Chapter 20 Basic dykes: xenoliths

An account of the basic dykes of Skye would not be complete without some notice of the *foreign or derived material* which, in the form of distinct rock fragments (*xenoliths*) or isolated crystals (*xenocrysts*), is found enclosed in so many of the dykes. This peculiarity is observable, in different degrees, in other groups of intrusive rocks described in this memoir. We have seen that in certain circumstances the granite becomes crowded with partially digested debris of gabbro. The composite intrusions, dykes and sills, consisting of associated basic and acid rocks, exhibit more remarkable phenomena of the same order. The ordinary basic sills of the plateaux seem to be very poor in xenoliths; but in the inclined basic sheets, to be described later, which intersect the gabbro mountains, and in the basic dykes throughout much of the area surveyed, derived material, usually debris of plutonic rocks, occurs with remarkable frequency.

We may divide xenoliths in general into two classes, those which are merely *accidental* and those which are *cognate* with the enclosing rock.<ref> *Cf.* Harker, *Journ. of Geol.,* vol. viii., p. 394: 1900.</ref> The former are such as may be enclosed in almost any igneous rock, and represent merely fragments picked up by the magma from the "country" rocks which it has traversed. Under the latter head we include those cases in which there is a genetic relationship between the enclosed and the enclosing rocks, and here the xenoliths have probably a deeper significance. The facility with which the various Tertiary intrusive rocks of Skye have enclosed relics of one another seems to be a characteristic of the whole series. In many cases the dissolution of the enclosed foreign debris has materially modified the composition of the enveloping magma, and so of the resulting solid rock. We proceed to describe a few selected examples illustrative of the phenomena.

The most remarkable instance of *accidental xenoliths* is afforded by a dyke which crosses the long southerly ridge of Blath-bheinn at about 1300 feet altitude. It is a conspicuous object, having a width of about 27 feet, and presenting at a glance the appearance of a quartz conglomerate. Pebbles and fragments of white quartz and quartzite, sub-angular or rounded, up to several inches in diameter, are crowded together in a greenish-grey diabasic-looking matrix. The dyke is one of those already referred to as representing some of the feeders of the gabbro lacolite: traced northwestward it is found to be continuous with the gabbro, which itself at this place encloses pebbles of quartz.<ref>The spot is just 500 yards east of the most easterly point of Loch na Creitheach.</ref> Similar xenoliths are found in abundance in irregular sheet-like intrusions of granophyre close to this place and on the slope farther south.

The purely accidental nature of these xenoliths, consisting of vein-quartz and quartzite, is of course obvious. <ref>The dyke locally contains a few xenoliths of granite, which are of different significance, and fall under the "cognate" category.</ref> But, even if they had been of some igneous rock, their narrow restriction to one locality and the fact that at that locality they are found in three different kinds of intrusive rocks would be sufficient to prove that no close genetic relationship can exist in this case between the xenoliths and their enclosing matrix. In this case the probable source of the foreign material can be pointed out in the near vicinity. The Triassic conglomerate, as seen in some steep crags overlooking the foot-path to Strathaird<ref>The branch passing east of An t-Sròn, now generally disused.</ref> is locally composed of quartz-pebbles; and although some of the quartz-fragments enclosed in the dyke are of larger size and more angular shape, it is probable that better exposures might enable us to match these too from the conglomerate in place. The subjacent Torridonian grits also contain abundant small pebbles of quartz, which are doubtless the chief source of the xenoliths in the granophyre sheets, and may have contributed also to those in the dyke.

Thin slices of the conglomeratic dyke show numerous points of interest (S7478) [NG 523 201], (S7479) [NG 523 201]. The enclosed quartz-pebbles exhibit strain-shadows in polarised light, and are often traversed by fine fissures. These are probably mechanical effects of the heating, and from the same cause the quartz has been broken up into fragments, the smaller debris being distributed through the general matrix. Reactions have taken place at the contact of the quartz with the enveloping magma. As seen in the slices, the boundary of a pebble is often interrupted by gulf-like inlets, occupied mainly by felspar in narrow crystals or elongated fibres. Very often curved fibres of felspar are crowded together in divergent or imperfectly radiate aggregates, recalling the structure of some variolitic rocks; but, if we may judge by the nearly straight extinction of the fibres, the felspar is here of an acid species (Plate 24), Fig. 4. From these inlets narrow veins, also consisting essentially of little needles and fibres of felspar, penetrate the quartz of the pebble. The outer boundary of the pebble often shows a border with a similar development of fine felspar needles, but these are here associated with abundant pyroxene: a like border often surrounds the fragments resulting from the breaking up of the pebbles.

The matrix in which the pebbles are set is a rock of a peculiar kind, representing an originally basic magma greatly modified by absorption of silica. It does not appear that silica has crystallised out, as such, from the magma; the abundant quartz found being rather mechanically derived from the xenoliths; but the actual products of crystallisation none the less bespeak an abnormal composition for the magma. They are, in order of relative importance, felspar, enstatite, and augite. There is no olivine and little or no iron-ore. The felspar is in rather irregular striated crystals, referable by their extinction-angles to andesine. The rhombic pyroxene is in idiomorphic crystals, usually 1/50 to 1/20 inch in length, almost always converted to green pleochroic bastite. The colour of this latter indicates a certain content of iron, but where the original mineral is preserved it shows the pale tint of enstatite. This is especially in the neighbourhood of the quartz, and possibly the rhombic pyroxene was not all of the same composition. The augite is in shapeless grains, very pale in the thin slices.

Assuming the magma to have had originally the composition of a dolerite, as the field-evidence indicates, it is manifest that it has been greatly modified by absorbing silica from the enclosed xenoliths. It is also noteworthy that the rock has not the relatively coarse texture and the characteristic micro-structure of a dolerite. Doubtless the inclusion of so large a quantity of foreign material, derived from cold rocks, caused a relatively rapid cooling of the magma.

Among the dykes met with in our survey instances are rare in which accidental xenoliths play so prominent a part as in the case just described. Two dykes traversing the coarse pebbly sandstones of the Torridonian (Applecross group) of the Isle of Scalpay may be mentioned. One occurs on the western slope of Mullach na Càrn, and is a large dyke containing abundant xenoliths near one edge only; the other, to the north of Bealach Bàn, also shows a somewhat uneven distribution of the included material. In both cases pebble-like inclusions of quartz and quartzite are accompanied by pieces of granite, presumably derived from a deep-seated source, so that both accidental and cognate zenoliths seem to be represented. Mr Woodward has remarked a dyke carrying abundant pebbles at Rudha nan Leac on the east coast of Raasay, where it intersects the red sandstone of the Trias.

The remarks made in a former chapter concerning the necessarily abnormal composition of mixed or hybrid igneous rocks apply with greater force to such cases as these, where a molten rock-magma has enclosed, and in part dissolved, extraneous material of non-igneous origin. The resulting rock, even excluding any undissolved relics of the xenoliths, must have a chemical, and consequently a mineralogical, composition unlike those of any rock resulting from the crystallisation of a pure rock-magma.<ref> The special case of a magma which has dissolved quartz of extraneous origin is considered in the paper already cited: see *Journ. of Geol.,* vol. pp. 395, 396, and fig. 3; 1900.</ref>

The *cognate xenoliths and xenocrysts* in our basic dykes come mainly from two rocks, gabbro and granite: other types, such as troctolite, are more rarely represented. It is of the first importance to notice that, on the one hand, they are always of rocks familiar among the Tertiary intrusions of the region; on the other hand, the situation and proved age of the dykes are often such that the xenoliths cannot be derived from any known mass of the said rocks in the vicinity. This independence of the country rocks is to be regarded as a characteristic of cognate xenoliths. As regards distribution, it may be remarked that the phenomenon is not confined to any one type of dykes, but it is specially frequent in certain of the groups which we are able to distinguish by their petrographical characters and their relative ages. It is very common in some of the later groups, but comparatively rare in the earlier. This is quite in accord with what has been stated above; for the pre-granitic dykes are doubtless in most cases feeders of the lavas, and the immediately post-granitic dykes possibly feeders of the sills; and we have already seen that the lavas do not carry xenoliths and the normal basic sills do so but rarely.

The enclosed foreign material has often suffered considerable alteration in consequence of its inclusion in a molten magma. Despite this, distinct xenoliths, even when of quite' minute dimensions, are as a rule easily recognised; and even detached crystals, if not totally destroyed, are not so much disguised as to obscure their true nature. On the other hand, there may be some difficulty in recognising xenocrysts as such in the absence of characteristic alteration. The changes experienced arise from two causes, viz. from the mere heating of the crystals, which give rise to effects mostly of a mechanical kind, and from chemical reactions between the crystals and the enveloping fluid magma. Changes of the latter kind, which are the more unmistakable, are not always developed. They seem to depend generally upon the existence of a considerable difference in composition between the enclosing rock and that which has furnished the derived material.<ref>This principle, in one form or another, has been recognised by more than one writer: see, e.g., Zirkel, *Lehrbuch der Petrographie,* 2nd ed., vol. i., p. 599; 1893.</ref> Where debris from an acid rock has been enclosed in a basic magma, some minerals (the ferro-magnesian constituents in particular) are often totally destroyed, and the rest (excepting certain accessories, such as zircon and apatite) have constantly suffered more or less from the caustic action of the magma. A similar remark applies to basic material involved in an acid magma. But where the debris of a basic rock has been enclosed in a basic magma such chemical reactions are by no means universal. In particular, gabbro-felspar in a basalt or dolerite dyke may show little or no sign of caustic action. There seems to have been in such a case something like chemical equilibrium between the crystals and the environing medium. Evidence may still be forthcoming — from the form of the crystals and the nature of their minute inclusions, from their unequal distribution in the dyke or their association with actual gabbro xenoliths — sufficient to indicate their true origin. The source of the foreign elements enclosed in the dykes will be more appropriately considered after a description of some illustrative examples.

Good instances of *gabbro xenoliths* are afforded by the porphyritic basalt dykes about Suardal and in other parts of the Strath. Especially noteworthy is a 50-ft dyke a little S.W. of the fork of Allt an 't-Suidhe, to the N.W. of Loch Kilchrist, where gabbro debris makes up in places about half the bulk of the rock. The locality is not far from the exposures of the Kilchrist granophyre with abundant xenoliths of gabbro. This dyke intersects the volcanic agglomerate, but most of the other Suardal dykes occur in the Cambrian limestones. A numerous group of dolerite dykes rich in gabbro xenoliths may be examined to the north-east of Camasunary, viz. in the rocks of the Abhuinn nan Leac valley and in the basaltic lavas of the slopes above, rising to An Dà Bheinn or Slat Bheinn.

The appearances observed in thin slices of these rocks, or of some of them, may be described briefly. The felspars of the xenoliths are sometimes partially rounded where they have been in contact with the molten magma; more frequently they show no such change, though they may be fissured or partly shattered. They may show evidently secondary inclusions just within the border of the crystal (Plate 25)., Fig. 2, A, and the very turbid appearance seen in some cases is possibly attributable to more numerous and minute inclusions of like origin; but neither of these phenomena is so general as to be considered a distinctive criterion. Not infrequently there has been some addition of new felspar-substance, forming a border continuous with the xenocryst. Often none of these changes can be verified. The augite, like the felspar, may show rounding and bands of secondary inclusions (S7483) [NG 526 194]. It is more readily affected by chemical changes than the felspar. At the junction of the two minerals in a xenolith there has sometimes been a mutual reaction, giving rise to prisms of brown hornblende and granular aggregates of magnetite, set in a matrix of new-formed augite, new felspar (partly in continuity with the old), and a little quartz (S6712) [NG 623 205]. In detached xenocrysts the augite does not long survive. It gives rise presumably to new augite, which forms part of the enclosing rock, but also to granular magnetite with sometimes a little brown mica. Patches rich in these latter minerals may remain to indicate vaguely the site of vanished augite xenocrysts (S6718) [NG 602 213]. It is difficult to decide whether the magnetite of the gabbro ever escapes destruction. When apatite has been present, it is left unchanged after the disintegration of the containing xenolith (S6712) [NG 623 205].

As illustrating the phenomena of *granite xenoliths* in basic dykes, we may take first those so frequently encountered in the porphyritic basalt dykes which have been distinguished above as the Suardal type. As already stated, granite debris occurs locally in considerable abundance, and by its partial dissolution has sometimes modified in some degree the composition of the basalt-magma; but on the whole it is the earlier stages of alteration of the xenoliths that are best exemplified in the specimens studied from these dykes. Pieces of granite two or three inches in diameter occur, and the manner of their disintegration is clearly exhibited. It is partly a mechanical breaking up, consequent upon the different coefficients of expansion of the several minerals and upon shattering by heat of the individual crystals. But in every case there is a certain amount of corrosion by the enveloping magma, which finds its way even into very minute fissures and co-operates with the purely mechanical process; and there are also reactions between the different component minerals of the granite itself.

The ferro-magnesian element of the granite is the most readily affected, and biotite in particular is almost always destroyed at the outset. In some cases it seems to have been fused in the interior of the xenolith; but in general the material, or much of it, seems to have been removed by some leaching-out process. Even when a flake of biotite has been embedded in a felspar crystal, it is quite destroyed and represented only by some finely granular magnetite, this being arranged in fine lines in a way which indicates that the process was effected along the cleavage-planes. Such a vanished biotite-flake may be surrounded by a clear ring of apparently new-built felspar continuous with the surrounding crystal but differing slightly from it in optical properties (S6715) [NG 630 205]. Except when its place is marked in this way, the biotite of the granite is totally lost, and only partially represented by clotted granular magnetite or brown limonite not in the form of the original mineral. Sometimes a little granular augite is associated with the iron-oxide: less frequently some new-built brown mica.

The quartz of the xenoliths sometimes shows no change other than the formation of fine cracks. These occasionally tend to run parallel to the boundary of the grain (Plate 25)., Fig. 2, B, but very often they have been determined by rows of fluid-pores in the quartz, which have perhaps burst the crystal by the expansion of the contained fluid. In this case the cracks often show some degree of parallelism in each grain. Occasionally, along the border of a detached grain or along a crack, the quartz has become a rather finely granular aggregate with a clear interstitial substance which is isotropic and is probably hyaline silica (S6716) [NG 633 208].

The felspars (orthoclase and oligoclase) of the granite are, in this early stage of alteration of the xenoliths, more easily attacked than the quartz. This is especially the case where felspar has been in contact with a ferro-magnesian mineral in the granite. Here is formed, round the site of the latter mineral, a patch of new-built felspar with some admixture of iron-ore and perhaps new-built biotite. The new felspar is in small imperfect crystals or in fibres aggregated in fan-shaped bundles (S6751) [NG 622 204]. The felspar of the granite is only vaguely outlined against such a patch, but the quartz presents a sharp edge to it. Often again there is an alteration along the border of the felspar crystals of the xenolith at their contact with one another or with quartz. This takes the form of a zone of rather fine-textured new-built felspathic material. If it is orthoclase, it tends to a granular structure; if oligoclase, it forms an aggregate of little imperfect twinned crystals, which near the original oligoclase of the xenolith may assume a regular orientation with it. In their interior the felspars of the xenolith, at least until they become isolated from it, show little change in many examples; but some exhibit the peculiar shagreen appearance which Bäckstrom<ref> *Bihang til k. svenska Vet.-Akad. Handl.,* vol. xvi., pl. II., figs. 7–9; 1890.</ref> styles *gekörnelt* or granulated.

An excellent place for studying the more advanced dissolution of granite xenoliths in basalt is found close to Broadford, on the west shore of the bay. The locality is about 250 yards beyond the pier, and nearly north-east of Corry Lodge. Here two dykes (among others) are exposed at low tide, running out into the water in a S.S.E. direction. Both contain abundant debris of granite, and in the second (*i.e.* the more north-easterly one) large patches of that rock are locally present in various stages of breaking up and dissolution. The xenoliths, however, have not been uniformly distributed through the dykes, and this enables us by comparison of specimens to demonstrate the reciprocal modification of the basic magma consequent upon incorporation of the acid material.

A specimen of the first dyke, taken as free as possible from extraneous material, is a dark grey, finely but evidently crystalline rock, of specific gravity 3.03 and clearly of basic composition. It has no phenocrysts nor xenocrysts. A slice (S6719) [NG 644 243] shows it to be a normal sub-ophitic dolerite composed of labradorite, augite, and magnetite (Plate 25)., Fig. 3, A. The little felspars are about 1/40 inch long. A specimen was selected for comparison which showed numerous xenocrysts, both quartz-grains and dull white felspars. Here the matrix is of a much lighter grey colour and of finer texture. A slice (S6720) [NG 644 243] shows the quartz-grains to be partially rounded and bordered by a ring rich in granular augite, due to reaction between the grain and the enveloping magma; a familiar feature in other districts where quartz-grains have been enclosed in basic rocks (Plate 25)., Fig. 3, B. The felspar xenocrysts, which are chiefly of oligoclase, are extremely turbid, excepting a clear patch in the interior of each crystal. The felspars of the matrix are of more slender shape than in the normal dolerite and not more than 1/100 inch long, while their nearly straight extinction proves them to be oligoclase, perhaps with some orthoclase. The augite also is smaller, and is in granules, and magnetite is less abundant. Finally there is a certain amount of quartz, in small interstitial patches, with all the appearance of an original constituent.

These two specimens, taken only a short distance apart, are undoubtedly parts of one dyke, and the abnormal characters of the second one are due to the modification of the basic magma by absorption of granitic material. The acidification shows itself especially in the formation of a relatively acid felspar and the presence of some excess of silica crystallised as quartz. The finer texture and rather different micro-structure of the modified rock as compared with the normal type are also interesting. We might refer them with some plausibility to the more rapid chilling consequent upon the inclusion of so much solid rock-debris. The contrast between the two specimens implies that no important diffusion has operated in the dyke during or after the corrosion and absorption of the granite debris. It may be taken as indicating that, although the xenoliths were brought up by the basic magma from some unknown depth, they did not begin to be dissolved to any considerable extent until after the intrusion of the dyke. A certain degree of super-heating in the magma, consequent upon relief of pressure, may have been the determining factor. The reciprocal action then proceeded energetically, and probably rapidly, for it must have been checked as cooling went on.

The second dyke shows phenomena closely comparable with those described above, but it is richer in granitic material, and no part of it that is exposed can be taken to represent the normal rock. A specimen was taken, however, from the portion poorest in quartz and other xenocrysts, and this gave the specific gravity 2.84. It is an evidently crystalline dolerite, generally resembling the normal type of the former dyke. A thin slice (S6721) [NG 644 243] shows that the little felspar crystals are labradorite, up to 1/20 inch in length: the pale brown augite has the sub-ophitic habit, and there are irregular grains of magnetite. Four specimens taken from near granite xenoliths, and themselves containing abundant xenocrysts, were sliced for comparison (S6722) [NG 644 243], (S6723) [NG 644 243], (S6724) [NG 644 243], (S6725) [NG 644 243]. The hand-specimens show a lighter colour and a finer texture than the preceding specimen, and one gave the low specific gravity 2.73. The quartz-grains in these slices show always more or less rounding and corrosion, and have the usual border of granular augite, sometimes decayed and represented by carbonates, etc. The derived felspars, both orthoclase and oligoclase, are very turbid throughout, or have only a clear patch in the centre. Sometimes there is in the interior of a crystal an incipient new formation of granular felspar, which is quite clear. The ferro-magnesian minerals of the granite are always totally destroyed. The matrix in which the derived elements are enclosed is like that described in the other dyke. The felspar is oligoclase, or at least gives sensibly straight extinction, and is in slender prisms usually not more than 1/100 inch long. The augite occurs in granules. There is in every case a certain amount of interstitial quartz. Another feature shown in some of the slices is the occurrence of small druses, with idiomorphic quartz projecting into the cavity, which has subsequently been occupied by calcite. We have pointed out the same peculiarity in the basic members of the composite sills of Cnoc Càrnach, etc. (p. 218.)

Sufficient examples have been given of the occurrence of foreign elements in noteworthy amount in the basic dykes. *Sporadic xenocrysts,* and to a less extent xenoliths, have, however, a much wider distribution in the Tertiary dykes than has been indicated by these particular occurrences. We do not refer to merely accidental inclusions of the country rock, which sometimes occur here as in other dykes, but call for no special remark. Nor need we do more than mention another not uncommon feature, viz. the inclusion of little fragments of rock of similar composition to the enclosing matrix but of finer texture. These probably represent a portion of the dyke-magma rather rapidly consolidated at an early stage of the intrusion, in contact with the wall of the dyke, and torn away by a later up-rush of the molten magma. We are concerned more especially with the inclusion in basic dykes of foreign material for which the known rocks in the neighbourhood do not afford any possible source.

Certain occurrences are perhaps to be explained by the supposition that an earlier dyke has been totally destroyed, excepting fragmentary relics, by a later one of a different kind, illustrating thus what may be regarded as an extreme case of a composite dyke. For instance, one of Mr Clough's specimens (S7364) [NG 598 012] is described as forming a band in a compound dyke and containing rows of pale-red weathering spots up to 2 or 3 inches. This is from two-thirds of a mile N.N.E. of the west end of Ard Thurinish, in the southern part of Sleat. The rock is a fine-textured ophitic dolerite of specific gravity 2.87. The spots are xenoliths of a spherulitic granophyre, containing little patches of brown ferruginous substance with radiate structure, probably representing the ferro-magnesian mineral of the granophyre.

No such explanation is applicable to the gabbro-felspars and granitic quartz and felspars, which occur usually as isolated xenocrysts but occasionally grouped so that they may be called small xenoliths. They are found sparingly but not infrequently in basic dykes, not only in the mountain district and in Strath but in Sleat, the rock mentioned in the preceding paragraph being an example. Rarely in the outlying portions of the area does the enclosed debris occur in such quantity and of such a kind as to modify the composition of the enclosing rock in the fashion already described, but this is sometimes seen. One of Mr Clough's specimens, from Loch Doir' an Eich, about two miles S.E. of Ord, carries quartz-grains in unusual abundance. It has no doubt come from a basic magma, but has been considerably acidified. The little felspars are found to be oligoclase, and there is some interstitial quartz (S6853) [NG 645 117]. The specific gravity of the rock is only 2.75, and it compares closely in all respects with the occurrences described above near Corry Lodge, Broadford.

In addition to detached xenocrysts. actual xenoliths of both gabbro and granite are recorded by Mr Clough from localities in the southern part of Sleat, ten or twelve miles from any considerable outcrop of like rocks. Thus in the Tarskavaig neighbourhood several of the basic dykes about Camas Daraich and the coast north eastward are described as very full of gabbro inclusions. A. more remarkable case occurs about a mile east of another Camas Daraich near the Point of Sleat. Here a dyke on the shore, besides porphyritic crystals, contains numerous large pieces of felspar, one measuring 18 by 9 inches and another 2 feet in length and 3 inches in breadth. They are of specific gravity 2.70, and give an extinction-angle of 5° in basal cleavage-flakes, agreeing with acid labradorite, Ab_1An_1. Some of the large pieces are single crystals, but others are complex; and we are probably to regard them as xenoliths of anorthosite, a varietal form of gabbro. Dykes enclosing gabbro are found also near Tormore and Gillean. "A dolerite dyke on the coast rather less than two-thirds of a mile W.S.W. of Gillean is unusually full of gabbro inclusions, or pieces of felspar which seem of the same kind as the felspar in the gabbro inclusions. Many of the inclusions are four or six inches long, and for a breadth of six or eight feet they take up as much space as the including rock. A specimen of one of the felspar lumps has the specific gravity of 2.68.

The inclusions in a dolerite dyke (S6135) [NG 620 138] on the coast rather more than a quarter of a mile S.S.W. of Rudha Duhh Ard, near Ord, vary greatly in abundance in different parts. Near high-water mark a breadth of two or three feet on the W. side of the dyke is nearly without inclusions, but the other part is crowded with them. Between this place and about sixty yards south of it no inclusions were noticed; farther on to the S.W., for more than 100 yards, the inclusions nearly equalled the dyke-rock in bulk. Some of the inclusions are three or four inches long and one or two broad. The longer axes are rudely parallel to the sides of the dyke. There are some inclusions, an inch or more in breadth, which seem entirely composed of quartz like that in the granophyre inclusions, but the rock from which they have been derived must have been unusually coarse in grain". (C. T. Clough.) Numerous inclusions of granite or granophyre were noticed by Mr Clough in a dyke a mile north-east of the mouth of Gillean Burn, near Tarskavaig, and in another farther south, on the coast N.W. of Loch Nigheann Fhionnlaidh. Another example is a coarse dolerite dyke on the west side of Ardvasar.

In the country to the west and north of the Cuillins the basic dykes less frequently contain foreign inclusions of an easily recognisable kind, but evident xenoliths of gabbro do sometimes occur at considerable distances from the plutonic intrusions of the Cuillins. One locality is the coast immediately west of Fiskavaig. One of the dykes here contains abundant pieces of gabbro, some with a diameter of three or four inches, although the place is nearly nine miles from that rock as exposed *in situ.* Detached crystals which seem to be of foreign origin are of more frequent occurrence, and some of these are of minerals belonging to acid rocks. We have already mentioned the orthoclase enclosed, in a greatly corroded state, in a basic dyke at Am Bile, to the north of Portree: notwithstanding the occurrence of orthoclase as a normal constituent of the same rock, these are probably to be ranked as xenocrysts. (*See* p. 348.)

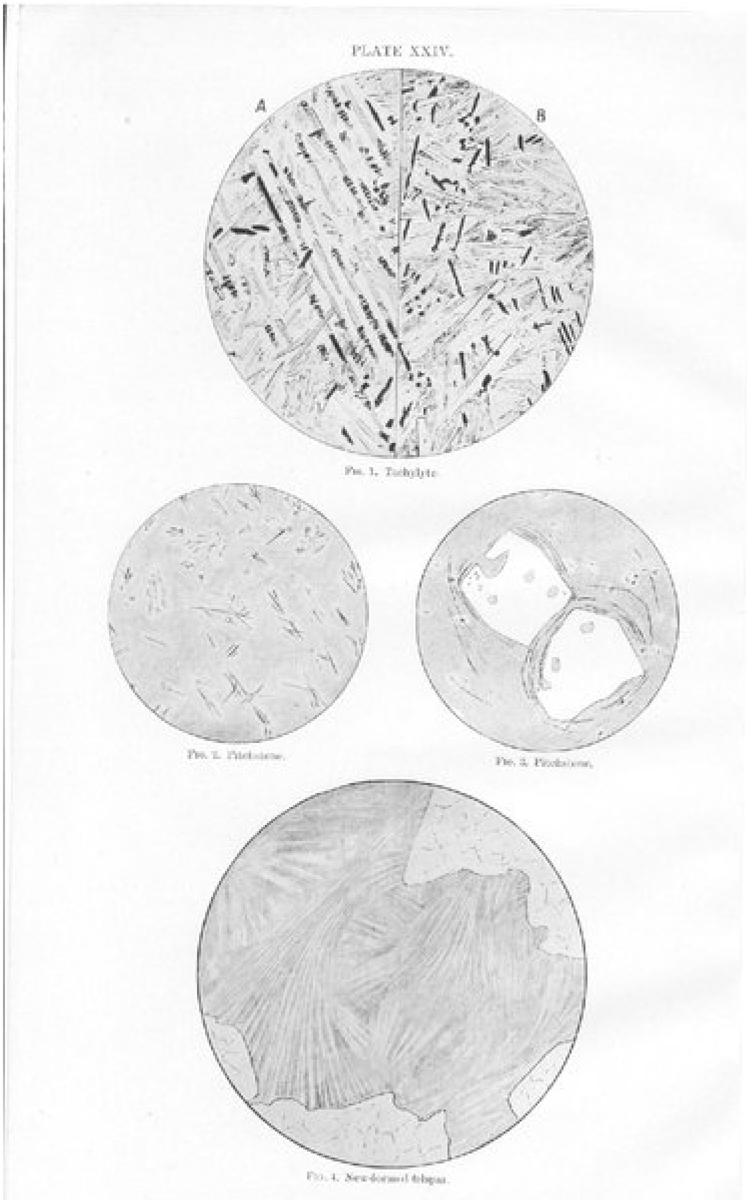
The characters of the sporadic xenocrysts do not call for very full description, being closely similar to those already detailed above and, we may add, to those of other occurrences which have been described by many petrologists.<ref> The literature of xenoliths and xenocrysts is very extensive. The most exhaustive treatment of the subject is to be found in Lacroix's memoir *Les enclaves des roches volcaniques,* Macon, 1893.</ref> The felspars, when they have suffered any appreciable change, have not always behaved in the same fashion. Sometimes there is a formation of fissures following the two cleavages and incipient fusion along these fissures, which, carried farther, would break up the crystal into minute fragments. More commonly in the examples studied the crystal is not disintegrated. A certain amount of fusion or corrosive action on the edges has produced a partially rounded outline, and this reaction with the basic magma is especially noticeable in the case of the alkali-felspars. The most common change observable in the felspar xenocrysts is, however, the production of secondary glass-and other inclusions. Not infrequently these occur along a zone just within the border of the crystal. They follow the shape of this, however it may have been modified by rounding (*cf*. (Plate 25)., Fig. 2, A). In the case of a xenolith or group of crystals the zone of secondary inclusions is found only along that border of a crystal which is in contact with the enclosing matrix. It results probably from the fusion of primary inclusions in the felspar, but there has apparently been an enlargement occasioned by a reaction between this fused matter and the surrounding felspar-substance. Very often the felspar xenocrysts are extremely turbid throughout, or perhaps with the exception of a clear patch in the centre, and it seems probable that this appearance is due to a multitude of minute secondary inclusions. Outside the nearly opaque xenocryst there may be a clear border of new-formed felspar, in continuity with the old. This is frequently to be observed. When the augite of the enclosing rock has the granular habit or an idiomorphic tendency, it can sometimes be seen that the clear felspar-border is moulded upon the little grains of augite, proving its later growth. The derived quartz-grains in the dykes constantly show rounded contours, and are invariably surrounded by a ring or shell of granular augite.

The source of these xenocrysts is evidently a question of some difficulty. Even in dykes situated near the gabbro and granite intrusions the derived elements cannot always be attributed to the source which seems most obvious. Thus, a dyke a little to the south of the Beinn an Dubhaich granite contains abundant derived grains of granitic quartz (S7060) [NG 616 199]; but the dyke is metamorphosed by the granite, and must therefore be older. That an earlier suite of plutonic rocks, both gabbro and granite, exists, or has existed, concealed from view beneath the mountain district we know from the evidence of the volcanic agglomerates, and this is a possible source of some of the foreign debris in our basic dykes; but, if we are to extend this explanation to dykes carrying xenocrysts throughout the island, we must postulate a much wider extension of these concealed rocks than is indicated by any other line of evidence. The question must be considered in connection with various records, scattered through the literature of the British Tertiary intrusions, which suggest that the phenomena to be explained have a very wide distribution. Besides descriptions of evident xenocrysts, such, for instance, as the occurrences noticed by Dr Corstorphine in the southern part of Arran,<ref>*Tscherin. Min. Petr. Mitch.* (N.S.), vol. xiv., pp. 443–452, p1. X.; 1895.</ref> we find in the accounts of not a few "porphyritic" basalts, etc., observations which suggest that the enclosed felspar crystals may be in some sense not normal constituents of the rocks in which they occur.

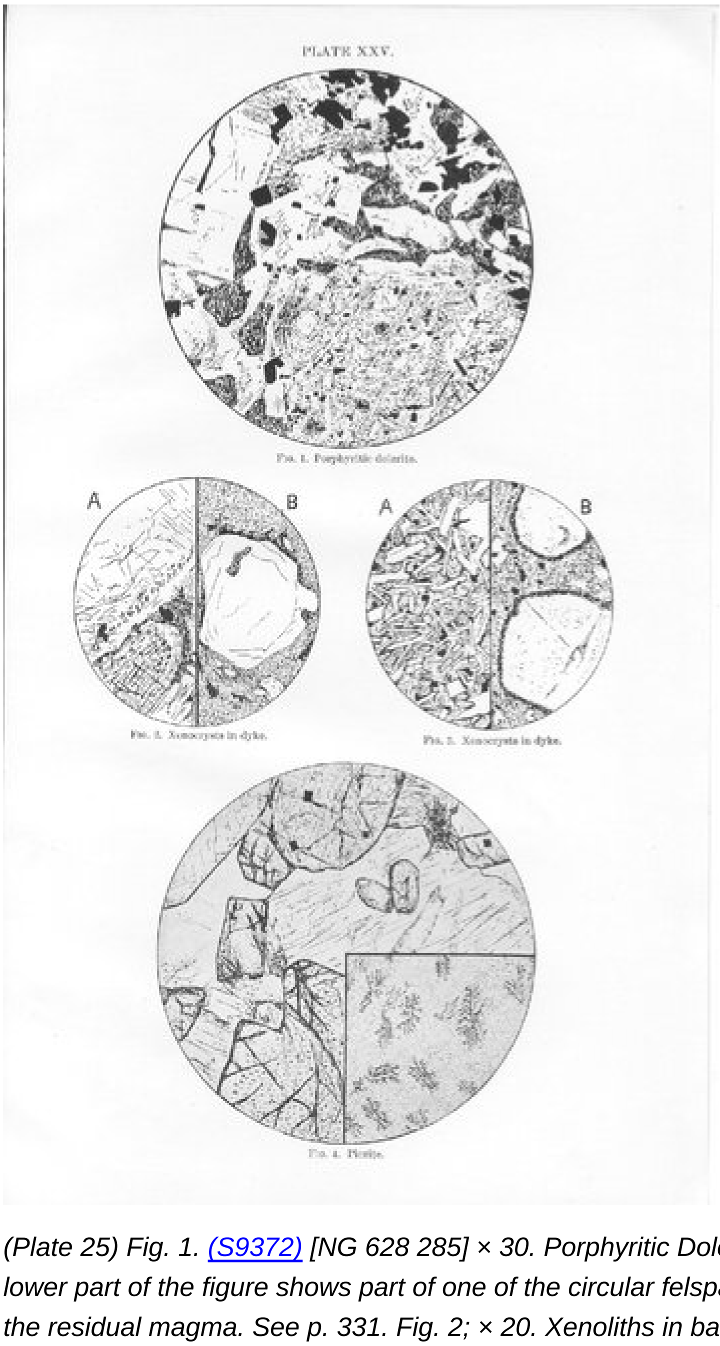
For instance, Mr Holland,<ref>*Min. Mag.,* vol. viii., p. 155; 1888.</ref> describing the large felspars in a basalt near Tobermory, Mull, remarks that they frequently exhibit schillerisation. Even so far away as the North of England Tertiary, or probably Tertiary, dykes exhibit some peculiarities in porphyritically enclosed felspars. That the crystals have not usually been corroded or otherwise evidently altered by the magma<ref>Lacroix describes and figures a felspar xenocryst from the Cleveland dyke at Great Ayton, which shows the characteristic breaking up by fusion along cleavage-cracks (*Les enclaves des roches volcaniques,* pp. 653, 654, pl. II., fig. 1). Since, however, the dyke at this locality has probably traversed the Great Whin Sill, this xenocryst may be of the accidental kind.</ref> does not, as we have seen, preclude the possibility of a derivative origin The Tynemouth dyke, with so much as 58.30 per cent. of silica, encloses felspars which were proved by analysis to be anorthite.<ref>Teall, *Quart. Journ. Geol. Soc.,* vol. xl., pp. 234, 235, pl. XIII; 1884.</ref> They are unevenly distributed in the dyke, and occur usually in aggregates; the component crystals being irregularly bounded in the interior of an aggregate, but externally presenting good faces, which Mr Teall ascribes to a later addition. He suggests that these aggregates were formed under plutonic conditions, and were broken up and carried away by movements which took place after this consolidation had progressed to a certain extent.<ref>*British Petrography,* p. 141: 1888.</ref> Comparable in some respects with this is the peculiarity which Professor Judd has termed the "glomero-porphyritic structure", as exemplified in the ophitic dolerite (doubtless an intrusive sill) of Fair Head, in Antrim.<ref>Quart. *Journ. Geol. Soc.,* vol. xlii., p. 71, pl. VII., fig. 3; 1886.</ref> The rock encloses little patches, from 1/10 to ■ inch in diameter, consisting of anorthite and olivine with the mutual relations of a plutonic rock (troctolite). Professor Judd detected no clear indication of change where these patches are in contact with the enclosing matrix, but he remarks that the felspar crystals are much fissured, and contain a large number of secondary inclusions.

These troctolite-patches, in that they are foreign as regards composition to the rock in which they occur, may perhaps without impropriety be called xenoliths. Whether the anorthite-crystals in the Tynemouth dyke, as explained by Mr Teall, are to be styled xenocrysts, seems to be merely a question of terminology. In this view the sharp distinction between phenocrysts and cognate xenocrysts breaks down genetically as well as diagnostically, the difference becoming one of degree rather than of kind. Phenocrysts in a dyke are probably the results of crystallisation in the dyke-magma prior to its intrusion,<ref> To this statement we must admit some exceptions, as pointed out in another place (p. 270).</ref> under "intratelluric", but not in the general case plutonic, conditions. We can, however, easily concede the possibility of such crystallisation taking place in some cases in a deep-seated magma-reservoir, where truly plutonic conditions obtained; and crystals so formed must be expected to possess characters (*e.g.* schiller-structures) proper to a plutonic origin. If we conceive such crystallisation in the magma-reservoir to proceed undisturbed, perhaps locally, until continuous portions are consolidated, there is no difficulty in supposing the rocks so formed to be subsequently broken up and portions of them involved in the magma as forced upwards to supply dykes. On such lines as these we may perhaps seek an explanation of the xenocrysts of gabbro-felspar and xenoliths of gabbro in our basic dykes; and it is clear that such an explanation, if admitted, will account for a distribution of xenocrysts coextensive with that of the dykes themselves.<ref>The phenomena in question are not confined to the strictly British portion of the large "petrographic province". See, *e.g.,* Bréon, *Notes pour servir à étude de la géologie de l'Islande.,* Paris, 1884.</ref> Crystallisation in the deep-seated magma-basin, being supposed slow and progressive, would afford a reason for the prevalence of these quasi-foreign elements in the later rather than the earlier dykes of the series.

To apply this explanation to the granitic xenocrysts and xenoliths in the basic dykes as well as to those of gabbro, we must postulate the coexistence of acid and basic magmas in the supposed deep-seated reservoir and the beginning of crystallisation in both. To such a hypothesis we have already been led by the phenomena of the associated basic and acid intrusions of the region. If we conceive crystals to be formed in an overlying acid magma and to sink into an underlying basic one, we find a possible clue to some of the peculiar features described above, and one which may be worth pursuing both in this region and in others.<ref>*Cf.* Harker, The Lamprophyres of the North of England, *Geol. Mag.,* 1892, pp. 199–206, and On Porphyritic Quartz in Basic Igneous Rocks, *ibid.,* pp. 485–488.</ref>



(Plate 24) Fig. 1. (S8850) [NG 708 183] × 150. Tachylyte, dyke ¾ m. N.E. of Kinloch, Sleat district: a quasi-spherulitic rock. See pp. 349, 350. A. Outer portion of one of the large spherulitic bodies, showing parallel rods of augite, with some magnetite, embedded in a colourless glass. B. Central part of a spherulite, showing abundant felspar, as well as augite and magnetite, with a smaller proportion of glassy base. Fig. 2. (S6794) [NG 617 233] × 20. Pitchstone, dyke in Allt a' Choire, above Coirechatachan, near Broadford: showing groups of crystallites, each surrounded by a clear ring. The turbid appearance of the rest of the glassy mass is due to a crowd of more minute crystallitic growths. See p. 407. Fig. 3. × 20. Pitchstone, E. slope of Glas Bheinn Mhòr; showing perlitic cracks surrounding phenocrysts of quartz: also groups of crystallites, each surrounded by a clear ring. See p. 405. Fig. 4. (S7479) [NG 523 201] × 30. Xenolith of quartzite from a basic dyke, S. end of Blath-bheinn. The figure shows the quartzite corroded by the basic magma and an inlet occupied by radiating fibres of new-formed felspar, probably oligoclase. See p. 352.



(Plate 25) Fig. 1. (S9372) [NG 628 285] × 30. Porphyritic Dolerite, dyke 400 yards N.W. by N. of Scalpay House. The lower part of the figure shows part of one of the circular felspathic areas which represent vesicles filled by the oozing in of the residual magma. See p. 331. Fig. 2; × 20. Xenoliths in basic dykes. A. (S7483) [NG 526 194]. Edge of ga,bbro xenolith in dyke in Abhuinn nan Leac, Strathaird; showing the earliest stage of breaking up by the formation of numerous fissures; also the development of secondary inclusions in both felspar and augite. See pp. 355, 361. B. (S6716) [NG 633 208]. Detached quartz-grain from granite xenolith in dyke on ridge N. of Ben Suardal, near Broadford; showing the earliest stage of breaking up by the formation of fissures, which here tend to run parallel to the outline; also incipient corrosion. See p. 356. FIG, 3. × 20. Basic dyke carrying granite xenoliths, on shore N.E. of Corry Lodge, Broadford. See p. 357. A. (S6719) [NG 644 243]. The normal dolerite, where free from foreign material. B. (S6720) [NG 644 243]. Portion enclosing abundant debris of granite, of which two detached quartz grains are shown, eack with its corrosion-border of

granular augite. The matrix, partly obscured by alteration, is of fine texture and of much less basic composition than the normal dolerite. Fig. 4. (S8723) [NG 436 182]. Picrite, An Sgùman. A. (occupying three quadrants); × 30. Showing olivine, augite, anorthite, etc. The dendritic inclusions of magnetite in the olivine are conspicuous in the large crystal in the lower left-hand quadrant: in the crystal at the top of the figure they are cut at right angles to their plane, and so appear like rods. See p. 381. B. (lower right-hand quadrant); × 110. Showing the dendritic inclusions more highly magnified. See pp. 68, 69, 381.