in the coarser bands the quartz is in complex grains arranged parallel to the foliation. There is a diversion of the cleavage-planes in traversing the grit bands. The rock is a mica-schist.

A good example of the patchy mode of occurrence of garnets in the slate is afforded in a small cutting on the electric-tramline on the south-west shoulder of Snaefell, about 900 yards northwest of the hotel on the high-road. Dark sheared slate, with steeply inclined bedding crossed by a nearly horizontal strain-slip cleavage, includes a band of hard sandy slate an inch in thickness, much spotted and altered, and for an inch on both sides of this band the slate is thickly crowded with clear red garnets, up to ¼ inch in diameter. Similar garnets are plentiful for about 6 inches farther, afterwards becoming gradually more thinly scattered, but are still visible on the north-west side, to a distance of 3 feet from the central band, though not so persistent on the opposite side.

(E2493) [SC 39194 87522] Garnetiferens Slate: tramline S.W. side of Snaefell, E. of B.M.. 1150′ 0″.

Micro. A phyllite with garnets often of a good shape: a little chlorite often developed in association vie the garnets.

In another cutting, where the tram line rounds the northern shoulder of the mountain a short distance below the summit, the highly-sheared slate adjoining a discontinuous quartz-vein contains numerous garnets, up to about inch in diameter; and the same conditions recur around the outcrop of another quartz-stringer in the craggy ground ¼ mile to the north-eastward. The garnets sometimes show signs of crushing, though their growth was evidently later than the principal shear-movement.

South-west of Snaefell, on the southern slopes of Beinn-y-Phott and in the upper reaches of the Baldwin River, associated with the altered slates there are a few curiously altered sheared dykes of greenstone, of which some account will be found in Chapter 8, p. 310.

Farther south-westward again, on the eastern side of Greeba Mountain not far below the summit, a remarkable and unusual change is exhibited by a schistose dyke of micro-granite, which shows a new development of garnet and chloritoid, apparently as the result of the regional alteration (p. 318).

Still following the same direction and crossing the central valley at Greeba, we find on its southern slope a pronounced alteration of the slates interstratified with grits, in the lower part of the crags of *Creg y Whualliam,* (p. 168). From this point southward the metamorphism becomes rapidly intensified, and expands over a broader area, the change being well displayed in the stream-beds of Cooillingill and Glion Darragh. Around the heads of these glens, the slate has been metamorphosed into a knotted micaceous schist studded with garnets and other minerals, and the intrusive 'greenstone' dykes are converted into actinolite-schists (p. 164).

This highly altered tract stretches southward for about half a mile, to the crest of the Archallagan rise, where it is exposed in two small old quarries; it then appears to fade gradually in this direction, and to merge into the halo of less conspicuously altered slate surrounding the Foxdale Granite; but this portion of the tract is poorly exposed. Westward, the highly-altered phase extends for about a mile, and the slates then revert to their normal condition. In the middle of the tract, at the head of Glion Darragh, where the metamorphism is most intense, a shaft of the old Cornelly or Townsend lead mine, previously referred to, has been sunk to the depth of 840 feet. At the depth of between 300 and 400 feet, the shaft passed out of the altered slate into a granitic rock closely resembling the Foxdale granite (p. 315), and the lower workings appear to have continued at the edge of an irregular pipe or boss of the intrusive rock down to the bottom of the mine (see p. 516 for details). This rock is not visible at the surface, and it is only from the accident of the shaft-section that we discover the existence of any massive igneous rock nearer than the Foxdale granite, 1½ miles distant, though the intervening ground is traversed by several small dykes, both acid and basic (p. 1(4). The presence of this concealed intrusion and the possibility of its underground extension to Foxdale seem at first sight sufficient to explain the metamorphism of the slates at the surface, but there are several considerations which weigh against this conclusion. In the first place, if the alteration be entirely due to the igneous rock it is curious that the same kind of alteration should not be found in the sedimentary rocks of similar composition which surround the outcrop of the Foxdale Granite; furthermore, the same type of mineral change, somewhat modified, is found in other places in the altered belt, sometimes, as we have seen, under conditions which preclude the possibility of a buried igneous mass within an appreciable depth; and again, there are indications, already alluded to, that the schistose condition was attained prior to the intrusion of the granite. With this statement of the complicated factors, this problem must be reserved for further investigation.

The following slides will show the structure of the altered slates of this area. Some of the altered dyke-rocks are described in Chap 8, p. 313.

(E2668) [SC 31096 79335] Altered slate: Cooillingill stream, 100 yds. above B.M. 380′ 8″.

Micro. Contorted mica-schist chiefly consisting of small flakes of brown and white mica with some larger crystals of brown mica usually set at right angles to the foliation.

(E2666) [SC 29795 78592] Altered slate: northernmost old quarry, Archallagan.

Micro. Quartz-muscovite schist with augen of garnets in all stages of passage into tangles of chlorite. This specimen proves that the round and hexagonal tangles of chlorite in other slides have been derived from garnets. Also large crystals of chlorite, generally arranged parallel to foliation: a smaller amount of brown mica.

(E2669) [SC 29246 79650] Altered slate: w. branch of Glion Darragh, N. side of Archallagan.

Micro. This is a definite augen-schist, the augen being of garnet, sometimes associated with crystals of brown mica and.in other cases of brown mica alone: few large chlorites. There is also another mineral in the augen, which has not been determined.

(E2894) [SC 29651 79586] Altered rock: spoil-heap of Cornelly Mine.

Micro. This is a muscovite-schist, well foliated and consisting of quartz, felspar and muscovite. It contains numerous large prismatic crystals of chlorite with straight sides and ragged ends, set sometimes parallel to, and at other times at a high angle, even at a right angle with, the foliation. There are other roundish or hexagonal patches of matted chlorite, round which there are augen of muscovite. All the chlorite contains minute colourless crystals round which there are pleochroic halos.

In another slide (E2673) from the same locality as the last, large garnets were still recognisable, though "eaten into" by quartz and chlorite.

Continuing the examination of the altered belt south-westward, we find indications in the southern slopes of South Bar-rule of its persistence at the same stratigraphical horizon; and reach another tract, of very limited extent, in which the metamorphism is conspicuously intensified, near the head of the Silverburn valley, 2¼ miles distant from the nearest outcrop of the Foxdale Granite, and without visible association with any other igneous intrusion. This is best seen in the gullies at Whallag, and Reash [SC 25559 74398], near the Castletown Waterworks Reservoir under conditions described in the next chapter (p. 169). The highly altered slate is here associated with thick bands of grit and strings of vein-quartz, and the mineral change is most pronounced in the immediate vicinity of these hard masses, where the slate is most crushed. The extent of the change may be judged from the following descriptions of slides:

(E2084) Altered slate: gully at Whallag, adjoining water-works reservoir.

Macro. A crumpled schist with layers of granular quartz separated by folia of white mica on which needles of schorl are recognisable.

Micro. The quartz-mosaic is made of grains with rectilinear edges in contact with one another and without any intervening substance, so that the elastic structure must be secondary. The folia are of tourmaline, bluish brown to pale yellow in tint. The crystals bend round the curves, and at the summit of the latter there is usually a development of coarse quartz-mosaic. Along the planes of much movement the quartz is laden with inclusions. A few small garnets occur.

(E2085) [SC 25357 74642] Altered slate: gully at Whallag, N.E. side of reservoir.

Macro. Crumpled sericitic quartzose schist, with fewer tourmalines.

Micro. Flattened phacoidal quartz grains set in layers of muscovite with much iron-ore dust; in other layers, a brown fibrous mineral occurs1 which is not isotropic but very faintly pleochroic and passes into an opaque brown substance; whorl in isolated needles.

(E2086) [SC 25354 74676] Altered slate: gully at Whallag, 40 yards above N.W. corner of reservoir.

Macro. A dark phyllite dotted with what look like rotted pyrites and a little very fine schorl.

Micro. Some clear layers of quartz with muscovite, alternating with layers in which the latter mineral is associated with the brown mineral described in (E2085) [SC 25357 74642]; in these are knots containing quartz (and possibly felspar ?); scales of graphite in plenty, imparting a dark colour to the rock; a few tourmalines, but no garnets.

(E2087) [SC 25121 74726] Altered slate: bed of Silver Burn 200 yards below top dam, Cringle.

Micro. Dark and light bands fingering into one another, both made of close quartz-mosaic, dirty with inclusions of graphite-dust; the darker layers have rods and plates of graphite in quantity; biotite in crystals, often across the foliation planes.

To the west of the Silverbum Valley, the ground across which the altered belt would pass if prolonged, is much obscured by drift, and yields no further information. If the belt extend to the western coast, it may occupy the great precipices north of Fleshwick, and is inaccessible to observation.

In reviewing the evidence, it is noteworthy that the greatest degree of alteration is attained where the planes of the dominant "shear-cleavage" are flat or nearly so, which again suggests relationship between the cleavage-producing movements and the metamorphism. It will be observed, also, on examining the transverse sections of the massif given on (Plate 2). that the altered belt lies near the centre of the synclinorial trough, where the rocks are likely to have been buried deepest and where the crumpling and packing of the more plastic beds has been most intense. It is, however, likewise the case that the central zone of the massif embraces the two principal intrusions of granite, and that the dykes connected with these granites, as shown in the sketch-map (Figure 29), p. 84, accompany this zone throughout the island and are not found beyond it. Fence, while the metamorphism cannot be satisfactorily explained by the intrusions alone, these may nevertheless have played their part in raising the temperature of the rock-mass and bringing it nearer to the critical stage. But the actual re-crystallization seems to have been in some way directly dependent upon earth-movement.

Age and correlation of the Manx Slate Series

It is natural that an attempt should have been made to correlate the slate-rocks of the Isle of Man with the Skiddaw Slates of the Lake District, their nearest analogues in geographical position and in lithological character; but, as already pointed out, the basis for this correlation is inconclusive, especially since the supposed identification of the Borrowdale Volcanic Series in the Island has proved unfounded (p. 26).

As previously mentioned (p. 27), I have myself made traverses of the Skiddaw Slates in the typical exposures on the mainland, in the hope of more firmly establishing the correlation; but beyond a general resemblance, such as might exist between any two tracts of Older Palaeozoic rocks of like composition, I failed to find any definite points of similarity.

Even if we allow the correlation in general terms, the absence, so far as is known, throughout the Island, of the characteristic fauna found in the upper portion of the Skiddaw Slates, seems to limit the possible equivalents of the Manic Series to the lower part of the Skiddaw group. Our knowledge of the Skiddaw Slates themselves, and especially of their lower portion, is still very imperfect; and in fact, as with the Manx Slates, oven their order of superposition has not been conclusively established. According tope Mr. J. E. Marr, who is our chief authority on the subject, the beds which have yielded most of the fossils appear to constitute only the higher portion of the series, and these "are folded in boat-shaped synclines amongst what is probably a very much greater thickness of older rocks, the palaeontology of which is practically unknown<ref>J. K Marr, "Notes on the Skiddaw Slates", Geol Mag., dec. iv., vol, i. (1894), pp. 122–130.</ref>. This uppermost "graptolite-bearing portion of the Skiddaw Slates" has been provisionally classified by Mr. Marr as follows:

2d.Milburn Beds = Uppermost Arenig or Lower Llandeilo.

2c.Ellergill Beds.

2b. *Tetragraptus* Beds. Upper,with *Didymograptas* nanus./Lower

2a. *Dichograptus* Beds.'

1. *Bryograptus* Beds = Tremadoc Slates.

Hence if we accept the classification which includes the Tremadoc with the Upper Cambrian, even the upper fossiliferous part of the Skiddaw Slates ranges downward through the lowest horizons of the Lower Silurian into the Upper Cambrian, with still a great mass of underlying strata of higher antiquity. Although on the maps of the Geological Survey the tracts of Skiddaw Slates are all coloured as Lower Silurian from lack of any practicable means of differentiation, we find that Clifton Ward, who was mainly responsible for the mapping, fully recognised their downward extension into the Cambrian,<ref>"The Geology of the Northern Part of the English Lake District", Mem. Geol. Survey, p. 47.</ref> and in correlating them with the rocks of North Wales, proposed the following divisions<ref>"On the physical history of the English Lake District", Geol. *Mag.,* dec. ii, vol. vi. (1879), p. 124.</ref>:

Arenig Slates, Lower Silurian.

Arenig Grit, Lower Silurian.

Tremadoc Slates, Cambrian.

Lingula Flags, Cambrian.

Similarly, Prof. H. A. Nicholson, though at first considering the Skiddaw Slates to be altogether of Lower Llandeilo age<ref>"An essay on the Geology of Cumberland and Westmorland". London, 1868.</ref> afterwards placed them provisionally in the Upper Cambrian.<ref>"A Manual of Palaeontology". 8vo. Blackwood & Sons, 1872, p. 513. </ref> If, therefore, the Manx Slates were deposited in the same basin of sedimentation as the Skiddaw Slates, but represent, as appears most likely, only the lower portion of the mainland-series, they can scarcely be newer than Upper Cambrian. On these grounds the Cambrian colour and symbol, with a mark of interrogation, have been adopted for them on the published map; and until more satisfactory evidence is forthcoming it is scarcely practicable to attempt a closer definition of their age.

The basis for a comparison of the Manx Slates with the Cambrian strata of North Wales and of the east of Ireland is even slighter than for the Lake District. In both countries the Cambrian sediments comprise highly disturbed and altered slates, greywackes, grits and quartzites; but during a personal examination of some of the Irish sections I failed to find any salient points of resemblance, and am not aware of any features in the Welsh rocks which, in the absence of fossils, would furnish definite grounds for correlation with the Manx Series.

Estimated thickness of the Manx Slates

The only method of measuring the thickness of a series so greatly disturbed as the Manx Slates with any approach to accuracy, is to identify the component strata and obtain their thickness separately under favourable conditions—a method which, as we have seen, has unfortunately not been found practicable in this case. All that can be attempted, therefore, is to give some idea of the probable relative thickness of the different divisions, with a vague estimate of the possible value in figures.

Commencing with what we have taken to be the highest member of the series: the Barrule Slates, in spite of their extended outcrop and great depth in the hills of the centre of the Island, may originally have been not more than a few hundred feet in thickness, though now packed to a vertical thickness of not less than 2,000 feet in the vicinity of the Snaefell ridge.

The Agneask Grits and corresponding belts of similar quartz-veined grits in the south and west of the Island are known to have a restricted vertical range, even where their outcrops are wide and dips steep. The strata which have been crumpled up to form these belts need not originally have been more than 100 feet or so in thickness.

The Lonan and Niarbyl Flags and the banded slates of the 'unseparated' tracts must however have been of much greater extent. Their diversity of composition, their downward continuation, without change of type and without any indication of a base, to over 1,500 feet below sea-level in the Great Laxoy Mine (see p. 522), and the deep straight-limbed character of the folding which pervades them, seem to necessitate great original thickness; so that even granting the most persistent repetition by folding, we cannot allow less than a thousand feet for the initial thickness of these flags, and shall most likely then be considerably under-estimating them

By combining these estimates, we obtain for the whole series a possible minimum original thickness of, in round numbers, from 1,500 to 2,000 feet, with the probability that this may be much below the truth.

Conditions of sedimentation

There are no deposits among the Manx Slates indicative of shore-conditions. Even their sandy portions are comparatively thinly bedded; and in the coarsest grits, viz., those of St. Ann's Head and vicinity, the larger fragments rarely attain a diameter of more than a quarter of an inch. The series appears to have been deposited in a sea of moderate depth, into which a constant but not heavy supply of sediment was swept and widely distributed by currents.

In the absence from these rocks, as from the Skiddaw Slates of the mainland, of any known base, the only evidence of older formations is afforded by the small worn rock-fragments in the grits and flags. These, as stated in the petrographical notes, include abundant grains of vein-quartz, some felspar and mica, and a few relics of older sedimentary rocks, including fine-grained quartzite, greywacke, and perhaps slate, with occasional fragments of andesite. Except in the small obscure outcrop of tuff or brecciated andesite near Dalby, described on p. 163, the Manx Slates appear to include no volcanic material beyond the above-mentioned fragments in the grits.

Tectonic structure of the Manx Slate Series

From the preceding account, it will be understood that any attempt to explain the tectonic arrangement of the Manx Slates must, m the present state of our knowledge, be more or less hypothetical. It has been pointed out that, instead of the supposed anticlinal structure, deduced by previous observers from the dominant outward dips on the opposite sides of the Island, the evidence tends as a whole to indicate that the folded belts of strata sink gradually, though irregularly, towards the interior axis, and that the most probable structure is a compound syncline ('synclinorium' of Dana; 'exocline' of Laworth; 'inverted fan-structure' of Heim).

On a small scale this structure is readily illustrated by laying a few leaves of paper together and crumpling the sheet into a succession of small sharp folds, and then lifting its opposite sides so that the centre forms a trough. The paper in this model gives a diagram of a synclinorium such as might occur if folding took place in beds of slight thickness, which were free to move upwards and downwards. But if, instead of a few leaves, we take a pile of paper several inches in thickness, and seek to make a similar arrangement, we shall find the task of producing a system of isoclinal folds exceedingly difficult; and a corresponding difficulty arises when we attempt to draw a section to represent isoclinal folding in strata of considerable thickness, because of the tendency of the crests and troughs to fill in and become obliterated both upwards and downwards. Hence we often find that in diagrammatic drawings of this kind, sharp folding is represented in only a few thin bands in a section and is more or less evaded elsewhere. Nevertheless we know that, in nature, folding of this kind prevails throughout great masses of strata, as in the case of the Manx Slates.

It is clear that where thick series of rocks are packed together in closed folds, each individual fold must undergo considerable modification of character along its vertical axis, because of the changing stresses in different parts of the fold. Thus in each anticline there will be an upper portion in which the strata in the vicinity of the crest have been in a state of tension; and an under portion in which they have been in a state of compression; while in each syncline the same phenomena will be exhibited in reverse order. Where stretching has predominated, the fold will be simply elongated but m the area of compression, subsidiary plications will be developed and will increase in relative amplitude as their vertical distance from the node or neutral belt of the governing fold increases. With the growth of these interpolated folds, the comparative importance of the governing fold is gradually diminished upwards and downwards, until eventually, in a homogeneous sequence, some member of the subsidiary order is in turn advanced to the first rank, and forms the centre of a now system. Thus in each fold of a complex system there must be a medial plane at which the fold attains its greatest individual development, and above and below which it tends to split up and lose its identity.

In a heterogeneous rock sequence isoclinally folded, it is evident that the medial plane of the principal folds will occur in the rock-band best adapted lithologically to form master-folds under the given stresses; and the folds will therefore decrease in amplitude upwards and downwards from a definite horizon. These are the principles which I believe to have governed the folding of the Manx Slate Series. They are illustrated in the above theoretically-constructed diagram of a synclinorium, which I have taken as the basis of my interpretation of the tectonic structure of the central massif of the Island.

The practical application of this hypothetical diagram is shown in the three transverse sections forming (Plate 2).

These sections are drawn across the Island at right angles to the strike of the Slate Series, and the centre of the synclinorium is made manifest in each by the deep infold of Barrule Slate under the highest elevations of the surface. The igneous dykes are omitted, as they are too numerous and too small to show on this scale; and the Dhoon Granite, which appears in Section No. 1, is the only large intrusive mass traversed. Section No. 3 crosses the basin of Lower Carboniferous rocks of the south of the Island, showing their position in regard to the Manx.Slates.

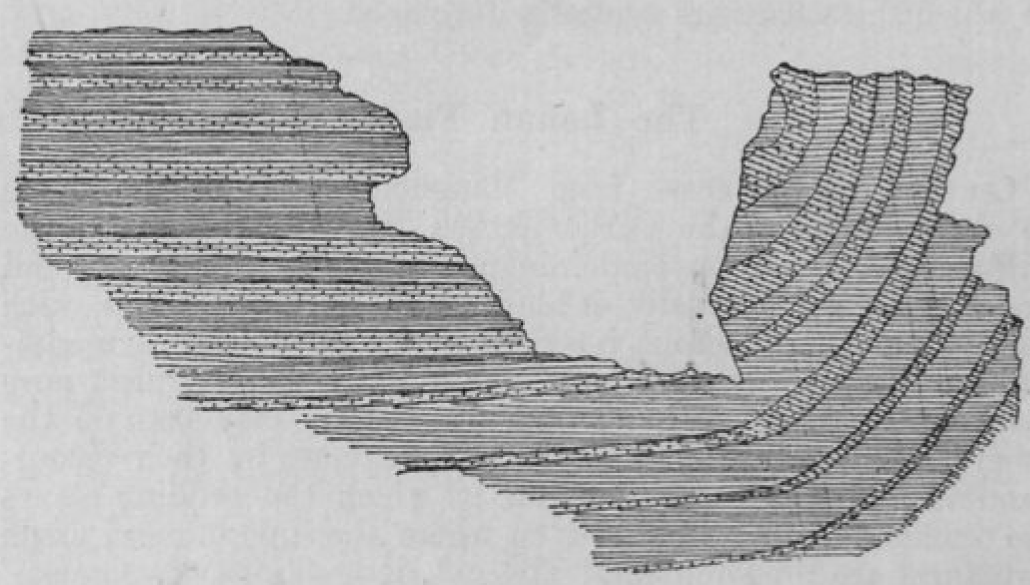
These sections will be found to incorporate all the leading facts of the field-evidence as to the structure and general relationship of the sub-divisions of the Slate Series given in the foregoing and subsequent pages.

FIG. 32. *Ideal section through synclinorium of Manx Slates.*

3. Slates. 2. Grits. 1. Flags.

(Figure 32) Ideal section through synclinorium of Manx Slates. 3. Slates.2. Grits. 1. Flags.

FIG. 2. *Cliff-section 700 yards S.S.E. of Maughold Head, showing recumbent fold in striped slates with thin grit bands. Height, about 15 feet.*

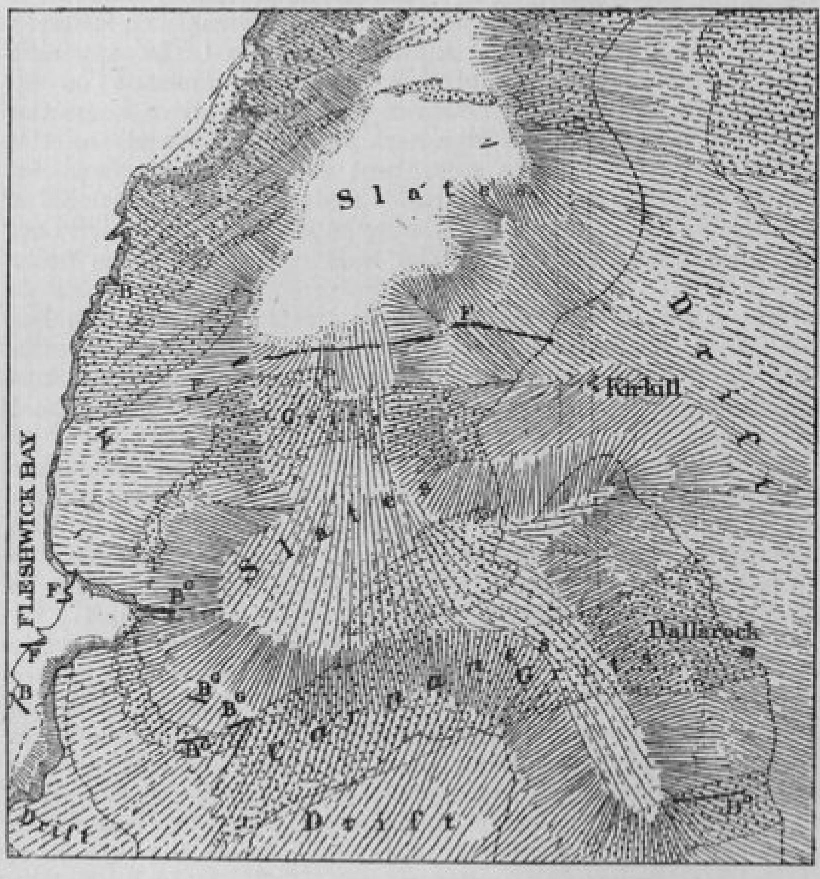


A faint cleavage parallel to the stratification in the limbs of the fold crosses the beds in the upfold, diverging somewhat in the gritty bands.

(Figure 2) Cliff section 700 yards S.S.E. of Maughold Head, showing recumbent fold in striped slates with thin grit bands. Height, about 15 feet. A faint cleavage parallel to the stratification in the limbs of the fold crosses the beds in the upfold, diverging somewhat in the gritty bands.

FIG. 4.—*Map of coast and vicinity north of Fleshwick Bay.*

Scale 4 inches = 1 mile.



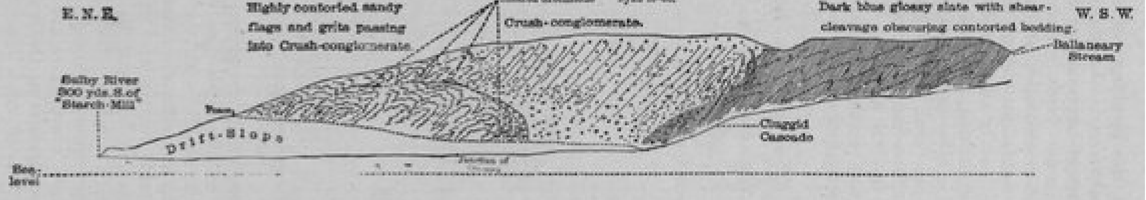
B Olivine-dolerite dykes (Tertiary ?).
B^D Greenstone dyke with large crushed felspars.
B^G Altered greenstone dykes.
F Micro-granite dyke (Foxdale Granite type), broken into segments.
The grits are represented by stippling.
The shading indicates the shape of the ground.

(Figure 4) Map of coast and vicinity north of Fleshwick Bay. Scale 4 inches = 1 mile. B Olivine-dolerite dykes (Tertiary ?). B^D Greenstone dyke with large crushed felspars. B^G Altered greenstone dykes. F Micro-granite dyke (Foxdale Granite type), broken into segments. The grits are represented by stippling. The shading indicates the shape of the ground.

FIG. 7.—*Section across the zone of Crush-conglomerate on the eastern side of Sulby Glen*

(From Quart. Journ. Geol. Soc., vol. li.)

Scale, horizontal and vertical: 6 inches = 1 mile.



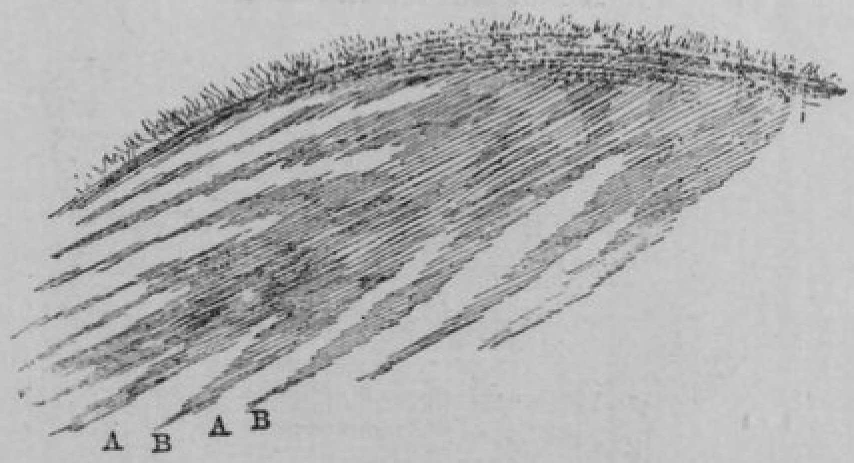
The section is not drawn strictly vertically, as it combines all the outcrops of the hill-side which slopes at about 40°.

(Figure 7) Section across the zone of Crush-conglomerate on the eastern side of Sulby Glen. (From Quart. Journ. Geol. Soc., vol. li.) Scale, horizontal and vertical: 6 inches = 1 mile. The section is not drawn strictly vertically, as it combines all the outcrops of the hill-side which slopes at about 40°.

FIG. 26. *Section in crag on western slope of Glen Dhoo, Ballaugh (opposite "T. Mill" of 6 inch map, Sheet 7), showing extreme shearing of strata in the crest of a fold.*

(From Quart. Journ. Geol. Soc., vol. li.)

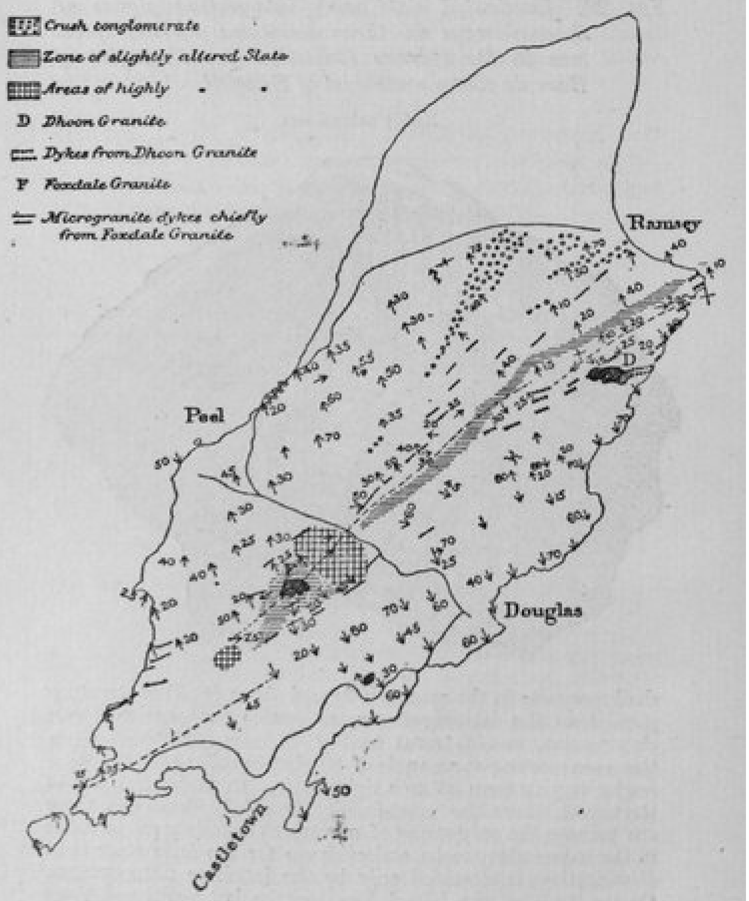
Length, about 3 feet.



A, A, Sandy and B, B, slaty bands, fairly well defined in the limbs of the fold, but frayed out into reconstructed schistose material in the crest.

(Figure 26) Section in crag on westernslope of Glen Dhoo, Ballaugh (opposite "T. Mill" of 6 inch map, (Sheet 7)), showing extreme shearing of strata in the crest of a fold. (From Quart. Journ. Geol. Soc., vol. li.) Length, about 3 feet. A, A, Sandy and B, B, slaty bands, fairly well defined in the limbs of the fold, but frayed out into reconstructed schistose material in the crest.

FIG. 29. *Sketch-map of the Isle of Man, showing (a) principal cleavage; (b) position of metamorphosed slates; (c) position of granitic intrusions and of dykes connected therewith; and (d) distribution of crush-conglomerate.*

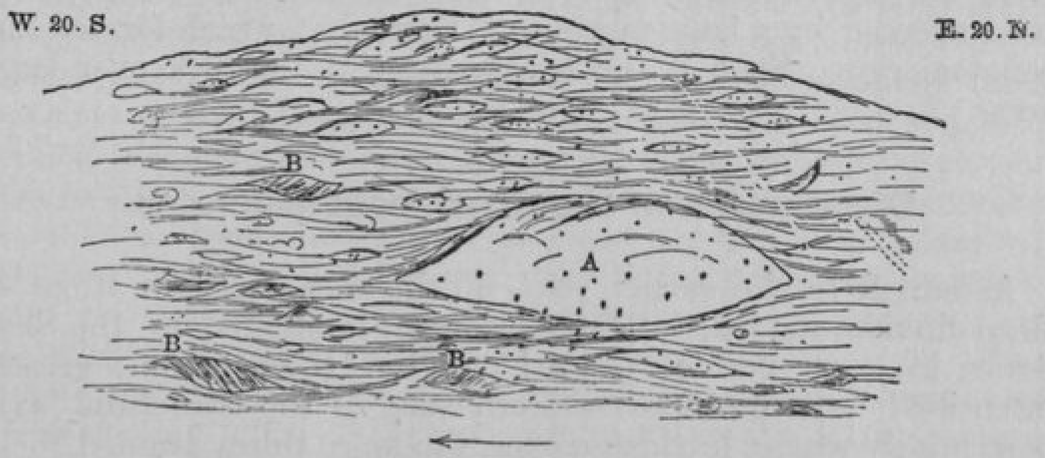


The arrows show the direction of dip of the dominant cleavage, and the figures the amount in degrees. The broken line indicates the position of the somewhat interrupted anticline of cleavage. The continuous lines mark the railways.

(Figure 29) Sketch-map of the Isle of Man, showing (a) principal cleavage; (b) position of metamorphosed slates; (c) position of granitic intrusions and of dykes connected therewith; and (d) distribution of crush-conglomerate. The arrows show the direction of dip of the dominant cleavage, and the figures the amount in degrees. The broken line indicates the position of the somewhat interrupted anticline of cleavage. The continuous lines mark the railways.

FIG. 6.—*Crag of Crush-conglomerate at the southern edge of Cronk Sumark, Sulby; showing fragments of grit, fine-grained flag-stone, and hard clay-slate, in a matrix of bluish slaty material.*

(From Quart Journ. Geol. Soc., vol. li.)



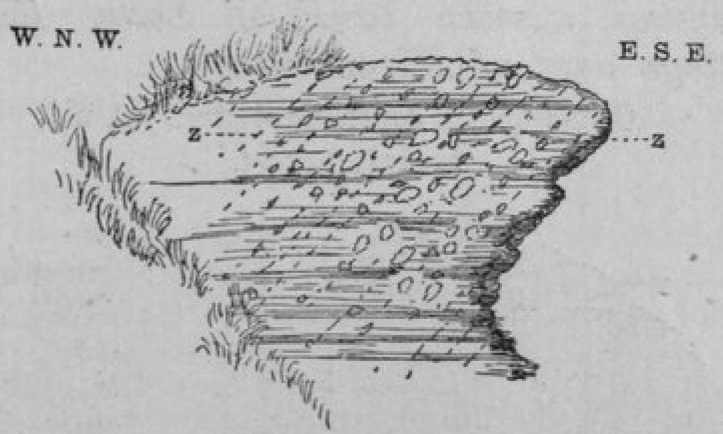
A. Block of sheared slightly felspathic grit, about 8 feet long.
B. Fragments in which the original bedding is still visible.
The arrow indicates the probable direction of the movement during shearing.

(Figure 6) Crag of Crush-conglomerate at the southern edge of Cronk Sumark, Sulby; showing fragments of grit, fine-grained flag-stone, and hard clay-slate, in a matrix of bluish slaty material. (From Quart Journ. Geol. Soc., vol. li.) A. Block of sheared slightly felspathic grit, about 8 feet long. B. Fragments in which the original bedding is still visible. The arrow indicates the probable direction of the movement during shearing.

FIG. 9.—*Sketch of crag of Crush-conglomerate on northern slope above Druidale stream, at junction with Sulby River.*

(From Quart. Journ. Geol. Soc., vol. li.)

Length, about 3 feet.

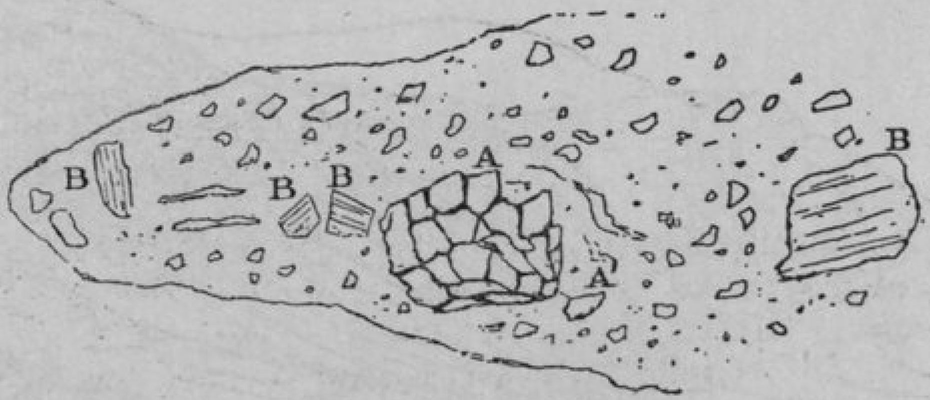


Z—Z. Shear-cleavage planes, developed subsequently to the brecciation, and obliquely to the linear arrangement of the grit-fragments which show a prevalent dip to north-west. The dip of the shear-cleavage is N. 20° E. at 35°, the section being along the strike.

(Figure 9) Sketch of crag of Crush-conglomerate on northern slope above Druidale stream, at junction with Sulby River. (From Quart. Journ. Geol. Soc., vol. li.) Length. about 3 feet. Z–Z. Shear-cleavage planes, developed subsequently to the brecciation, and obliquely to the linear arrangement of the grit-fragments which show a prevalent dip to north-west. The dip of the shear-cleavage is N. 20° E. at 35°, the section being along the strike.

FIG. 12.—*Plan of Crush-conglomerate in floor of a cave south of Gob y Deigan, showing breaking-up of flaggy inclusions.*

Area, about 9 square feet.

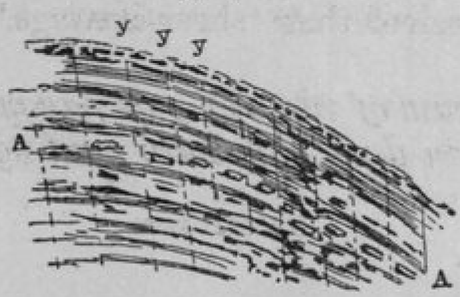


A. Portion of a flaggy band with deep cracks filled with the blue slaty matrix.
A′. Fragment just separated from A.
B. Blocks of flaggy slate showing remains of original bedding.

(Figure 12) Plan of Crush-conglomerate in floor of a cave south of Gob y Deigan, showing breaking-up of flaggy inclusions. Area, about 9 square feet. A. Portion of a flaggy band with deep cracks filled with the blue slaty matrix. A′. Fragment just separated from A. B. Blocks of flaggy slate showing remains of original bedding.

FIG. 23. *Crest of fold in Niarbyl Flags in cliff at northern side of The Ladder, Contrary Head.*

(From Quart. Journ. Geol. Soc., vol. li.).
Length, 4 feet.



A, A. Pale band in slaty flags, pulled apart into pebble-like lenticles 1 to 2 inches in length.
y, y. Faintly-developed planes of strain-slip.

(Figure 23) Crest of fold in Niarbyl Flags in cliff at northern side of The Ladder, Contrary Head. (From Quart. Journ. Geol. Soc., vol. li.). Length, 4 feet. A, A. Pale band in slaty flags, pulled apart into pebble-like lenticles 1 to 2 inches in length. y, y. Faintly-developed planes of strain-slip.

FIG. 8.—*Part of a crag in Sulby Glen (100 yards north of " Limekiln," Glen Mooar, of 6-inch map, Sheet 4).*

(From Quart. Journ. Geol. Soc., vol. li.)

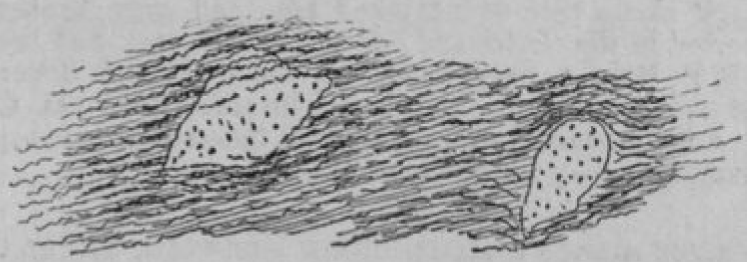
Length, about 3 feet.

The fragments in the crush-conglomerate are of pale greyish flagstone or fine grit, up to 3 inches in diameter, the larger of which show an arrangement suggestive of a recumbent fold.

(Figure 8) Part of a crag in Sulby Glen (100 yards north of "Limekiln", Glen Mooar, of 6-inch map, (Sheet 4)). The fragments in the crush-conglomerate are of pale greyish flagstone or fine grit, up to 3 inches in diameter, the larger of which show an arrangement suggestive of a recumbent fold.

FIG. 10.—*Enlarged view of Crush-conglomerate in crag adjacent to that shown in the last figure.*

About one-half natural size.



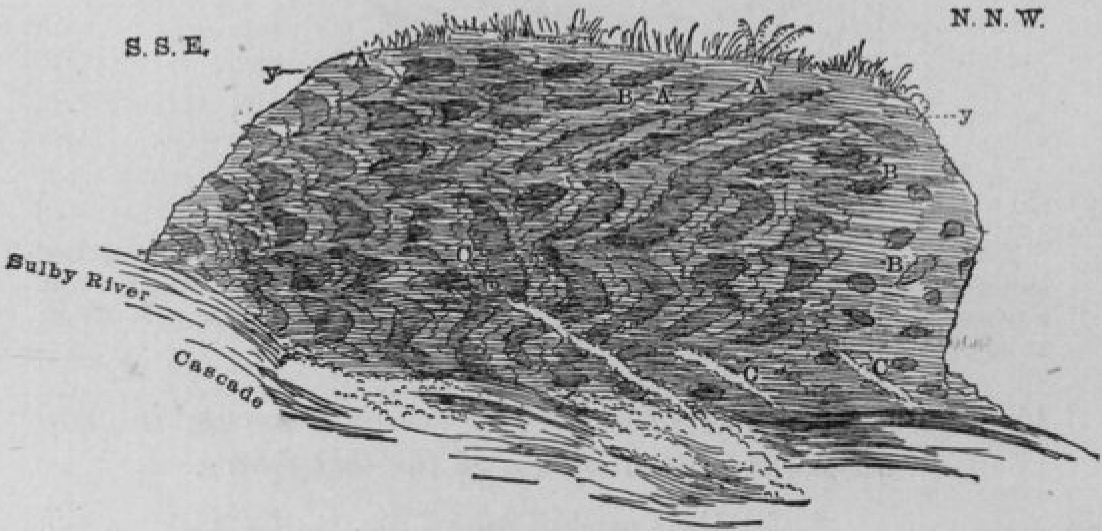
The shear-cleavage planes traversing the shaly ground-mass partly swerve around and partly cross pebble-like fragments of fine-grained grit.

(Figure 10) Enlarged view of Crush-conglomerate in crag adjacent to that shown in the last figure. About one-half natural size. The shear-cleavage planes traversing the shaly ground-mass partly swerve around and partly cross pebble-like fragments of fine-grained grit.

FIG. 11.—*Passage of banded slate into breccia in crag forming western bank of Sulby River under cottage west of Slieaumonagh.*

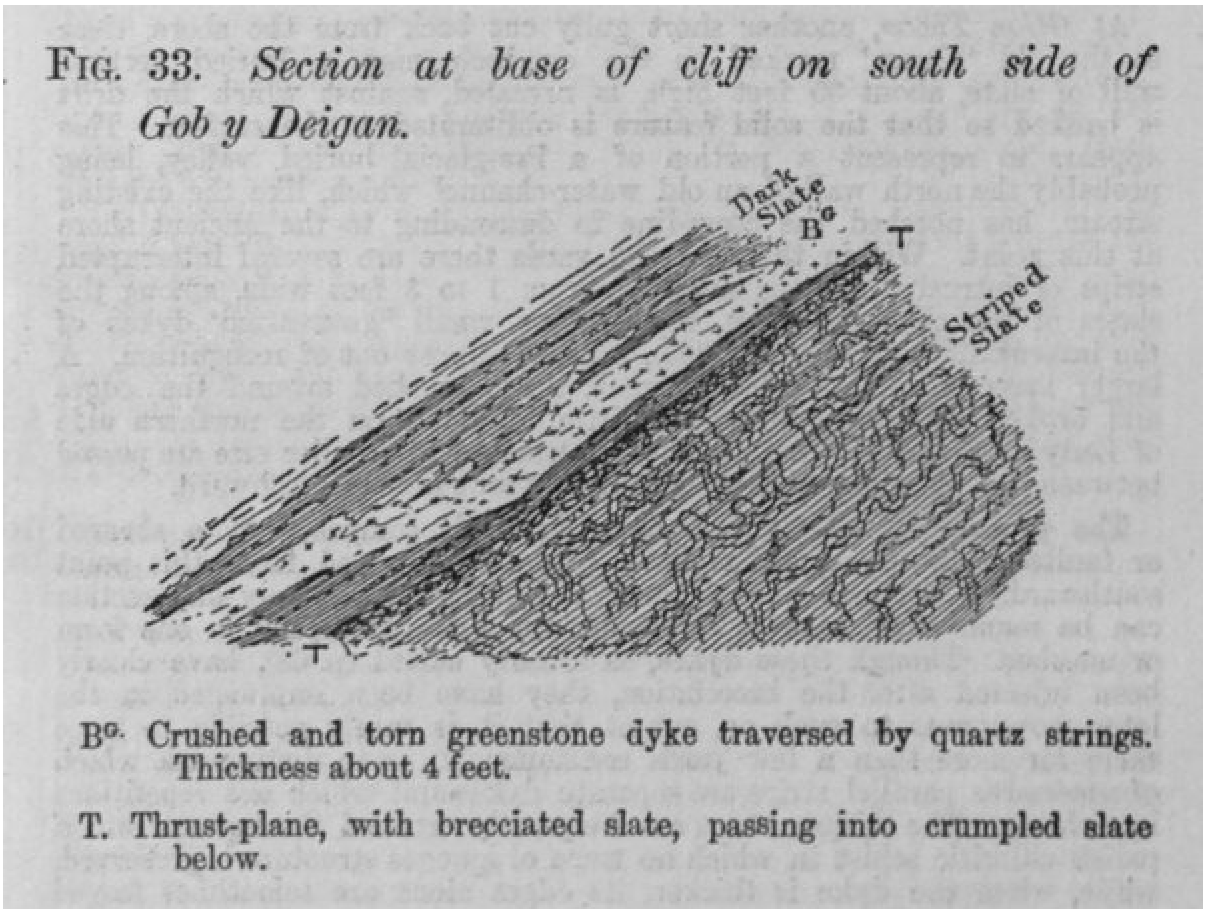
(From Quart. Journ. Geol. Soc., vol. li.)

Length, 12 feet.

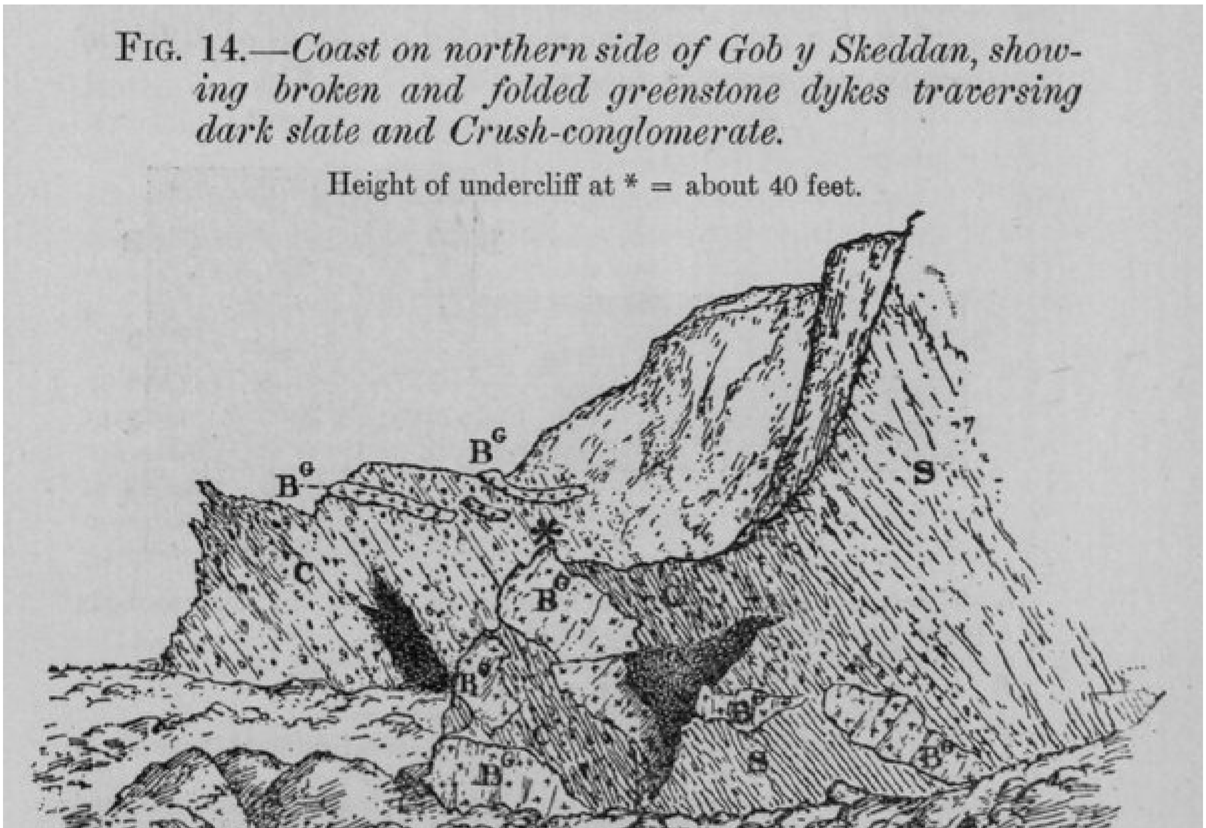


Firm flaggy slates with well-marked blue and grey banding, A, A, A; highly contorted in the centre and left side of the crag, and broken up into fragments, B, B, B, in a slaty matrix on the right and upper part. The thickness of the bedding is exaggerated in this figure. C, C, C, Quartz veins, 2 to 4 inches thick, disturbed and twisted, but not participating in the brecciation. y—y Later shear-cleavage.

(Figure 11) Passage of banded slate into breccia in crag forming western bank of Sulby River under cottage west of Slieaumonagh. (From Quart. Journ. Geol. Soc., vol. li.) Length, 12 feet. Firm flaggy slates with well-marked blue and grey banding, A, A, A; highly contorted in the centre and left side of the crag, and broken up into fragments, B, B, B, in a slaty matrix on the right and upper part. The thickness of the bedding is exaggerated in this figure. C, C, C, Quartz veins, 2 to 4 inches thick, disturbed and twisted, but not participating in the brecciation. y—y Later shear-cleavage.



(Figure 33) Section at base of cliff on south side of Gob y Deigan. B^G- Crashed and torn greenstone dyke traversed by quartz strings. Thickness about 4 feet. T. Thrust-plane, with brecciated slate, passing into crumpled slate below.

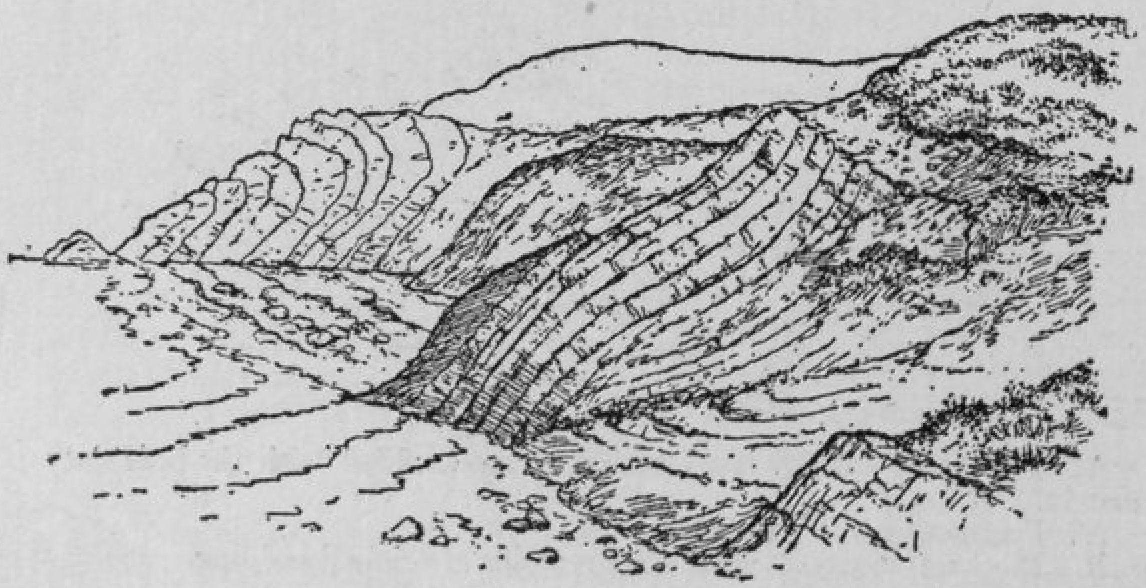


*(Figure 14) Coast on northern side of Gob y Skeddan, showing broken and folded greenstone dykes traversing dark slate and Crush-conglomerate. Height of undercliff at * = about 40 feet. S. Dark slate, greatly sheared, but still occasionally showing traces of bedding. Quartz veins abundant. C. Crush-conglomerate. B^G.Palish 'greenstone' dykes; the upper and*

lower bands of BG in the foreground unite on the farther side of the nearer headland.

FIG. 13.—*Folded flags at margin of Crush-conglomerate at Ballanayre Strand. Cliff capped by glacial drift.*

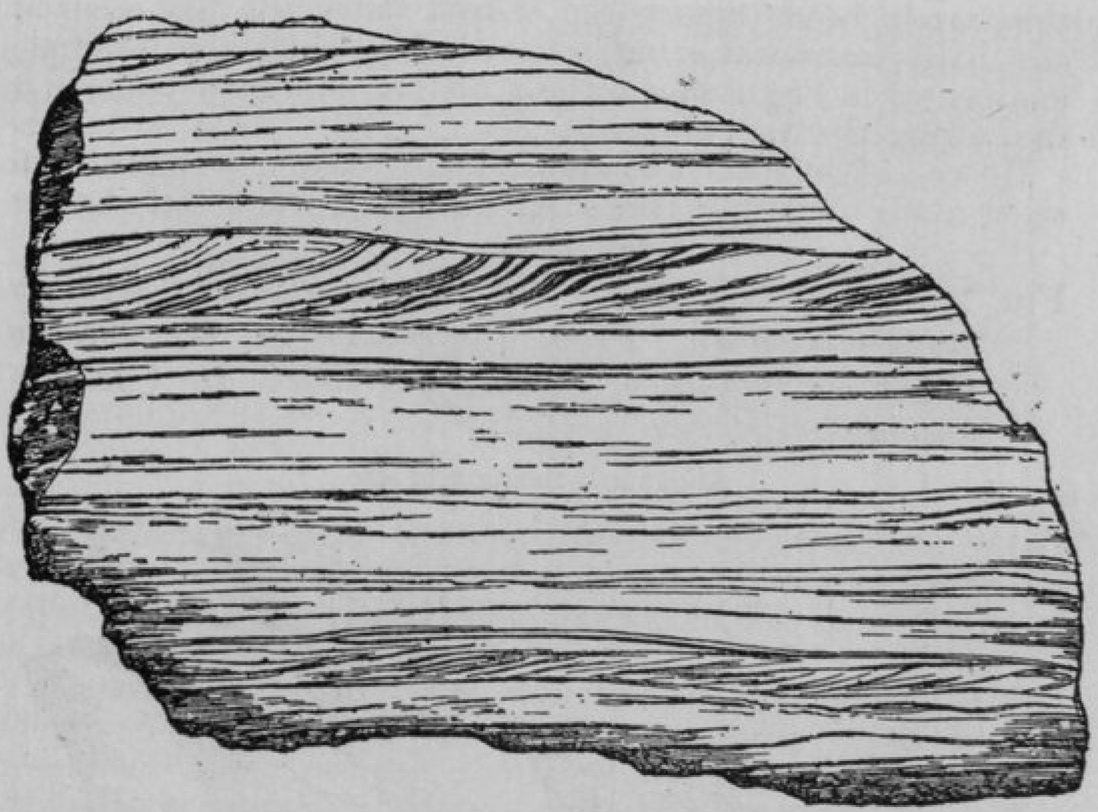
Height about 60 feet.



(Figure 13) Folded flags at margin of Crush-conglomerate at Ballanayre Strand. Cliff capped by glacial drift. Height about 60 feet.

Fig. 16. *Laminated slate with disturbed bedding simulating cross-bedding. From a specimen in the Survey Collection obtained near Ramsey.*

About two-thirds natural size.

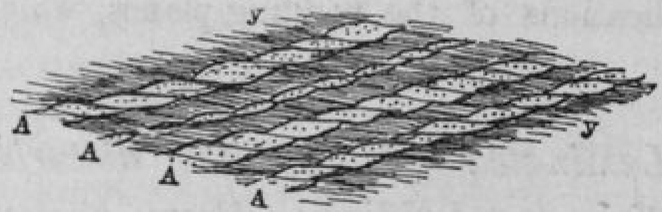


(Figure 16) Laminated slate with disturbed bedding simulating cross-bedding. From a specimen in the Survey Collection obtained near Ramsey. About two-thirds natural size.

FIG. 17. *Section in crag on western side of Sulby Glen, west of bench-mark* 137′ 6″ (*six-inch map, sheet* 4), *showing method of production of pseudo-ripple marking by strain-slip-faulting.*

(From Quart. Journ. Geol. Soc., vol. li. Compare Fig. 18.)

Length, about 2 feet.



A A A. Bands of grit 1 to 3 inches thick, cut displaced and lengthened by (y—y) oblique strain-slip planes. Dark slate, much sheared, between the grit-bands.

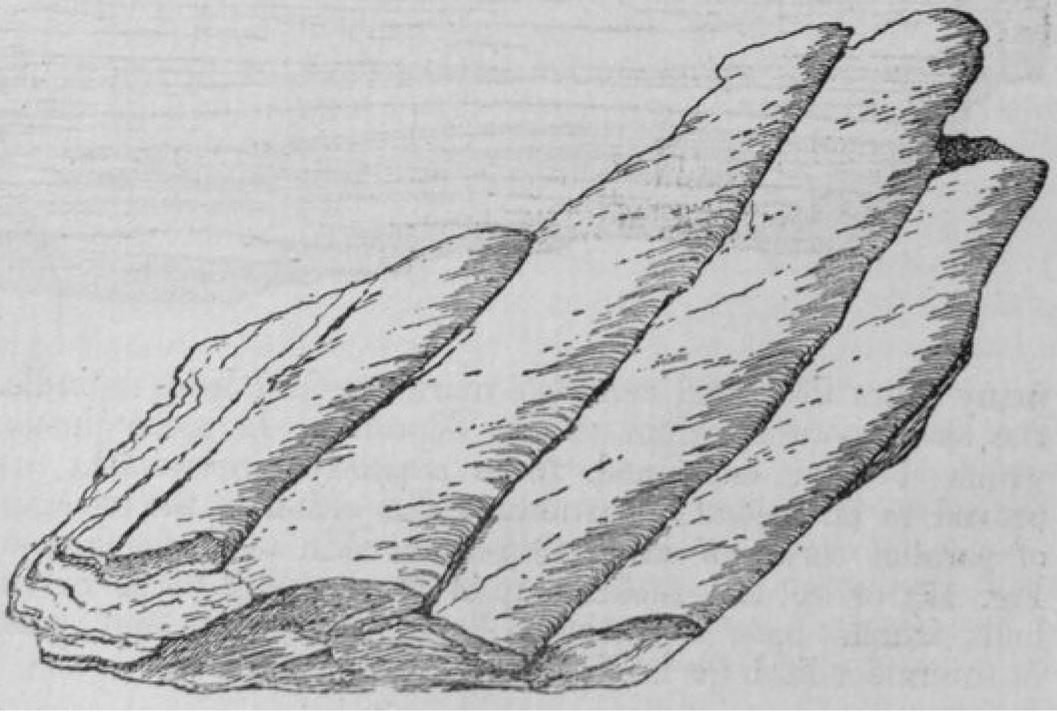
This pseudo-ripple-marking is commonly developed in the thin sandy bands among the striped slates, but may occur in any hard seam traversing softer beds. Thus, the example represented in Fig.19 shows the structure, on a small scale, in a thin segregation-vein of quartz.

Hence, although the rocks are in many places of a character in which ripple-marking may once have existed, it is doubtful whether

(Figure 17) Section in crag on western side of Sulby Glen, west of bench-mark 137′ 6″ (six-inch map, sheet 4), showing method of production of pseudo-ripple marking by strain-slip faulting. (From Quart. Journ. Geol. Soc., vol. B. Compare (Figure 18)) A A A. Bands of grit 1 to 3 inches thick, cut displaced and lengthened by (y—y) oblique strain-slip planes. Dark slate, much sheared, between the grit-bands.

FIG. 18. *Rock-rippling of thin gritty layer in slate by earth-morement. From a specimen in the Survey Collection obtained on the foreshore at Cass-ny-hawin.*

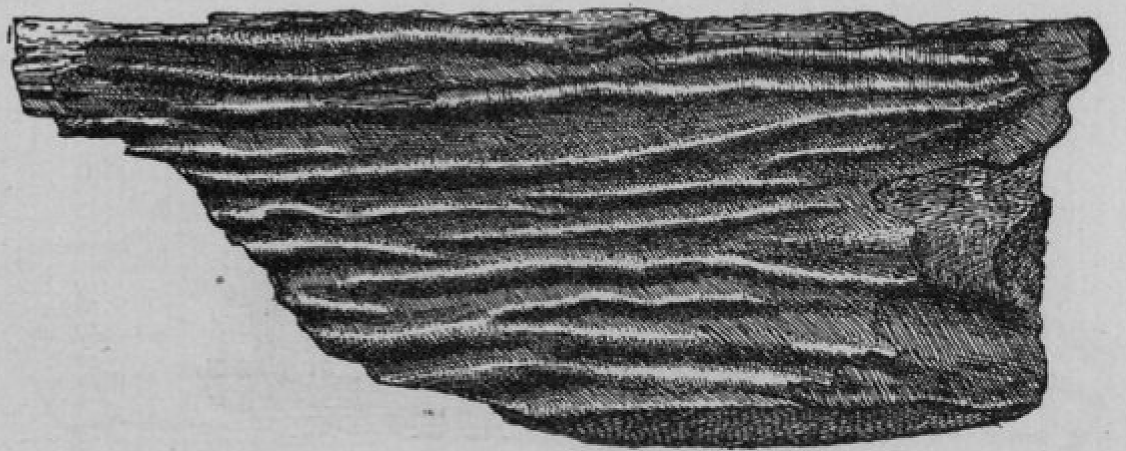
About half the natural size.



(Figure 18) Rock-rippling of thin gritty layer in slate by earth-morement. From a specimen in the Survey Collection obtained on the foreshore at Cass-ny-hawin. About half the natural size.

FIG. 19. *Rock-rippling affecting thin quartz vein in slate. From a specimen in the Survey Collection obtained on the slope beneath Gob y Volley.*

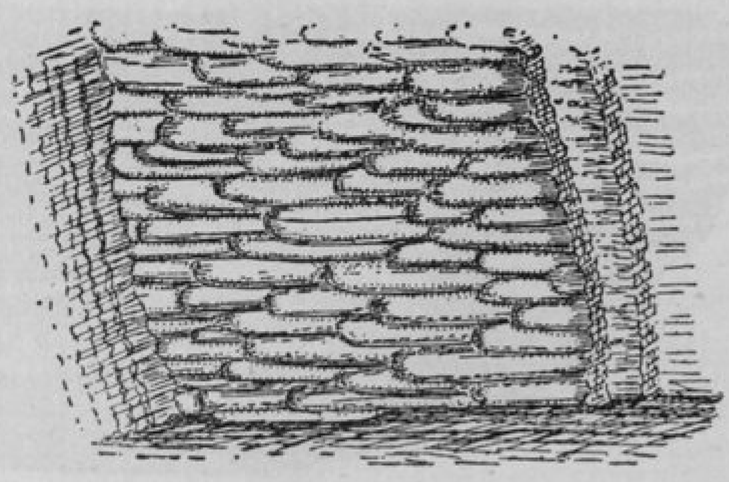
Slightly reduced.



(Figure 19) Rock-rippling affecting thin quartz vein in slate. From a specimen in the Survey Collection obtained on the slope beneath Gob y Volley Slightly reduced.

FIG. 20. *Corrugated surface of grit-band in flaggy slate, in west bank of gully south-west of Fistard village near Port St. Mary.*

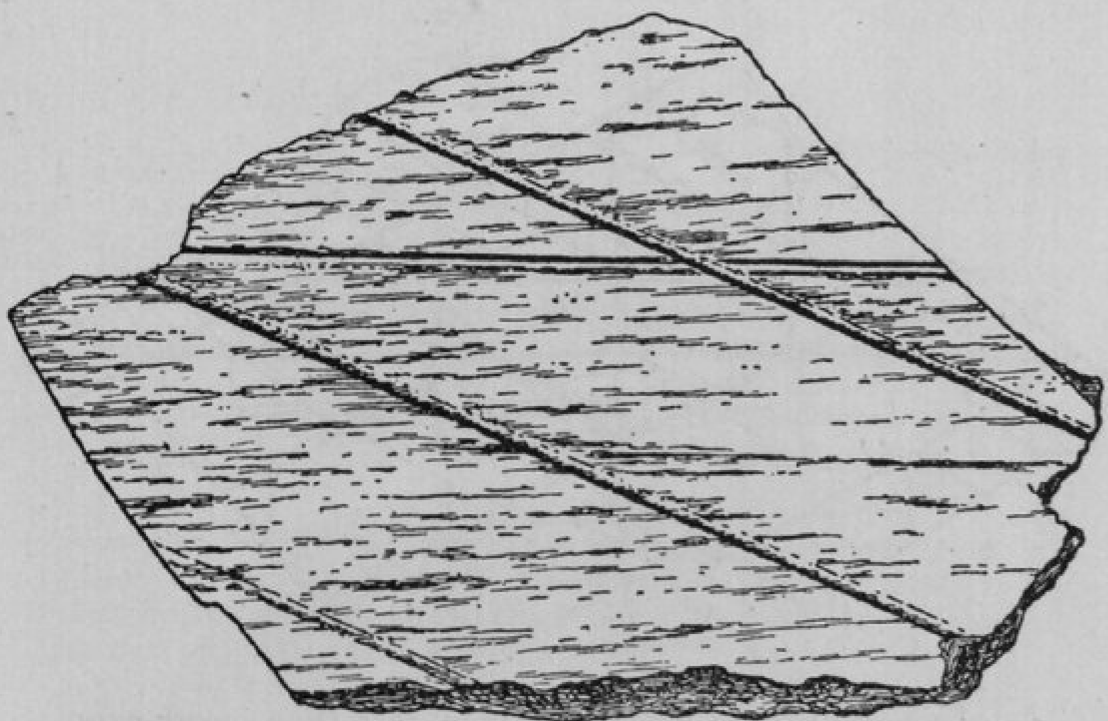
Dimensions, 12 inches by 8 inches; the finger-like ridges are from ½ to 1½ inches broad.



(Figure 20) Corrugated surface of grit-band in flaggy slate, in west bank of gully south-west of Fistard village near Port St. Mary. Dimensions, 12 inches by 8 inches; the finger-like ridges are from ½ to 1½ inches broad.

FIG. 21. *Puckerings on bedding-plane of fine-grained flags (Niarbyl Flags); from specimen in the Survey Collection obtained on the coast near Dalby Point.*

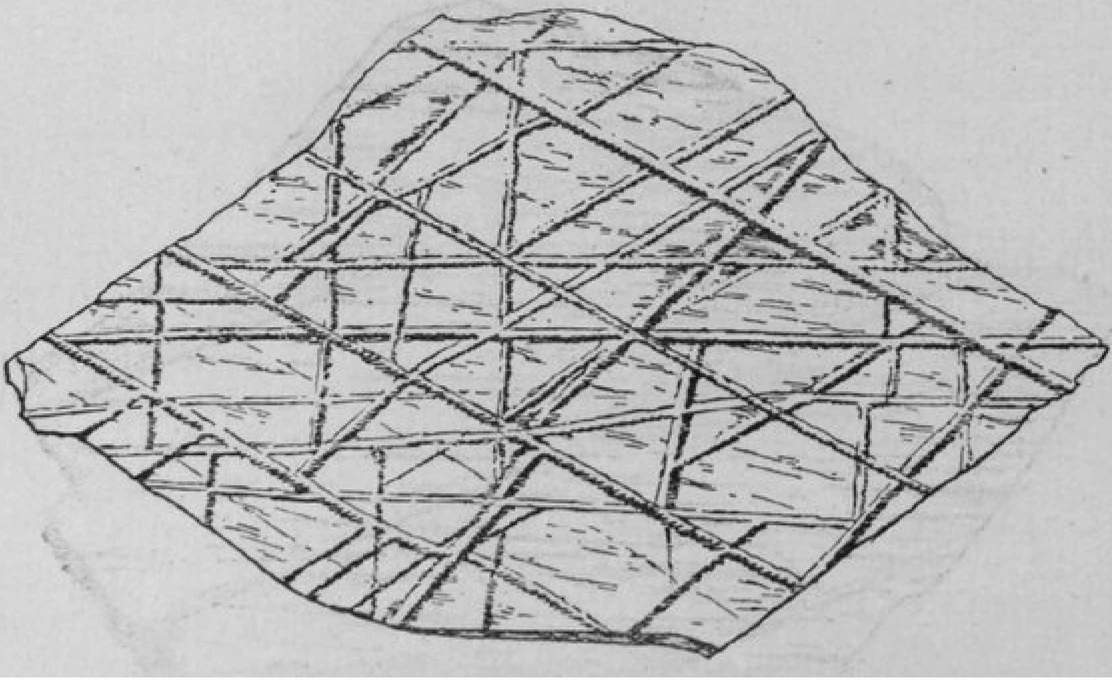
About one-third natural size.



(Figure 21) Puckerings on bedding-plane of fine-grained flags (Niarbyl Flags); from specimen in the Survey Collection obtained on the coast near Dalby Point. About one-third natural size.

FIG. 22. *Tessellated puckering on bedding-plane of Niarbyl Flags; from specimen in the Survey Collection obtained on the coast near Dalby Point.*

About one-third natural size.

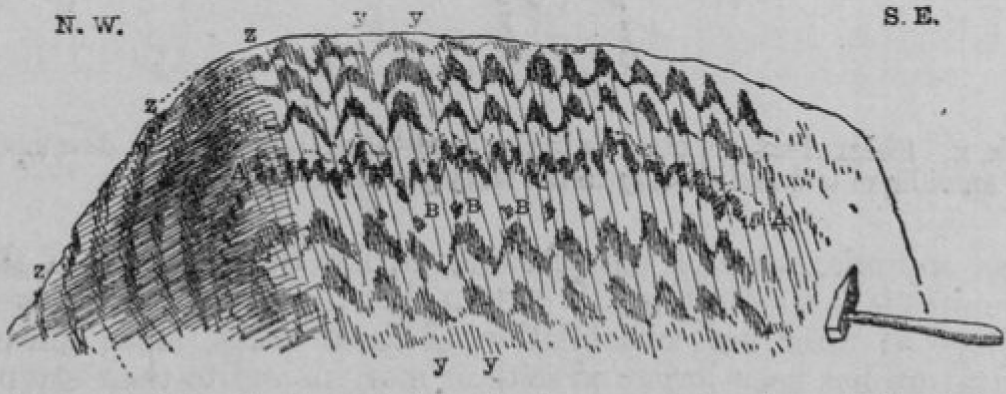


(Figure 22) Tessellated puckering on bedding-plane of Niarbyl Flags; from specimen in the Survey Collection obtained on the coast near Dalby Point. About one-third natural size.

FIG. 24. *Crag of strongly-banded sandy slate in eastern bank of Sulby River below Snaefell,* (450 *yards north of* "*Lead-mine*" *of six-inch map, Sheet* 7).

(From Quart. Journ. Geol. Soc., vol. li.).

Length, about 5 feet.



A, A. Grit-band, about ½ inch thick, crumpled and partially broken, among puckered slates.

B, B, B. Isolated pebble-like fragments of grit, apparently squeezed out from the band A.

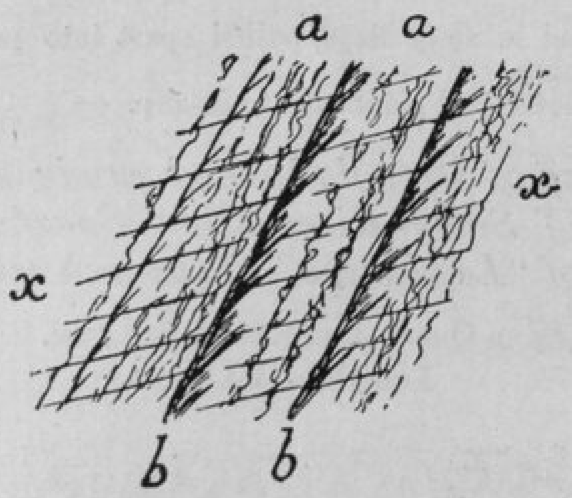
y, y. Strain-slip planes, cutting and displacing the bedding.

z, z. Later 'shear-cleavage,' with the same strike as the bedding (N. 40° W.) but a different degree of dip (about 30°).

(Figure 24) Crag of strongly-banded sandy slate in eastern bank of Sulby River below Snaefell, (450 yards north of "Lead-mine" of six-inch map, (Sheet 7)). (From Quart. Journ. Geol. Soc., vol. li.). Length, about 5 feet. A, A. Grit-band, *about ½ inch thick, crumpled and partially broken, among puckered slates. B, B, B. Isolated pebble-like fragments of grit, apparently squeezed out from the band A. y, y. Strain-slip planes, cutting and displacing the bedding. z, z. Later 'shear-cleavage', with the same strike as the bedding (N. 40° W.) but a different degree of dip (about 30°).*

FIG. 25. *Diagram of edges of pale flaggy mudstones* (*a*, *a*) *with thin dark blue slaty partings* (*b*, *b*).

Natural size.

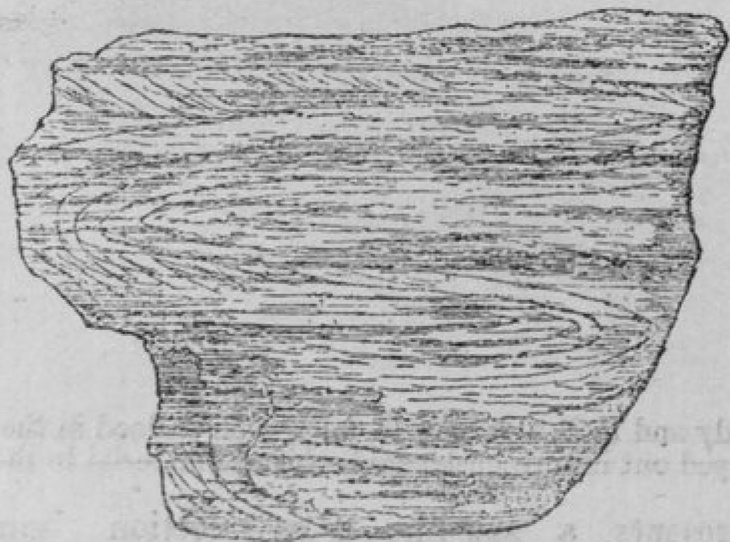


x, **x**. Shear-cleavage, obscure in the mudstones, but strongly developed as an oblique serrated frilling in the slaty partings.

(Figure 25) Diagram of edges of pale flaggy mudstones (a, a) with thin dark blue slaty partings (b, b). Natural size. x, x. Shear-cleavage, obscure in the mudstones, but strongly developed as an oblique serrated frilling in the slaty partings.

FIG. 27. *Belts of strain-slip traversing crumpled slate and producing an appearance resembling stratification. From specimen in the Survey Collection from the Barrule Slates near Snaefell.*

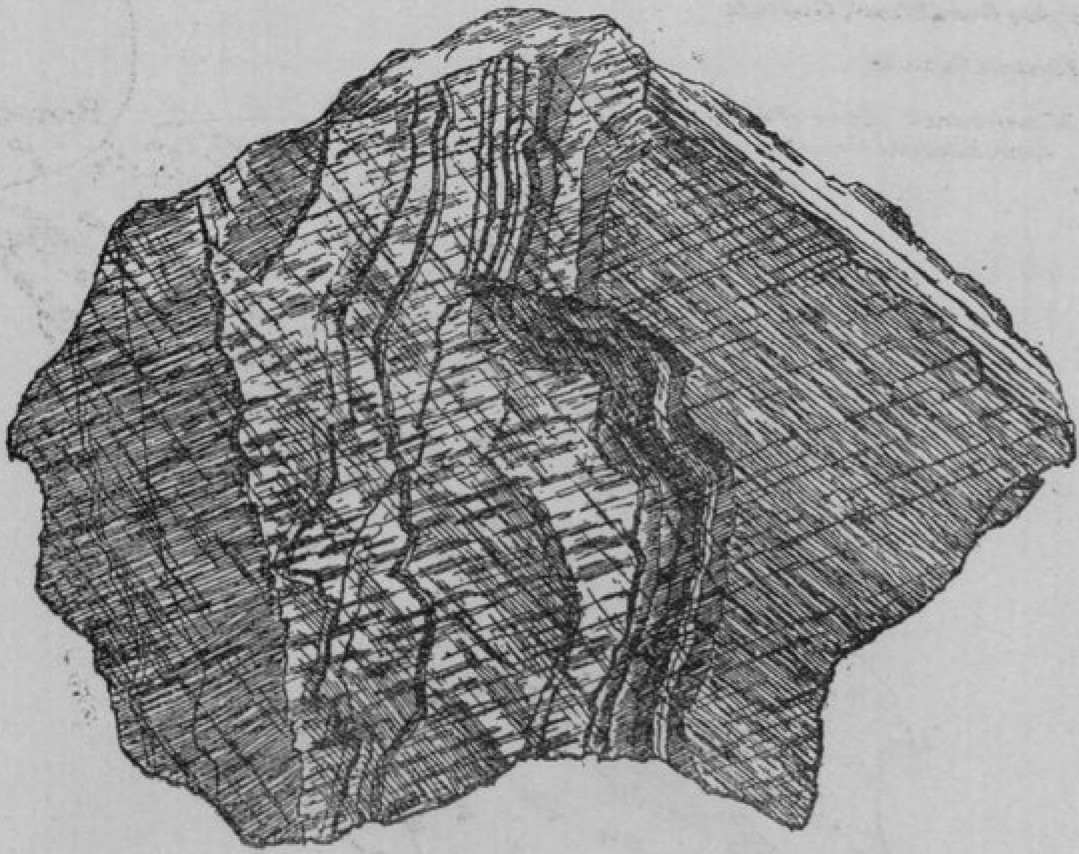
About half natural size.



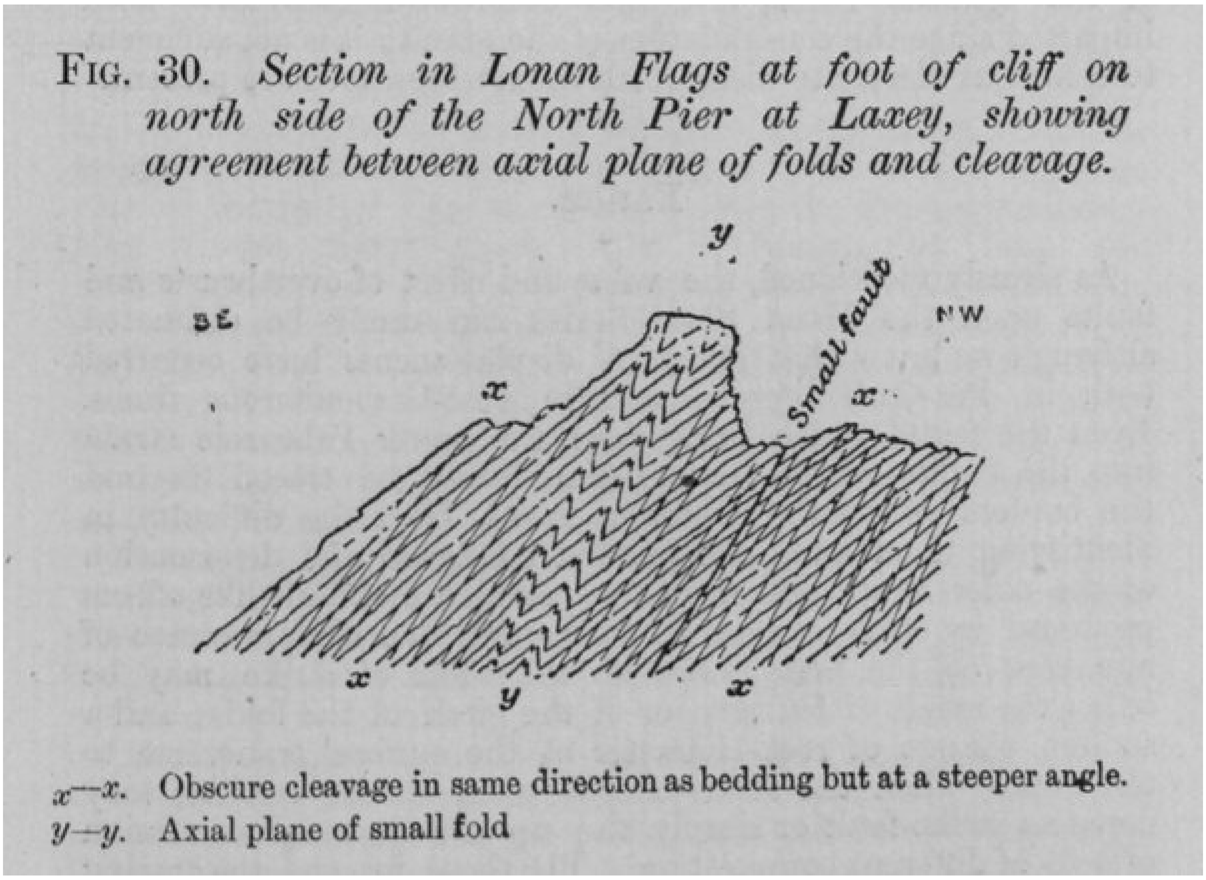
(Figure 27) Belts of strain-slip traversing crumpled slate and producing an appearance resembling stratification. From specimen in the Survey Collection from the Barrule Slates near Snaefell. About half natural size.

FIG. 28. *Laminated slate with intersecting planes of shear-cleavage in three directions. From specimen in the Survey Collection from margin of Barrule Slates south-east of Snaefell.*

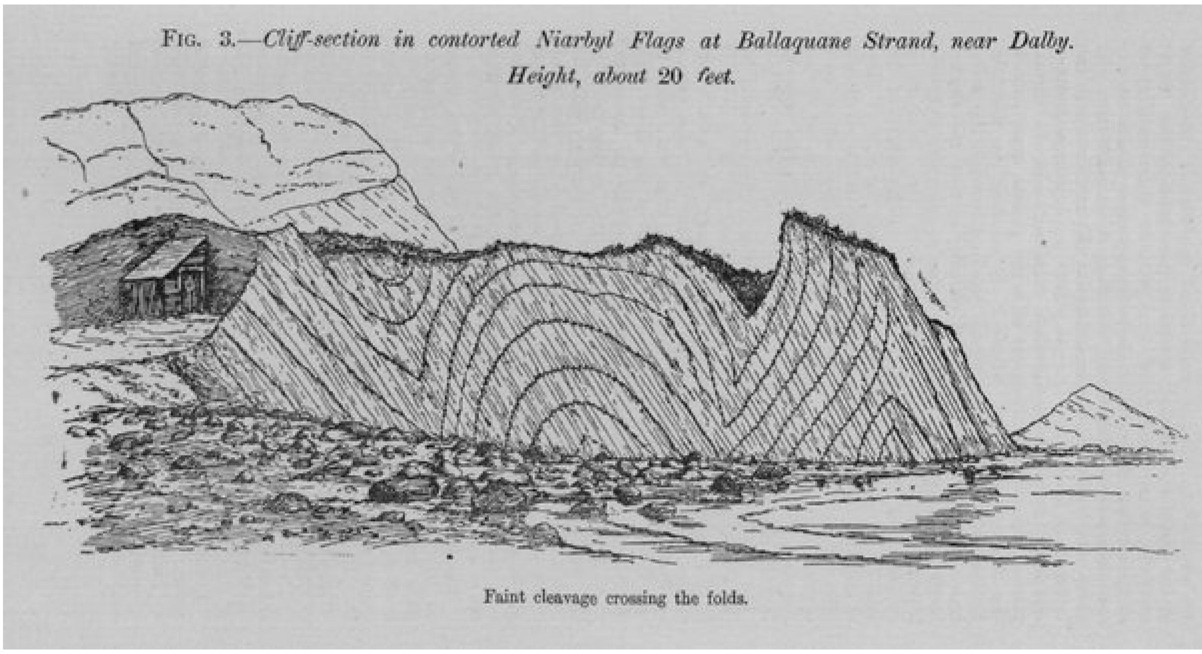
Nearly natural size.



(Figure 28) Laminated slate with intersecting planes of shear-cleavage in three directions. Front specimen in the Survey Collection from margin, of Barrule Slates south-east of Snaefell. Nearly natural size.



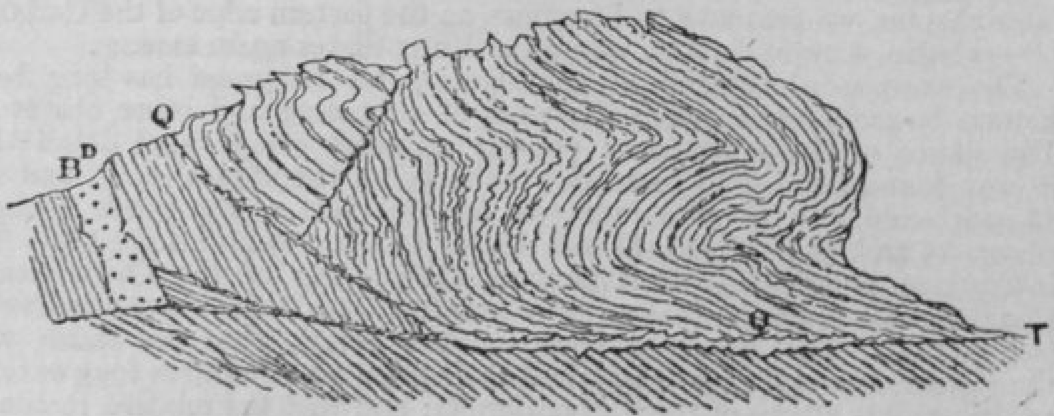
(Figure 30) Section in Lonan Flags at foot of cliff on north side of the North Pier at Laxey, showing agreement between axial plane of folds and cleavage. x—x. Obscure cleavage in same direction as bedding but at a steeper angle. y—y. Axial plane of small fold.



(Figure 3) Cliff-section in contorted Niarbyl Flags at Ballaquane Strand, near Dalby. Height. about 20 feet. Faint cleavage crossing the folds.

FIG. 44. *Section on north side of Horse Gullet, Langness, showing thrust-planes and accompanying plication of thinly-bedded sandy slates.*

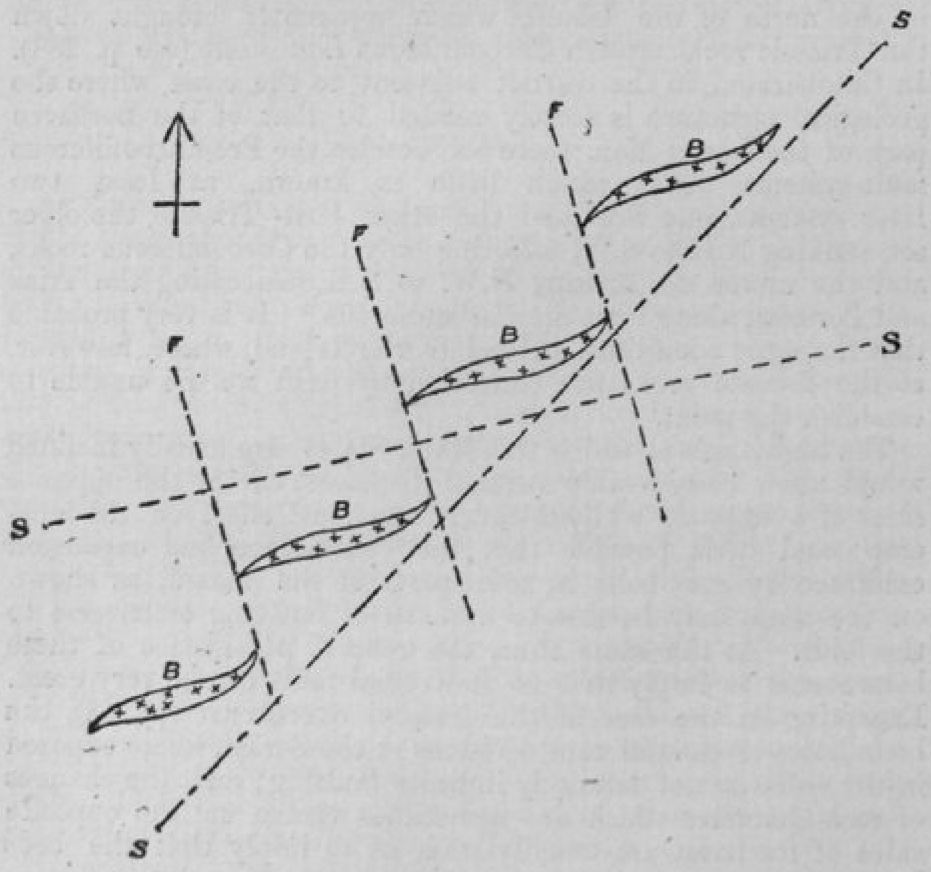
Height about 12 feet.



B^D. Greenstone dyke, 2 feet thick.
T. Thrust-plane, with Q, quartz-veins.

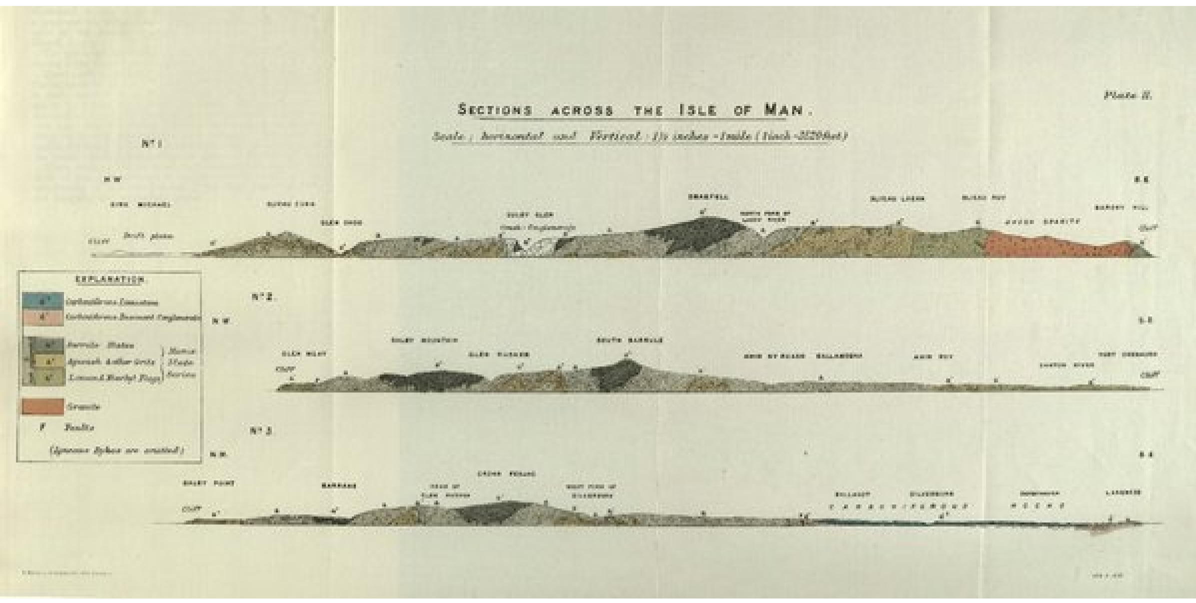
(Figure 44) Section on north side of Horse Gullet, Langness, showing thrust-planes and accompanying plication of thinly-bedded sandy slates. Height about 12 feet. B^D. Greenstone dyke, 2 feet thick. T. Thrust-plane, with Q, quartz-veins.

FIG. 31.—*Diagram (plan) to illustrate common structure in hard bands, whether dykes or layers of grit, in Manx Slates; showing divergence between strike of segments and strike of band as a whole.*



B, B. Segments of hard band, pinched at terminations.
F, F. Dislocation-lines (? normal or overthrust faults).
S - - S. Direction of strike of individual segments.
S —- — *S*. Direction of average strike of hard band.

(Figure 31) Diagram (plan) to illustrate common structure in hard bands, whether dykes or layers of grit, in Mans Slates; showing divergence between strike of segments and strike of band as a whole. B, B. Segments of hard band, pinched at terminations. F, F. Dislocation-lines (I normal or overthrust faults). S- -S.Direction of strike of individual segments. S — - — S. Direction of average strike of hard band.



(Plate 2) Sections across the Isle of Man. Scale: Horizontal and Vertical 1½ inches = 1 mile (1"=3520 feet)