

Waulsortian or Tournaisian in their faunas. My own view, from a comparison of the Belgian and British fossils, is that the zone of *P. giganteus* in Great Britain and Ireland corresponds to the whole of the Belgian series; for none of the fossils which are relied upon by MM. De Koninck and Lohest to identify the lower beds in both areas are in Great Britain and Ireland confined to the Lower Limestone Shales, but are found in abundance, and in a full condition of growth, at the top of the zone of *P. giganteus*.

The faunas contained in the beds of shale differ markedly from those contained in limestones, the shales being much richer in Lamellibranchs and Crustaceans, and comparatively poor in Brachiopods and the Actinozoa. Consequently the faunas of the same zone, taken as a whole, vary very much according to locality and the nature of the sediment. Consequently the zone of *P. giganteus* in Scotland, in which the limestones are separated by thick beds of shale, contains a very different fauna from that which obtains in the same zone in Derbyshire, where the shales are practically absent, and the limestone exists in one mass, made up of beds of various lithological characters.

IV.—THE CONTACT-ROCKS OF THE GREAT WHIN SILL.

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IN what follows, it is proposed to give a general description of the effects of contact-metamorphism, observed in the rocks altered by the intrusion of the Great Whin Sill in Durham and Northumberland.

The work, of which this is the condensed result, has been carried on for the last four years in the microscopical, and to some extent chemical, study of a large series of specimens collected at many points along the course of the Whin Sill exposure by Mr. E. J. Garwood, and also, to a very much smaller extent, by myself. Mr. Garwood has been for a long time engaged in a detailed examination of the geology of the district, and will in due course publish the results of his work, which is not yet complete. It was at his suggestion and request that I undertook the petrological study of the specimens collected.

As is well known, the rocks into which the Whin Sill mass has been intruded consist mainly of limestones, shales, and sandstones of the Lower Carboniferous beds. The special interest and value of the contact-effects here displayed, are enhanced by the fact that the rocks acted upon were all in what may be called a perfectly simple and elementary state. We know exactly what they were like before they were altered by the intrusion, and can study them as fully as we wish, in their original and normal condition, in the same and other districts. Thus, the shales, the metamorphism of which gives us the most interesting portion of the material, with the most important bearings upon the question of contact-action in general, are in all respects counterparts of those from the Coal-measures and the Lower Carboniferous, which I have described in

full detail in previous papers in this Magazine. None of the rocks affected had undergone any sort of "development" previous to the intrusion of the Whin; and as they have not been in any way changed, except by weathering, since the consolidation and cooling of the igneous mass, we are able to see with considerable certainty just what mineralogical and structural changes are to be ascribed to contact-metamorphism.

Such comparatively simple and reliable conditions, in a contact-area of such importance, are so very rare that it is at once apparent how valuable are the indications we may derive from them, and how great is the assistance they may render to us in our endeavours to understand the much more complex cases usually presented to us. I say "in a contact-area of such importance" because, as I shall show, we have here exactly reproduced for us a large portion of the phenomena we are accustomed to see round the intrusions, on a much mightier scale, of granite, etc. It makes no difference that in greater contact-areas the mineralogical and structural details are more striking as to size, so long as on the smaller scale they are equally clear and distinct.

I propose to deal with the altered rocks in the following order: pure or almost pure limestones, argillaceous limestones, shales, calcareous shales, sandstones. These, however, pass over into one another in all degrees, and there is, of course, no sharp division between limestones, argillaceous limestones, calcareous shales, shales, quartzey shales, argillaceous sandstones, and sandstones or grits. It is among some of the intermediate rocks that the most interesting effects are produced.

When a sufficiently large number of specimens had been sliced and examined, it became evident that there was no use in multiplying them beyond a certain point. It was clear that the same results of alteration could be found at intervals all over the long course of the Whin Sill, wherever the chemical nature of the invaded rocks was the same. For this reason, in the following descriptions, particular localities of occurrence will only be mentioned when specially interesting or pronounced developments have taken place, which are qualified to serve as good types of the alterations in general.

Commencing, then, with the limestones, we find that when these are pure, or at all events are non-argillaceous, the action of the Whin Sill upon them has been limited to a recrystallization of them. In some cases this recrystallization is very finely marked, and may stand alongside of the "marmorization" of similarly pure limestones by intrusions of granite.

Whether interfusion has taken place to any extent between the Whin and the purer limestones, at some points, is a question which it is not possible to answer decisively. In many actual contact-slides examined there does not seem to be evidence that any such action has occurred at all; the division line is quite sharp and clear, the Whin is small-grained but quite crystalline right up to the junction, and the recrystallized limestone begins equally sharply on

the other side of it. If there be recrystallized quartz, this also often comes quite sharply up to the contact-line.

In some instances there does appear to be a very narrow streak of more indefinite matter, possibly denoting interfusion; and there are other cases where a very noticeable band is seen of what has clearly been of a tachylitic nature; though whether we ought to regard it as a true tachylite,—i.e. a product simply of rapid cooling of the edge of the molten igneous rock,—or whether it is more a result of interfusion, I think cannot be settled, because chemical analysis would not here give a sufficiently definite answer. So far as microscopical evidence can help us, I rather incline to the view that it points to interfusion having taken place to some extent. Thus, the most striking example is one from Middleton Wood, near Belford. In the hand-specimen the tachylitic material was some two inches thick, and in the slide prepared from it, over the line of contact, there is nearly half an inch of it. The limestone is simply crystallized, as is also silica which it contained. It has not had any new minerals formed in it, but *quite close* to the junction there are a few colourless garnets, just a narrow string of small crystals and grains. Then comes the tachylitic band, mainly a yellow to red-brown glass, with a good deal of indefinite, speckly, felsitic-looking matter, and chloritic decomposition products, but with some feldspars and augites of good size dispersed in it, and a few prisms of enstatite. With these is also a good deal of garnet in small grains, and at some parts patches of it of much larger size. As no garnet occurs in the altered limestone except at the actual contact, and as it occurs in the tachylitic band, it seems likely to be a product of the interaction of limestone and Whin. No garnets seem ever to occur in the normal Whin Sill rock.

In some other specimens examined there is, again, a narrow band of what appears to be another product of such interaction. There is a seam of what appears to have been tachylitic, now very much obscured by calcite and chlorite due to decomposition. The limestone is perfectly free from any new mineral formation. But on the side towards the Whin comes a zone of close-grained igneous rock, a narrow strip of which is coloured brownish-red of a peculiar shade. Under higher powers it can be made out that this reddish band contains swarms of minute flakes of mica, and that it is from these that it derives its colour. Here and there the compact swarms of this mica open out, and become more scattered and larger in size, some individuals being seen as fairly well-bounded crystals, which can be recognized as a deep brown-red very dichroic biotite, some of the best flakes giving a good optic figure in convergent light with $\frac{1}{12}$ inch objective. None of this mica is ever seen in the normal Whin, and I have not seen any signs of it except at contacts with pure limestones. It certainly appears to be an endomorphic formation in the igneous rock, brought about by interaction with the limestone, though it does not seem easy to explain the chemical reactions which have been concerned in it. I do not recollect any mention of a similar result on an intruded igneous rock, and have certainly never seen it myself in any other case.

We will now pass on to the altered argillaceous limestones, including under that head all such rocks as are still safely to be recognized, microscopically and chemically, as having been dominantly limestones, but which have contained sufficient shaly material to provide a noticeable amount of silica and alumina, with some alkali and magnesia, which latter will also be present, more or less, in any case, in most of the limestones. Rocks of this class, of varying degrees of admixture, occur at many points along the Whin Sill, and have given rise to very interesting contact-products. The new minerals formed are garnet, augite, idocrase, wollastonite, epidote, hornblende, feldspar, chlorite, sphene. The garnet is the most persistent, being seen in all the slides examined from rocks of this class, whereas most of the above minerals may be present in some cases and absent in others.

One or two typical examples will serve to give a general idea of the nature of the alterations produced. Thus, from specimens of not very impure limestones from Burtreeford, sections have been cut which show the actual contact-line. First comes a narrow band (about $\frac{3}{16}$ inch) which seems to mark some sort of interfusion. Though now much obscured by fine-grained secondary calcite, it is distinctly defined both on the side towards the Whin and on that towards the limestone. The Whin is very fine-grained, but contains a good many perfectly fresh and distinct crystals of feldspar of larger size. Occasionally one of these crystals projects just into the edge of the interfusion-band, and may be seen to have been melted away in it and left with a rounded end.

Along the edge of the band towards the limestone lie many small but good crystals, and some irregular grains, of idocrase. The largest crystal in these particular slides is a prism $\frac{3}{16}$ inch long by $\frac{1}{16}$ inch wide, very fresh and perfect. A very few lie also a little further in, but none occur at any distance from the contact-line. It is interesting to note the mode of occurrence of these crystals, some of which are completely bedded in quartz, some again in calcite, and others in grains of calcite which are surrounded by quartz.

Then comes another narrow zone, about $\frac{1}{16}$ inch, which consists largely of recrystallized quartz as a sort of ill-defined mosaic, intermixed with varying amounts of calcite. This quartz is all full of inclusions of small garnet grains and indeterminable microlites, and clearly dates from the original metamorphism of the limestone by the intruded Whin, being strongly distinguished from later quartz which has filled in small cracks, etc., and which contains no such enclosures. This quartz band passes abruptly into coarse-grained, highly crystalline, saccharoid limestone, the calcite crystals containing numerous small garnets in rounded grains. A deep-coloured, very dichroic sphene, in good-sized crystals and grains, is also present.

Rather more impure limestones are represented by specimens from Rumbling Churn, near Dunstanburgh. Garnet is again very abundant, mainly in very small crystals and rounded grains

averaging about $\frac{1}{1000}$ inch in diameter, but in some cases reaching $\frac{1}{100}$ inch and a little over.

At some parts of the slides these garnets are packed so close that scarcely anything else is visible. They vary from colourless to yellow and greenish, and some are a rich red-brown. Often the centre is coloured, and the outer rim is colourless. Augite occurs plentifully with the garnet, in good-sized crystals and large irregular complex grains. It is all perfectly fresh, and some of it is of a very decided green colour, and slightly dichroic. Both garnets and augite come right up to the contact-line, and in one slide may be seen lines of very small augite crystals, clearly of contact-origin, growing out from the edge of the Whin, like the teeth of a saw, into the limestone. A very pale hornblende in slender needles is also present at some parts; epidote and sphene are well represented, and there is a good deal of recrystallized quartz, which frequently encloses garnet and augite. The remaining calcite of the limestone is completely recrystallized. There are often large fields of one uniform grain of it, with numerous garnets and augites contained in it.

In the mosaic of recrystallized quartz in these highly calcareous rocks one may often suspect feldspar to be present, but without being able to make sure of it, owing to absence of cleavages and the impossibility of making reliable optical tests. In one specimen from near Dunstanburgh, however, an altered limestone shows numerous small crystals, together with more or less irregular grains, of well-cleaved fully-individualized feldspar. Some few of the crystals even allow of identification, with much safety, as anorthite or a closely-allied species (sections with parallel cleavage, extinctions 30° – 40° , with emergence of good axial bar inside the field). They lie in amongst very coarse-grained recrystallized calcite, near the junction with the Whin. It will be seen later on that some of the altered shales contain abundant new feldspar. The above specimen shows also a few garnets, some epidote, a good amount of recrystallized quartz, together with a considerable amount of wollastonite, mainly in tufts and bunches of often sheaf-like, radiating fibres, with here and there bits of sufficient size for the application of optic tests. This mineral appears to be not of frequent occurrence in these rocks. Indeed, it may be noted that, so far as concerns the limestones which are reasonably free from any admixture except silica, there seems seldom to be any reaction between the lime and the silica. Calcite and quartz recrystallize side by side, and it is rare to see in these particular rocks any formation of wollastonite, or of any calcareous hornfels-like products, such as are more frequently encountered round granite-contacts.

Sometimes there were little bands of sandstone in the pure limestone, quite close to the contact. A specimen from near the Roman station of Borgovicus, close to the Whin, is sliced so as to show both recrystallized limestone, very saccharoidal, and sandstone converted into a well-cemented quartzite, with some new feldspar among the interstitial matter. The division-line of the two products is very clear and sharp, and there has not been a trace of action between them.

It is not only close to contact that these limestones have been affected. Complete recrystallization is seen at more than 60 feet away, and small augite crystals are seen in a specimen over 40 feet distant.

We may now turn to the consideration of the alteration-products of the shales. These shales along the contact-area of the Whin Sill have varied in nature in every degree, from argillaceous beds almost quite free from quartz, to others in which that mineral has formed a large proportion. For our present purpose we will call them all shales, speaking of them as more or less sandy, and only draw the line where the quartz has increased so largely that we must recognize them as argillaceous sandstones and classify them accordingly. Of this class of rock a very large number of specimens have been examined, but here again a few examples will suffice to give a clear idea of the general lines on which the metamorphism has proceeded. The intensity, and to some extent also the character, of the alteration varies more or less at different places. This is partly due to different composition, notably the variation in the amounts of quartz and of alkalis contained affecting the susceptibility of the beds to contact-action. Partly it is due also to the varying bulk of the intruded rock at different points, and sometimes we cannot account for the variation except by assuming some difference in the local conditions of the invaded beds, as to temperature, degree of hydration, etc., before the intrusion occurred.

Outwardly the change undergone by the originally soft shales consists in great induration, accompanied by more or less lightening of colour. In the inner zones of action, nearer the igneous rock, (sometimes also at considerable distances), the soft, fissile, dark-coloured shale has been altered into a hard, compact, grey or greenish-grey rock, with often very little fissility remaining, and in many cases completely replaced by a conchoidal or almost flinty fracture.

Inwardly, as revealed in thin sections, the most constant and striking change lies in the production of new mica, with chlorite, with a totally new structure as well as new mineralogical composition. Newly crystallized quartz is also frequently a main feature, in some cases felspar has been abundantly produced, and we have examples of the appearance of special contact-minerals in the form of biotite, andalusite, anthophyllite, etc.

If we take first the purest shales, which have had little, if any, quartz, and which have a chemical composition like that of some of the purest "fireclays," we find that where the contact-action has been most intense we have a complete recrystallization of the entire rock, with formation of a new mass of white mica throughout. Instead of the minute flakes of the indefinite micaceous mineral which has been produced in the fireclay or shale, making its main constituent, and lying nearly all in one plane, we get a network of much larger, well-developed flakes and crystals of white mica, lying criss-cross in all directions. In many cases a good deal of it is grouped together in fans and sheaves, and roughly spherulitic

aggregates giving more or less black-cross figures in polarized light. Intimately mixed and interwoven with this new mica is an abundant chloritic mineral. This chlorite forms part of the sheaves and spherulitic groups, and all over the slides is seen to have been formed flake for flake *with* the mica, as a result of one and the same process. No such chlorite exists in the unaltered beds; as I have previously pointed out, both it and the white mica are the result of a splitting-up and higher development of the impure and complex micaceous mineral of the clays and shales. In some cases there is a certain amount of biotite formed, with a similar mode of occurrence, but this is not frequent among these rocks. The formation of "spots" may also be seen on a copious scale in some specimens; and these spots, though small, are exactly analogous to the larger ones seen at some granite contacts, being due to the aggregation of the chloritic material which is separated out during the recrystallization of the rock constituents.

One or two special examples of the alteration of these pure shales may be given in illustration. Thus, a specimen from Rowntree Beck, taken 18 feet below the Whin, is very highly altered but still contains good fossils. An analysis of it gives—

Silica	...	...	...	...	51.40	per cent.	
Alumina	...	...	...	...	26.85	"	
Ferric Oxide ¹	...	...	...	...	6.15	"	
Lime	...	...	...	...	0.56	"	
Magnesia	...	...	...	...	2.38	"	
Potash	...	...	...	...	5.21	"	} 6.99
Soda	...	...	...	...	1.78	"	
Water	...	...	...	...	6.45	"	
					<hr/>		
					100.78		

This composition shows the rock to have been originally of the nature of a fireclay, closely resembling some of the series of which I published analyses in a former paper (*GEOL. MAG.*, 1894, Dec. IV, Vol. I, pp. 36-45 and 64-75). It is now a muscovite-chlorite rock, with abundant "spots" all over it. Into these spots is concentrated nearly all the pigmental matter of the rock, together with chlorite and numerous dark grains and microlites, so that the spots are dark in a light field. Parts of this field are almost clear and colourless. In polarized light they are seen to consist of an interlacing mass of muscovite and pale chlorite. Sheaves and spherulitic bundles of mica and chlorite abound all over the section, and there is no sign of any definite orientation of these minerals in any direction. The entire rock is crowded with small grains and crystals of rutile recrystallized from the original "needles" of the shale.

Another interesting spot-rock comes from near High Force. In ordinary light a section of it shows a sort of marking off into roughly polygonal, or approximately circular, clear spots, framed in

¹ In this and following analyses *all* the iron is reported as ferric oxide, no special determination having been made of the portion which is always present as ferrous oxide. This often causes more or less excess in the totals, but is not of any importance for the purposes for which these analyses were made.

darker greyish and brownish pigmental matter. The spots are mostly of a very pale greenish colour, and proper illumination enables us to see countless flakes and crystals of a chloritic mineral. With crossed nicols the whole slide is resolved into a network of muscovite flakes, lying again in every possible direction, and amid the brightly polarizing mass of this mica the chloritic spots are more or less dark and isotropic. In some the transition from the bright frame of mica is quite sharp; in others mica projects more or less into the spot, and only the centre is free. Many spots show a field of quite isotropic, pale-green substance, in among which a dim and speckly fine-grained mosaic polarization is discernible. These spots are again in all respects exact counterparts of what may be seen at some granite-contacts. It is curious to observe that, whereas in the previous example the dark pigmental matter has concentrated inside the chloritic spots, in the present case it has remained completely outside them, and is mixed in with the mica. I have made no analysis of this rock, but it shows only a very small amount of recrystallized quartz, and is no doubt very closely the same in composition as the last. No trace of clastic muscovite remains in either of these, and, indeed, in nearly all the highly altered fine-grained shales examined, it has absolutely disappeared and entered into the same complete recrystallization which has affected the main mass of secondary micaceous and other material of which the shales and clays were composed.

Perhaps among these very fine shales examined, the most interesting case is shown in a specimen from near Winch's Bridge, in Teesdale. It is from a body of rock which has been caught up by the Whin. It contains—

Potash	5.71	per cent.	} 7.20
Soda	...	...	...	...	1.49	„
Water	...	...	...	...	7.40	„

This is very nearly the maximum of alkali which I have found in any of the carboniferous shales and clays. It can have contained but little quartz. When it is examined under the microscope it is seen to consist, to a very large extent, of the peculiar substance which I have previously described in detail as being found in varying quantity in so many altered rocks around granites (GEOL. MAG., January and February, 1894). I traced and described its various modifications and developments, and endeavoured to show the probable nature of its origin and the part it plays in the changes going on during contact-metamorphism. There seems every reason to regard it as a product of the *solution*, or “aqueous fusion,” of original materials preliminary to recrystallization. Sometimes we see it in a quite amorphous state. Its first stage of development from this shows a faint minutely-speckly polarization. At very thin edges, with high powers and suitable illumination, it is seen to be very finely granular. We can see it in contact-slates in all stages of evolution, from the first appearance in it of very few and small mica-flakes, up to a full development of new mica out of it.

I alluded, in the paper referred to, to the fact that this substance could be seen in the contact-rocks of basic intrusions, but in less amounts than at granite-contacts. I had not at that time seen the specimen we are now considering, which shows the substance in greater amount than any other I have ever seen, and which strikingly confirms the view at which I had arrived concerning its origin and nature. It here forms a sort of base, or groundmass, all over the slide, and is nearly colourless, there being very little iron present. None of it is quite amorphous, but it has the speckly minutely felsitic polarization. Mica has formed in it throughout, but not regularly diffused, so that whilst at some parts there are patches, large enough to fill the field of a half-inch objective, in which but a few small distinct flakes are to be seen, we have other portions made up so entirely of mica that little of the base-substance can be seen among it. We can trace the growth of the mica in all stages. It is to a large extent in tufts and sheaves and rosettes; many of these of all sizes, as well as single flakes and crystals, and crossed and interlaced groups of them, may be seen brilliantly polarizing, floating free, as it were, in the nearly amorphous material out of which they have grown.

It is quite clear that what we here see is an intermediate stage,—an interrupted development,—on the road towards some such final product as the two examples we have just been studying. Had the conditions suitable for the crystallization of the mica continued long enough, we should have had a complete and uniform development of that mineral, together with its attendant chlorite, as before. But it is just the fact that the conditions did *not* continue long enough for completion of the process, which gives such particular interest and value to this occurrence. Such interrupted cases, when we can get them, are capable of teaching us more of what actually “goes on” in these contact-metamorphisms than any number of completed examples, where often all trace is lost of the steps by which the final result has been arrived at.

The rutile of the altered shale has crystallized out in much larger and more definite crystals than the original needles, many of them as “hearts” and “kites,” and the entire slide, mica as well as base-substance, swarms with them. A good proportion of the mica, in this case, is brown and strongly dichroic, especially some of its larger tufts and sheaves. There is no clastic quartz remaining; what little there was evidently entered into the general process of solution, and has reappeared as newly-formed mineral. It is also interesting to notice how the numerous small zircons of the original shale have resisted, as they so frequently do, the solution which has destroyed all trace of everything else, and how they remain quite unaltered among the new products.

The greater number of shales affected by the Whin Sill have not, however, been as purely argillaceous as the above examples. They have mainly been more or less sandy. But their alteration has proceeded on much the same lines as those described, and it will not be necessary to consider them in much detail. In some of the more

highly metamorphosed beds all original quartz has disappeared, and has been replaced by newly-formed contact-quartz. Where the amount of it is sufficient, we sometimes get a good "mosaic" of the same nature as what we see so universally at granite-contacts. Where there is less of it, we see it disseminated among the micaceous part of the rock in single grains, and groups of grains. In less intensely affected cases we get more or less clastic quartz remaining; sometimes it does not seem to have been attacked at all, and again, we may be able to see various degrees of its attack and corrosion by the processes of solution which took place. With the more or less regenerated quartz we nearly always see that the argillaceous position of the shale has given rise to just the same products as those we have been considering, the mica and chlorite, the spots, and the residual speckly substance, all appearing in the same relationships as to individual forms and general structures.

Among these altered sandy shales, however, there are some occurrences which are of such special interest that they must be here alluded to, in connection with the review of the whole contact-phenomena of the Whin Sill and their bearings on the general question of contact-metamorphism. In a former paper ("An Interesting Contact-Rock," *GEOL. MAG.*, March and April, 1895) I gave minute descriptions of the rocks to which I allude, and I would refer students of the subject to that paper, limiting myself here to a recapitulation of the particular points involved.

The principal rock in question is a bed of shale 8 feet thick, at Falcon Clints. It occurs 75 feet below the Whin, a series of limestones, sandstones, and shales intervening. It contains at some parts large numbers of approximately spherical nodules like peas. Thin sections show, in ordinary light, a grey groundmass in which are bedded grains of clastic quartz. In polarized light it is seen that this groundmass consists largely of an isotropic substance, in which lie numerous grains, rounded, irregular, or more or less definitely-bounded, of newly-formed quartz and some felspar. At parts these grains are so numerous and closely packed that they amount to a true interlocking mosaic, with very little isotropic matter. At other places they are more separated, and we get quite large spaces of the isotropic substance, but containing small flakes of mica and other things. These grains are not yet fully individualized; they are not water-clear, and have still so much dimness about them that they cannot be properly made out at all except in polarized light. They are absolutely distinguished from the original clastic material; not one of them could ever for a moment be mistaken for anything but a newly-formed secondary product.

The clastic quartz-grains remaining are seen to be all more or less attacked and corroded by the surrounding groundmass; their original angular outlines are in nearly all cases preserved, but the outer portions are no longer quartz, but an altered substance often containing a considerable amount of white mica and sometimes of felspar, whilst in some cases anthophyllite and andalusite are seen.

In the nodules considerable fields of clear, almost colourless, quite isotropic material are seen, in which bundles and sheaves and pseudo-spherulites of felspar, with some quartz, have been formed. Anthophyllite and andalusite are also seen in some of them.

Here, again, we have preserved for us one of those interesting cases of interrupted development. All the finer-grained material of the shale,—the impure micaceous mineral and the minuter quartz,—has been taken up into solution, or aqueous fusion; and out of the substance so formed a mosaic of quartz with some felspar, together with muscovite, has been in process of crystallization. But this process was arrested before it was complete, and so we are again able to see the unfinished stages, to observe the residual indefinite, isotropic, intermediate matter, and to note also the larger quartz-grains which were being attacked and dissolved, and would have all disappeared if the solution stage of the contact-action had been able to continue somewhat longer.

Sections from other parts of this bed show us mainly a fine-grained aggregate of newly-formed quartz and felspar, passing down into a quite cryptocrystalline felsitic-looking mixture (adinole), but opening up, on the other hand, here and there into numerous clear and glassy patches, which in polarized light are seen to consist of groups of well-twinned plagioclase felspar, which can often be identified as albite, whilst the extinctions also point to the presence of a species allied to oligoclase.

From the neighbourhood of Rowntree Beck, again, come specimens of shale altered to adinoles, and showing nodules up to two inches across, with anthophyllite.

We come now to the calcareous shales, and find that among these we have some of the most intensely altered rocks of all. Sometimes they occur as narrow bands in connection with purer limestones, sometimes as patches and lenticular masses in such limestones, and sometimes as thicker independent layers.

The most striking occurrence is at Falcon Clints. The specimens show a compact hornfels-like brown rock, with a jaspersy sort of appearance and fracture. It contains many garnets of sufficient size to be easily seen with the naked eye. Thin sections show that these garnets are the most prominent mineral contained. They very much resemble those in the altered impure limestones round the Shap granite, and like them are polysynthetic and show a good deal of birefracton. They are, however, here not so often well-defined crystals, but more irregular grains and patches. They are often very much cracked, the cracks being infilled with chlorite and other substances. They occur irregularly, some parts of the rock being free from them and others containing swarms of small grains and crystals.

In some specimens idocrase occurs with the garnet, some of it as good large, well-defined crystals on which characteristic angles can be determined. It is nearly all quite fresh and good, and in every way of normal character.

Both garnet and idocrase crystals may be seen containing large numbers of small crystals of spinel, the garnet much more so than

the idocrase. No spinels are seen except as enclosures in those two minerals. The greater portion of them are of a good deep-green colour, and exactly resemble those seen in altered limestone of bombs from Somma; there are also colourless and pale reddish-brown crystals.

If we take several thin sections of specimens from this occurrence and average, as it were, the results of microscopic examination, we find that a large proportion of the rock consists again of a base or groundmass, which varies greatly in its texture and fineness of grain. Sometimes it is a close-grained, felsitic-looking mass, quite cryptocrystalline, and nothing definite can be made out as to its component minerals. At other parts it becomes coarser, and examination with high powers seems to show that much of it is quartz and felspar; this conclusion being confirmed when we come upon good-sized patches, like glassy spots in ordinary light, which with crossed nicols are seen to consist of well-twinned felspar with sometimes more or less quartz. This groundmass may be described as a calcareous adinole. In it are bedded many new minerals besides garnet and idocrase.

Wollastonite occurs at some parts in considerable abundance, mainly as radiating sheaves and bunches, with sphene, epidote, and recrystallized calcite. In some slides are well-developed chloritic "spots," as well as others of the pale yellow-green, almost quite isotropic, granular matter; and there are some which appear to be cordierite in early stages of development, corresponding exactly with similar spots seen to occur together with undoubted cordierite in other contact-rocks.

A large hand-specimen of this rock from Falcon Clints I have analyzed. It contains:—

Silica	...	...	...	...	53.80	per cent.	
Alumina	...	...	...	...	20.25	"	
Ferric Oxide	...	...	...	...	8.15	"	
Lime	...	...	...	...	3.27	"	
Magnesia	...	...	...	...	3.02	"	
Potash	...	...	...	...	2.32	"	} 8.86
Soda	...	...	...	...	6.54	"	
Water and Carbonic Acid	...	...	...	...	2.90	"	
					<hr/> 100.25		

Another occurrence of a similar calcareous adinole is found at Sneblazes. A thin section shows the same sort of groundmass. No garnets or idocrase appear in the specimen examined, but there is a good deal of augite in small crystals, and felspar is again seen here and there. The analysis of this rock gives:—

Silica	...	...	...	...	50.60	per cent.	
Alumina	...	...	...	...	20.35	"	
Ferric Oxide	...	...	...	...	8.30	"	
Lime	...	...	...	...	7.75	"	
Magnesia	...	...	...	...	2.58	"	
Potash	...	...	...	...	2.39	"	} 6.75
Soda	...	...	...	...	4.36	"	
Water and Carbonic Acid	...	...	...	...	3.80	"	
					100.13		

Another specimen of a like nature, from close to contact, near to Crag Lough, Bardon Mill, has the following composition :—

Silica	...	...	...	...	48.20	per cent.	
Alumina	...	...	...	...	17.30	"	
Ferric Oxide	...	...	...	...	12.50	"	
Lime	...	...	...	...	10.08	"	
Magnesia	...	...	...	...	2.17	"	
Potash	...	...	...	...	1.93	"	
Soda	...	...	...	...	4.59	"	} 6.52
Water and Carbonic Acid	...	...	...	...	4.05	"	
					100.82		

It resembles the others in general composition, but shows hornblende among its new minerals.

It now remains to consider the sandstones, of which a large number have been collected from different points. There is not very much to be said about them, because when they are pure, or nearly so, the alteration is limited to a compacting and conversion of them more or less into quartzites; and where they are less pure, the interstitial matter has undergone the same alterations as have been above described. Thus, where there has been any noticeable amount of argillaceous deposit with the quartz-grains, it is now often seen to consist largely of the same mixture of new white mica and chloritic matter; and in this way we pass back again towards altered sandy shales, as the interstitial constituents increase.

It is noticeable, however, that whereas among the altered shales it is but seldom that brown mica is seen as a contact-mineral, and then only to a very subordinate degree, we find it more frequently and much more plentifully among the argillaceous sandstones. In one case from Rumbling Churn, near Dunstanburgh, there is as large a development of this biotite as might occur at any granite-contact, and all the characteristics of the mineral are the same.

In previous allusions to the contact rocks of the Whin Sill (GEOL. MAG., April, 1895) I had occasion to refer to the interesting question of the supposed transfer of soda from the igneous rock to the altered shales, etc., in such cases of *basic* intrusions. I pointed out that observers of the contact-effects of such rocks elsewhere had been forced to come to the conclusion that such a transfer does often take place, a very considerable mass of chemical and other evidence rendering any other verdict difficult, or even impossible. Most of our knowledge on this point comes to us from German petrologists, though instances of altered rocks rich in soda are not lacking in this country.

When I commenced working at the petrology of the Whin Sill contact I naturally gave attention to this very important point, and it so happened that some of my first analyses, and separate determinations of alkalis in altered shales, very strongly confirmed the views expressed by the German authorities. In the course of the work I have made a considerable number of further determinations, the general result being that the answer obtained is not at all uniform in its direction. There are many of the shales in which soda

has increased very considerably; but there are also plenty of others in which this is not the case, even with highly altered rocks close to the contact, the normal excess of potash over soda having remained undisturbed; and the evidence, as will be seen, is rendered all the more contradictory by the fact that in a given vertical section of beds we may have a rock quite near the Whin, showing this chemically unchanged condition, whilst another one, further away from contact, shows a great increase of soda relatively to the potash.

As previously pointed out, the rocks along the Whin Sill are not specially favourable for the study of the chemical aspect of the metamorphism, inasmuch as the igneous mass is intruded parallel to their strike, and we cannot take any one bed at a distance and follow it gradually up to the contact. All we are able to do is to rely on the fact that, apparently without any exception, the normal shales of the Carboniferous show an excess of potash over soda within certain limits. All the trustworthy chemical evidence available shows this to be the case, and I have myself confirmed it by large numbers of careful determinations, published and unpublished, on specimens from various localities; the two latest being a fireclay and a shale which I took from the neighbourhood of Bardon Mill, near to the exposure of the Whin Sill and its contact-rocks, but quite outside the area of its metamorphic action. The alkalies contained are respectively:—

Potash	...	...	...	2.62 per cent.	and 2.66 per cent.
Soda	...	...	...	0.98	„ and 1.24 „

The three analyses given above of calcareous adinoles are all striking instances of a large increase in soda. The total alkali-contents are all three high, though not higher than may be seen in some cases of chemically normal shales. But soda far exceeds potash in all of them. No shales of similar composition exist outside the contact-zone, and however we may *explain* the transfer of soda, we cannot very well deny its occurrence. This increase of soda, as a chemical fact, is accompanied by the mineralogical fact of the appearance of albite in the altered rock. Had we these cases only before us, there would not seem to be much difficulty in accepting the statements of previous observers on the subject.

(*To be continued.*)

NOTICES OF MEMOIRS.

I.—SOME CHARACTERISTIC GENERA OF THE CAMBRIAN.¹ By G. F. MATTHEW, LL.D., D.Sc., F.R.S.C.

THE paper gives in brief the history and use of several generic names, and the distribution of certain species to which they have been applied. These genera have an important bearing on the antiquity of the *Olenellus* Fauna. *Bathyuriscus*, Meek, known as a Middle Cambrian genus in Montana and Nevada, occurs in the *Olenellus* Fauna of Eastern North America. It is nearly allied

¹ Paper read in Section C (Geology), British Association, Toronto, August, 1897.