Chapter 19 Paleozoic metasomatism

Introduction

At several places in Anglesey<ref>It will be remembered (see pp. 58, 69, 90, &c.) that there are certain cases of silicification that can be shown to be older than the great movements of the Mona Complex, and that are ascribed to solfataric action connected with its vulcanism. Others accompany its dynamic metamorphism. All the cases of metasomatism dealt with in this chapter appear to be long subsequent to the metamorphism of the Complex.</ref> the rocks have been affected by metasomatic replacements, certain substances from without being substituted in varying proportions for the original materials. For some time the structures are able, especially if coarse, to survive the change in chemical and mineral composition, but in advanced stages they disappear, and the original nature of the rock is discoverable only with some difficulty. The principal cases are:

Parys Mountain

Llangaffo

Holland Arms

Llanddona

Mynydd Bodafon

Holyhead

Llanfairynghornwy

Pant-y-gaseg

Llaneilian

In one only of these, Parys Mountain, have the changes taken place upon a great scale: at the others the masses of rock affected have been comparatively small.

Parys Mountain

General aspects

The original materials and the structure of Parys Mountain have been dealt with in Chapters 14, 15, 17, and 18, and its famous copper mines will be described in Chapter 36. About a square mile of country is affected by the metasomatism, including the Parys hill itself, the West Hill of Pensarn (shown by the 300-foot contour west of that village), and some smaller ones beyond, the whole tract being two miles in length. The metasomatic phenomena can be studied to perfection in the two great open pits, whose crags, 100 feet or more in height, are absolutely unobscured by vegetation, are indeed (see Chapter 36) utterly barren, from the incessant oozing of metallic salts that results from the weathering of their sulphides. To this barrenness, as much as to their magnitude, we owe the wonderful clearness of the great sections, concerning which it was remarked by Dr. Flett that what can be inferred in other districts of the kind can here be actually seen. The rocks affected are the Palaeozoic sills, the Silurian and to a less extent the Ordovician shales; and three metasomatic replacements can be distinguished.

Silicification<ref>Most of the specimens and slides of the silicified rocks of Parys Mountain were kindly examined by Dr. Flett, who also visited the ground with the writer.</ref>

The Felsite — The original characters of this rock (p. 534) have nearly disappeared, though. it retains the general external aspect of a felsite, being compact and homogeneous, pale bluish internally, and weathering very white. But there is a general absence of porphyritic crystals, and the body has a granular texture not quite like that of the matrix of a rhyolite. In thin section hardly anything is to be seen but a very fine mosaic, with here and there a vein or aggregate of quartz. The mosaic itself is almost wholly quartz. On the brow of the northern escarpment 260 yards east-north-east of the Windmill, however, porphyritic felspars have been detected (E10247) [SH 445 907], pseudomorphs, now, in a quartz-mosaic which differs a little from that of the matrix. It is, indeed, from this section that the original nature of the rock has been put beyond doubt. The whole of the great sill, both within and without the metalliferous area, has been highly silicified.

The basic sills — An amygdaloidal diabase at Pen-y-nant, and a chloritic schist west-north-west of the 'P' of Pensarn, have been found to be silicified. The felspars of the diabase (whose pyroxene had already perished) are pseudomorphed in granular quartz, the igneous texture being preserved, so that the great change which the rock has undergone is not apparent in ordinary light.

The shales — The Ordovician shale near the summit of the hill is hardened and full of secondary quartz. But by far the most striking metasomatic changes are those in the Silurian shales between the limbs of the felsite fold, and as the phenomena are admirably exposed in the pits, they afford petrological studies of great interest.

Where unchanged, the shales are black, slabby, and rather soft, their graptolites being beautifully preserved. But within them occur great quantities of a totally different material. It is not fissile, but breaks with a conchoidal fracture, and is fine in texture, very hard, with somewhat of a chert-like aspect, and dark grey internally, though usually weathering to a sulphurous-looking brown. It occurs in masses of very variable size and shape, and is involved with the shales in a most intimate manner, capricious in its distribution, and following no particular horizons. Thin sections reveal, as in the rest of these altered rocks, an extremely fine, clear, colourless mosaic, in which nothing but quartz has been detected.

There is, however, an interesting variety whose quartz-elements are oval or spindle-shaped, about 0.5 mm. long, and lie in all directions. Their major axes coincide with the optic axis, so that they are really hypidiomorphic crystals.

Now this material is repeatedly found to replace the shale without any displacement; and in many clear sections, particularly in the eastern parts of the West, and western parts of the East Pit (for these terms, see Chapter 15), gradual passages into it from unmodified shale can be seen in the space of a few feet or even inches. Moreover, the fine parallel bedding of the shale passes on into the siliceous rock, which here and there contains a Silurian graptolite. There cannot, therefore, be any doubt whatever but that this peculiar flint-like material is really the shale itself, richly impregnated with secondary silica.

Micacisation

Most of the silicified rocks contain a little white mica, and some are very rich in it. This metasomatic mica can be distinguished from that which was developed in connexion with the earth-movements, for it is nnfoliated, and usually in larger crystals. One of the best examples is the rock with hypidiomorphic quartz just described, for the interspaces are filled with a ground-mass of white mica, whose flakes lie in all directions. Very clear also is the case of a felsite from the East Pit, containing pyrite, whose crystals are surrounded with halos of beautifully developed mica-plates that reach 0.5 mm. in length, radiating outwards from the faces of the cube.

Pyritisation

None of the rocks are free from pyrite, generally cubic iron-pyrite. From a few scattered cubes, we may pass to rocks containing aggregates and groups, or streaks and clouds of pyrite-dust, and thence to others which are crowded with it. Sometimes the shale, but still more the schistose portions of the felsite, are so full of pyrite for yards together that we have a third kind of metasomatic replacement, which may be called pyritisation. When copper sulphides predominate, we have a variety of this, which may be termed chalcopyritisation. These pyritised rocks have become quite unrecognisable as either felsite or shale, and being generally silicified and micacised as well, nothing but the clear field-evidence makes it possible to determine their origin.<ref>The Parys rocks may be studied in the following slides:(E622) [SH 460 909], (E6433) [SH 442 904], (E6434) [SH 442 904], (E6435) [SH 442 904], (E8419) [SH 459 907], (E8447) [SH 461 909], (E10245) [SH 457 906], (E10246) [SH 457 906], (E10247) [SH 445 907], (E10248) [SH 444 903], (E10249) [SH 46 91], (E10250) [SH 45 91], (E10251) [SH 436 898], (E10252) [SH 433 902], (E10253) [SH 433 903], (E10254) [SH 437 898], (E10255) [SH 440 903], (E10256) [SH 442 902], (E10257) [SH 444 906], (E10258) [SH 444 903], (E10259) [SH 461 906], (E10260) [SH 449 908], (E10261) [SH 433 903], (E10262) [SH 445 906], (E10263) [SH 444 903], (E10288) [SH 448 907]–(E10289) [SH 448 907], (E10309) [SH 445 906], (E10428) [SH 447 905].</ref>

Chemical composition

The following silica-percentages have been taken by Mr. J. O. Hughes:

Silicified Diabase. 83 yards north of Pen-y-nant, Parys Mountain (E10251) [SH 436 898]	SiO_2 = 61.34
Silicified Felsite. West Hill of Pensarn, Summit (E10245) [SH 457 906]	SiO_2 = 76.66
Silicified Banded Felsite. Brow of South Escarpment, Parys Mountain, 250 yards east by north from Pen-y-nant (E10254) [SH 437 898]	SiO_2 = 77.14
Silicified Porphyritic Felsite. Brow of North Escarpment, Parys Mountain, 260 yards east-north-east of Windmill (E10247) [SH 445 907]	SiO_2 = 80.41
Unmodified Shale with Silurian Graptolites. East Pit, Parys Mountain (E10263) [SH 444 903]	SiO_2 = 55.49
Silicified Shale, Hard and Flinty. Road (at north bend) through West Pit, Parys Mountain (E10288) [SH 448 907]	SiO_2 = 91.02

The unsilicified portions of the diabase are chiefly chlorite and epidote. In the other silicified rocks analysed all that is not quartz is seen in thin section to be metasomatic mica with a little pyrite.

The lodes

Details concerning these and their ores will be found in Chapter 36, but their geological characters and relationships belong to the present subject. All of them, except two 'cross-courses' in small faults, run along the strike, and dip at high angles about north by west. Of the 12 that are recognised in the mines, the most important were the Great' Lode in the Silurian, the North Discovery and Careg-y-doll Lodes in the Ordovician shales. The Great Lode (which is that of the two open pits) has been worked almost entirely away, and so have the more remunerative parts of the others.

The old underground workings are not now easy of access, and the exact nature of the deposits is a little difficult to realise. Phillips remarks that they were not, strictly speaking, true lodes at all. Now, although they were chiefly worked for chalcopyrite, there is abundant evidence that its mode of occurrence was essentially the same as that of the ferropyrite that can still be studied in daylight. This is, as has been seen, of the nature of an impregnation. But much is also arranged in tolerably definite bands running along the cleavage, expanding here and there into bunches, and sending out small transverse veins; and this is precisely the behaviour of the copper lodes as represented in the plans of the mine. It appears, therefore, that those lodes were, essentially, zones of maximum chalcopyritisation; sufficiently definite, however, to possess individuality not unlike that of a true fissure-lode.

Ferrification

The term 'gossan', applied in most mining districts to the weathered outcrop of a lode, is used rather differently in Parys Mountain. True gossan (for a discussion of which see Chapter 36) is hardly to be seen, and appears to have been rather rare. The Parys 'gossan'<ref>A strict regard for chronology would have excluded it from this chapter, but its inclusion is convenient.</ref> is locally described as a substance that 'always overlies everything else'. Its best exposure, at the side of the road going down into the West Pit, shows a coarse conglomerate with boulders up to two feet long, so richly impregnated with iron oxides that both boulders and matrix are stained a deep red colour, and the original characters of the deposit no longer discernible. Closer scrutiny, however, reveals that the boulders, in spite of their coating, are scored with glacial striae; and the conglomerate itself can be traced on into unstained and typical boulder-clay. 'Gossan', therefore, is boulder-clay that has become ferrified.

The escarpments and higher ridges of the hill are clear of drift, but a sheet of it creeps up the central hollow from the north-east, and some 20 feet of it are cut through by the West Pit. Surrounded on three sides by higher ground, this receives a good deal of surface water, and the iron salts have been carried down to it. Why, however, iron rather than copper salts, for the waters of the hill dissolve (see Chapter 36) abundance of copper? The reason seems to be that the salts taken up by surface waters are derived less from rock in place than from the immense piles of refuse with which all the upper parts of the hill are covered; and this refuse *is* refuse because, pyritous though it is, it contains relatively little chalcopyrite. This would, indeed, restrict the ferrifying process to about 150 years, and ferrified boulder-clay does not seem to have been found when the mines were first opened. Mr. Fanning Evans states that the formation of 'gossan' is still going on, which in itself points to a rather short period of production of it, otherwise the boulder-clay might be expected to be much more extensively ferrified than it is.

Chronology

Is it possible to assign these remarkable metasomatic phenomena to anything like a definite geological interval? Fortunately, the relations of metasomatic to dynamic structures afford a *terminus a quo,* and a section a few miles away supplies a clear *terminus ad quod.*

1. At many places in the mines, especially in the East Pit, silicified and unsilicified shale are to be seen in contact. A straight, parallel cleavage is well developed in the unsilicified shale. But, instead of being deflected round the hard siliceous masses, or tearing them out into augen, it passes straight on into them and gradually dies out, obliterated and healed-up ' by the fine secondary silica. In (Plate 33), the cleavage (which is there at a gentle inclination) is visible on the upper crags, and can be seen to die out downwards, till, at the dark chasm on the left, it is represented only by a few cracks at intervals. At other places, particularly by the road which crosses the West Pit, though divisional planes parallel to the cleavage do traverse the silicified rock, there is no sign of deformation, shearing, or slickensiding on them; but they are rough and mamillated, like surfaces coated with stalagmite or chalcedony often are. They are evidently fissures that have been opened out along the cleavage by percolating water, and coated with silica carried in solution.
2. Two slides [(E6433) [SH 442 904]–(E6434) [SH 442 904]] were cut by Dr. Flett from hard silicified shale that showed a good stratification-banding. Their micas were found to have an orientation obliquely across that banding, and at a high angle to it, indicating that the rock was a slate before it was silicified.
3. Where the silica takes the form of hypidiomorphic quartz, the crystals are not only unbroken and ungranulitised, but show scarcely any sign of optical strain, the great majority extinguishing sharply. The silicification, therefore, is subsequent to the movements that produced the cleavage.
4. But so also is the micacisation, for the metasomatic micas are undeformed, and can readily be distinguished from those of the foliation. The felsite which contains the pyrite-cubes with mica-halos (E10309) [SH 445 906] is highly sheared and full of fine foliated mica. But the micas of the halos are not only (with one or two slight exceptions) undeflected, not only optically undamaged, but when examined with a high power can be seen to penetrate for short distances into the micas of the body and to transgress their foliation.
5. The pyritigation is also subsequent to the same movements, for the rocks are full of perfect and undeformed cubes of pyrite; the lenticular pyritous masses which run along the strike are not sheared; and many veins which proceed from them cut sharply across the cleavage at high angles.

   There is abundant evidence, therefore, that all the metasomatic changes, silicification, micacisation, and pyritisation, took place after the great movements that set up the slaty cleavage, thus giving us a *terminus a quo.*

Can we go further, and discover any order of succession among the metasomatic changes themselves? A simple answer to this question cannot be given, as there is reason to suppose that the different types of impregnation recurred more than once. But a *general* order can be recognised, for each type was *dominant* at particular stages, and at the other stages merely subordinate.

First, then: though small mica-flakes are found as inclusions within quartz, yet the great body of the metasomatic mica is external to the quartz, and when that quartz is hypidiomorphic, the matted mica of the interspaces is moulded on the prisms, and therefore of later date. Next: the large dense nests of pyrite do not seem to contain any later silica-cement, and the veins that pass out from them turn round and cut across the banding of the already silicified shale. So the pyritisation also is later than the silicification. Lastly: some mica is later than some pyrite, for the mica-halos already mentioned grow out from cubes of pyrite: But this appears to be a case of early pyritisation: for while the large pyrite-nests are unmicacised, the silicified shale cut by their vein-apophyses *is* micacised, and that extensively; so that the principal pyritisation must be later.

It thus appears that in a general way Silicification was dominant in the early stages, was followed by the principal Micacisation, and that by the principal Pyritisation. And as it is evident that the chalcopyrite was intimately associated with the ferro-pyrite, we are able to assign the famous ore-deposits to their proper place in the chronology.

The fortunate preservation of a piece of evidence of a different kind supplies a first *terminus ad quod.* Facing Parys Mountain, some four miles to the south-east, is the curving grey wall of the Carboniferous escarpment, present limit of the slow retreat of the great sheet of later Palaeozoic deposits under which all this region once lay buried. In the Lligwy Bay Conglomerate (Plate 35) and (Figure 291), a coarse deposit at the base of the Carboniferous Limestone, are many iron-stained and rusty boulders (some of them two feet in diameter), full of green and yellow sulphurous-looking films along the joint-cracks, exhaling an odour of hydric sulphide where freshly broken, and vividly recalling the rocks described in this chapter. Under the hand-lens they are found to consist of siliceous matter richly impregnated with pyrite; and the microscope (E10296) [SH 498 871] reveals the same fine siliceous mosaic, sometimes even the same hypidionlorphic crystals of quartz with interstitial mica, that is so characteristic of the altered rocks of Parys Mountain. Some are identical with the silicified shale, others with the Careg-y-doll Lode, others with the felsite, and there can be no doubt whatever that when these Carboniferous deposits were being laid down the peculiar type of alteration was as complete as it is to-day.

The conglomerates of the Old Red Series have not furnished any decisive evidence; but they contain small pebbles of indurated mudstone, in one of which are aggregates of secondary mica, with strings and clots of iron-ores that appear to be pseudomorphs of pyrite. The Old Red Sandstone itself shows no sign whatever of having been affected by the metasomatic processes, and leaves no doubt that they are anterior to its deposition.

Returning to the silicified area; although the metasomatism is certainly later than the cleavage, yet hard silicified masses do sometimes behave as cores or augen to fissile seams that curve about them. On the West Hill of Pensarn the schistosity of the felsite between the cores has not been healed-up' as has been the cleavage of the shales in the mines. The Rhwnc thrust-plane (Figure 212) appears to be later than all the structures of the felsite and the shales. In Chapter 18 it has been shown that the thrusting and shearing phase of the movements was subsequent to the compressing phase that produced the cleavage, and the interval may have been considerable. To that interval, accordingly, it would seem that the metasomatism should be, for the most part, assigned. We thus obtain a closer *terminus ad quod,* but it is not an absolute one, shutting in all cases. There are some that are later than the minor and earlier thrusts and slides. In the latter part of this chapter (p. 570) a case of metasomatism will be described that is later than the production of the Carmel Head thrust-plane. No other is known, however, along its 14 miles of outcrop, even where it passes quite close to Parys Mountain. Later still must be the cross-courses in the transverse faults. Combining all the evidence, we may with confidence regard the whole of these metasomatic phenomena as having been produced in the intervals of the thrusting phase of the Post-Silurian movements, with recurrence as late as the succeeding stage of cross-rupture and settlement, which (pp. 556–7) does not seem to have been long after.

The minerals of Parys Mountain

Prof. Harold Hilton has kindly compiled the following list, founded in part upon various old lists, in part upon his own examination of the collection in the Institute at Amlwch and of that of Mr. Thomas Prichard at Llwydiarth Esgob

Anglesite

Asbestos

Barytes

Blende

Chalcanthite

Chalcopyrite

Copper

Cuprite

Galena

Hematite

Malachite

Melanterite

Minium

Pyrite

Quartz

Selenite

Serpentine (?)

Silver

Sulphur.

To these (see Chapter 36) can now be added:

Alum

Chalcocite

Chlorite

Hydro-glockerite

Melaconite

Tetrahedrite

White Mica

Sporadic metasomatism

Llangaffo

At three places in the Llangaffo ridge (viz., at the second '1' of Ty'n-y-pwll, at a knob 250 yards to the south-south-west of this place, and along a zone about half-way between Glan-morfa and the 100-foot contour), thin bands of compact siliceous matter lie along the foliation-strike of the mica-schist. They recall the silicified material of Parys Mountain, being composed of a quartz-mosaic studded with cubes of pyrite. Some of it still has the remains of a foliation, some is a breccia. It must therefore be regarded as an old cataclast of the mica-schist which has been silicified and pyritised long after the completion of the Penmynydd anamorphism. A glassy-looking, dark, spotted variety is traceable for a few yards in the bosses north-east of Tyddyn-y-fawd. The little white spots are dusky spaces of finer mosaic than the rest, and the dark tinge is due to flakes of a foliated iron-ore.

Graig-fawr, Holland Arms

On the high knobs of the hornblende-gneiss, about 350 yards north-east of Graig-fawr, there is a zone of quartz-schist, about 20 feet wide. On the south-east side of the zone is a granitoid portion of the gneiss. In this an increase of quartz appears and goes on until the felspar has vanished, leaving a pseudomorph of the rock in foliated quartz. Thin strips of hornblendic gneiss also pass into quartz-rock, both along and across the strike. As the Ordovician sediments and the Palaeozoic dykes are not affected, this case of silicification may be Pre-Cambrian. Yet it is quite local and exceptional in the gneiss itself. And as it closely resembles those of the Gader Inlier, described below, it is placed in this chapter.

Llanddona

On the rocky slopes, at a spot about 500 yards south-south-west of the church and 300 west north-west of Pen-yr-allt, there is an old level that. was driven for lead. In the vicinity of this the Gwna Green-schist is permeated by much compact matter; which is a fine mosaic of siderite and quartz.

Mynydd Bodafon

Along a little feature that runs north-west and south-east through a point 200 yards south-south-west of the middle of the lesser tarn, is a thin zone of a pink flinty rock full of fragments of greenish quartz-schist. The matrix is a mosaic in which many of the elements are hypidiomorphio quartz like-that of Parys Mountain. The rock may therefore be regarded as a silicified friction-breccia, later than the metamorphism.

Holyhead

About 600 yards north-east of Twr the Holyhead Quartzite has been curiously reconstructed, being converted into an aggregate of thin plates that have sometimes a rudely radial arrangement. They are composed of granular quartz (E9317) [SH 223 824] with a sort of flattened spherulitic structure, and their surfaces are coated with little pyramidal apices. Dr. H. H. Thomas regards this product as due to crystallisation of secondary silica along zones of brecciation, and suggests that it may perhaps be called a spherulitic veinstone. There are no vein-walls, but the structure is venous, and is evidently subsequent to the metamorphism of the Mona Complex.

Llanfairynghornwy

In this extreme corner of the Island there is a good deal of sporadic silicification. At the brow of the north cliff of Porth-yr-hwch, in granite, and about 150 yards to the north-west (Folding-Plate 13), in granitoid gneiss, are two masses of quartz-rock, the second of which forms a conspicuous white knob, and is nearly 100 yards long. Much of the rock is massive in aspect save for some undulating divisional planes which are so far, structurally, from being folia that they are toothed with little quartz-crystals like the cheeks of a vein, and near its north end it simulates a sedimentary quartzite. Yet, laterally, this passes into quartz-rock that really has a rude foliation; then felspar begins to appear, and this increasing, a passage can be traced into it from granitoid gneiss. Surviving flakes of gneiss can also be found within the quartz-rock. The foliated portion is, therefore, a pseudoinorph of the gneiss in quartz, but in the advanced stages no traces of gneissose structure remain. In thin section (E10350) [SH 290 922]–(E10351) [SH 290 922] survivals of the gneiss can be seen in the foliated portion; and both in this and in the massive there is abundant hypidiomorphia quartz like that of Parys Mountain. The smaller mass at Porth-yr-hwch is a similar pseudomorph after granite. And in both masses the later shearing structures are pseudomorphed, so that the silicification is later than the last catamorphic movements of the Mona Complex. The finer part of the gneiss on the south cliff of the great headland also contains perfect little quartz crystals lying in all directions (E10366) [SH 289 923], which are evidently of metasomatic origin.

About 370 yards to the east of Porth-yr-hwch (Folding-Plate 13) is an ice-polished knob about 140 yards in length, composed of finely granular quartz, faintly rose-coloured. It must be regarded as one of the Gwna quartzites, but is unusually silicified. Along its southern margin, which adjoins Ordovician shales with nips of felspathic grit, is a zone of much finer quartz rock, of a rather dark grey tint, closely resembling the silicified shale of Parys Mountain. In thin section the dark tint is seen to be due to abundant streaks Of shaly matter, in a mosaic largely composed of small hypidiomorphic elements, whose axes lie in all directions. This quartz-knob, therefore, is partly a second silicification of a Gwna quartzite, partly a first silicification of Ordovician grit and shale. It is later than the Ordovician cleavage, and must be later than the thrust-plane across which it has spread.

On the eastern slopes of Pen-bryn-yr-eglwys the folded inlier of conglomerate and grit within the shale area ((Folding-Plate 13) and p. 464) is considerably silicified on its north-west margin, greatly obscuring its structures, and the strip of similar rock that runs along the slope close to its north-east side is even more obscure from the same causes.

There is also a zone of silicification 50 yards wide that runs along the outcrop of the Carmel Head thrust-plane above Hendre-fawr for more than a quarter of a mile, confusing the structures of the Ordovician rocks with those of the Mona Complex, and making it difficult to be sure of the true position of the thrust-plane. This case of metasomatism is therefore exceptionally late. In several of these cases a little pyrite is associated with the silica.

Pant-y-gaseg

The coarse grey grits of the Glenkiln Series are slightly silicified on the northern slopes of Graig Wen, but very much more so on Pant-y-gaseg ridge, where they have been converted into a white quartzite. As they contain many pebbles of the Gwna quartzites, the unusual relation can be studied of one quartzite enclosing pebbles of another. The silicification extends into the Mona Complex, and along the western portion of the ridge has taken the form of a sort of quartz-lode which has been worked for copper. About a quarter of a mile south-east of Trwyn-bychan there is a small spoil-bank at the mouth of an old shaft, among the materials of which (kindly examined by Mr. Allan Dick) are chalcopyrite, an amber-coloured blende, and a nearly colourless siderite.

The Kaolinite — But the chief interest of this 'lode' is that it has now been found to be the source of the crystalline kaolinite that was described by Messrs. Dick and Percy, and figured in Dr. Teall's British Petrography', plate XLIV, Fig. 5. Specimens may still be found at the spoil-bank, in which the siderite is coated with delicate crusts of kaolinite. Mr. Dick writes that this material resembles that which has been described by him, excepting that it 'seems to want wholly the clinopinacoidal crystals figured by me and measured by Dr. Miers, though the face is present on all, even on the thinnest basal crystals such as you send. It is, I think, always present on basal crystals from any locality'. The original figured material was not obtained from this shaft, but from a level driven in from the sea, at the foot of the northern cliffs, about 383 yards from Trwyn-bychan. The kaolinite was found in a short cross level going west, about 166 yards from the sea, in small cavities, and the crystals ran as loose as sand.<ref>Mr. J. O. Hughes explored these old levels in 1912. The exploration was by no means easy, on account of the great quantity of water met with. He obtained no kaolinite, but much fine powder of quartz, angular and sharp. Mr. Dick tells me that such quartz-powder is found in other mines. Its origin is unknown, In a drier season, Mr. Griffith J. Williams succeeded in obtaining kaolinite from cavities in the roof.</ref> Little doubly-terminated crystals of quartz, with rhoncibs of calcite (Mr. Dick adds) were also found in these cavities, 'and are often covered with adherent crystals of kaolinite'; and he suggests that both may have been originally formed within a soluble material such as limestone, which was afterwards removed in solution, leaving these loose crystals to be carried into the cavities. Three small outcrops of the Gwna limestone occur within 80 yards of that of the 'lode', so that Mr. Dick's suggestion is probably correct. Full particulars concerning the crystallographic and optical characters of the mineral will be found in Mr. Dick's papers, references to which are given on pp. 32, 35. The analysis by Tookey, published in Percy's account, was:

SiO_2	46.53
Al_2O_3	38.93
H_2O (by diff.)	14.54
	100 00

Llaneilian

A number of rocks, igneous for the most part, have been affected by metasomatic changes.

At the old copper mine of Rhos-mynach-fawr p. 535) the compact siliceous rock has a close external resemblance to the Parys Mountain felsite. It contains fine mica, some of it foliated, but chiefly in 'criss-cross' arrangement, while radial mica exists in the margins of spherulites that have been partly ground out in the cutting. Strong mylonitic planes traverse the rock, but neither the quartz of the mosaic nor the little 'criss-cross' micas are affected by them.

Many of the Palaeozoic basic sills between Mynydd Eilian and the eastern sea are traversed by numbers of quartz-veins, sometimes with a little pyrite or even chalcopyrite. One of them, at a spot about 250 yards south-east of Pant-y-groes, has become quite hard and granular, and in thin section this is seen to be due to grains of quartz disseminated all through the rock. But the process has been carried further still. A conspicuous object in the valley below the steep escarpment of Mynydd Eilian north-west of the 394-foot level, is a white boss that suggests an uprise of the Gwna quartzites. But it is really part of a basic sill, excessively, though irregularly, silicified. In the midst of the quartz-rock are survivals of the original igneous material (E10469) [SH 478 917], some parts retaining the texture of a diabase, others converted into a chlorite-schist. The basic matter is permeated in all directions by a rather coarse quartz-mosaic, in which are many hypidiomorphic elements. The quartz is unaffected by the deformation of the diabase; and at one junction, a quartz prism, optically uninjured, lies across the foliation of the chlorite-schist, almost at right angles. Better evidence of the late date of the silicification could not be desired.

On the high brow that overlooks Porth-y-gwichiaid, about 250 yards west-south-west of Trwyn-du, is a sill of diabase 100 yards in length, which has been partly converted into a chloritic schist, with epidote and iron-ores. Scattered through it are abundant grains of quartz, many of which are hypidiomorphic. Parts of this rock (E10470) [SH 488 918] are crowded with little white spherulites about an eighth of an inch in diameter, which occur in groups, and weather out. They are composed of sharply polarising elements of quartz, with a tendency to radial grouping. Generally there is a core of chlorite and white mica, some of which is in little radial groups, whose presence causes the spherulites to weather hollow. The deformation of the body of the rock does—not affect them, so they can be neither varioles nor amygdules, but must be regarded as a special mode of the metasomatism.

In a level driven to the south of Porth-y-gwichiaid a good deal of loose powdery haematite was found, some of which was kindly given me by Mr. Barbagli, of Bryn-fuches. The flakes yield a dim uniaxial figure, and some of them show an angle of the hexagon. The mode of occurrence recalls that of the powdery kaolinite.

On the foreshore in the middle of Porth-y-gwichiaid is a singular soft and lustrous rock, lying among the shales, which appear more altered in its neighbourhood. It is composed for the most part of white mica, and seems to be an extreme case of micacisation, though of what rock is unknown. Some parts of it are silicified and pyritised.

Many small developments of metasomatism are to be found about the northern parts of Anglesey.

Sporadic dolomites

In this connexion it will be well to describe certain little brown dolomites which, though they resemble in some cases the limestones of the Mona Complex, can be shown to have really no connexion with them. They have been observed at the following places:

Llanerchymedd, 170 yards west of the farm in the south part of the Bryn Gallen inlier of gneiss.

Pen-bryn-yr-eglwys, 130 yards north of Porth-yr-hwch.

Pen-bryn-yr-eglwys, 300 yards west-south-west of the south Beacon.

Headland east of Rhos-mynach-fawr, Llaneilian. Three masses.

Llanwenllwyfo, 400 yards north-north-west of Plâs-uchaf.

Porth-y-dwr, Llanfairynghornwy, one each side of the stream's mouth.

Cliff, 258 yards north-west of Porth Llechog Inn.

Coast, 517 yards west-south-west of Stanley Gate, Holy Isle.

Porth-y-defaid. Large mass and small mass in cove.

Porth-y-defaid. foreshore north-west of cove.

Porth-y-defaid. south by west from Castell.

Amlwch, south of word 'Cave' (west side).

Amlwch, about 170 yards east of Graig-ddu.

Porth-yr-ychain, Llaneilian. One in each cove.

Porth-y-gwichiaid, north bank of stream, 170 yards from shore.

Ogo-fawr, Llaneilian (south side).

Most of them are only two or three feet thick, but the southern one at Porth-y-defaid reaches 30 feet, and those on the coast at Rhos-mynach are, taken together, 100 yards in width. All are very impersistent. Externally they are of a strong russet-brown, internally of a light straw colour, but with much variation. Their texture is generally fine, and their aspect rather dull, but some are coarse and vein-like. Irregular venous quartz is frequent, and films and small aggregates of chlorite are usually present. In the large mass at Porth-y-defaid there are rudely lenticular aggregates of almost pure—chlorite, foliated, with seams of iron-ores. Often they are faintly schistose, the Defaid mass markedly so, but the structure is probably pseudomorphic of that in the surrounding rocks. Those on the Rhos,-mynach-fawr coast, indeed, can be seen to be really calcareous replacements of the Gneisses on a large scale, the alteration sometimes proceeding across the strike. Intermediate stages exist, and even in the 'limestone' zones some of the old structures still survive (E10270) [SH 492 911], the large bleached biotites of the gneisses being pseudomorphed in carbonates. That calcite and dolomite are both present is shown by the fact that, in the rocks of Amlwch and Porth-yr-ychain, dilute hydrochloric acid sets up effervescence upon some of the crystals but leaves others unattacked. The Plâs-uchaf rock was found by Mr. J. O. Hughes to be magnesian and also ferruginous in a qualitative analysis.

A suspicion that these dolomites do not really belong to the Mona Complex begins to arise when it is seen that even where they occur within highly crystalline gneisses, their ferro-magnesian constituent is nothing more than chlorite: it is strengthened when they are found to occur in three distinct members of the Complex, the Gneisses, the Church Bay Tuffs, and the New Harbour Group: it changes to certainty when they are seen to frequent thrust-planes that are oblique to the strike, and that of Amlwch even to branch and cut across the beds. Positive evidence as to their age and associations is afforded by those near Mynydd Eilian, which lie within Ordovician rocks. That of Ogo-fawr lies along the north margin of the eurite sill, and is full of inclusions of cleaved shale. It is therefore later than the eurite intrusion, later than the cleavage, and later than the thrust-plane which has destroyed the intrusive junction.

Chronology of the sporadic metasomatism

The rocks affected by this range, it will be seen, from the Mona Complex to Silurian, but not later. Where Palaeozoic rocks are not involved, the metasomatism is later than all the local structures of the Mona Complex, which in several cases are its final cata-morphic movements, and the products usually resemble those of known Pahnozoic examples, with which, on the Gader, they are associated. Where Palaeozoic rocks are involved, the alteration is later than the cleavage. The processes (if we put aside the exceptional case of the dolomites) are in every case essentially the same as those of Parys, being silicification, with varying degrees of pyritisation and chalcopyritisation; and it may be remarked that there are two sporadic maxima, one at Llanfairynghornwy, the other at Llaneilian, the latter almost adjoining Part's Mountain. The sporadic metasomatism may therefore be referred with some confidence to the same general period as that of Parys; the thrusting episode, that is, of the Post-Silurian movements, with its sequel of settlement and final quieting-down.

An interest attaches to this, because it-enables us to indicate at least a probable date for the kaolinite.<ref>Mr. Dick writes me, however, 'So far as I can see, there is no reason why it should not be forming now; but I have the same want of certainty as to whether all vein-deposits are not going on now'.</ref> It cannot have been formed in the interval between the cleavage and the thrusting, for, although it is in the immediate vicinity of several thrust-planes, its delicate crystals display no trace of deformation. Yet it is without doubt a product of a metasomatic zone which there is no reason whatever to separate in time from all the other cases, including that of Parys Mountain. It may therefore be reasonably assigned to the final metasomatic stage, that which followed upon the episode of the settlement faulting.<ref>The slides of the sporadic metasomatism are (E9798) [SH 573 804], (E9921) [SH 434 679], (E9922) [SH 434 679], (E9923) [SH 428 675], (E10047) [SH 466 848], (E10270) [SH 492 911], (E10348) [SH 296 922],(E10349) [SH 296 922], (E10350) [SH 290 922], (E10351) [SH 290 922], (E10454) [SH 483 920], (E10462) [SH 488 916], (E10463) [SH 488 916], (E10469) [SH 478 917], (E10470) [SH 488 918], (E10471) [SH 488 918], (E10472) [SH 488 920], (E10473) [SH 481 913] (E11386) [SH 272 800].</ref>

Genetics of the metasomatism

The conditions precedent — Such being the date of these phenomena, we may look for a causal connexion between them and the thrusting-phase in question.<ref>Local silicification has been found (see p. 69) to accompany some of the similar phases of the Mona Complex.</ref> The dynamo-metamorphism induced by the Post-Silurian movements is but moderate (see Chapter 18); so, apparently, a considerable proportion of the energy took the unusual form of solution with transportation and permeation.<ref>The pyrite-beds of Rammelsberg, which appear to have some resemblance to those of Parys Mountain, adjoin a plane of over-thrust. But silicification, such a feature of all the metasomatism of Anglesey, seems, from the descriptions, to be absent. To what degree it is present at Rio Tinto and other great pyritic localities I have not been able to ascertain.</ref>

There is another group of phenomena, the igneous intrusions, that we have found to belong to the period of the movements, and to them, therefore, especially to the acid sills, we might be tempted to ascribe the metasomatism, but for the fact that it is undoubtedly subsequent to their consolidation and deformation. The distribution of the sills is certainly suggestive of some connexion, for where they are numerous and some of them are acid, there we find frequent metasomatism.

Yet there must be some other factor, for, there is considerable metasomatism at Pant-y-gaseg and other places where igneous intrusions are absent. Let us turn for a moment to the North-West Highlands of Scotland. In that region, the classic land of thrusting-movements, and where, moreover, there are large igneous intrusions, metasomatism such as that of Anglesey is never found. Now, between the two countries there is a dynamical difference of significance. In Anglesey the thrusting was preceded by compression-folding that induced a cleavage. In the North-West Highlands, the absence of true slaty cleavage is remarkable. Further, the same coincidence is found within Anglesey itself. In the Palaeozoic rocks of the centre of the Island, however near to the Carmel Head thrust-plane, cleavage is feeble or absent, and there is no metasomatism. In their north-western and north-eastern wings (see Chapter 18), cleavage is powerful, and we come at once upon frequent metasomatism. Cleavage, then, appears to be the missing third factor.

Let us recapitulate. The Carmel Head thrust-plane runs all across the Island. But where it over-rides rocks in which thrusting is subordinate to folding, in which the isoclinal infolds are shallow and at low angles, in which cleavage is absent, and in which there are but a few igneous intrusions, all of these being basic; there metasomatism is unknown. Where it over-rides rocks in which almost every fold is thrust, in which the isoclinal infolds are very deep and at steep angles, which are powerfully cleaved, and among which igneous intrusions, some of the largest being acid sills, are numerous; there we find metasomatism, frequent, extensive, and sometimes intense. At Pant-y-gaseg, where, without igneous intrusions there is both cleavage and thrusting, metaso-matism is on a moderate scale. Away from the zone of thrusting and acid intrusions it is trifling or absent, even though there be a cleavage. Thus: a coincidence of intrusions (especially acid intrusions), cleavage, and thrusting, appears (in Anglesey at any rate) to be the condition precedent for metasomatism.

Possible mode of operation — When, however, we attempt an explanation of the ways in which these factors operated,. many perplexities appear. Still, some suggestions in aid of a temporary working hypothesis may be of some service.<ref>The suggestion thrown out in this paragraph must be understood to be *for Anglesey only,* not as any attempt at a general theory of metasomatism, for which a comparison of all known metasomatic districts would be needed.</ref> .

The first perplexity is the time-interval interposed by the cleavage between most of the igneous activity and the metasomatism. But even the earlier intrusions appear (pp. 510, 516) to have been unusually late, so that the contribution made by the cleavage might have been made before they had had much time to cool. Where numerous they would raise the subterranean isotherms into a local upward curve. The heat generated by the resistance of the rocks to compression, followed by the advent-of the post-compression sills, might maintain that curve in position. At the same time the compression of the shales would tend to inhibit the escape, of any heated waters, and bring about local conditions that would resemble those of the hot sealed tubes of Daubree's experiments, enabling the waters to take up substances normally insoluble. Then came the thrusting and shearing, which bent and ruptured the cleavage and reduced cohesion generally, providing an exit for the solutions into cooler zones of low pressure, where, accordingly — precipitation ensued. This would take place at an early stage, long before the development of the great overthrusts, but might be expected to recur during intervals of the thrusting, and to continue for a short time after its close, which is what we have found to be the case. Further: as the dynamics of the thrusting were those of shearing stresses under heavy weight, they did not give rise to gaping fissures. Consequently, we have no true lodes, but impregnations that spread on all hands from innumerable capillary channels running along the strike, now sealed up by quartz and imperceptible.

Sources of the materials — The source of the quartz and mica presents no difficulty. Their elements could be obtained in unlimited quantities from the Mona Complex.<ref>It would he interesting to enquire whether, in view of the sodium-content of the Complex (see pp. 144–9), much of the metasomatie mica be paragonite.</ref> The hmatite, kaolinite, and dolomite, which occur on but a moderate scale, are easily traceable to the same source.

But the sources of the vast quantities of metallic sulphides that are concentrated in Parys Mountain remain, in great part, a mystery. This is of course a difficulty that is presented by ore-deposits in general, whose exceptional substances can seldom be traced to any definite source. Here, however, it may be alleviated in several ways. We cannot, indeed, look to the felsite intrusion; but the many basic rocks of the Mona Complex, not to speak of the basic magma of the Palaeozoic Intrusions, are more than sufficient to supply the iron. What, however, has become of their calcium and magnesium? The sulphides of those metals, it may be recalled, are (as produced in the laboratory), unstable, relatively soluble, and easily oxidised to soluble sulphates, which would be carried away.; and some has actually been retained, for two of the ores (see Chapter 36) have yielded .90 and 1.10 per cent. of MgO respectively, while selenite, though certainly not abundant, is given in the list (p. 568) of the Parys minerals. The zinc and lead, being in moderate quantity, are easily accounted for by Sandberger's principle. That investigator found that ordinary rocks and rock-forming minerals could, if sufficient quantities were taken, be made to yield small proportions of the ore-metals; and he suggested that ore-deposits were concentrates from the metal-contents of large masses of rock.<ref>Stelzner's criticisms on Sandberger's analyses only apply to minerals in the immediate vicinity of a lode; Van Hise's recent theory is in reality a greatly extended application of that of Sandberger.</ref>

The real difficulties are the copper and the sulphur, of which there are such great accumulations. For the copper, we may with considerable probability invoke Sandberger's principle again. Small patches of copper salts, usually carbonates, are not uncommon on the rocks of the Mona Complex in various parts of the Island; and with these visible to the naked eye, we may be sure that the basic silicates of the Complex hold more copper in combination than has been suspected. For the sulphur, there seems hardly enough pyrite in any of the older formations, even on Sandberger's principle. A solfataric sequel to the Paleozoic Intrusions may reasonably be invoked, but as the accessible parts of those rocks could not yield the required sulphur, the source remains undetermined, and we have really referred it once more to the region of the unknown.

Recapitulation

At Part's Mountain and other places, many different rocks, including gneissoid granite's, basic and acid gneisses, Penmynydd mica-schist, Gwna Green-schist and quartzite, Church Bay Tuffs, New Harbour Beds, Holyhead Quartzite, Ordovician basal Grits (of both horizons), the Bifidus, the Parys green shales, and the Silurian shales, with intrusive diabases and felsita, are affected by meta-somatic replacements. The Parys developments are on a large scale; the rest are merely sporadic. The processes include silicification, micacisation, pyritisation, chalcopyritisation, hiematisation, dolomitisation, and kaolinitisation. The chalcopyritisation was accompanied by the advent of other sulphides, chiefly of zinc and lead, and was often concentrated along zones, which occasionally simulate lodes, and constitute ore-deposits of great importance. Silicification is the most frequent of the processes, and is the chief both in magnitude and in intensity. It is also, on the whole, the earliest, was followed by micacisation, and that by the principal pyritisation. The whole group of metasomatic phenomena was subsequent to the compressive part of the Post-Silurian earth-movements, and appears to have been contemporaneous with their shearing and thrusting phase, recurring also for a short time after its close. The metasomatism is therefore to be regarded as a byproduct of that great period of terrestrial unrest.

(Plate 33) Silicification obliterating cleavage. Parys Mountain.

(Plate 35) The-Lligwy Bay Conglomerate. Careg-ddafad.

FIG. 291.—SECTION THROUGH THE CONTEMPORANEOUS DISTURBANCE AND THE LLIGWY BAY CONGLOMERATE, CAREG-DDAFAD.

(Figure 291) Section through the contemporaneous disturbance and the Lligwy Bay conglomerate, Careg-ddafad. Scale: one inch = 75 feet.

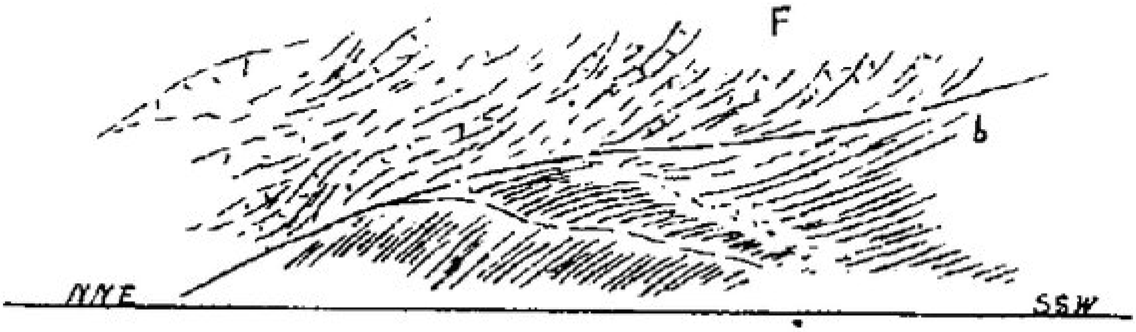
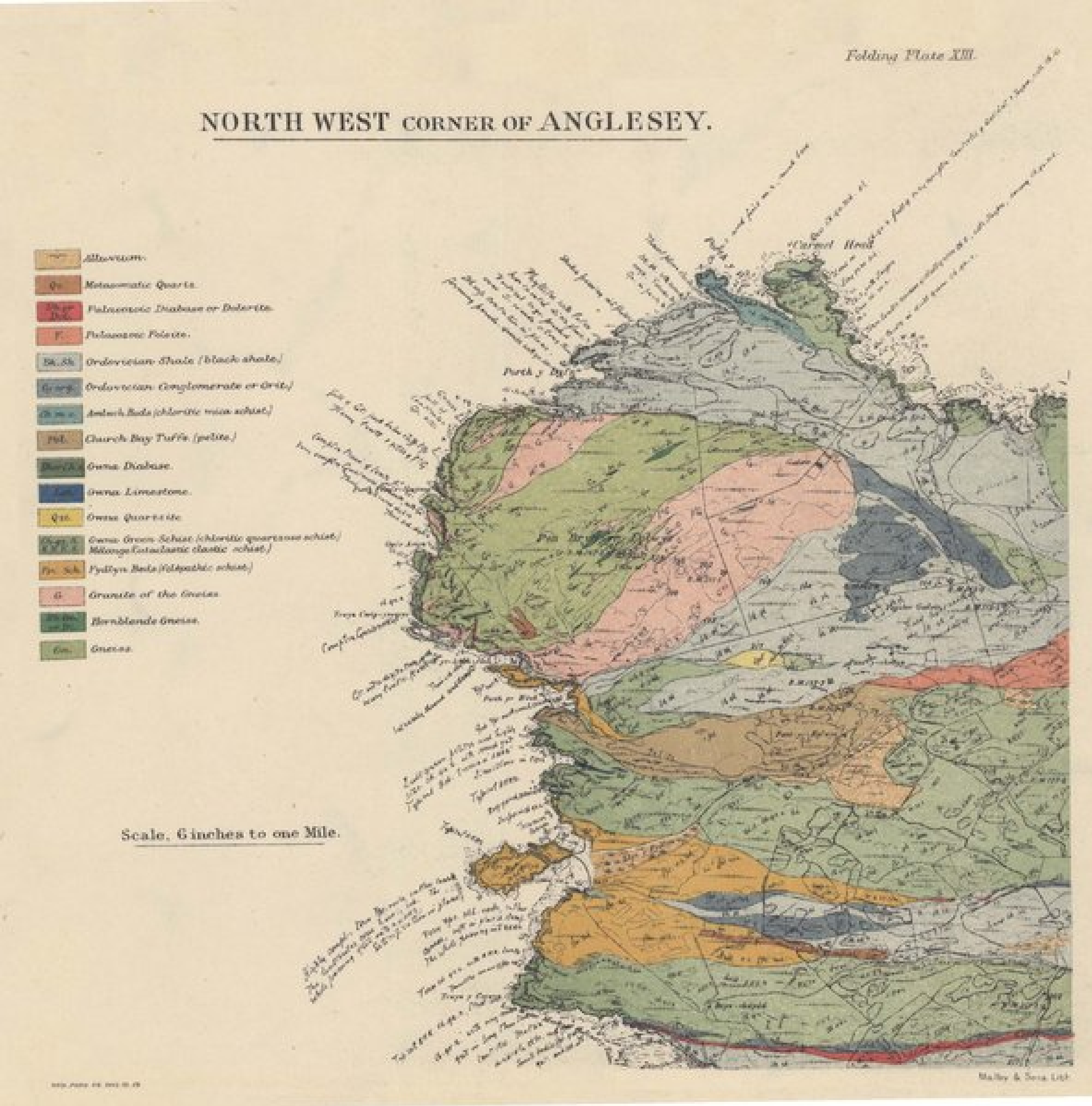


FIG. 212.—THE RHWNC THRUST-PLANE AT RHWNC.

(Figure 212) The Rhwnc Thrust-plane at Rhwnc. Height about 10 feet. F = Sheared felsite. b = Arenig shales.



(Folding-Plate 13) The North-West corner of Anglesey. Reproduction of manuscript six-inch map.