Chapter 12 Composite sills and dykes: general features.

In the preceding chapter we have seen how in certain places the granite (including granophyre) of the Red Hills enters into remarkable relations with the gabbro (on Marsco) and with sills of a peculiar hybrid basic rock (on Glamaig). We have next to describe somewhat analogous phenomena exhibited in minor intrusions outside the mountain tract. These intrusions take the form partly of composite dykes, partly of composite sheets, which from their regularity and parallelism with the bedding may be termed sills. Some of the composite dykes stand in close relation to the composite sills, and have doubtless been their feeders.

The frequency of multiple basic dykes and sills in Skye shows the strong tendency for later intrusions of the basic magmas to follow channels already selected by earlier intrusions. The tendency to be thus guided is, however, much stronger where an acid magma has been intruded in the neighbourhood of earlier basic dykes and sills. Even the granite bosses show this disposition occasionally. The Beinn an Dubhaich granite, intruded through Cambrian limestones, as we have already remarked, truncates a number of pre-granitic basic dykes. In one or two places about Torran the granite has sent out irregular tongues along these earlier dykes. Such a tongue always clings closely to the side of its dyke, and sends veins into it, but never into the limestone. The acid magma has evidently been guided by these dykes, just as it has been by the marscoite sills on Glamaig. The destructive action of the acid magma on these dykes is much less than in the case of the Glamaig sills, but it is still to be perceived; and it is probable that the facility with which an acid intrusion finds its way along a basic dyke or sheet results in general from a certain amount of reaction between the acid magma and the surface of the basic rock. It is noteworthy that, although the acid magma has sometimes insinuated itself along the side of a single basic dyke or sill, it has more frequently selected the surface of junction of two contiguous dykes or sills. The composite intrusions which include acid members are, as a rule, not merely double but triple or multiple. Moreover, where such a composite dyke or sill includes an acid member with two or more basic ones, the acid rock seldom, if ever, occupies an outside position.

For purposes of description it will be convenient to distinguish among composite intrusions, whether dykes or sills, two main types, *symmetrical* and *unsymmetrical.* The symmetrical type has usually a central member consisting of one kind of rock, flanked on either side by marginal portions consisting of another kind of rock: it may be represented by XYX. More rarely three kinds of rock enter into the complex, the arrangement being then represented by XYZYX. In the other type no such bilateral symmetry exists, and we have such arrangements as XXXYX, XYXYXY, XYZXX, etc.

Since composite dykes and sills, consisting of basic and acid rocks in intimate association, seem to be a characteristic feature of the British Tertiary province, it will be useful to collect here the scattered records of their occurrence. The only examples of which detailed descriptions have yet been published are certain composite dykes in Arran and in County Down, but brief references are numerous in the literature of the region.

Little is to be gleaned from the writings of the earliest observers. Jameson<ref>*Mineralogy of the Scottish Isles,* vol. i., pp. 81, 102–105: 1800.</ref> seems to have partially appreciated the nature of the Cir Mhòr dyke in Arran, and gives a fairly clear account of the "stratified veins" at Tormore in the same island; but the complex dykes incidentally noticed by Macculloch<ref>*Trans. Geol. Soc.,* vol. iii., Pl. IV., Fig. 2: 1816. *Description of the Western Islands,* P1. XVIII., Fig. 1: 1819.</ref> in Skye seem to be merely accidental conjunctions. One of the first clear references comes from the Mourne district in Ireland, where in 1835 Patrickson<ref>"A Descriptive List of the Dykes appearing on the Shore which skirts the Mourne Mountains…", *Journ. Geol. Soc. Dubl., vol.:* 1835.</ref> recorded at Glasdrummon Port a porphyritic acid dyke bounded by two "hornblende" dykes in parallel contact. In 1840 Necker,<ref>Documents sur les Dykes de Trap d'une partie de l'Ile d'Arran, *Edin. Phil. Trans.,* vol. xiv., pp. 677–698, Pl. XXIII.: 1840.</ref> in cataloguing a number of dykes on the Arran coast, remarked that each consists in general of a single kind of rock, but noted two exceptions to this rule. One is a "dyke composée" at the foot of "Kidvoe", consisting of pitchstone in the centre, flanked by "argilolite" on both sides, and further flanked by "trap" also on both sides: the other is an assemblage of alternating dykes of greenstone and "porphyre argilolitique", six members in all.

Here we have examples of the two types distinguished above, the symmetrical and the unsymmetrical. "Kidvoe" is evidently Cir Mhòr, disguised by transliteration and accidental error, and the dyke in question is that which was briefly described in the following year by Ramsay<ref>*The Geology of the Island of Arran from Original Survey,* p. 26: 1841.</ref>. P Bryce<ref>*I Geology of Clydesdale and Arran,* pp. 81, 82: 1859. *Cf.* Zirkel, *Zeits. deuts. geol. Ges.,* vol. xxiii., p. 41, Pl. II., Fig. 6: 1871; and Allport, *Geol. Mag.,* 1872, pp. 5, 541.</ref> observed in 1859 that almost all the dykes of Arran are simple, but "a few, of which the most remarkable are those of Tormore, are composed of parallel bands of different substances". Subsequently<ref>*The Geology of Arran and the other Clyde Islands,* p. 164: 1872.</ref> he added something to Ramsay's account of the Cir Mhòr occurrence, and both these Arran localities have since been fully described in an important paper by Professor Judd.<ref>On Composite Dykes in Arran, *Quart. Journ. Geol. Soc.,* vol. xlix., pp. 536–565, P1. XIX.: 1893.</ref>

In Ireland composite dykes have been mapped by the Geological Survey and mentioned in the published Memoirs, Professor Hull<ref># *Explanatory Memoir to accompany Sheets 60, 61, and Part of 71* of *the Maps of the Geological Survey of Ireland,* p. 39: 1881.</ref> noting in particular one at Murphy's Point, County Down, which consists of a 35-ft dyke of greyish "felstone-porphyry" flanked by two 8-ft dykes of basalt. Professor Cole<ref>On Derived Crystals in the Basaltic Andesite of Glasdrummon Port, Co. Down, *Sci. Trans. Roy. Dubl. Soc.* (2k, vol. v., pp. 239–245, Pl. XXVI.: 1894.</ref> has since given a description of Patrickson's dyke, already mentioned, and has entered into some interesting speculations relative to the interpretation of its phenomena.

The first clear notice of the composite sills of Skye is found in Sir A. Geikie's memoir on "The History of Volcanic Action during the Tertiary Period in the British Isles", published in 1888,<ref>*Edin. Phil. Trans.,* vol. xxxv., pp. 21–184: 1888. See p. 174.</ref> though the intrusions at Carn Dearg, Suishnish, had attracted notice earlier, as mentioned below (Chapter 2). That such sills are not confined to this island seems probable from certain observations of what may prove to be similar cases in Ardnamurchan;<ref>Judd, *Quart. Journ. Geol. Soc ,* vol. xxx., p. 271, footnote: 1879.</ref> and Arran,<ref>Corstorphine, Tscherm. Min. Petr. Mitth. (N. S.), vol. xiv., pp. 18–23, 29, 30 : 1895. See also Boué, Essai géologique sur Z'Ecosse, p. 296, Pl. IV., Fig. 20; 1820. Delesse, Ann. des mines (5), vol. xiii., pp. 349, 350: 1858. </ref> but no detailed account of any of these occurrences has yet appeared.<ref>Since this was written, the occurrence of composite sills in Arran has been more definitely announced, and some account has also been published of an interesting example in southern Bute, which differs from others in having the basic rock in the middle with acid borders above and below. See *Mem. Geol. Sur. Scot., The Geology of North Arran, etc.,* pp. 98, 99 (W. Gunn) and 114–117 (A. Harker): 1903.</ref> Sir A. Geikie has, however, furnished some additional information, as regards both dykes and sills of composite habit in Skye, in his later writings.<ref>*Quart. Journ. Geol. Soc.,* vol. lii., pp. 393–395: 1896. *Ancient Volcanoes of Great Britain,* vol. ii., pp. 162, 163, 433, 434: 1897. See also brief notes in *Ann. Rep. Geol. Sur.* for 1896, pp. 73, 74.</ref>

A few composite dykes are known on the mainland of Scotland. The Eskdale dyke takes on this character at Wat Carrick, a compact, more or less vitreous rock forming a band 16 to 18 feet broad between two 8-ft bands of dolerite.<ref>Geikie, *Proc. Roy. Phys. Soc. Edin.,* vol. v., pp. 219–253, P1. V., VI.: 1880. *Ancient Volcanoes of Great Britain,* vol. ii., p. 137.</ref> Other dykes of the symmetrical triple kind have been recorded by Mr Symes<ref>*Summary of Progress of Geol. Surv.* for 1898, p. 154.</ref> in the district south of Oban.

Records of composite dykes in extra-British areas are not numerous. The district which presents most analogy in this respect with Skye is undoubtedly the north-western part of the Thuringer Wald. Composite dykes seem to have been observed there by J. L. Heim<ref>*Geologische Besehreibung des Thüringer Waldebürgs,* part 2, section 1, p. 138, footnote, etc.: 1798.</ref> as early as the end of the eighteenth century, and they have been described in some detail by Senft,<ref>*Zeits. deuts. geol. Ges.,* vol. x., pp. 305–355, Pl. IX., X.: 1858.</ref> Pringsheim,<ref>*Ibid.,* vol. *xxxii.,* pp. 111–182, Pl. X., XI.: 1880.</ref>t Weiss,<ref>*Ibid.,* vol. xxxiii., pp. 483–489: 1881.</ref> and Bücking<ref>*Jahrb. k. preuss. geol. Landesanst.* for 1887, pp. 119–139, Pl. V.: 1888.</ref> All these are of the symmetrical type, usually triple (XYX), sometimes quintuple (XYZYX), and they compare closely with the British examples. The unsymmetrical type (*e.g.* XYXYXY) is, however, also met with in the Thüringer Wald, and has been described by Loretz<ref>*Ibid.,*pp. 100–118.</ref> and others. Weiss<ref>*Ibid.* for 1883, pp. 213–237, Pl. XX.: 1884.</ref> has remarked among other examples a dyke showing alternations of quartz-porphyry (silica-percentage 69) and porphyry (60), *i.e.,* an association of an acid and an intermediate rock, for which we have found no precise parallel in our own country. On the whole these

Thuringian composite dykes, probably of pre-Permian age, show a remarkable correspondence with the Tertiary examples in Skye. The sills are wanting in the foreign area, but this is sufficiently explained by the intrusions there occurring in a tract of granite and gneiss. It cannot be doubted that in the two groups of intrusions here compared, in different areas and of different ages, some factor was operative which in most groups of basic and acid intrusions has been absent.

In the foregoing citations we have expressly excluded all cases in which heterogeneity in a dyke is *manifestly* due to differentiation subsequent to injection, since this explanation is certainly inadmissible for the composite dykes of Skye. On this point a few remarks are necessary. Professor Judd, in an instructive paper on composite dykes already referred to, distinguishes between those in which a differentiation has gone on in the material that has filled the dyke and those in which there has been injection of different materials into the same fissure. What is here premised of dykes may be extended also to sills and, in a general sense, to larger and more massive intrusions. Although the distinction seems to be logically an absolute one, it is, however, probably less fundamental than it appears. Professor Judd indeed recognises that there are cases which seem to constitute a link between the two classes, and this becomes much more evident when we turn from the dykes to the large bosses. The leading characteristics of composite intrusions are common to both classes: such are, in dykes and sills, the bilateral symmetry of the arrangement, the disposition of the most acid member at the centre and the most basic at the sides, and probably we may add the indications of what Iddings has called "consanguinity" among the different associated rock-types. Moreover the criterion which naturally suggests itself for discriminating the two classes, viz. the contrast of a gradual transition in the one case with abrupt boundaries in the other, sometimes breaks down in practice.

With this understanding, it may be said that the composite dykes and sills of Skye fall under the second of the two heads, the phenomena being the result of successive injections of different rock-magmas into one channel. Many single dykes in Skye exhibit variations due to differentiation in place, but these variations have in any given case a very limited range, and present no unusual features.

It results from the strong tendency of the acid intrusions to be guided by pre-existing basic ones that the area of distribution for the composite (basic with acid) dykes and sills is nearly coextensive with that for the acid dykes and sills in general. The acid sills are more restricted in range than the acid dykes, and the composite sills show a like restriction as compared with the composite dykes. We shall notice first the composite dykes of unsymmetrical type, since these exhibit the least peculiarity of habit, and have nothing abnormal in their petrographical characters.

In many instances the association of acid with basic dykes is only of a loose kind. This is well seen in the Strathaird peninsula, and especially in a group of acid dykes on the slopes of Ben Meabost, about 1000 yards west of the summit. Here we find one acid dyke running alone; another, after running alone for some distance, impinges obliquely upon a basic dyke, to which it clings thenceforward; another runs throughout in contact with a basic dyke, thus constituting a double composite dyke; and still another has insinuated itself between two contiguous basic dykes, so as to form a triple composite dyke of symmetrical type. East of Elgol there are other examples showing how a felsite dyke may run independently until it meets a basic dyke, to which it then adheres. One of the same group, about 800 yards east of the School, runs by itself throughout its course, and is obliquely cut by a number of basic dykes. This is instructive as illustrating the fact that, while the acid dykes have taken advantage, as described, of any pre-existing basic dykes in their neighbourhood, they are themselves earlier than the majority of basic dykes in the district.

Double composite dykes, consisting of one basic and one acid member, occur in numerous localities, intersecting the Jurassic strata, the basaltic group, or the gabbro. Examples may be seen east of Camas Fhionnairidh; south-east of Sgùrr nan Each (striking N.N.E.); north-east of Vikisgill Burn, which drains into Loch Harport; and on Glas Eilean, opposite Harrabol, Broadford. Unsymmetrical multiple dykes including one or more acid members are also found quite frequently in certain parts of the area, and some of these will be mentioned later in connection with the common multiple basic dykes. Good examples occur in the Allt Daraich gorge near Sligachan and in Allt Airidh Meall Beathaig, a tributary of the Varragill River. As already intimated, an acid member almost always occurs between two basic ones; and, when evidence of their relative age is obtainable, the acid rock is always found to be newer than its immediate neighbours, though not necessarily newer than all the basic members of the complex. Another point is worthy of note. The basic members of a multiple dyke often show chilled edges against one another, which may be taken to imply a certain lapse of

time between successive intrusions: in the acid members of composite dykes, on the other hand, we often find no such evidence of chilling at the edges; which suggests that the acid intrusion in such a case may have followed its neighbours after no long interval of time. In like manner, we may sometimes see that in a merely double composite dyke the acid member shows clear indications of chilling on the side towards the country-rock, but not at its junction with the associated basic member. A good example, intersecting the gabbro, crosses Allt Dearg Beag about 1000 yards below the Basteir ravine.

A very common case among composite dykes is that in which an acid member has forced its way between the two members of a double basic dyke, thus forming a symmetrical triple dyke. A fine group of these, with the normal direction, occurs along a belt extending from near Drynoch to Coire na Creiche, a distance of about 3½ miles. Several triple composite dykes of this group are well exposed on the moorland west of Beinn Bhreac, in Coire Gaisteach, and in Allt Coir' a' Mhadaidh. A smaller group traverses the gabbro in Allt nan Clach an Geala, east of Sgùrr nan Gillean, and one example is seen on Bealach na Beiste, between Garbh-bheinn and Belig. The general type of these is a central member of granophyre flanked by two of basalt or dolerite. There are no peculiarities of a petrographical kind, and it is evident that the bilateral symmetry is only an accident, resulting from the propensity of the acid magma to insinuate itself between two contiguous basic dykes.<ref> *Cf.* Sir A. Geikie's remarks on an example described by him at Market Stance, Broadford, *Quart. Journ. Geol. Soc.,* vol. lii., p. 394: 1896; and *Ancient Volcanoes of Great Britain,* vol. ii., p. 163: 1897.</ref> Indeed in some of the composite dykes belonging to the group first mentioned this symmetry is lost, owing to the granophyre magma having been intruded into a multiple basic dyke instead of a merely double one. The two straight reaches of Allt Grillan follow multiple dykes of this kind, consisting of several basic and one acid member.

The intrusions which we shall now more particularly consider, and which will be described in detail in the succeeding chapter, are *triple composite sills and dykes* in which the *bilateral symmetry is* to be regarded as an essential feature, and they are characterised by peculiar petrographical phenomena indicative of remarkable *mutual reactions* between the two associated rock-types. The very distinctive characters common to these intrusions as a whole leave no doubt that they belong to one natural group, referable to a definite epoch and affecting a certain restricted area. They in no case intersect, but are clearly intersected by, such simple dykes as they encounter belonging to the phase of minor intrusions. The first manifestation of this phase was, as we shall see later, the injection of a great group of basic sills; but the basic members of the composite sills differ petrographically from the great group, and have certainly emanated from a different focus of eruption. We have not found direct field-evidence to determine whether they are older or younger, but other considerations indicate that they are older. The acid members of the composite sills differ in no respect from the granophyres of the Red Hills, which, as we have seen, locally enter into peculiarly intimate relations with the remarkable basic rock designated marscoite. The basic members in certain respects resemble the marscoite, and the relations to be described are in like manner analogous to those already noticed in the neighbourhood of Glamaig. These peculiar relations, whatever their interpretation, must depend upon a very nice adjustment of conditions, which was not likely to be realised at more than one epoch in the sequence of events in our. area<ref>It is possible, however, from phenomena observed in the Isle of Arran, that conditions in some respects comparable recurred locally at a much later epoch, that of the pitchstones.</ref>. We might then regard the intrusion of these composite sills and dykes as the closing event of the plutonic phase of activity or the opening event of the succeeding phase of minor intrusions. For reasons to be given later we prefer to regard the epoch as marking accurately the transition from the one phase to the other (*see* below, Chapter 25).

We shall for clearness refer to these peculiar composite sills as the *Cnoc Càrnach, type,* and we shall include with them, as undoubtedly belonging to the same natural group, certain composite dykes of like constitution. The composite sills of this type in Skye, where some twenty have been mapped, show a well-defined distribution (*see* sketch-map, Fig. 58, p. 273). They occur, with one exception, in or near the Lias, and are best developed in the country south of Broadford. Beginning not far from Suishnish Point, between Lochs Slapin and Eishort, a discontinuous belt of sills may be traced from the moorland between Carn Dearg and Beinn Bhuidhe north-eastward by Beinn a' Mheadhoin and Beinn a' Chàirn to Cnoc Càrnach and northward to Braigh Skulamus, reappearing after an interval to the north-west, on the west shore of Broadford Bay. The semicircle thus traced out has a diameter of about seven miles, and its distance from the large granite intrusions varies from a mile to 2½ miles. Ten miles to the W.N.W. we find the composite sill of Allt an' t-Sithean, near the head of Loch Sligachan. This interesting intrusion, only a mile from the peculiar sills of Glamaig, differs from the

rest in being situated in the basaltic lavas, and at a considerable distance above the base of the group. The gap between Rudh' an Eireannaich, near Broadford, and Allt an' t-Sithean, near Sligachan, is completed by that portion of Scalpay <ref>The sills at Suishnish Point in Raasay do not seem to belong to this group, their relations, as described by Sir A. Geikie, being of a different kind. *Quart. Journ. Geol. Soc.,* vol. lii., pp. 394, 395: 1896.</ref> which falls within the belt of country indicated. At Camas na Geadaig, on the north-west coast of that island, a perfectly typical composite sill is well seen in the Torridou Sandstone, and one or two others, either less perfect or less clearly exhibited, might be noted in other parts of Scalpay.

The composite sills in the Lias occur at various horizons, and sometimes at more than one horizon in the same place. This is seen on and to the east of Cnoc Càrnach (Figure 42). Again, the broad sheets of granophyre which form Beinn Mheadhoin and Beinn a' Chaìrn have apparently been continuous, but are now divided by a wedge-like strip brought up between two faults. In this, much broken by smaller faults, is seen a much lower sill, intruded in the Triassic conglomerate and even beneath it, in contact with the underlying Torridonian. Owing to their position, and to the synclinal disposition of the strata, the large sill of Beinn a' Mheadhoin and Beinn a' Chairn and that near Carn Dearg lie nearly flat, and their upper portions have been removed by erosion. Nevertheless the existing thickness must exceed 150 feet in the one case and 200 feet in the other. These two most southerly sills are the thickest. The former can be traced (disregarding the break referred to) for about a mile and a half, and the latter for a mile. The longest sill is that which forms the ridge of Cnoc Càrnach and can be followed northward to beyond Braigh Skulamus, a distance of two miles.

The typical constitution of these sills is, as already stated, triple. The middle and chief portion is of granophyre or other acid rock, while above and below it are sheets of a more basic rock, which for the present we may name basalt. The latter are usually much inferior in thickness to the middle part, not often exceeding six or eight feet in the largest sills and one or two feet in the smallest. These relations are well illustrated by examples easily accessible from Broadford; *e.g.* on the shore at Rudh' an Eireannaich and on the rough track leading to Heast, at Braigh Skulamus and for about

mile beyond. The posteriority of the acid intrusion to the basic is often clearly demonstrated by the metamorphism of the basalt at the junction and by the inclusion in the granophyre of abundant xenoliths of the basalt, which are also metamorphosed and rounded by corrosion. Further, as Sir A. Geikie has remarked, the granophyre often sends out numerous veins into the basalt, ranging in width from about an inch down to very minute dimensions. These are well seen as a fine network on an exposed dip-slope of the upper basalt, as, for instance, on the west side of Cnoc Càrnach. As seen in the field, the junction between the acid and the basic rock is usually quite sharp, however irregular it may be as a result of the acid magma corroding the basalt. Sometimes, however, there is, so far as the eye can judge, a transition, rapid but not abrupt, from the one rock to the other. That this is due to some sort of mingling of the two rocks, not to differentiation in place, is certain; for, tracing the junction along for a few yards, we may find the gradual passage giving place to the more usual sharply defined contact.

The symmetrical sandwich-like constitution of these triple composite sills is explicable a *priori* in two ways. The acid magma may have forced a passage along the surface of junction of two contiguous basic sills, as has undoubtedly happened in the case of many composite dykes; or it may conceivably have found a plane of weakness along the middle of a single basic sill, and thus split it into two. It seems possible that both cases are represented. The circumstances observed in some instances, and especially the local interposition of an inconstant basic sheet in the heart of the granophyre, seem to point to a pre-existing double or triple or even quadruple basic sill invaded by the acid magma. In other instances it will be shown that a single basic sill has been thus invaded while its interior part was still imperfectly consolidated, or at least still hot, and ready to be corroded by the acid magma. In such a case there may be so much intermingling of the two rocks as to give the general effect of a gradual transition, as described below for the sill of Rudh' an Eireannaich. We shall see that the intermingling which is there so strikingly demonstrated has operated also in varying degree in the other composite sills of the group, and there can be little doubt that the second alternative suggested is the one generally applicable.

We have next to notice the variations exhibited by some of these composite sills from what may be regarded as the ideal type, and first as regards their regularity and persistence. With respect to sills in general, in this district and doubtless in others, it may be remarked that the uniformity of their thickness and the accuracy with which they follow a given bedding-plane depend partly upon the "country" rock and partly upon the nature of the magma injected. In Skye the sills

always run most regularly in the basalt lavas and the Jurassic shales, In the bedded sandstones of the Lias they are less regular, and in the limestones the sill form is usually lost altogether. In the Durness Limestones and Torridon Sandstone, rocks usually without any good bedded structure, we find as a rule no sills. Further, the basic magmas, besides taking the sill form more readily than the acid and extending in that form for greater distances, also maintain their course with greater regularity. These general rules are illustrated by the behaviour of the triple sills. It can clearly be seen in several cases that the acid rock, though thicker, is less extensive than the basic. If the acid magma was not in great quantity, it merely formed a lenticular mass in the midst of the basalt, which is found to continue after the granophyre has died out. This is well illustrated at Allt an' t-Sithean, near Sligachan (Figure 44). If, on the other hand, the basalt failed while the granophyre was still in some force, the latter seems to have been reluctant to leave the former, and has swollen so as to present a blunt laccolitic termination instead of the usual acutely tapering form. This is well shown by a branch of the Beinn a' Chàirn mass, on the east side towards Heast. The same mass on its west side, near Allt na Pairte, illustrates another effect. The granophyre has reached the limit of the guiding basalt while still in such force as to be driven farther: it has then broken across the strata until it reached the Lower Lias limestone, and there entirely lost the sill habit.

Any want of correspondence with the bedding of the contiguous rocks is connected in these composite sills, as in the ordinary basic sills of the district, with imperfect development of the bedding-planes themselves as divisional planes. The example at Camas Geadaig in Scalpay, where the country rock is a coarse Torridon Sandstone, is an illustration of this. It preserves very well the regular sheet form, but does not follow the stratification of the sandstone (Figure 43).

The most common departure from the typical bilateral symmetry in these composite sills, and one to be observed more frequently in certain dykes of like habit, is an irregularity in appearance only. This is the absence, for some distance, of one or other (rarely both) of the flanking basalts, and it arises merely from the granophyre magma having totally destroyed the continuity of the basalt. Such breaks frequently occur for a short distance, the former presence of the basalt being attested by abundant xenoliths of it in the marginal part of the granophyre. These xenoliths, however, are themselves evidently in various stages of dissolution, and are sometimes represented merely by obscure debris in a matrix modified by the absorption of basalt material. It is easy to believe that in some circumstances all trace of the xenoliths may have disappeared and their substance been distributed through the general body of the granophyre. The flanking basalt sheets are never wanting in the smaller composite sills, but only in those in which the acid rock attains a very considerable volume.

Another, but rarer, departure from the regular type consists in the interpolation of relics of an additional basic sheet in the interior of the granophyre. A basalt in this position, invaded on both sides by the corroding acid magma, would doubtless be readily destroyed, and the relics of this kind that we have observed are of a very fragmentary sort. Only two instances are to be cited from our area, and, since they seem to illustrate two different cases, we may mention them more particularly. One example is presented by the large composite sill of Carn Dearg, near Suishnish. As now exposed, this is of the nature of an outlier, in that its present extent of nearly a square mile is determined in every direction by the progress of erosion, which has also removed all the upper portion (*see* (Figure 45), p.211). Round the greater part of the circumference there is seen merely a single sheet of basalt, usually 6 to 10 feet thick, forming the base of the much thicker granophyre; but at places on the south side we find relics of two other basic sills enveloped in the lower part of the granophyre mass. They differ petrographically from the type of basalt which forms the lower sheet and is found in these peculiar composite sills elsewhere; and it is probable that their inclusion here is only an accidental circumstance. We may suppose that in this case a triple or perhaps quadruple basic sill was invaded by an overwhelming volume of acid magma, and that only the lowest basic member (and probably the highest one, now removed by erosion) had a genetic relationship with the acid rock.

In the earn Dearg occurrence the departure from the usual arrangement is of an unsymmetrical order, but in the other case to be noted the regular symmetry is preserved, and the explanation is of a different kind. This is the quintuple composite sill of Allt an' t-Sithean, near Sligachan (Figure 44). Its shape is that of a laccolite rather than a sill, owing to the lenticular form assumed by the granophyre portion, which is traceable for only 400 or 500 yards along the strike. The maximum thickness of the whole is perhaps 150 feet, the greater part of which is granophyre; but, in addition to the upper and lower basalts, a thin sheet is seen in the middle of the granophyre, running for 300 yards or more. It is greatly metamorphosed and corroded into xenoliths, and it dies out in every direction before the granophyre.

One of the most remarkable features of these peculiar symmetrical composite sills has yet to be mentioned, and a full account of it will be deferred to the next chapter. Not only does the later rock, the granophyre or other acid type, carry xenoliths of the earlier basic one, but the earlier rock also encloses at least xenocrysts from the later. These are seen as crystals of alkali-felspars and grains of quartz scattered through the basalt, especially near its junction with the acid rock. Moreover, while the granophyre has locally been rendered less acid by incorporating in its magma dissolved debris of basalt, the basic rock has been modified in the opposite sense, and usually to a greater degree, by absorbing acid material. Indeed much of the rock which we have for convenience been styling basalt has petrographically no right to that title, being much more acid than any normal basalt. That the derived acid material, whether displayed as xenocrysts or absorbed, comes in great part from the contiguous acid rock will be made sufficiently clear in the sequel. The crystals of alkali-felspars and grains of quartz in the "basalt", like the basic xenoliths in the granophyre, become progressively more abundant towards the basalt-granophyre junction; and it is often evident, even when the dividing line is sharply defined, that the basic rock becomes more acid and the acid rock more basic towards the contact of the two. Only in certain extreme cases does the sharp division fail, and the two rocks appear to graduate into one another without any interruption.

At several places within the curved belt of country which includes the symmetrical composite sills of the Cnoc Càrnach type there occur *triple composite dykes* with like symmetrical constitution, consisting of the same pair of rocks with the same remarkable mutual reactions. The association of the dykes with the sills is of so close a kind as to leave little or no doubt that the former are, or have been, continuous with the latter, and have served as feeders to them Immediately south of Loch na Starsaich, a tarn lying to the north of Heast, a triple composite dyke can be followed for about 400 yards in an E.N.E.–W.S.W. direction, with a maximum width of over 100 feet. Westward it ends abruptly before reaching the neighbouring tarn Loch an Eilean; but eastward it can be followed to within a very short distance of a composite sill which is exposed just east of Loch na Starsaich. Just below the outlet of Loch an Eilean a similar dyke is seen, with the same bearing, and this is visibly continuous with a composite sill exposed for some 400 yards immediately south of the tarn. Another, seen 250 yards east of Loch na Starsaich, is continuous with the Cnoc Càrnach sill. In all these dykes granophyre is the predominant rock. The first one is flanked on both sides by basalt, but not continuously, the basic rock being represented in most places only by xenoliths in the marginal part of the granophyre. The second and third dykes have a border of basalt on the north side but not on the south. This imperfection is probably attributable to the caustic action of the acid magma on the basalt, which has in general been decidedly more energetic in the dykes than in the sills. Regarding the dykes as marking the channels which fed the sills, this difference may be ascribed to difference of temperature, the magma losing heat continually as it penetrated first through and then along the strata.

In other cases we find large dykes which are in visible continuity with the composite sills, but which are simply granophyre dykes without encasing basalt, at least on the side which is exposed. In the light of what has just been said it seems probable that here too pre-existing basalt dykes have been entirely devoured by the granophyre magma to which they served as guides. On the west flank of Cnoc Chrnach the granophyre of the composite sill which builds the ridge is succeeded by its upper basalt, running nearly N.–S. and dipping to the west. About 200 yards west of Loch a' Mhullaich, however, the boundary suddenly takes a turn to the W.S.W. and becomes vertical, the basalt disappearing. This continues for more than 200 yards, the vertical nature of the wall of granophyre being further proved by its crossing undisturbed a fault which causes a considerable displacement in the Liassic strata. Then the boundary turns again, and the basalt reappears with the same low dip as before. Here erosion seems to have brought to light the position of a portion of the channel which fed the granophyre sill and probably also the basalt sill which preceded it. A precisely similar thing is seen on the northern edge of the Carn Dearg composite sill, just west of Loch Fada (Figure 45).

In every case, where composite sills are found, there is a dyke of the kind under discussion at no great distance. The Allt an' t-Sithean sill, for example, is situated far from the others and, as remarked, among the basaltic lavas. No dyke which can represent its feeder is seen in visible continuity with it, but 300 or 400 yards to the north and pointing towards the sill there is a handsome triple composite dyke some fifty yards wide and with the typical characteristics. All these remarkable dykes are wide but short, and obey no evident rule as regards direction, in several instances running almost at right angles to the generality of dykes in the district. They consist typically of a wide granophyre dyke in the centre flanked by two narrower borders of basic composition. More frequently than in the sills this symmetrical disposition is disguised or lost by the destruction of one or both of the basic margins; but the other kind of departure from the ideal type, viz. the

interpolation of additional basic members in the midst of the granophyre, is not found in the dykes. This may be due to the same cause, the more intense corrosive action of the acid magma. In all cases where the flanking basic members are preserved they are found to be much corroded at their contact with the granophyre, to which they have furnished material in the form of xenoliths, etc. This clearly distinguishes these triple composite dykes associated with the sills from the others already referred to, in which the triple symmetry may be regarded as accidental. Of one of these latter, at Market Stance, Broadford, Sir A. Geikie<ref>*Quart. Journl. Geol. Soc.,* vol. lii., p. 394: 1896,</ref> has remarked that "the several parts of the dyke are as distinctly marked off from each other as they could have been had they been injected at widely separated intervals of volcanic activity".

The petrographical characters of the composite dykes associated with the Cnoc Càrnach group resemble those of the sills themselves, and the same curious phenomena of admixture are to be seen. These will be discussed in the following chapter. In this place, however, we shall briefly notice certain other intrusions which may be distinguished as *imperfectly symmetrical composite dykes.* These are not connected with sills, but constitute independent intrusive bodies. In certain parts of their course they present a composite structure with the regular triple symmetry, but elsewhere they are imperfect owing to the defect of the acid, or less commonly of the basic member. Since it appears doubtful on a first consideration whether these dykes should be assigned to the essentially symmetrical or to the unsymmetrical type, it may be profitable to examine them more particularly. They are best exhibited in the district, consisting of Torridonian grits and studded by numerous tarns, in the centre of the Isle of Scalpay.

Here the dykes are of moderate width, with a general E.–W. direction and a more or less pronounced bade to the south. The component rocks are a spherulitic granophyre and a basalt, of which the latter is the more persistent. It is of uniform aspect on a fresh fracture, but a weathered face shows numerous rusty sub-angular patches in basso-relieve, indicating xenoliths of a not very different rock. There are also scattered porphyritic crystals of felspar. Two of the dykes are shown on the small map (Figure 46). It will be seen that they are remarkable for their sinuous course and also for frequent interruptions of continuity, *i.e.* as regards the outcrop at the surface.

The first, at its eastern end, at Loch an Leoìd, has for some distance, A B, the typical arrangement, viz. a granophyre dyke flanked on each side by a narrower dyke of basalt. Farther west there are interruptions of continuity, and the granophyre is not seen again; but the unmistakable xenolithic basalt reappears in three detached exposures, C, D, E. The second dyke is seen continuously exposed for 800 yards, from F to K, with only one slight interruption, where it is displaced about 15 yards northward; and throughout this extent it has the typical constitution. At II the granophyre is 10 feet wide, the northern basalt 2 feet, and the southern one 1 foot. At G an additional basaltic member is added at the northern edge. This is non-xenolithic, about 10 inches wide, and sharply divided from its neighbour: it is probably a later intrusion. East of the continuous exposure two detached portions, L and M, show the triple symmetry as before, the granophyre being 7½ feet wide and each of the basalts 1 foot; but beyond this we find only sonic small isolated outcrops of the basalt alone, at N, and of the granophyre alone, at O. Westward a single small outcrop of the characteristic xenolithic basalt was observed at P: this may belong to one or other of the two dykes. Another dyke of the same group, nearly on the line of the second one, crosses the northern end of Loch a' Mhuillin, just outside the eastern border of the small sketch-map. On the east side of the tarn it has the typical triple constitution; on the west side the acid rock is not present as a distinct member, but is represented by a network of veins traversing the basalt.

These dykes may be taken as representatives of a number of others, specially well exhibited in the central and eastern parts of Scalpay, and their phenomena are very instructive for comparison with those of the typical composite dykes with triple symmetry throughout. The fact that incompleteness of constitution is found associated with a sinuous line of outcrop and frequent breaches of continuity is doubtless significant. In dykes in general these two latter features, and especially the last, seem constantly to indicate the upward dying out of the intrusions, the present surface of the ground passing near the upward limit of the dykes, in one place below and in another place above that limit. In these composite dykes it appears that the acid member was liable to die out before the basic, in the vertical as well as in the horizontal direction. In the first dyke noticed the complete triple portion is exposed at about 600 feet above sea-level, and the portions consisting of basalt alone at about 800 to 1000 feet. The second dyke does not illustrate the point in the same way, for the complete portion, from F to M, runs at an altitude of between 900 and 1000 feet, while the separate outcrops of basalt and granophyre at N and O are from 50 to 100 feet lower. As will be shown in a later chapter, however, the flow of molten magma in a dyke-fissure is not necessarily directly upward, but may take a direction considerably inclined to the vertical

and even in places approaching the horizontal. These imperfect composite dykes occur on the verge of the area affected by the typical composite intrusions of the symmetrical kind, and incline downward in the direction of that area. We may further suppose that when the intruded acid magma reached a point where it was nearly spent, its temperature had become considerably lowered; and accordingly these dykes do not present, at least to inspection in the field, any clear signs of reaction between the basic and acid members.

The tendency of an acid magma to be guided by a pre-existing basic dyke or sill is, as we have seen, a very general principle among all the rocks of our area. This tendency is, however, greatest in the case of the granophyres belonging to the Cnoc Càrnach group where they have encountered the xenocryst-bearing basalts of the same group. In this case we may even find a granophyre sheet sending out an offshoot along a basalt dyke. An instance of this exceptional phenomenon is seen on the north side of Beinn a' Chaìrn, about 500 yards N.W. of the summit. Here for some distance the lower basalt of the large composite sill has been destroyed but there is a basalt dyke of the type in question, which has probably served as feeder for this and the neighbouring smaller sills at a lower horizon, the acid magma, however, having in this case risen through some other channel. The dyke terminates at the base of the thick granophyre sheet of Beinn a Chàirn, and this has given off a tapering tongue which follows for a short distance the edge of the basalt dyke.

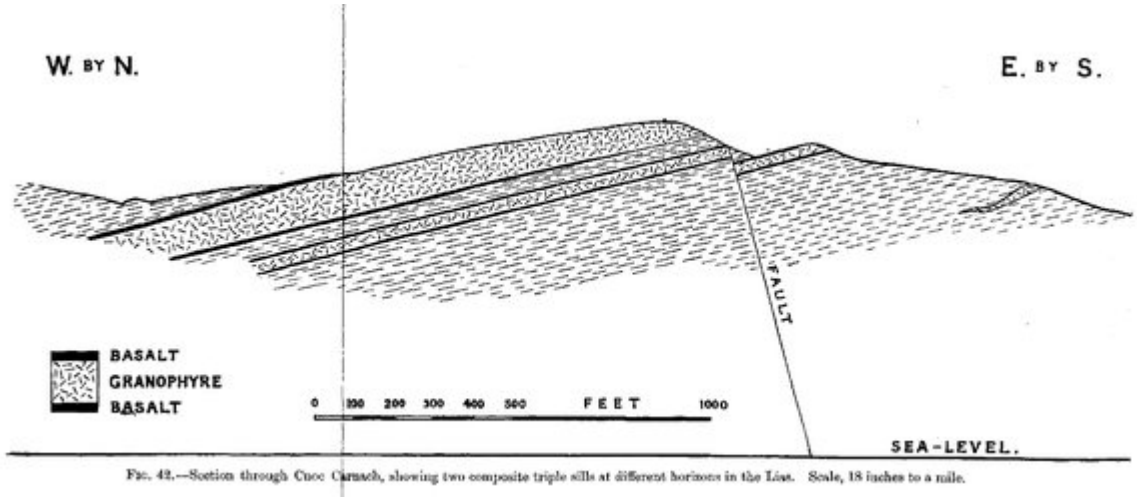

Fig. 42.—Section through Cnoc Carnach, showing two composite triple sills at different horizons in the Lias. Scale, 18 inches to a mile.

(Figure 42) Section through Cnoc Càrnach, showing two composite triple sills at different horizons in the Lias. Scale, 18 inches to a mile.

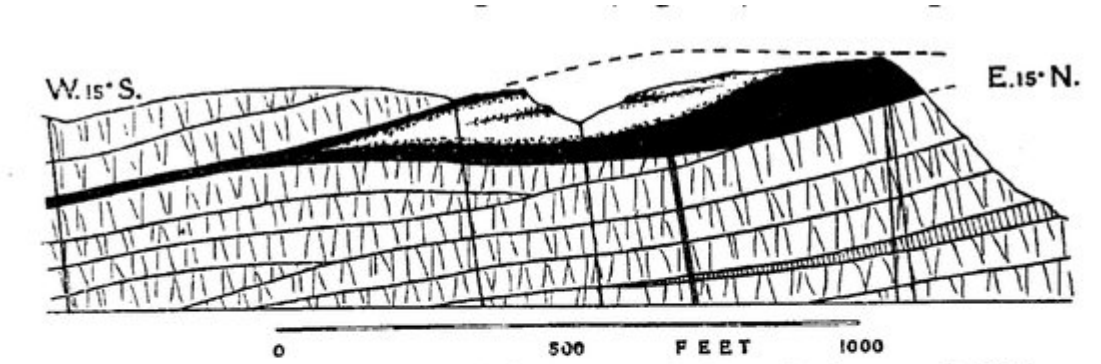

Fig. 44.—Section across Allt an 't-Sithean and through Cnoc an 't-Sithean, about 1¼ mile N.N.W. of Sligachan, to show the relations of the basalt (black) and granophyre (white) in the quintuple composite laccolite. The intrusion occurs in the basaltic lava group, and one of the ordinary dolerite sills is shown lower down. The triple composite dyke which has probably fed the laccolite does not appear in this section, but some later basic dykes of simple habit are shown, and these in some cases have failed to penetrate the thick mass.

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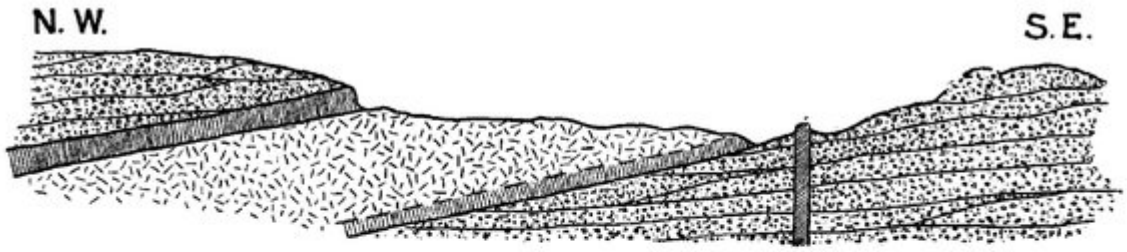

FIG. 43.—Section of triple composite sill intruded in the coarse pebbly felspathic sandstones of the Torridonian (Applecross Grits) on the southern shore of Camas na Geadaig, in the N.W. of Scalpay. The middle and principal member of the sill is a spherulitic granophyre; above is basalt, 4 ft thick, with a sharp junction; below is basalt, 2 ft thick, with the appearance of a more gradual transition. The junctions show reactions between the basic and acid rocks of the kind described below.

(Figure 43) Section of triple composite sill intruded in the coarse pebbly felspathic sandstones of the Torridonian (Applecross Grits) on the southern shore of Camas na Geadaig, in the N.W. of Scalpay. The middle and principal member of the sill is a spherulitic granophyre; above is basalt, 4 ft thick, with a sharp junction; below is basalt, 2 ft thick, with the appearance of a more gradual transition. The junctions show reactions between the basic and acid rocks of the kind described below.

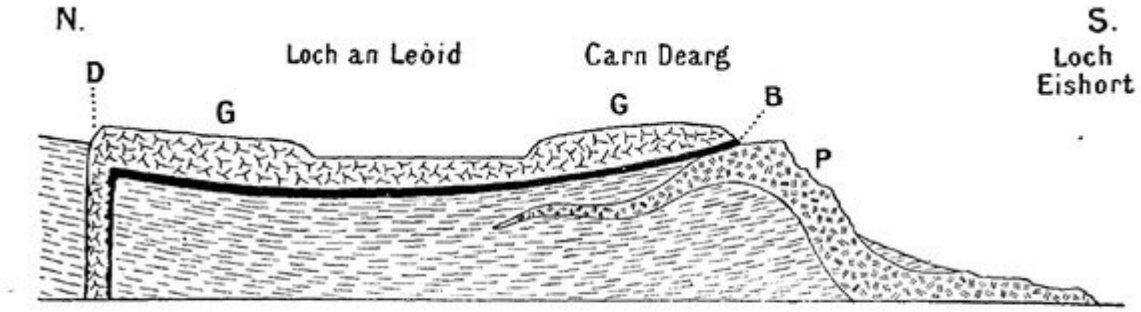

FIG. 45.—Section across the composite sill of Carn Dearg, near Suishnish. Scale, 6 inches to a mile. G, granophyre of sill; B, lower basalt member; D, supposed dyke-feeder of sill; P, later independent intrusion of rock varying from olivine-gabbro to picrite (see Chap. XXII.).

(Figure 45) Section across the composite sill of Carn Dearg, near Suishnish. Scale, 6 inches to a mile. G, granophyre of sill; B, lower basalt member; D, supposed dyke-feeder of sill; P, later independent intrusion of rock varying from olivine-gabbro to picrite (see Chapter 22).

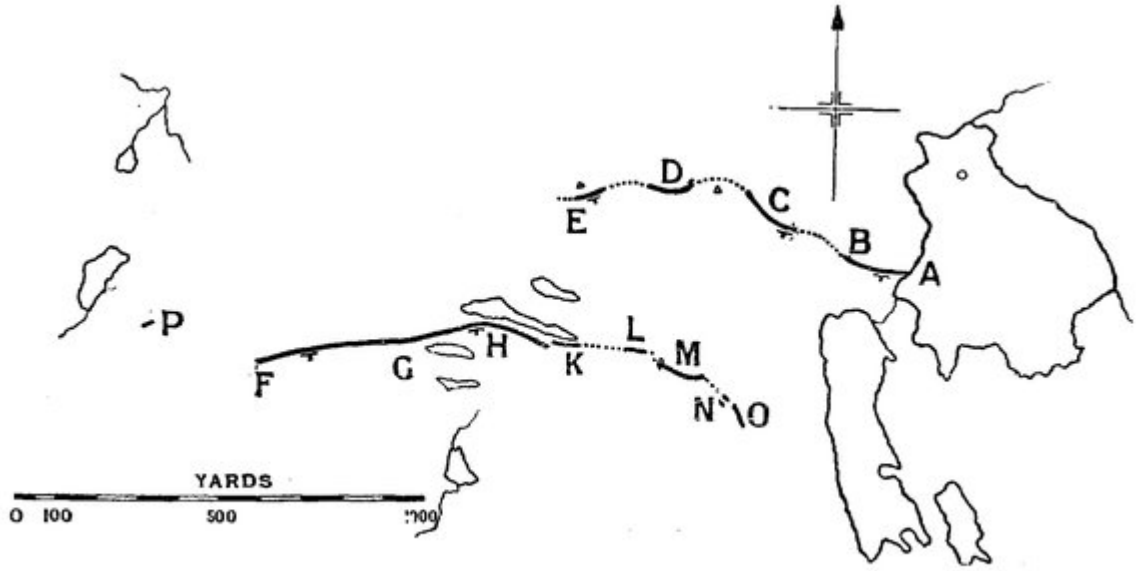

FIG. 46.—Sketch-map of a small area in the interior of the Isle of Scalpay: explanation in the text.

(Figure 46) Sketch-map of a small area in the interior of the Isle of Scalpay: explanation in the text.