Chapter 24 Sheets exclusive of cone-sheets: south-west Mull. Loch Scridain xenoliths<ref>The 'sillimanite' of the Mull xenoliths has been investigated by N. L. Bowen, J. W. Greig, and K G. Zies: Mullite, a silicate of alumina,' Journ. Wash.. Acad. Sci., vol. xiv., 1924, p. 183. They find that it agrees physically and chemically with the 'sillimanite' of artificial products. Its formula is $3Al_2O_3SiO_2$, whereas that of true sillimanite is $Al_2O_3SiO_2$. They have named it mullite, with Mull as type-locality. Their paper was received after this memoir had gone to press.</ref>

Introduction

The detailed account of the composite and xenolithic sill of Rudh' a' Chromain, given at the end of the preceding chapter, serves as a convenient introduction to the subject of the xenoliths of the Loch Scridain district in general. The xenoliths are referable to two distinct classes, cognate ' and 'accidental and these will be dealt with separately in the sequel. The accidental xenoliths are the more arresting in their appearance, and particular attention has been paid to them in regard to such matters as distribution; in fact, the statements of xenolith-localities (p. 272, and (Figure 42), p. 258) are drawn up with reference to them alone. 'Cognate' xenoliths are a feature of the sills north of Ben More (p. 289), as well as of those of the Loch Scridain district.

Following upon the descriptions of the xenoliths, a discussion is offered as to the condition, position, and date of the Loch Scridain Magma-Reservoir.

'Cognate' xenoliths (enclaves homogienes of Lacroix)

The 'cognate' xenoliths, referred to above as occurring in the tholeiite bands of the Rudh' a' Chromain sill, and more particularly in the lower band, are dark coarsely crystalline glomeroporphyritic patches, clearly marked off from the fine-textured tholeiite that envelops them. They consist commonly of bytownite and hypersthene (S16598) [NM 522 203], and more rarely of bytownite and green augite (S16612a), (S17173) [NM 5238 2024]; in either case, the pyroxene tends to be idomorphic towards the felspar. Olivine seems to be represented by occasional pseudomorphs (S17174) [NM 5238 2024].

Similar 'cognate' xenoliths have been recognized not infrequently in other sills of the district; and, in fact, were first noticed by Mr. Cunningham Craig, in the Tràigh Bhàn na Sgurra sill mentioned on p. 266. They are fairly abundant in the lower part of this sill, where they reach a foot or more in diameter. Dr. Flett, in the Memoir on Sheet 35, says that they consist of bytownite associated, sometimes with green augite, sometimes with enstatite or bronzite.

A few other instances of tholeiitic and andesitic sills with similar 'cognate' xenoliths are as follows (all in Sheet 44):

- A sill cutting the Gamhnach Mhòr Syenite in the Rudh' a' Chromain neighbourhood (S14597) [NM 5458 2057].
- A xenolithic rock half way between Rudh' a' Chromain and Loch Scridain, near the mouth of a tributary to Abhuinn nan Tòrr from Mullach Glac an t-Sneachda. The matrix of this rock (of which the margins are not exposed) largely consists of fused argillaceous material (buchite); the ' cognate ' xenoliths are isolated, and often exist as broken, crystals of hypersthene and augite (S16072) [NM 4996 2386].
- A sill with sheath-and-core structure, and abundant 'accidental' xenoliths, on the north shore of Loch Scridain, 'south of Seabank Villa. Some of the augite-crystals are almost two inches long (S18530) [NM 4861 2820].
- A sill with sheath-and-core structure in its central part, practically at the northern limit of the Loch Scridain district ((Figure 42), p. 258), north of Coir' a' Charrain (S17121) [NM 4798 3330].

'Accidental' xenoliths (enclaves énallogènes of Lacroix)

A full account of this interesting subject is not attempted here, since it would entail too lengthy an elaboration on the mineralogical and physical side, coupled with constant reference to literature which has only an indirect bearing upon Mull geology. At the same time, a statement is offered of the main theoretical conclusions, the grounds for which are given in greater detail elsewhere.<ref>H. H. Thomas, Certain Xenolithic Tertiary Minor Intrusions in the Island of Mull (Argyllshire), Quart. Journ. Geol. Soc., vol. lxxviii., 1922, p., 229.</ref> Special attention is paid to such aspects of the problem as may be of interest to those who wish to investigate the field-evidence.

Matrix

The sills which carry the 'accidental' xenoliths belong to the tholelite-andesite (and occasional felsite) suite of Chapter 25, and in most cases the andesitic rock is leidleite. A large proportion of them retain cores of glass in their more central parts, and a few of them, like the Rudh' a' Chromain sill, are strikingly composite. As stated above (p. 267), the 'accidental' xenoliths of the Rudh' a' Chromain sill are concentrated for the most part in the tholeiitic margins; though some are also found in the acid interior. Experience of other xenolithic sills, where a composite character is recognized or suspected, supports the view that this relative concentration of xenoliths into the more basic, upper and lower, parts (not including the actual chilled selvages) is a rule that is often observed; but further field-enquiry is desirable.

The matrix, in which the xenoliths are imbedded, is generally normal igneous rock with very little modification. A striking exception is afforded by an exposure already alluded to on account of its ' cognate ' xenoliths (Locality 29, p. 273), an exposure which may also be remembered as having supplied Mr. Anderson (p. 52) with the first sapphire-bearing material sent in for determination (S16072) [NM 4996 2386]–(S16073) [NM 4996 2386]. The matrix here is a dark grey amygdaloidal rock of fine texture, and of igneous aspect, as seen in the hand, except that it is studded with small lustrous plates of sapphire. Under the microscope, its igneous appearance all but vanishes, for it is found to be a sillimanite-buchite with little referable to an igneous source, except xenocrysts of hyper's thene and augite. Its apparent porphyritic felspars are broken bytownite and anorthite, derived, as explained in the sequel, from interaction between aluminous xenolithic material and tholeiite magma. That the buchite has acted as an intrusion is indicated by the fact that it is packed with aluminous and siliceous xenoliths of all sizes up to 6 ft. long. Its vesicles, now filled with zeolites and other low-temperature minerals, are another indication of its fluidity. Similar amygdaloidal developments are common in buchite-xenoliths throughout the Loch Scridain district; and, also, in the marginal buchite at Tràigh Bhàn na Sgurra, where Messrs. Clough and Cunningham Craig recognized intrusive contacts on a small scale (p. 266).

Field-characters

The main field-characteristics of the ' accidental ' xenoliths are:

1. Frequency and size; xenoliths occasionally attain to a length of six feet or more.

2. Diverse nature.

3. In many cases, intense alteration; marginal interaction between aluminous xenoliths and igneous magma has tended to develop conspicuous crystal-growths until checked by the rapid cooling brought about by sill injection.

H.R.T.

The xenoliths which have been identified may be grouped as follows:

a) Micaceous gneiss or granulite, and probably quartzite, belonging to the regionally metamorphosed pre-Devonian floor.

b) Granite and pegmatite. These are possibly fragments of some granitic intrusion of Old Red Sandstone age. The nearest visible rocks of this type are in the Ross of Mull granite-area, but the origin of these fragments has not been specially studied.

c) Sedimentary rocks later than the period of regional metamorphism.

d) Basaltic lava.

Of these four classes, the types included under (c) are the most numerous, and have received most attention. They may be subdivided into original sandstones, shales (in a broad sense), and carbonaceous reeks. The last may have been, in many cases, bituminous shales, and, in some cases, coals.<ref>Dr. Heddle, 'Mineralogy of Scotland, vol. i., p. 1, gives an analysis of graphite found by Earl Compton (? Locality 27, p. 273) with 83.56 per cent. carbon and 14.93 per cent, ash.</ref> The sandstone-xenoliths are usually the largest, often ranging up to several feet in diameter, while the intrusion, numbered (41) in the list given below (p. 273), contains a mass interpreted as altered sandstone, many yards in length.

As to the character of the xenoliths carried by the various sills, it is noteworthy that the degree of metamorphism is not always the same. Sandstone-xenoliths from Locality 43 appear but little altered, while cases of complete fusion (S17997) [NM 4892 3064] have been encountered at Locality 5. Again, in different sills, although all aluminous xenoliths are probably in the form of buchite, there is variation in the amount and coarseness of the crystalline material (corundum-anorthite-spinel) that we know to have been formed by the interaction of aluminous sediment and magma. For instance, at Locality 13, there is much less reaction-zone material, in conjuncticn with buchite, than in the case of xenoliths from Rudh' a' Chromain. Further, sapphires, which are large and abundant in the latter locality, are, in the former, small and relatively rare. A condition of relatively slight metamorphism is also characteristic of xenolith from Localities 28 and 39. It is thus seen that the degree of alteration of the contained xenoliths is to some extent peculiar to the sill in which they occur. E.M.A.

Reference has been made to the reaction-zone which often characterizes the outer portions of the aluminous xenoliths. This zone is composed of anorthite, sapphire, and spinel, with sillimanite enclosed in the anorthite. It is easily recognized in field-exposures, where the felspar is particularly conspicuous owing to its bulk, and the sapphire in small crystals attracts attention on account of its blue colour. The sillimanite cannot be seen individually, but often tints the enclosing felspar a pink or rosy hue—for instance at Rudh' a' Chromain, and, in Sheet 43, north-east of Eilean Bàn and west of Port Mòr. This phenomenon is all the more interesting as pink sillimanite is a great rarity in other parts of the world.

Distinctive aluminous xenoliths

The most typical occurrences of the argillaceous rocks, referred to above as shale in a broad sense, have had their origin in some sediment with the composition of a fireclay, except that, if Anal. XVI., ((Table 9)) (p. 34), is representative, the clay would appear to have been abnormally rich in alkali, with soda predominating over potash. That they have come from one common source is indicated by their uniform alteration to sillimanite-buchite, with a conspicuous development of sapphire, especially in their marginal crystal-zones where modified by igneous permeation. They differ in their metamorphic facies from the buchites and hornfelses developed from the common pelitic schists and gneisses of the district: these, owing to their greater content of SiO_2 and MgO, generally yield abundant cordierite when heated by granite, basalt, or camptonite, or indeed when melted artificially. Dr. Flett<ref>J. S. Flett, *in* The Geology of the Country near Oban and Dalmally, Mem. Geol. Surv., 1908, pp. 129–132,</ref> has described a very beautiful cordierite-buchite developed marginally to a camptonite-dyke in Ardmucknish (Sheet 45), and Dr. Pollard's analysis of the phyllite, which by melting has furnished this buchite, shows 2.04 per cent. MgO. Probably, the only near approach to the composition of the aluminous xenoliths, afforded by any argillaceous rock of Mull known in *situ,* is furnished by the thin Tertiary basal mudstone (Chapter 3). Very occasionally (p. 59), this mudstone is of a pale colour showing a poverty in iron. The analysed mudstone (Anal. XV., (Table 9), p. 34) is of a dark tint corresponding with a high iron-content; and this, it must be admitted, is very much more typical of the deposit as a whole.

H.H.T.

Localities

The following is a list of localities for sills with 'accidental' xenoliths within the Loch Scridain district. The data have been supplied mainly by Mr. Anderson and Dr. Clough, as indicated in Chapter 2, where the general progress of the discovery is sketched. Occurrences of sapphire and graphite are specially noted in this list, since these minerals are of great interest in themselves, and also because their wide distribution will be used presently in discussing the history of the magma that has yielded the Loch Scridain sills. It should be understood that most of the exposures detailed below belong to distinct individual sills ((Figure 42), p. 258).

Inland: North of Loch Scridain (Sheet 43)

(1) North-South sill, Culliemore (1 sapphire).

Inland: North of Loch Scridain (Sheet 44)

(2) Coir' a' Charrain (graphitic shale).

(3) 2/3 mile N.N.W. of Allt a' Mhuchaidh Bridge and a little below sill shown on 1-inch Map (sapphire).

(4) Abhuinn Bail' a' Mhuilinn, 100–200 yds. above bridge (sapphire, (S17993) [NM 4861 2885], (S17994) [NM 4861 2885], (S17995) [NM 4861 2885] (S20280) [NM 4867 2881]).

(5) Allt a' Mhuchaidh, 1000 yds. above bridge (sapphire, (S17996) [NM 4892 3064], (S17997) [NM 4892 3064], (S17997) [NM 4892 3064], (S17997) [NM 4892 3064], (S17998) [NM 4892 3064] [NM 4892 3064], (S17999) [NM 4892 3064], (S18529) [NM 4808 3075], (S20281) [NM 4855 2991]).

(6) 100 yds. N.E. of Killiemore House.

(7) 200 yds. E. of cairn on Maol na Coille Mòire (this sill is inninmorite).

(8) Sill parallel with coast, ½m. S.E. of same cairn.

North Coast of Loch Scridain (Sheet 43)

(9) ½ m. E.S.E. of Tavool House (sapphire).

(10) Slochd eastwards to Scobull Point (sapphire (S20798) [NM 4596 2687] [NM 4596 2687] [NM 4596 2687], (S20799) [NM 4683 2700], (S20800) [NM 4683 2700], (S20801) [NM 4679 2697] [NM 4679 2697]).

North Coast of Loch Scridain (Sheet 44)

(11) S.W. of Tiroran House (sapphire, (S18531) [NM 4750 2740]- (S18532) [NM 4750 2740].

(12) S. of Seabank Villa (sapphire, (S18528) [NM 4861 2820], (S18530) [NM 4861 2820].

(13) W. of Allt na Coille Mòire (sapphire, graphite, (S17266) [NM 5095 2932], (S17267) [NM 5095 2932], (S17268) [NM 5097 2942], (S17402) [NM 5095 2932], (S17403) [NM 5095 2932], (S17404) [NM 5095 2932], (S17405) [NM 5095 2932]).

(14) E. of Allt Earn Fiadh (sill not shown on 1-inch Map, (S17279) [NM 5212 2951]).

South Coast of Loch Scridain (Sheet 43)

(15) N.E. of Eileen Bàn (S18007) [NM 3685 2392], (S18024) [NM 3685 2392], (S18029) [NM 3685 2392]).

(16) Tòrr Mhòr (sapphire, (S18168) [NM 4154 2408]–(S18169) [NM 4143 2397])

(17) W. of Port Mòr. (sapphire, (S18001) [NM 4362 2387] [NM 4362 2387], (S18002) [NM 4362 2387], (S18003) [NM 4362 2387], (S18004) [NM 4362 2387], (S18005) [NM 4362 2387], (S20276) [NM 4362 2387], (S20277) [NM 4362 2387], (S20278) [NM 4362 2387], (S20279) [NM 4362 2387]).

South Coast of Loch Scridain (Sheet 44)

(18) ½ m. E.S.E. of Eilean an Fheòir (sill not shown on 1-inch Map).

(19) N. of Kinloch House (sill not shown on 1-inch Map).

Inland: S. of Loch Scridain northern half of Ross of Mull (Sheet 43)

(20) Sill turning S. at Capull Corrach, 800 yds. W.N.W. from Loch a' Charraigein (sapphire, graphite, (S18025) [NM 4274 2222]).

(21) W.S.W. sill, running from Coillenangabhar to Capull Corrach (sapphire, graphite, (S18006) [NM 4256 2303], (S18027) [NM 4224 2292]).

(22) N. of coast-road, W. of Allt Chaomhain (sapphire).

(23) 900 yds. W.S.W. of cairn on Beinn Bhùgan (sill not shown on 1-inch Map).

(24) Allt Chaomhain W. of Beinn Bhùgan (S20763) [NM 4509 2308].

Inland: S. of Loch Seridain, northern half of Ross of Mull (Sheet 44)

(25) Near mapped sill in Beach River, N. of Cnoc Reamhar (S16075) [NM 4755 2307].

(26) ½ m. S.E. of Goirtein Driseaeh (S16067) [NM 4778 2400].

(27) Waterfall S.E. of Torrans (?graphite).

(28) 1 mile N.W. of Mullach Glac an t-Sneachda (S16065) [NM 4893 2443], (S16071) [NM 4892 2440].

(29) Near mouth of tributary to Abhuinn nan Tòrr from Mullach Glac an t-Sneachda (sapphire; this exposure shows a buchitic matrix, (S16072) [NM 4996 2386], (S16073) [NM 4996 2386], (S20272) [NM 495 241], (S20273) [NM 495 241], (S20274) [NM 495 241], (S20275) [NM 495 241]).

(30) Junction of Uisge Fealasgaig with Leidle River (S14595) [NM 5315 2424].

Inland: S. of Loch Scridain, southern half of Ross of Mull (Sheet 43)

(31) Scoor House, S. of old chapel, on borders of Sheets 35 and 43.

(32) Beside road N. of east corner of Loch Assapol.

(33) Stream junction, 1300 yds. W. of cairn on Cruachan Mìn, and (perhaps same sill) 1500 yds. S.S.W. of same cairn.

(34) S.W. sill, 800 yds. S.S.W.. of cairn on Cruachan Mìn (sapphire (S20762) [NM 4450 2078], (S20755) [NM 4377 2043]), and (perhaps same sill) 700 yds. S. of same cairn (S20761) [NM 4471 2096].

(35) In stream, 700 yds. W.S.W. of cairn on Cruachan Mìn.

(36) E. and W. sill, ½ mile S.S.E. of cairn on Cruachan Mìn.

(37) 500 yds. S.W. of cairn (1119 ft) on Beinn Chreagach.

(38) 100 yds. N.E. of same cairn (sapphire).

(39) Big sill, at 500–600 ft. level, on margin of Sheets 43 and 44 (S13845) [NM 4184 1911].

Inland: S. of Loch Scridain, southern half of Ross of Mull (Sheet 44)

(40) E.W. sill, crossing path 800 yds. N.N.W. Àiridh Mhic Cribhain.

(41) Intrusion, crossing stream 500 yds. N.N.E. of Binnein Ghorrie.

(42) Two sills, E. of Àiridh Fraoch, one traced ¾ mile E.S.E. to stream W. of Beinn Chreagach.

(43) In stream 1000 yds. W. by N. of cairn (1235 ft) on Beinn Chreagach (S16070) [NM 5086 2179].

(44) Above 600 ft. contour, ½ mile, S.W. of same cairn (sill not shown on 1-inch Map).

(45) Above stream-head between Cnocan Buidhe and Dùnan na Marcachd.

(46) Streamlet, N. of Plantation, W. of River, 200 yds. N.W. of Feorlin Cottage, Carsaig (sapphire, (S18492) [NM 5342 2220], (S18493) [NM 5342 2220], (S18494) [NM 5342 2220], (S18495) [NM 5342 2220]). Also old road 100 yds. N.W. of Feorlin Cottage (S20283) [NM 5342 2229], (S20284) [NM 5342 2229], (S20285) [NM 5342 2229], (S20286) [NM 5342 2229], (S20287) [NM 5342 2229], (S20288) [NM 5342 2229], (S20289) [NM 5342 2229]. Neither exposure shown on 1-inch Map.

(47) 700 yds. E. of Loch na Géige (lettered F on 1-inch Map).

South coast of Mull (Sheet 35)

(48) Tràigh Bhàn na Sgurra (S13839) [NM 4236 1877], (S13840) [NM 4236 1877] (S13841) [NM 4233 1876], (S14388) [NM 4229 1874], (S14389) [NM 4233 1876], (S14390) [NM 4233 1876], (S14441) [NN 1764 7487]; for full description see Memoir on Sheet 35).

South coast of Mull (Sheet 49)

(49) East shore of Tràigh Cadh' an Easa' (this sill is an inninmorite, not shown on 1-inch Map, sapphire (S16595) [NM 4803 1949].

(50) Rudh' a' Chromain and Nuns' Pass (sapphire, (S14893) [NM 5234 2021], (S14894) [NM 5237 2027], (S14895) [NM 5237 2027], (S14896) [NM 5228 2017], (S16596) [NM 5238 2025], (S16597) [NM 5203 2028], (S16598) [NM 522 203], (S16599) [NM 522 203], (S16600) [NM 522 203], (S16601) [NM 522 203], (S16602) [NM 522 203], (S16603) [NM 522 203], (S16604) [NM 522 203], (S16605) [NM 522 203], (S16606) [NM 522 203], (S16607) [NM 522 203], (S16608) [NM 522 203], (S16609) [NM 522 203], (S16610) [NM 522 203], (S16611) [NM 522 203], (S16612) [NM 522 203] [NM 522 203], (S16612) [NM 522 203] [NM 522 203], (S17170) [NM 5238 2024], (S17171) [NM 5238 2024], (S17172) [NM 5238 2024], (S17173) [NM 5238 2024], (S17174) [NM 5238 2024], (S17175) [NM 5238 2024], (S17176) [NM 5238 2024], (S17177) [NM 5238 2024], (S17178) [NM 5238 2024], (S18480) [NM 5237 2031], (S18481) [NM 5237 2031], (S18482) [NM 5237 2031], (S18483) [NM 5237 2031], (S18484) [NM 5237 2031], (S18485) [NM 5237 2031], (S18486) [NM 5237 2031], (S18487) [NM 5237 2031], (S18488) [NM 5237 2031], (S18489) [NM 5237 2031], (S18490) [NM 5240 2027], (S18491) [NM 5240 2027], (S20271) [NM 5235 2034].

A visitor wishing to familiarize himself with the field-evidence is recommended to the coastal exposures on the north shore of Loch Scridain (Sheets 43 and 44), the south shore of Loch Scridain (Sheet 43), Tràigh Bhàn na Sgurra (Sheet 35), and Rudh' a' Chromain (Sheet 44). These are thoroughly representative, and easy, both to find, and to approach. E.B.B.

Petrology

The microscopic petrology of the 'accidental' xenoliths is summarized in the following pages. As already stated, the reader can find a fuller treatment in Quart. Journ. Geol. Soc., vol.lxxvii., where the subject-matter is illustrated by five plates from microphotographs.

Siliceous xenoliths

The siliceous xenoliths, as might be expected, show relative fusion of felspathic constituents, involving the marginal solution of quartz-grains and the production of glass (S20763) [NM 4509 2308]. On cooling, there has been an almost universal formation of tridymite around the relict grains of undissolved quartz (S20283) [NM 5342 2229]. The tridymite-fringes are recognized by their identity of form with what is commonly met with in furnace-linings; the tridymite itself no longer exists as such, but has reverted to quartz in optical continuity with the quartz-grains which have served as nuclei for its growth. Fringes of augite, or rhombic pyroxene, occur round the quartz-grains, where the interstitial melt has been of somewhat basic composition to begin with, or has been modified in this direction by magmatic transfusion. Cordierite has sometimes been developed to a small extent in contaminated interstitial melts (S16067) [NM 4778 2400].

Aluminous xenoliths<ref>See footnote, p. 268</ref>

(Anals XVI. and XVII.; (Table 9), p. 34).

It has been pointed out that the characteristic *aluminous xenoliths* of the district started as shale, or, mudstone , poor in lime, magnesia, and iron. The first step in their metamorphism has been the production of sillimanite-buchite (S18005) [NM 4362 2387], a compact grey-blue or lilac-coloured rock consisting of glass crowded with minute felted or parallel needles of sillimanite from 1 to 2 mm. long. The sillimanite is peculiar on account of its pink pleochroism. It exists, partly as a residuum left during the vitrification of the clay, and partly as a precipitation during the cooling of the aluminous melt in which it lies embedded. Sapphire (blue corundum) is a common associate of the sillimanite of the buchites, and occurs as small isolated tabular crystals of deep-blue colour and brilliant lustre. These represent the excess of alumina over that required for the formation of sillimanite and melt, and are to be regarded as the earliest solid phase to separate out from the aluminous melt. They rarely form 1 per cent. of the buchite, and .usually less than 0.5.

The' general fate of the sillimanite of the buchite has been to serve at later stages of its history as a source of alumina for the production of other aluminous minerals—anorthite, spinel, sapphire, and cordierite. Very occasionally, it appears to have concentrated its resources, and to have developed relatively large rose-pink crystals, presumably as a result of long-continued heating (S18001A). The sapphires, as a rule, during subsequent changes, seem to have added to their number at the expense of the sillimanite.

In general, all the Mull sapphires are of the same blue colour and tabular habit; and in exceptional cases they range up to 1½ cm. across.

Anal. XVI., (Table 9) (p. 34), may be taken as representing such a sillimanite-buchite as has been described above.

The further history of the buchite is very interesting. Obviously, its contact with the tholeiite-magma was marked by instability. So long as the sedimentary and igneous melts lay side by side, they must have tended to mix by diffusion; and diffusion would continue (given the requisite temperature conditions) until uniformity of composition was attained—except in so far as some mineral might be permanently precipitated, insoluble even in the final combined melt. In the case under investigation, cooling has checked the process of diffusion long before uniformity was attained; and one can thus read a most interesting story of selective diffusion and temporary precipitation.

In the first place, as regards selective diffusion, it is common to find the sillimanite-buchite xenoliths extremely modified in their external parts through the selective immigration of lime, and, to a less extent, of magnesia and iron, from the adjoining tholeiite-magma. The outer portions of the xenoliths have thus developed crystalline aggregations composed for the most part of anorthite, accompanied by sapphire and spinel: the former more abundant towards the buchite, and the latter towards the tholeiite. These crystalline aggregates represent modified sediment, rather than modified magma, since their anorthite is crowded with sillimanite needles (S16603) [NM 522 203], (S17177) [NM 5238 2024]–(S17178) [NM 5238 2024], (S17405) [NM 5095 2932], (S20271) [NM 5235 2034]—there has indeed been a partial resorption of sillimanite accompanying the marginal modification of the buchite, but much has still not been incorporated.

The phenomenon of selective diffusion from magma to xenolith is evident, under the microscope, from the relative concentration of anorthite in these modified borders. Naturally, such a phenomenon is extremely difficult to follow up by chemical analysis; for each minute layer, while liquid, had a composition peculiar to itself, and was undergoing continual modification by interchange with its neighbour-layers on either side. Moreover, once crystallization set in, it would lead to a local concentration of certain constituents, quite out of proportion to that obtaining in the liquid from which their crystallization commenced.

The only point, which emerges from comparison of the chemically modified xenolith (Anal. XVII., (Table 9), p. 34) with the merely thermally modified part of another xenolith (Anal. XVI), is that, while the alumina percentage has remained roughly constant, there has been a fall in silica combined with a rise in all non-aluminous bases, other than soda; and, further, such changes cannot be accounted for by any process of unselective admixture of original xenolithic material (as represented by Anal. XVI., (Table 9)) with original tholeiitic magma (as represented by Anal. IX., (Table 2), p. 17).

A little further detail may now be given regarding the microscopic characters of the highly characteristic anorthite-sapphire-spinel aggregates. This assemblage is extremely prevalent, as a marginal modification of the aluminous xenoliths of the district and it is evidently the normal result of modification of the xenolithic material by the magma at a certain stage of its career. Sometimes, it occurs completely enclosing a kernel of buchite to a depth of several inches. Wherever found in connection with other mineral developments, it retains its proper position next to the buchite. It need not, however, occur on all sides of a xenolith. Cases are common where the anorthite -sapphire -spinel development is met with on one side, while a different later development is found on the other. In such cases, one is probably often dealing with xenoliths that became detached from the lining of the magma-reservoir at a comparatively late stage, or else with early xenoliths subsequently broken.

The anorthite-sapphire-spinel aggregates are almost holocrystalline. The anorthite occurs in large crystals reaching a length of several inches; they mutually interfere with one another's growth, except towards the buchite, where they are separated to some extent by glass and are more noticeably idiomorphic, or even skeletal. As already stated, the anorthite encloses much vestigial sillimanite. The sapphire becomes more abundant, as the buchite, the source of alumina, is approached. Its association with the anorthite is of a type that points conclusively to crystallization from a common solution of these two substances, in some cases under eutectic conditions. The spinel is of a deep-green variety (hercynite-pleonaste, Anal. XVIII., (Table 9), p. 34). It occurs more especially towards the tholeiite-margin of the aggregates, and this is in keeping with its iron-magnesia content. Its manner of association with anorthite indicates contemporaneous crystal-growth with a gradual convergence towards a eutectic composition of melt.

Altogether, the modification of the external parts of the xenoliths points to a preferential immigration of lime, and, less rapidly, of iron and magnesia, from the adjoining tholeiite-magma. The resultant melt dissolved some portion of the sillimanite-felt, and, with very gradual fall of temperature, precipitated anorthite, sapphire, and spinel, more or less simultaneously.

For a long time, transfusion from either side of the zone of crystallization seems to have maintained the requisite composition for an approximate sapphire-anorthite-spinel eutectic condition. It must be remembered, however, that this crystallization was proceeding in one particular liquid of a whole series of liquids, all in unstable contact one with another. Thus, from the point of view of the complex as a whole, the crystallization of the border-zone of the xenoliths was premature.

Outside these xenoliths, one must suppose the tholeiite-magma itself in a modified condition, presumably enriched in almost every constituent, including magnesia, as compared with lime. Many micro-sections illustrate the interaction of this modified tholeiite, both with the modified xenoliths—the anorthite-sapphire-spinel association—, and also with the sillimanite-buchite. There has often been disruption of the coarsely crystalline border-zone, and resorption of the anorthite and its contained sillimanite. This has been followed by an additional crystallization, on the remaining anorthite, of an increasingly acid plagioclase that ranges through labradorite to oligoclase. Such later-formed felspar is free from included sillimanite, and the excess of alumina thus furnished has separated either as sapphire or spinel (S16601) [NM

522 203], (S17998a), (S18492) [NM 5342 2220]. The latest crystallization of felspar is usually oligoclase, either as an outer zone to pre-existing more basic felspars, or as skeletal growths (S16601) [NM 522 203], (S17177) [NM 5238 2024], (S17178) [NM 5238 2024], (S18493) [NM 5342 2220], (S20271) [NM 5235 2034]. The accompanying spinel may be black, brown, or plum-coloured.

Where the modified magnesia-rich tholeiite has come in contact with the sillimanite-buchite, it has, to some extent, permeated it and, to some extent, dissolved it. In the former case, large crystals of cordierite have grown into the buchite, keeping pace with the diffusion of magnesia. Much of the sillimanite of the buchite is resorbed, but a considerable proportion generally remains undissolved in the usual form of slender needles; these may often be seen passing across the boundary of a cordierite-crystal into the buchite beyond (S18532) [NM 4750 2740].

Where the magma has dissolved, rather than permeated, the sillimanite-buchite, a special type of cordierite-buchite (S17997) [NM 4892 3064], or cordierite-sillimanite-buchite (S18529) [NM 4808 3075], results. The cordierite is colourless and free from pleochroism, and builds single rectangular crystals or small simple and complex twins.

The formation of cordierite in, or about, the xenoliths appears in all cases to belong to a comparatively late date. The proportion of cordierite to spinel is determined by the relative amounts of magnesia and silica available; absence of spinel indicates an excess of silica.

Where sapphire, spinel, and cordierite have crystallized from a contaminated igneous melt, the sapphire and spinel are sometimes enclosed by clear anorthite (S17999) [NM 4892 3064], and the spinel by cordierite (S17405) [NM 5095 2932].

This is as, far as the story of the modification of the xenoliths takes us. Apparently, sill-intrusion was now initiated, and the rapid cooling that ensued brought the uncompleted assimilation to a close. To the intrusion-period we may reasonably refer the deformation, which characterizes many of the xenoliths, and also the frequent development of vesicles in the buchitic glass.

Condition, position, and date of Loch Scridain Magma-Reservoir

In a physical discussion of the evidence outlined above, the elusion is reached (Quart. Journ. Geol. Soc., vol. lxxviii., pp. 250–4) that the metamorphism of the xenoliths was initiated at a temperature of about 1400° C., and was continued through a prolonged period of slow-cooling until about 1250° C.; and that, after this, rapid cooling intervened as a, result of sill-intrusion of the magma. It is to the later part of the interval of slow cooling that we may reasonably assign the development of the 'cognate' xenoliths (p. 268). H.H.T.

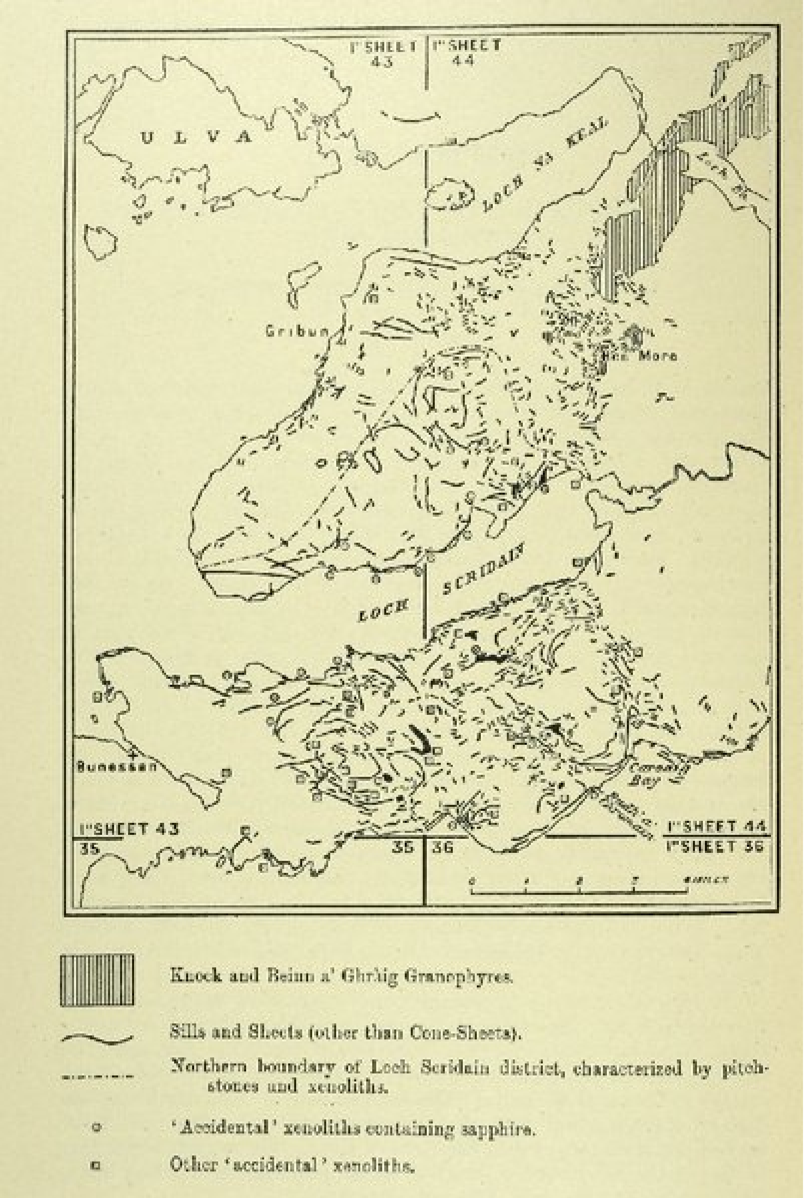
The field-distribution of the 'accidental' xenoliths is certainly in keeping with the idea developed by Dr. Thomas that these xenoliths were mostly derived from the lining of a single magma-reservoir. The great majority of the sills are met with cutting lavas; and yet their common conspicuous xenoliths are of sedimentary, gneissic, or granitic origin: they are decisively far-travelled erratics. Moreover, the peculiarity of composition of the aluminous xenoliths, first recognized by Dr. Thomas, makes it very difficult to match them with any rock known *in situ* in the West Highlands (p. 271). It is easier to derive such peculiar material from the lining of some single reservoir, than to picture it caught up indiscriminately by individual sills. The same remark applies, though with less force, to the graphitic xenoliths: in this case, a few Tertiary coals and carbonaceous shales, with which the xenoliths may well be compared, are known in such widely separated districts as South-West Mull (Sheets 43 and 44) and Morven (Sheet 52). E.B.B.

Bearing in mind the non-metamorphic character of the sediments which furnished many of the characteristic xenoliths, we are justified in placing some boundary of the magmatic reservoir in the space-interval between the Tertiary lavas and the Pre-Mesozoic floor of gneiss and granite. It is suggested that the roof of the reservoir may have roughly coincided with the base of the lavas, in part of the subsidence-area of central Mull, east of the head of Loch Scridain. It seems that the reservoir was of considerable depth, since it was able, in many instances, to supply material of widely different composition to individual composite sills. It is pointed out (p. 33) that this probably indicates a marked difference of temperature between the upper and lower parts of the reservoir, so that crystals of felspar and augite, precipitated in the relatively cool upper regions, remelted as they fell into the relatively hot lower depths. A concentration of xenoliths, both 'cognate' and 'accidental' in the more basic portions of the magma is exhibited in the Rudh' a' Chromain sill and certain other good examples, and is indeed regarded as a feature of the district. Such a concentration is in keeping with the idea of gravitational differentiation within a magma-basin of the type here advocated.

An unsolved problem of considerable local interest is the date of the Loch Scridain Magma-Reservoir. The petrology of the typical sills, as described in Chapter 25, virtually negatives any reference of them to the Plateau Lava period; though one can never reach certainty on such evidence, since, as pointed out already, the Staffa Type of lavas are of tholeiitic composition, in spite of their occurrence (where present) at, or near, the base of the Plateau Group. If one accepts the argument, developed in Chapter 14, that the bostonites as a group belong to the first paroxismal phase of the Mull centre, it follows that the Loch Scridain sills are, at any rate, no earlier than this epoch of explosions, for the Rudh' a' Chromain sill cuts a bostonite ((Figure 45), p. 267; the bostonite is omitted from the one-inch Map). Not improbably, they belong, like their fellows of Ben More (p. 290), to some stage of the long period of activity marked by intermittent intrusion of cone-sheets. The petrological assemblage of the Loch Scridain sills can be matched, either towards the beginning of this period, when composite sheets with craigmurite-centres, were a feature (Chapter 19), or during the latter half, which was dominated by the intrusion of a tholeiitic magma with many acid accompaniments (Chapters 28–32). The xenolithic facies of the Loch Scridain magma has not been recognized among cone-sheets. The nearest approach to it is in the case of two presumably early cone-sheets of the Scallastle-Fishnish district above the Sound of Mull (p. 229). The xenoliths in these cone-sheets are of a far-travelled 'accidental' type, much altered; but, as they are not strikingly numerous, and have not been noticed to include the typical aluminous variety, their agreement with those of Loch Scridain is not particularly close. On the whole, it is thought probable that the Loch Scridain Reservoir dates from the latter half of the cone-sheet cycle, and that it did not itself supply material to form cone-sheets at levels accessible to present-day observation. H.H.T., E.B.B.

The only other general point deserving attention is that the Loch Scridain sills seem uniformly earlier than the north-westerly faults which affect their district.

Such little evidence as is available shows that intrusions of inninmorite are cut by leidleite or tholeiite. This is the case in the bed of Abhuinn nan Tòrr (Locality 6, (Figure 43)), and also at Culliemore and Allt na Crìche, on the two sides of Tavool House (Sheet 43). It would be rash, however, to generalize upon three examples. What appears certain is that the inninmorites are a very subordinate, though well-characterized, product of the Loch Scridain Reservoir. It is significant, in this connexion, that they sometimes occur with tholeiitic borders, and also occasionally carry typical 'accidental' xenoliths, with, or without, sapphire (Localities 7 and 49, p. 272). E.B.B., E.M.A.



(Figure 42) Map of South-West Mull, showing distribution of Sills and Sheets other than Cone-Sheets.

TABLE IX.

	Phenocrysts		Amygdale—Minerals													Mud-Stone	Xenoliths and enclosed Spinel			
			Outside Pneumatolysis Limit								Inside Pneumatolysis Limit			Inside Contact-Zone						
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIIa.	XIII.	XIV.	XV.	XVI.	XVII.	XVIII.	
SiO_2	49·72	53·80	53·74	53·41	52·95	53·29	45·91	46·51	46·62	46·75	46·21	46·10	45·6	38·60	37·66	30·26	49·74	38·67	0·77	SiO_2
TiO_2	0·85	—	—	—	—	—	—	—	—	—	—	nt. fd.	—	0·12	0·72	1·52	·19	0·90	0·50	TiO_2
Al_2O_3	0·90	31·84	0·62	1·76	1·71	—	0·11	2·40	3·90	24·82	27·00	25·65	26·0	23·54	21·21	27·31	31·39	37·27	57·81	Al_2O_3
Fe_2O_3	1·72	—	—	—	—	—	—	1·14	0·61	—	—	—	—	6·07	1·67	1·57	1·33	2·78	4·20	Fe_2O_3
FeO	27·77	—	—	—	—	—	2·07	1·85	1·08	—	—	0·55	—	0·22	0·34	17·18	4·34	5·07	24·00	FeO
MnO	0·98	—	—	—	—	—	2·27	—	—	—	—	nt. fd.	—	0·29	0·53	0·13	0·13	0·17	0·15	MnO
(Co, Ni)O	nt. fd.	—	—	—	—	—	—	—	—	—	—	nt. fd.	—	nt. fd.	nt. fd.	0·04	nt. fd.	nt. fd.	nt. fd.	(Co, Ni)O
MgO	12·69	—	—	—	—	—	0·56	0·47	—	—	—	0·32	—	0·49	0·45	0·34	0·66	2·35	9·37	MgO
CaO	3·89	12·83	31·19	31·69	31·48	33·41	40·39	33·49	33·08	13·90	13·43	14·17	14·2	22·79	33·36	0·74	0·98	4·85	0·36	CaO
BaO	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	nt. fd.	nt. fd.	—	—	BaO
Na_2O	0·23	3·56	9·94	8·11	6·04	8·89	0·22	0·26	0·80	0·89	—	tr.	—	tr.	1·17	1·09	1·76	3·63	—	Na_2O
K_2O	0·12	tr.	nt. fd.	2·42	2·47	—	1·16	1·15	0·57	—	—	0·03	—	0·03	0·73	2·05	1·72	3·01	—	K_2O
Li_2O	tr.	—	—	—	—	—	—	—	—	—	—	nt. fd.	—	tr.	nt. fd.	nt. fd.	tr.	nt. fd.	—	Li_2O
H_2O -105°	1·87	0·22	2·38	2·66	4·07	4·16	4·17	12·91	12·11	13·64	13·78	13·78	13·6	0·29	0·20	7·20	3·44	1·08	0·14	H_2O +105°
H_2O at 105°	0·08	—	0·6	—	—	—	—	—	—	—	—	0·13	—	0·09	nt. fd.	1·44	0·61	0·22	nt. fd.	H_2O at 105°
P_2O_5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·24	0·86	—	—	P_2O_5
CO_2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·04	—	—	CO_2
FeS_2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	nt. fd.	nt. fd.	—	—	FeS_2
	100·13	99·05	99·67	101·05	100·67	100·06	100·76	100·19	99·81	99·80	100·44	100·13	100·0	100·21	100·19	100·04	100·21	100·35	100·39	
Spec. grav.	3·44	2·78	—	—	—	—	2·605	—	2·423	—		2·285		3·458	3·61		2·65	2·91	3·887	

I. Uniaxial Augite. II. Labradorite. III.–VI. Pectolite. VII. Xonotlite. VIII, IX. Tobermorite.[1] X.–XII. Scolecite. XIII. Pink Epidote. XIV. Garnet. XV. Basal Mudstone (altered). XVI. Uncontaminated argillaceous xenolith. XVII. Contaminated argillaceous xenolith. XVIII. Dark-green Spinel.

[1] In British Museum Students' Index Tobermorite is listed as a synonym of Cyrolite.

(Table 9) Analyses other than bulk anayses of igneous rocks, made from material collected collected in the Mull District.

TABLE II.—NON-PORPHYRITIC CENTRAL MAGMA-TYPE OF FIG. 2.

	Tholeiite Salen Type	Basalt Staffa Type			Basalt Compact Central Type		Tholeiite Brunton Type		Quartz-Dolerite and Tholeiite Talaidh Type		
	I.	II.	III.	A	IV.	V.	VI.	VII.	VIII.	IX.	
SiO_2	47·35	47·80	49·76	52·13	50·54	53·78	51·53	51·63	52·16	53·97	SiO_2
TiO_2	1·75	....	0·94	....	2·80	2·28	1·57	2·00	3·25	1·24	TiO_2
Al_2O_3	13·90	14·80	14·42	14·87	12·86	12·69	11·05	11·77	11·95	14·65	Al_2O_3
Fe_2O_3	5·87	....	3·95	....	4·13	3·44	2·73	3·23	4·86	3·62	Fe_2O_3
FeO	8·96	13·08	7·77	11·40	8·75	8·94	10·98	10·47	9·92	6·32	FeO
MnO	0·23	0·09	0·20	0·32	0·32	0·53	0·45	0·35	0·18	0·30	MnO
(Co, Ni)O	nt. fd.	....	nt. fd.	....	0·06	nt. fd.	nt. fd.	0·04	....	nt. fd.	(Co, Ni)O
MgO	5·97	6·84	5·30	6·46	4·63	2·58	5·21	5·02	3·77	4·49	MgO
CaO	10·65	12·89	10·22	10·56	8·74	6·36	9·68	9·34	7·14	7·98	CaO
BaO	....	....	0·04	....	nt. fd.	0·09	nt. fd.	0·03	....	0·04	BaO
Na_2O	2·73	2·48	2·49	2·60	2·89	2·74	3·48	2·90	2·36	2·54	Na_2O
K_2O	0·54	0·86	1·83	0·69	1·43	2·27	0·86	0·91	1·74	1·52	K_2O
Li_2O	....	....	tr.	....	nt. fd.	nt. fd.	tr.	nt. fd.	....	tr.	Li_2O
$H_2O - 105°$	1·16	1·41	1·03	1·19	2·25	2·19	1·26	1·40	1·95	0·94	$H_2O - 105°$
H_2O at 105°	1·04		2·04		0·17	1·19	0·71	0·68	0·56	1·92	H_2O at 105°
P_2O_5	0·24	....	0·21	....	0·34	0·55	0·22	0·29	0·24	0·27	P_2O_5
CO_2	0·32	....	0·06	....	0·33	0·08	0·08	0·11	0·18	0·51	CO_2
FeS_2	....	....	0·04	....	nt. fd.	0·42	0·26	0·08	....	0·09	FeS_2
S	0·23	....	....	....	....	....	....	....	0·18	....	S
	100·94	100·25	100·30	100,22	100·24	100·13	100·07	100·27	100·44	100·40	
Spec. grav.	2·96	....	2·72	....	2·90	2·68	2·93	2·95	2·91	2·83	

(Table 2) Non-Porphyritic Central Magma-Type of Figure 2

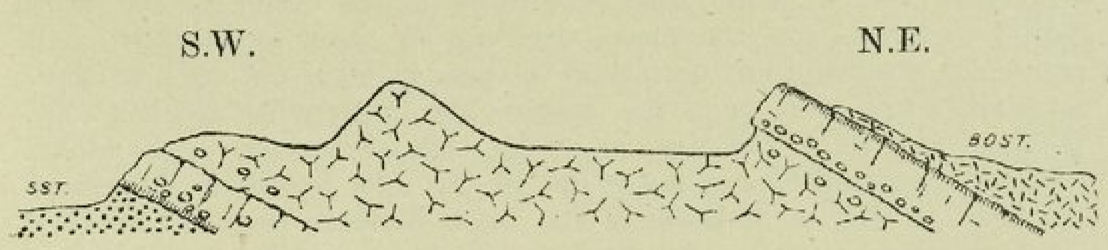


FIG. 45.

(Figure 45) Section at Rudh' a' Chromain across xenolithic composite sheet, showing external chilled margins against sandstone (SST) and bostonite (BOST). Quoted with minor alterations from Quart. Journ. Geol. Soc., vol. lxxviii, 1922, p. 234.

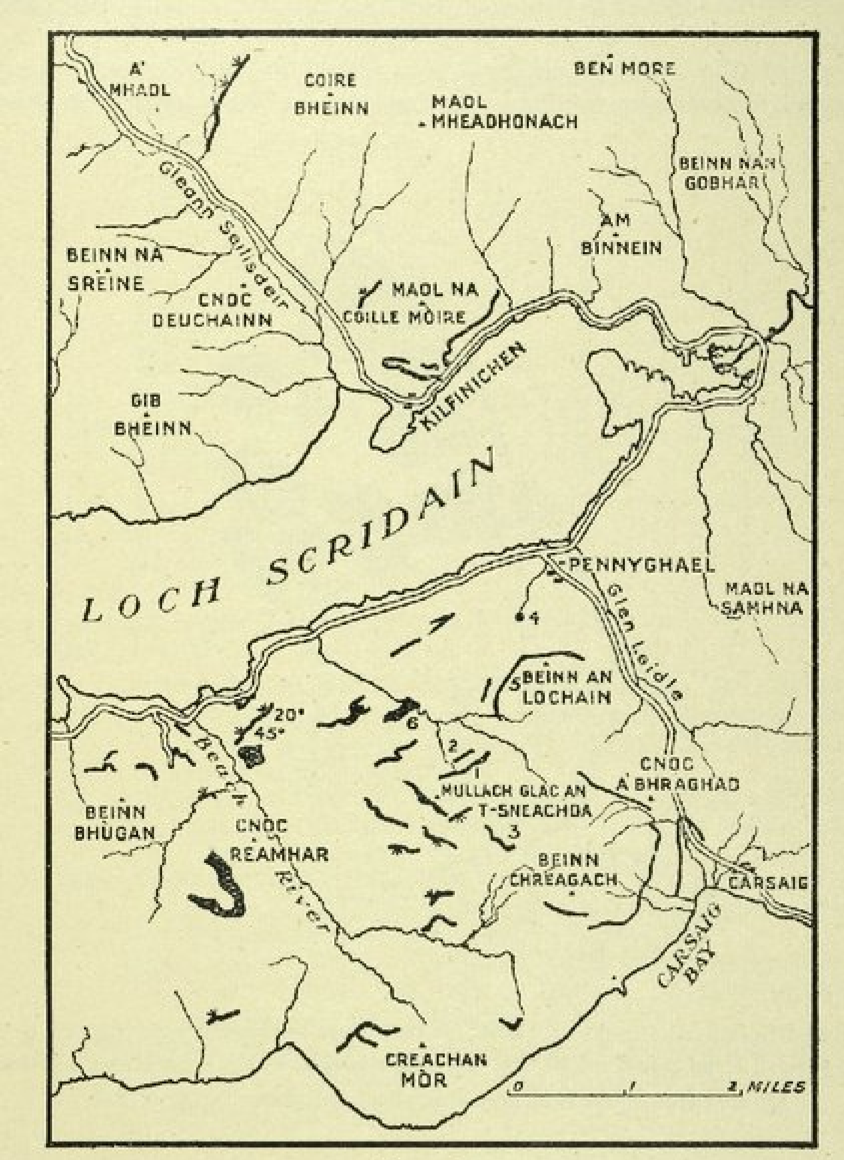


FIG. 43.

(Figure 43) Map of some of the occurrences of Pitchstone in Loch Scridain district. Quoted from Quart. Journ. Geol. Soc., vol. lxai., 1916, p. 206.