Chapter 16 The petrography of the Torridonian Formation

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The Torridonian rocks in the area under consideration consist of breccias, conglomerates, grits, felspathic sandstones, micaceous sandstones, and shales or slates. A few inconspicuous bands of calcareous grit occur near the base of the series in one or two localities, but limestones are conspicuous by their absence. The Torridonian formation is one of the largest as well as one of the most ancient masses of mechanical sediment in the British Isles.

In the northern portion of the area in question, and in the district from which the formation takes its name, the prevailing rock is a red felspathic sandstone or arkose, in which pebbles of rocks unrepresented in the Lewisian gneiss frequently occur. In the southern part of the area finer-grained deposits of a grey or greenish-grey colour constitute a large part of the whole series. In districts where the Torridonian rocks have been affected by the post-Cambrian movements important modifications in structure, and to a certain extent also in mineralogical composition, have been produced.

The constituents may be classified as follows:

1. Fragments and pebbles of older rocks derived partly from the Lewisian Gneiss and partly from formations as yet unknown in the North-West of Scotland;
2. Mineral constituents derived from older rocks;
3. Minerals developed *in situ.*

In disturbed regions the forms of the original clastic constituents, whether rocks or minerals, have often been considerably modified. The allothigenic constituents may therefore be divided into two classes: (1) those which have retained the form in which they were deposited (allothimorphic), and (2) those in which that form has been modified by earth-stresses (authimorphic).<ref>Milch, Beiträge sur Lehre von der Regional-metamorphose. *Neus. Jahrb. Beilage,* Band ix. (1894), p. 101.</ref>

Fragments and pebbles from older rocks

Where the coarse-grained Torridon Sandstone rests on the uneven surface of Lewisian Gneiss, after the fashion of all great continental formations, it frequently contains angular blocks, of all sizes, derived from the immediately underlying rock. A detailed petrographical description of the contents of these basal breccias is unnecessary, as it would involve a repetition of what has been said in describing the Lewisian Gneiss. On passing upwards from these breccias into the main mass of the Torridon Sandstone, the fragments of local rocks are seen to disappear, and pebbles which cannot be matched in the underlying formation are met with. These pebbles merit a closer attention, as some of them have been derived from sedimentary formations of older date than the Torridon Sandstone, which is itself of pre-Cambrian age.

A miscellaneous collection of pebbles made by Dr. Horne north of Strath Lingard, E.N.E. of Loch Maree, yielded on examination the following result:

	per cent
Vein quartz	50
Quartzite	20
Chert and jasper	16
Grit	8
Felsite and felspar-porphyry	6
	100

The vast majority of the true pebbles belong to the types above referred to, but a few exceptional varieties may be occasionally recognised. No special importance must be attached to the figures given above. The relative proportions of the different varieties vary from place to place, as will be seen by referring to the results obtained by Mr. Clough (page

333).

The pebbles of vein-quartz are so uniform in character that only one section has been prepared. The pebble, which is from the Applecross district, is white with reddish staining along cracks. It is composed of large irregular grains of quartz which interlock with each other along sutural junctions. The rock is in every way identical with that which occurs so commonly in veins in disturbed regions.

The quartzite-pebbles are light-grey, red, or liver-coloured. They are sandstones which have been indurated by the deposition of secondary silica on the original grains, whose outlines are frequently recognisable by a coating of ferric oxide (S6197) [NG 72 48]. One specimen (S6191) [NG 72 48] consists of more or less rounded grains of quartz cemented by brown isotropic interstitial matter.

The cherts are usually black or yellow, with occasional patches and streaks of red. They sometimes contain areas of crystalline quartz, and, less frequently, drusy cavities lined with small crystals of quartz. No hard and fast line can e drawn between the cherts and jaspers. The black cherts arbe represented by specimens from Ben More, Coigach, Ross-shire (S3894) [NC 09 04], (S3937) [NC 09 04], and from Cape Wrath (S6351) [NC 257 740]. They consist of crypto- or micro-crystalline silica, and are frequently traversed by veins of crystalline quartz. Pseudomorphs in the form of rhombs, wholly or partly composed of ferric oxide, are often present. They doubtless indicate the presence of ferriferous carbonates such as are commonly found in cherts associated with sedimentary deposits. The sections of chert have been carefully searched for organic structures, but up to the present nothing definite has been found. The structures represented in (Plate 50), Fig. 1, occur in a pebble from Ben More, Coigach.

It has somewhat the appearance of a silicified oolite. The irregular oval grain near the centre of the right-hand half of the figure shows traces of concentric structure at the margin. The interior is formed of clear crypto-crystalline silica. Immediately below this is another grain without any definite radial or concentric structure. It is circular in outline, and appears to be made up of a number of small spherical bodies, the sections of which measure 0.04–0.05 mm in diameter. Traces of similar bodies can be made out in other portions of the slide.

Dr. Hinde has shown<ref>On Beds of Sponge-remains in the Lower and Upper Greensand of the South of England, *Phil. Trans. Roy. Soc.,* Part II., 1885.</ref> that the colloid silica of sponge-spicules frequently passes into a globular form. The globules, which may occur singly or in groups, vary in size from 0.0014 to 0.045 mm The peculiar bodies in these Torridon pebbles are on the average somewhat larger than the globules described and figured by Dr. Hinde, but they agree with them as regards their mode of aggregation. Somewhat similar bodies have been described by Vogelsang<ref>*I- Die Krystalliten.*</ref> in a silicified rhyolite from Hungary.

The yellow or buff-coloured cherts are composed of crypto- and micro-crystalline silica. Some of them (S6353) [NC 257 740] consist of well-rounded grains of amorphous chert embedded in a chalcedonic matrix.

Pebbles of jasper are common in the Torridon conglomerates. They consist of crypto-crystalline and micro-crystalline silica often deeply stained with ferric oxide. Brecciated structures are frequently recognisable. A specimen from Cape Wrath shows a well-marked spherulitic structure. The central portions of the spherulites ((Plate 50), Fig. 2) are formed of clear, cryptocrystalline silica, in which a few small deeply-stained spheres may sometimes be observed. The marginal portions of the spherulites are also deeply stained. They consist of crystals which interfere with each other laterally, and are so arranged that their optic axes are approximately coincident with the radii ol the sphere. The intervening spaces are filled with crystalline quartz containing scattered specks of ferric oxide. The individual crystals which form the peripheral portion of a spherulite are, as a rule, prolonged beyond the deeply-coloured zone so as to form a part of the unstained interstitial aggregate. This pebble, so far as structure is concerned, has many points of resemblance to the spherulitic felsites of the "Lea Rock" type, and as such felsites occur amongst the pebbles of the Torridonian conglomerates the question arises as to whether it may not be a silicified rock of that type. The impregnation of trachytic and rhyolitic rocks by secondary silica is known to take place, and occasionally even the felspars of such rocks have been replaced by quartz. It is quite possible, therefore, that some of the jasper pebbles may represent silicified felsites.

The felsites are dark-purplish compact rocks, usually less red in colour than the jaspers, but not always to be easily distinguished from them. They consist of porphyritic crystals and crystal-groups of felspar in a spherulitic, micro-pegmatitic, micro-granitic, or micro-poikilitic ground mass.

Spherulitic structures are well represented in specimens from the neighbourhood of Kinlochewe (S4201) [NG 96 68] and Applecross (S6189) [NG 72 48].

Figs. 1 and 2, (Plate 51), represent portions of the latter rock. Some of the structures in this rock are identical with those of the Tertiary Hungarian liparites described by Vogelsang. They furnish, therefore, a striking illustration of the uniformity of volcanic phenomena throughout geological time.

The oldest components (S6189) [NG 72 48] of this rock are certain phenocrysts of quartz and felspar. These are embedded in a matrix which shows various foams of intergrowths of quartz and felspar, as well as a certain amount of micro-crystalline interstitial matter, in which traces of perlitic structure may be recognised. Next in order of formation to the phenocrysts come spherulites of the type represented in Fig. 2, (Plate 51). These show radial and concentric structures, but do not give a black cross in polarized light. They are often irregularly polygonal in outline, and sometimes give off branches in which a plumose or sheaf-like arrangement of the doubly refracting substance and also of the trichites may be seen. The spherulites in question and the branching processes connected with them are exactly similar to the corresponding structures in the slides of a rhyolite from Szanto, Hungary.

As the process of consolidation continued, spherulites of the type represented in Fig. 1, (Plate 51), were formed. These frequently enclose fragments of the earlier and more deeply-stained structures, as well as phenocrysts of quartz, one of which in the form of a rounded grain is represented in the figure.

They consist of two substances, felspar and quartz, and the radial structure is due to the fact that the felspar takes the form of thin and often branching fibres which run out from the centre towards the circumference.

The separation of the felspar from the quartz in the central parts of the spherulite can only be made out by using the Beckê effect, but in the narrow zone which surrounds the main spherulite Fig. 1, (Plate 51) it is quite distinct. Here the distribution of the felspar is rendered visible by red pigment which is not present in the quartz. It will be seen that the felspar takes the form of microscopic trees or bushes, which have thm roots, as it were, in the main body of the spherulite. This narrow zone clearly proves that the later stages of spherultti'"Ming were characterised by a well-marked separation of the two minerals, quartz and felspar, of which the spherulites are composed. Other portions of the slide illustrate the same point in a still more striking manner. Thus, the feather-like patches seen in the upper part of Fig. 1, (Plate 51), consist of felspar and polarize as individuals. They lie in a matrix composed of large individuals of quartz which interlock with each other, irrespective of the distribution of the felspar substance, so that this portion of the slide may be said to possess a micro-poikilitic structure.

From the facts above described it is evident that this rock contains every gradation from an ultra-microscopic intergrowth of quartz and felspar to one in which the two minerals are clearly recognisable. The spherulites of acid rocks have been compared<ref>British Petrography, p. 402.</ref> with those formed during the slow cooling of eutectic compounds. A study of this specimen appears to show that the comparison was justified.

In addition to the phenocrysts and spherulitic intergrowths, there is a small quantity of micro-crystalline interstitial matter which obviously represents the latest phase of consolidation. It consists of quartz and felspar together with specks of iron-oxide, and is traversed in parts by well-marked perlitic cracks. These cracks sometimes traverse the individuals which form the micro-crystalline aggregate — a fact difficult to account for on the supposition that the aggregate is the result of secondary devitrification.

Other specimens of spherulitic felsite (S4201) [NG 96 68] consist of phenocrysts of felspar and quartz, round which spherulites have in many cases been formed. The latter show an imperfect black cross in polarized light and have somewhat ill-defined margins. The matrix may be either micro-crystalline or micro-pegmatitic. The marginal portions of the spherulites are micro-pegmatitic intergrowths of quartz and felspar, and the coarseness of this structure decreases towards the centre until it becomes unrecognisable. The conclusion that the central parts of the spherulite are formed of ultra-microscopic intergrowths of a pegmatitic character is therefore irresistible. This specimen (S4201) [NG 96 68] is also interesting as furnishing evidence of the formation of micro-pegmatite at two distinct stages in the process of consolidation, for in one or two cases small patches of micro-pegmatite form the nuclei of spherulites.

The other felsites of which sections have been prepared may be described collectively. Phenocrysts are often though not always present. They consist of oligoclase in crystals, crystalline fragments, and crystal-groups, and also of orthoclase, which is, however, much less common and often intergrown with a plagioclase felspar (micro-perthite). Ferro-magnesian minerals are never recognisable, and must have been almost entirely absent. Their former presence is suggested by the occasional occurrence of chlorite and epidote. Quartz has not been observed as a phenocryst.

The ground mass which always makes up the greater portion of the rock can in general be resolved with high powers into an aggregate of quartz and felspar with which some grains of magnetite and specks of iron-oxide are associated. Micropegmatitic and micro-poikilitic structures are common; microFranitic structures rare. One specimen from Applecross (S6196) [NG 72 48] is mainly composed of micro-pegmatite of so fine a grain that its true character can only be recognised with high powers. In this rock the following sequence of events is recorded. First a few small idiomorphic felspars were formed, then the main mass, which was probably an eutectic compound of quartz and felspar, consolidated as micro-pegmatite.

Micro-poikilitic structure is well seen in another specimen from .Applecross (S6188) [NG 72 48]. A few phenocrysts of felspar occur in this rock, but the main mass is a micro-poikilitic aggregate. Quartz forms, as it were, the substratum of this rock. so that if the felspar and iron-ores were removed a spongy mass of quartz would remain retaining the original form of the specimen.

In most of the rocks from which sections have been prepared, the fact that the ground mass is an aggregate of quartz and felspar can be made out with high powers. This, however, is not always the case. In one specimen (S6192) [NG 72 48], which shows well-marked fluxion structure, the matrix is crypto-crystalline. A few phenocrysts of felspar are present, and the flow-structure is indicated by grains of iron-oxide and by thin micro-crystalline folia which are arranged parallel to each other throughout the slide.

These felsites have been described at some length because of the interest attaching to them on account of their age. They occur as pebbles in a pre-Cambrian group of sedimentary rocks, and must therefore have been derived from a still earlier formation, of which no other trace has been found in the north-west of Scotland. They are identical in all essential respects with the felsites belonging to the Uriconian series of Shropshire.

Apart from the fragments occurring in the basal breccias, schistose and highly metamorphic rocks are rare in the Torridon conglomerates. The collection of the Geological Survey includes a fine-grained pinkish quartzo-felspathic mica-schist (S3895) [NG 995 692], Ben Slioch, Loch Maree), a fine-grained quartz-magnetite-schist ((S6176) [NG 72 48], Applecross), a medium-grained silvery mica-schist (S6378) , south-west side of Loch Maree), a bright-green rock composed of quartz and fuchsite ((S6354) [NC 257 740], Cape Wrath), a quartz-tourmaline rock ((S6179) [NG 72 48], Applecross), and two or three rocks, mainly composed of quartz, showing marked signs of dynamic action (S6181) [NG 72 48], (S6186) [NG 72 48], Applecross) .

The quartz-fuchsite-rock bears a most striking resemblance to the green aventurine said to come from the Bellary district in Southern India. It is composed of micro-crystalline quartz and bright-green biaxial mica, which gives the reaction for chromium in the borax bead, and shows the following colors x, greenish-blue; y, yellowish-green; z, green. The x-colour for fuchsite is described by Dana as robin's-egg blue, a statement which is somewhat puzzling to British readers, as our robin lays eggs of a dull white colour marked with reddish spots, but which receives a perfect explanation when it is remembered that the American robin is a thrush. The peculiar colour is that of most thrushes' eggs.

The quartz-magnetite rook is composed of micro-crystalline quartz associated with grains, crystals, and crystalline groups of magnetite. It possesses a well-marked parallel structure which is brought out by the distribution of magnetite. This pebble must have been derived from rocks allied to those already described as occurring in the altered sedimentary series of the Loch Maree district.

The quartz-tourmaline rock is compact, dark, composed of micro-crystalline quartz and grains of brown tourmaline. It is probably a tourmaline-hornf els, due to contact action of granite upon a sedimentary rock. It is very similar to rocks occurring round the granitic masses of Cornwall, and also as pebbles in the Triassic conglomerates of Central England and in the drifts of the South of England.

(2) Mineral constituents derived from older rocks

In those areas which have not been affected by the post-Cambrian earth-movements the mineral constituents are, as a rule, allothigenic and allothimorphic. Secondary enlargement of quartz-grains and the development of minute scales of mica in the felspars are the only important agencies which have modified the original constituents. But in the moved areas the original clastic grains have been modified both in external form and internal structure. The nature of these modifications will be described under the different minerals.

Clastic quartz occurs abundantly in all except the finest-grained argillaceous deposits. The larger grains (1 mm or more) are often well rounded, but the smaller (0.1 mm or less) are, on the contrary, always angular. The minute hair-like inclusions so characteristic of the blue quartz of the pyroxene-gneisses are very rare. The behaviour of the quartz when subjected to arusotropie stresses is well illustrated by many specimens from the neighbourhood of Kinlochewe ((S3713) [NH 018 589], (S3714) [NH 018 589], (S3715) [NH 018 589], (S3716) [NH 018 589], (S3717) [NH 018 589], (S3718) [NH 018 589], (S3719) [NH 018 589], (S3720) [NH 018 589], (S3721) [NH 018 589], (S3722) [NH 018 589], (S3723) [NH 018 589], (S3724) [NH 018 589], (S3725) [NH 005 566], (S3726) [NH 005 566](S3726) [NH 005 566], 3727, (S3728) [NH 005 566], (S3729) [NH 005 566], (S3730) [NH 005 566], (S3731) [NH 005 566]) and Loch Kishorn ((S2263) [NG 833 423], (S2264) [NG 84 40], (S2265) [NH 007 496], (S2266) [NH 007 496], (S2267) [NG 84 40], (S2268) [NH 007 496], (S2269) [NH 007 496]). The first evidence of strain is the absence of definite extinction under crossed nicols. Sometimes the shadows sweep uniformly over the section; at other times the grain is divided into stripes or patches which have a fairly uniform orientation, the adjacent portions being separated by a narrow zone in which the extinction .positions change rapidly. A difference of 18° or 20° may sometimes be observed between adjacent patches of what was originally a clastic grain with uniform extinction. If examined in convergent polarized light the strained portions give the figure of a biaxial mineral with small optic axial angle.

As deformation progresses more important changes take place in the external form and internal structure of the grains. They frequently become lenticular, and the original grain may be replaced by a micro-crystalline (granulitic) or crypto-crystalline (mylonitic) aggregate. Not infrequently a large individual may be converted into smaller lenticular individuals separated by micro- and crypto-crystalline material. As these changes take place the original grain often becomes frayed at the edges and loses itself gradually, so to speak, in the secondary granulitic or mylonitic substance, which frequently constitutes a considerable portion of the rocks in which these phenomena are seen.

In the coarser-grained rocks felspars are almost as abundant as quartz. Microcline, microcline-microperthite, orthoclase, and oligoclase have been recognised. The characteristic felspar of the red sandstones or arkoses, which form such an important feature of the Torridonian series, is microcline and microcline-microperthite. The other felspars are, as a rule, much more altered than the microcline, and more deeply stained with ferric oxide. On this account they are frequently undeterminable. Oligoclase may, however, often be recognised, and it is probable that most of the altered felspar belongs to this species.

When subjected to deforming stresses felspar does not behave in the same way as quartz. It is more liable to actual fracture, and broken fragments, which evidently belonged to one individual, are frequently seen, under the microscope, to have been separated from each other. Individuals of quartz have often changed their forms by passing into aggregates without any separation of the constituents of the aggregate. Felspars, on the contrary, have changed their forms by actual fracture, and the authiclastic fragments have often been dragged apart by internal movements in the rock-mass. In the rocks with a pronounced fluxion (micro-flaser) structure lenticular grains of felspar with tail-like endings, largely composed of broken fragments of the grain itself, may irequently be observed.

The felspars often show the micaceous type of decomposition, and much of the sericitic mica in the sheared varieties of the coarser rock has doubtless been formed at their expense.

Clastie micas occur in the finer-grained sandstones and sandy shales. Both brown and white micas are present, and the former is often as abundant as the latter. Grains of epidote are common in many of the finer-grained sediments, and especially in the rocks belonging to the base of the series.

The heavy minerals so commonly found in the finer-grained sandstones of all geological periods occur also in those of the Torridonian series. They include magnetite, ilmenite, sphene, garnet, tourmaline, zircon, and rutile. Black bands mainly composed of titaniferous iron-ore occur in the Middle Torridonian group of Skye (S5072) [NG 711 252]<ref>These grains were roughly isolated and partially analysed by Dr. Pollard. Iron reckoned as Fe_2O_3, 73.7; TiO_2 14.1; SiO_2 9.8; Al_2O_3 &c., 2.2; loss, 0.6. They are but slightly affected by a weak magnet.</ref>, and also in beds provisionally referred to the Upper Torridonian group in Crowlin Island, south of the Applecross peninsula (S8761) [NG 69 35].

(3) Minerals developed in the rocks

The very important question of the relation of the Torridonian formation to the crystalline (Moine or Eastern) schists is expressly omitted from consideration here. Leaving out of account, therefore, certain crystalline rocks which may eventually be accepted on all hands as Torridonian, those which remain do not show any striking development of new minerals unless the secondary mylonitic and granulitic aggregates, containing mica and chlorite, of which the sheared rocks are often largely composed, be included under this head.

Sericitic mica is abundant in all the sheared rocks. It has evidently been developed at the expense of the felspar, and coats the planes of differential movement. Chlorite is common in the green grits and fine-grained greywackes which occur so largely in the Lower Torridonian rocks of Skye and the district about Loch Carron.

The intensely-sheared epidotic grits which occur at the junction of the Torridonian and Lewisian Gneiss at Fernaig (Loch Carron) contain numerous idionaorphic crystals of magnetite. As these crystals vary considerably in size and are quite unlike the clastic grains of titaniferous iron-ore above referred to, it is probable that they have been developed *in situ.* The secondary micro-crystalline mosaic of this rock (S4102) [NG 849 334], though fine in grain, has all the distinctive characters of a true crystalline schist. Detached flakes of chlorite are scattered through it exactly in the same way as those of mica in typical Moine-schists.

General description of the rocks

The rocks include all types of mechanical sediment from the finest argillaceous deposits to the coarsest conglomerates and breccias. Calcareous deposits are represented only by a few thin bands of calcareous grit and impure limestone. The Upper Torridonian group of Cailleach Head (Loch Broom) contains phosphatic matter in impersistent bands and nodules.

The red felspathic sandstones or arkoses which constitute so large a part of the series between Cape Wrath and Applecross resemble those of other great continental formations both in their petrographical characters and in their relation to the underlying floor of Lewisian Gneiss. The principal constituents are quartz, alkali-felspar, and oligoclase. The red colour is due partly to a staining of the more or less altered felspars or fragments of felsite, which sometimes form a not inconsiderable portion of the rock (S8751) [NG 990 969], and partly to a thin pellicle of ferric oxide coating the individual grains. This coating is probably the result of subaerial decomposition on the old land surface from which the materials were derived. The basal breccias which often flank the buried mountains are, as already explained, of the nature of scree material. They consist of fragments of the local rocks embedded in a sandstone matrix. The conglomerates on the other hand, are probably torrential deposits brought down from a district very different in geological structure from that of the area in which the Lewisian Gneiss occurs. Some information as to the nature of this district is furnished by the pebbles, of which a description has already been given. It must have contained representatives of sedimentary, plutonic, volcanic, and metamorphic rocks. In interpreting the evidence furnished by the pebbles, it must, of course, be remembered that some of these may have existed as pebbles in still earlier formations. Such rocks as quartzite, chert, jasper, tourmaline-hornfels, and vein-quartz possess great powers of resistance, and pebbles formed of them have often been handed on from one formation to another during the progress of geological time.

Although red rocks constitute a very large part of the Torridonian formation, they by no means make up the whole. Dark shales occur both at the base and at the top of the series in certain localities. The basal shales are well seen in the narrow strait, dry at low tide, separating the Isle of Fladda from the northern part of Raasay. They are indurated so as to resemble slates, but they do not possess a true cleavage. The upper junction with the red beds is here well exposed, and the abrupt change in colour is very striking. At the upper limit of the dark shales there are beds of a grey, banded calcareous sandstone, about two or three inches in thickness. This rock (S5876) [NG 589 502], (S5877) [NG 589 502] is composed of angular grains of quartz and felspar (0.1–0.2 mm), flakes of biotite and white mica, a few grains of garnet, sphene, iron-ores, and epidote, and a matrix of calcite. The heavy minerals and the micas are arranged in layers parallel with the stratification, and doubtless owe this mode of distribution to the sorting action of gentle currents. Portions of the calcareous matrix possess a very peculiar granular structure. They are composed of more or less rounded grains of calcite of approximately uniform size (about 0.02 mm). The grains occur singly and in clusters. The meaning of this structure is very obscure. It may possibly be organic, but, if so, the nature of the organism is unknown.

The beds of calcareous grit are interstratified with the upper part of the black shales, and the portion of the series containing them is immediately succeeded by red felspathic sandstones. The abrupt change in colour certainly indicates a sudden and important change in the conditions of deposition, probably allied to that indicated by a similar change in colour at the junction of the Keuper and Rhtic series in England.

The shales of the Upper Torridonian group are well developed at Cailleach Head, Loch Broom (S8758) [NG 985 980], (S8760) [NG 987 987], where they are associated with micaceous sandstones containing two micas (S8759) [NG 986 986]. One specimen (S8760) [NG 987 987] is of great interest on account of the presence of black phosphatic lenticles. It is distinctly laminated, and contains minute grains of quartz, felspar, and epidote (0.05 mm or less) associated with two micas. The lenticles (1 x 1 x ¼-in) consist of the finer portions of the sedimentary material cemented with brown amorphous phosphate. In transverse sections the lamination of the rock can be distinctly traced into the lenticle, but the laminae are further apart in the lenticle than they are in the shale, thus proving that there has been greater compression in those portions of the rock which have not been cemented by phosphate.

The general appearance of the phosphate is precisely similar to that of the concretions which occur in many geological formations, and, as is almost always the case, it is associated with some carbonate. Under these circumstances it becomes interesting to search for traces of organic structure. Under the microscope the amorphous brown phosphate is seen to contain minute spherical bodies (about 0.01 mm), which occur both singly and in groups; also brown fibres, about 0.004 mm in breadth, and of lengths varying from a few hundredths to several tenths of a millimetre. These fibres may be either straight, curved, or even looped.

Seeing that phosphates of this type are always associated with organisms, it seems impossible to avoid the conclusion that these peculiar structures are of organic origin; but the evidence at present available is not sufficient to indicate the nature of the organisms.

The facts above described clearly indicate that a concentration of phosphatic matter took place during or immediately after the accumulation of the sediment. A similar concentration has occurred in sedimentary rocks of many different geological periods; but in most cases the loose deposit in which the action took place has been winnowed away by a process of contemporaneous erosion, so that the nodules are not, as a rule, embedded in their original matrix as they are in this case.

The Lower Torridon groups of the thrust areas, extending from Loch Kishorn to the Point of Sleat in Skye, include an extensive series of grey and greenish-grey, fine-grained schistose grits or greywackes. These rocks answer to the "grauwackeschiefer" of German petrologists. They alternate with other cleaved rocks which, in their original condition, must have been sandy shales. In these rocks the dominant felspar is plagioclase instead of microcline, and epidote and chlorite are not uncommon.. The lowest beds in this district are often extremely rich in epidote, and on this account are often referred to as epidotic grits and conglomerates.

The dynamic metamorphism of Torridonian rocks

The effects of dynamic metamorphism upon the Torridonian rocks are very marked in certain places. A series of specimens (S2263) [NG 833 423], (S2264) [NG 84 40], (S2265) [NH 007 496], (S2266) [NH 007 496], (S2267) [NG 84 40], (S2268) [NH 007 496], (S2269) [NH 007 496] from the district of Lochs Kishorn and Carron, collected by Sir Archibald Geikie, the Director-General, well illustrates these effects on medium-grained grits, essentially composed of quartz, microcline, and oligoclase. The least altered rocks are easily recognisable as grits, but the outlines of the grains are not so well defined as in the unaltered specimens, and a marked fluxion structure is seen on transverse surfaces. The quartz grains have often been drawn out into lenticles and even into thin folia which wind round "eyes" of pink felspar (S2263) [NG 833 423]. The hand specimens are traversed by planes of schistosity which are glazed with sericitic mica (S2263) [NG 833 423] and (S2266) [NH 007 496], and in extreme cases may be termed sericitic schists (S2269) [NH 007 496]. Under the microscope the rocks are seen to consist of more or less deformed grains of quartz, alkali-felspar, and oligoclase, with a variable amount of secondary crypto- or micro-crystalline material. The series illustrates all the points referred to in describing the effects of dynamic action on quartz and felspar. The secondary crypto- or micro-crystalline material with which the sericitic mica is associated is of special interest because it approximates, in structure, to crystalline schists of the Moine type. It suggests the conclusion that, if the deformation had taken place under a greater load, and therefore in all probability at a higher temperature, a holocrystalline schist of true Moine type might have been produced.

Another important series illustrating the effects of dynamic metamorphism. near the inverted base line of the Torridon Sandstone near Coulin, over the Kinlochewe thrust-plane, was collected by Dr. Horne. (S3713) [NH 018 589], (S3714) [NH 018 589], (S3715) [NH 018 589], (S3716) [NH 018 589], (S3717) [NH 018 589], (S3718) [NH 018 589], (S3719) [NH 018 589], (S3720) [NH 018 589], (S3721) [NH 018 589], (S3722) [NH 018 589], (S3723) [NH 018 589]. The first of the series is from a point 40 feet below the junction line, and the others follow in order up to the junction of the two formations. The locality is 3 miles south of Kinlochewe. The rocks vary in colour from pale pinkish-grey to dark greenish-grey. Dark greenish rocks, weathering to a light cream or buff colour, predominate. They are all- more or less schistose, and in texture vary from medium-grained to compact. When the schistosity is even and regular the finer-grained rocks break with a platy fracture reminding one of that of the Moine-schists. The constituents are quartz, microcline, oligoclase, white mica (mostly sericitic), iron-ores (scarce), and a micro-crystalline or crypto-crystalline matrix. Microcline is the dominant falspar. The larger constituents show the pressure phenomena already described, and the quartz grains especially often merge into the crypto-crystalline matrix in such a way as to show that they have contributed to its formation. Flakes of clastic mica may be recognised in some of the finer-grained specimens, but the sericitic mica which is associated with the matrix is mainly of secondary origin.

The matrix gives a felsitic appearance to many of the hand specimens in which the original structure has almost entirely disappeared. Under the microscope it cannot be resolved into distinct grains. The structure is crypto-crystalline verging on micro-crystalline. It is associated with streaks of sericitic mica. This matrix in_ which the relics of the original grains are embedded represents in part the finer-grained sedimentary material and is in part of secondary mylonitic origin.

Looking at the series as a whole, it is noticeable that the least-altered specimens occur furthest from the junction line of the Lewisian and Torridonian rocks, while the most altered specimens are those from its immediate neighbourhood. The increase in alteration is not, however, uniform. Bands exhibiting the effect of intense shearing alternate with others in which the effects of shearing are much less marked.

Fig. 1. Chert. x 30.

Fig. 2. Jasper. x 30.

(Plate 50) 1.

Plate LI.

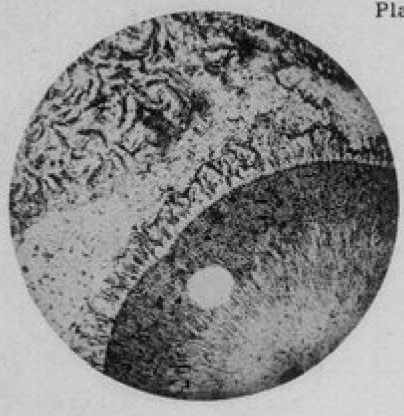

Fig. 1. Spherulitic Felsite. × 30.

Fig. 2. Spherulitic Felsite. × 30.

(Plate 51) 1.