The minor intrusives of Kirkcudbrightshire

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THE MINOR INTRUSIVES OF KIRKCUDBRIGHTSHIRE.

Introduction:

The One Inch Geological Survey Map of the area (Sheet 5, Scotland) shows an extensive suite of minor intrusives whith have been mapped as "porphyrites" and, more rarely as "lamprophyres". These rocks have been intruded as sheets, sills and dykes and are most abundant over an area about five miles square to the north-east of Kirkcudbright.

The country rocks are strongly folded slates and grits of Silurian and Ordovician age, with a prevailing N.E.-S.W. strike and high angle of dip. Over many square miles these have been invaded by the Criffel-Dalbeattie Granodiorite, which forms an irregular oval extending north-eastwards from the neighbourhood of Bengairn and Auchencairn Bay. A metamorphic zone averaging approximately one mile in width surrounds this intrusion.

Along a narrow strip of the Solway shores, Lower Carboniferous conglomerates, grits and sandstones, composed largely of igneous detritus, unconformably overlie the Silurian slates. In the extreme west a patch of Upper Old Red Sandstone underlies the Carboniferous. Nowhere do the intrusives cut the Old Red Sandstone or Carboniferous strata, nor are the latter metamorphosed by the granodiorite. The age of the igneous rocks is therefore known within definite limits.

Not infrequently, too, "porphyrite" dykes and sills are

PLATE I.

Map of the Area to the North-East of
Kirkcudbright, showing the distribution
of igneous rocks.

PLATE I.
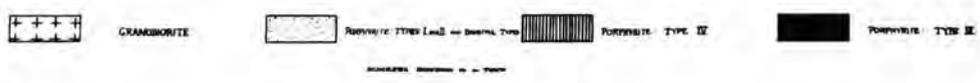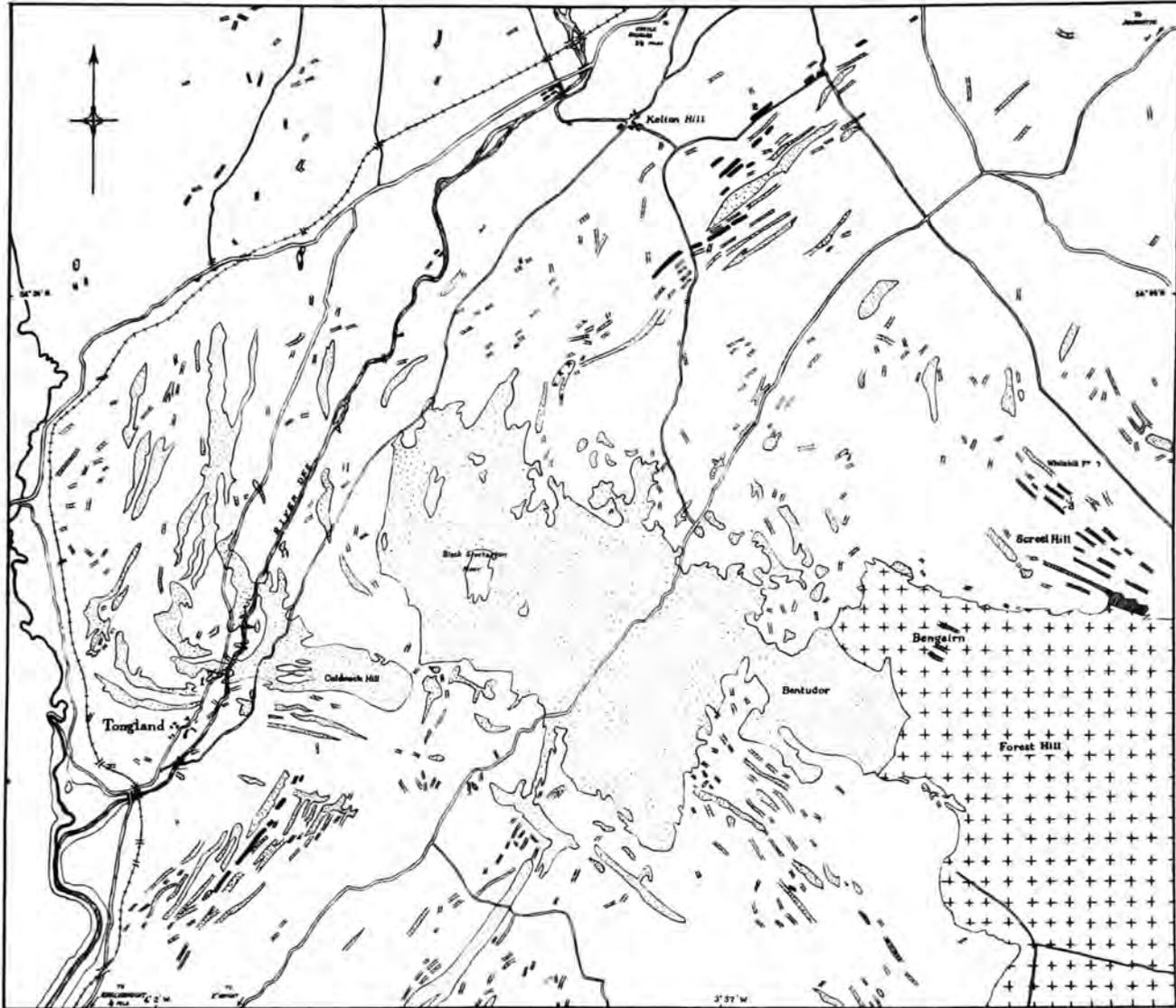
to be found penetrating the granodiorite, hence the relative ages of the plutonic and some of the hypabyssal intrusives can be demonstrated.

The only previous work on the minor intrusives has been carried out by the officers of the Geological Survey, who mapped and briefly described them in the Memoir (Explanation of Sheet 5, 1896). Here, J.J.H.Teall, who was responsible for the petrology, classified the hypabyssal rocks as "porphyrites", "diorites" and "mica-traps". He suggested "that the structural differences between the porphyrites and the hornblende-granites or quartz-diorites are due to differences in the conditions under which the magmas consolidated".

During the present study a general investigation was made of these intrusives. It was found possible in the field to recognise a number of distinct types, which were subsequently confirmed and further discriminated under the microscope. The relative paucity of good exposures inland and the high degree of alteration are severe obstacles in the way of a regional survey of the whole suite. It has been found convenient, therefore, to restrict detailed work to a few localities where good exposures occur of each of the types recognised. (See Plate II).

General Petrological and Field Relations:

The classification of these rocks has been based on purely petrological grounds. At the same time a notable

PLATE II.

Map showing Localities referred
to in Text.

Type I: Diorite-porphyry	Locality 5.
Type II: Albite-porphyrite	Localities 2 and 8.
Type III: Albitophyre	Locality 1.
Type IV: Albite-porphyry	Localities 3 and 4.
Type V: Plagiophyre	Locality 7.
Type VI: Xenocrystic type	Locality 6.
Type VII: Lamprophyre	Locality 9.

PLATE II.
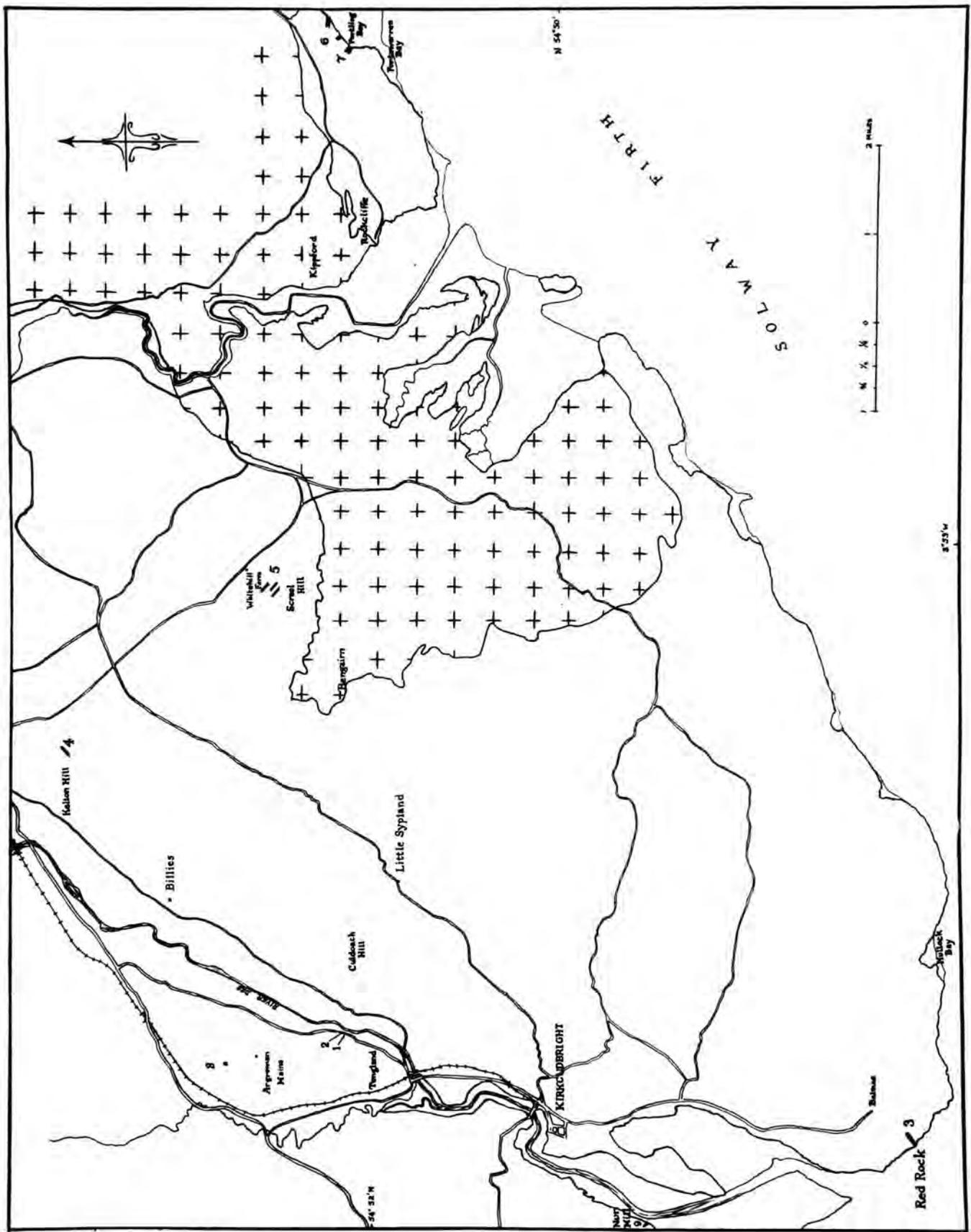
conformance obtains betwwen these divisions and the nature of emplacement of the rocks concerned.

Type I: Quite the most unaltered type, this includes handsome, grey, porphyritic rocks with zoned plagioclase, frequently accompanied by biotite and hornblende. With increase of the latter minerals the rock assumes a lamprophyric appearance. They will be termed "diorite-porphyrite".

All the members of this type encountered are dykes with regular margins and cross-strike trends. They occur principally to the north-wast and south-west of the granodiorite area of Bengairn and Forest Hill and are mainly confined within the metamorphic aureole.

Types II and III: These are by far the most abundant rocks of the area. Type II includes red or pink albite-bearing rocks (albite-porphyry) which sometimes internally lose the characteristic porphyritic texture and develop a finely granitic appearance in the hand-specimen. Type III includes reddish- or purplish-green non-porphyritic rocks, also albite-bearing, and possessing an orthophyric felted texture. Greenish, chloritic clots are a common feature of the hand-specimen. They will be termed albitophyre.

Both types are always more or less intensely hydrothermally altered; a process, which, it will be shown, is an essential feature of their petrogenetic evolution.

Between Tongland and Bengairn wide stretches are occupied by these rocks. It is impossible to determine the

exact form of the intrusions owing to the absence of continuous exposures.   Their undoubted hypabyssal characters, limited effect on the country rocks and the occurrence within their boundaries of outliers and inliers of overlying and underlying slates, show, however, that their thickness is relatively small.

The discordant relationships of these intrusions to the Ordivician sediments renders the term sill or laccolith inapplicable, nor can the form be regular since it is impossible to recognise any systematic relation between limits of outcrop and contours.   It seems most probable, therefore, that the intrusions in question comprise a series of irregular sheets.

Irregular dyke and sill intrusions are common and some of them are connected with the sheets.   Their outcrop, modes and trends often vary considerably in different parts of their length, whilst their contacts with the country rocks are always highly irregular.   To this type belong the excellently exposed dykes in Tongland road-cutting.

The precise relation between intrusions of type II and those of typeIII is not quite clear.   In Tongland road-cutting the two form distinct dykes.   In the area of sheet intrusions to the east the two may form neighbouring exposures, suggesting a closely related origin.   Unfortunately, on account of the lack of critical exposures and the complexity in the modes of emplacement of the sheets, no conclusive field-evidence, bearing on the relationship of the two types has been observed.

Type IV: This type occurs as strike dykes, such as that at
Balmae Haven, having well-defined vertical walls, and made up
of pale cream or pink coloured, compact rocks, with pronounced
porphyritic textures.   The dyke margins, except for local
coincidences, cut across the dip-planes.   Albite is the
dominant mineral, with rare dark constituents and rather
abundant calcite.   Quartz, although constituting no less than
26.6 per cent of the normative composition, is quite invisible
in the microscope section.   These rocks will be termed
"leucocratic albite-porphyry".

Type V: Here are included the rocks of a number of intrusions
from the Rockcliffe district, characterised by a felted, ortho-
phyric texture and having zoned plagioclase felspars.   Albite,
quartz, chlorite and calcite, all of hydrothermal origin, are
important constituents.   The rocks form irregular dyke-like
intrusions.

Type VI: Another distinct type, so far observed only forming
irregular dykes in the Rockcliffe area, contains abundant
large felspar aggregates and resorbed phenocrysts, suggesting
derivation from xenoliths.

Type VII: A number of lamprophyres have been examined.   All
occur as narrow, irregular dykes and are typical kersantites or
minettes, olive-green in colour and containing abundant flakes
of biotite.   The felspar can but rarely be identified.

The maps (Fig. I and II) indicate the approximate distrib-
ution of the various types and the localities referred to
in the detailed descriptions.

PETROGRAPHIC TYPES:	MODE OF OCCURRENCE, TREND, ETC:
II: Albite-porphyry	
III: Albitophyre	Sheets, Irregular Dykes and
V: Plagiophyre	Sills.
VI: Xenocrystic Dykes	
IV: Leucocratic Albite-porphyry	Regular Strike Dykes.
I: Diorite-porpyrite	Regular Cross-Strike Dykes.
VII: Lamprophyre	Small Irregular Dykes.

TYPE I: DIORITE-PORPHYRITE.

This, the simplest, least altered type, is conveniently considered first.

A number of dykes of this type occur in the metamorphic aureole of the granodiorite, of which typical examples may be seen on the slopes of Screel Hill, behind Whitehill Farm. Similar dykes are also found south-west of Bengairn and Forest Hill.

Characteristically the dykes cut across the strike of the country rocks at right angles, and lie more or less parallel to the granodiorite margins. The contacts are commonly sharp and straight, while the width of the dykes is rarely above five or six feet.

The dyke-rocks are usually of striking appearance, with large white felspars and dark flakes and prisms of mafic

minerals in a grey matrix of medium grain.   They are characteristically unaltered.

Petrography:

The texture is porphyritic, with large tablets and glomero-porphyritic aggregates of plagioclase, together with biotite and hornblende, in a fine-grained groundmass. (Pl.V, 1).

The plagioclase is often quite clear, but may show a patchy clouding due to a "kaolin" type of mineral, while flakes of a "sericitic" mica are common.   Occasionally more heavily clouded felspars are traversed by irregular channels occupied by a clear albitic felspar of low refractive index.

Beautifully zoned crystals are frequently seen; often oscillatory in composition.

	Extinction Angles:	$12°- 16°$.	
	Optic Sign:	Negative.	
	Refractive Indices:		

	Calcic Zones.		Sodic Zones.
α	1.546	1.545	1.543
β	1.551	1.549	1.547
γ	1.554	1.553	1.551

These characters correspond to oligoclase-andesine ranging in composition from $Ab_{70}An_{30}$ to $Ab_{75}An_{25}$.

The hornblende occasionally possesses euhedral diamond-shaped or rectangular outlines; more commonly, however, the crystal edges are minutely irregular and the centres are riddled with acicular apatites.   It is of a brownish-green

colour, and has optical characters normal to common hornblende:

Extinction Angles: $(Z_\wedge c)$ $21° - 23°$.

Pleochroism: $X < Y < Z$.

Optic Sign: Negative.

The degree of alteration varies somewhat from dyke to dyke. Clear green flakey chlorite (penninite), granules of epidote and patches of calcite are the secondary minerals.

Biotite is frequent as ragged, fibrous crystals. The colour is a deep fawn-brown with strong pleochroism, but bleaching and chloritisation have usually effected considerable alteration marginally and along the cleavage planes. The Chlorite is less flaky than that associated with hornblende and shows abnormal indigo-blue or rusty-brown interference tints. Basal sections with hexagonal outlines occur: percussion figures are sometimes seen.

The matrix is fine-grained and generally light-coloured, with a suggestion of flow-structure. Felspar pre-dominates but microlites of biotite and hornblende are also abundant.

Accessories are apatite and rare zircon, as well as pyrite and black ores.

As a type these rocks correspond in mineral composition to diorite, of which they appear to represent the hypabyssal equivalent. On these grounds, therefore, the name diorite-porphyrite is fully warranted.

MINERAL SUMMARY: TYPE I.

A.   PHENOCRYSTS.

Primary Minerals:	Secondary Minerals:
Plagioclase: $(Ab_* An_{**})$ Form: **sub**hedral tablets and glomero-porphyritic aggregates. Lamellar Twinning. Oscillatory Zoning. Extinction Angles: $\qquad 12° - 16°$. Refractive Indices: (various zones) $\quad \alpha$ 1.546 1.545 1.543 $\quad \beta$ 1.551 1.549 1.547 $\quad \gamma$ 1.554 1.553 1.551 Optic Sign: Negative.	Clouding of;- $\qquad$ "Kaolin" mineral. Channels of;- $\qquad$ clear Albite.
Hornblende: Form: often euhedral; frequently riddled with apatites. Colour: brownish-green. Simple Twinning. Extinction Angles: $\qquad Z_\wedge c \quad 21° - 23°$. Optic Sign: Negative. Pleochroism: $X < Y < Z$.	(able: Alteration not consider- Flakes of Penninite, Granules of Epidote.
Biotite: Form: ragged fibrous crystals; occasionally somewhat rounded. Colour: deep fawn-brown. Pleochroism: $X > Y = Z$ (strong).	Alteration: Bright green Penninite (with indigo-blue and rusty-brown int. tints) Epidote granules. Replacement by Calcite along cleavages.

Accessories:

$\qquad$ Needles and tiny hexagons of Apatite.
$\qquad$ Pyrite and Black Ores.
$\qquad$ Rare Zircon.

B.   MATRIX.

Primary Minerals:	Secondary Minerals:
Matrix fine-grained, light-coloured and cryptocrystalline with microlites showing tendency towards flow-structure.	
Plagioclase: Form: tiny squares and rect-angles, often with indefinite outlines.	Alteration slight: "Kaolin" clouding.
Hornblende and Biotite: Tiny dark microlites and shapeless grains.	Chloritisation general.

TYPE II: ALBITE-PORPHYRY.

The northern dyke at Tongland road-cutting has been examined in greatest detail and is, therefore, taken as the type example.   Similar dykes or sills occur near Billies Farm and near Little Sypland, a few miles north-east and east, respectively, of Tongland.

The southern margin of the Tongland dyke makes a sharp contact with the country rocks.   These are here greenish-grey, highly cleaved slates, dipping steeply away from the dyke.   The latter cuts obliquely across the cleavage, which appears in no way to affect the trend of the igneous contact. Near the dyke margin the slates contain "splashes" or patches of porphyry of varying shape and size, up to an inch or more in diameter.   In none of the cases examined could these

PLATE III.

Diagrammatic Section of Dykes seen
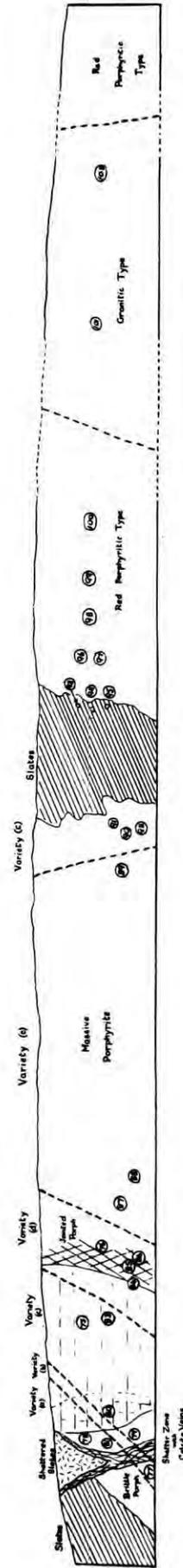in Tongland Road-cutting.
(Not drawn to scale).

PLATE III.

NORTH DYKE

SOUTH DYKE

Not accurately to Scale

Total length of Section approximately 180 yards

Width of South Dyke about 30 yards

Figures refer to Specimen Numbers

be traced to the main dyke, but they may have been originally connected via a mass now removed.

Inwards from the contact, the igneous rock, at first markedly porphyritic, with phenocrysts up to about 3 - 4 mms. in length, gradually becomes more even-grained owing to increasing coarseness in the texture of the matrix.   Even in the field this change is clearly evident, since from being porphyritic the rock develops a fine-grained granitic texture.

Further norhh in the cutting, the porphyry becomes bleached, crumbly and very susceptible to weathering by surface waters.   When, further on, the fresh rock reappears, it is again of the porphyritic variety and, although the northern contact cannot be seen owing to the termination of the cutting, the approximate position of the junction can be located. Evidently the porphyritic variety is the marginal facies to the granitic variety of the interior.   (See Plate III). Petrography: (See Plate V, Fig. 2).

The phenocyysts are :

    (a) felspar, easily dominant;

    (b) hornblende, often partially or completely pseudomorphed by chlorite; and

    (c) a pale green chlorite, thought to represent original biotite.

The hornblende, in particular, frequently shows nearly euhedral outlines.

(a).   Occasionally the felspar phenocrysts are euhedral;

m

more commonly, however, they are aggregates of several crystals, irregularly disposed and intergrown. The crystal edges often show re-entrants and acute angles, but either resorbtion (if they are xenoliths), or incomplete growth (if they are segregations) is suggested where the boundaries are rounded or indistinct. The fact that both phenocrysts and aggregates occur right up to the contact indicates that they were in existence before the emplacement of the magma, an inference which is supported by the frequent occurrence at the dyke margin of cracked crystals, due, presumably, to the stresses set up during intrusion. The occurrance of cracked crystals also suggests a probable explanation for the angular form of certain phenocrysts, which thus appear to be fragments of formerly larger felspars.

Further evidence regarding the mode of development of the felspar phenocrysts is provided by a dyke of the same general type occurring near a small quarry about one mile N.N.W. of Argrennan Mains (two miles north of Tongland). Here all the felspars, although often nearly euhedral in form, are riddled with patches of matrix. Commonly a narrow marginal zone is free from inclusions, which presumably precludes the possibility of corrosion of pre-existing crystals by the matrix magma. (Cf. MacGregor, 1931). The inference is, therefore, that portions of the matrix were enclosed while the felspars were crystallising. Frequently such a "sieve" texture is encountered in metamorphic rocks, where a mineral has developed in a solid medium, e.g. "sieved" pyroxenes, whilst chiastolite presents a similar,

though not quite comparable, phenomenon.   (Plate IX, Fig. 2).

The riddled phenocrysts also raise the question of whether the "shadowy-looking" felspars of type II as a whole have ever been more completely developed than they now are. A comparison with the "incipient" felspars of the matrix, (q.v. pp. 17 - 18) which have only begun to crystallise, suggests that the phenocrysts themselves may be similarly imperfectly formed.   Such an assumption would materially help in reconciling the two apparently incompatible ideas:

(i) that some of the felspars were already crystallised before the emplacement of the magma, and

(ii) that in other cases the felspars have developed during the consolidation of the matrix.

It is only a question of the circumstances controlling the clearing strength of growing crystals, as to which size alone is demonstrably no gauge.

The felspar phenocrysts are usually more or less clouded. Most sections show lamellar twinning, but zoning is never seen.

Extinction Angles: $17° - 18°$.

Optic Angle: Large - approaching $90°$.

Optic Sign: Positive.

Refractive Indices:
(measured $\perp$ Y)

α 1.528

γ 1.537

These characters correspond to those of albite.

Apart from the presence of patches and channels of clear

secondary albite, clouding is ubiquitous; it resolves under high power to diffuse, brownish specks, suggesting dispersion of a kaolin-like substance.

Tiny flakes of a white "sericitic" mica, recognised by its bright interference tints, are usually present. Generally they show a parallelism to the traces of the dominant cleavage direction ob twinning planes in the section.

Little clear, pale green flakes and fibres of chlorite are occur similarly, though less abundantly than the mica.

Occasionally, too, quartz occurs as flakes, nests and fine- veinlets and calcite as greyish patches, resolved into numerous tiny crystals under high-power. These minerals have effected replacement of a somewhat different nature from that of the other products of alteration of the felspar. Both quartz and calcite occur in the matrix and phenocrysts indiscriminately.

Some difficulty is encountered in attempting to establish the sequence of formation of these minerals. Clouding and sericitisation appear to be the earliest, since they are almost invariable and are absent where channelled by clear albite. Similarly chlorite, quartz and calcite would appear to represent the probable order among the later minerals.

(b). The hornblende in some specimens (e.g. 95) is entirely or largely unaltered. Commonly it occurs as medium-sized, approximately euhedral phenocrysts, up to a millimetre or so in length and having characteristically rectangular or diamond-

shaped outlines. The cleavages, where developed at all, are generally fine.

The colour is a brownish olive-green, most sections showing a moderately strong pleochroism.

Simple twins are not uncommon. The twinning plane is (100), since it is parallel to the length in longitudinal sections which show moderately low birefringence, and bisects the acute cleavage-angle in basal plates.

Extinction Angles: $(Z_\wedge c)$ $22° - 23°$.

Pleochroism:	X	Y	Z
	Pale yellowish-green.	Brownish green.	Deep brownish-green.

$$X < Y < Z.$$

Birefringence:	0.023.
Optic Angle:	Moderate.
Optic Sign:	Negative.

A suggestion of marginal zoning to a darker variety has been noted. These properties indicate a hornblende of about normal composition; the brown colour may be due to a relatively high soda content.

Although unaltered hornblende is found, obvious pseudomorphs in chlorite and calcite are more common. All gradations exist between the two extremes, and intermediate forms, with residual patches of optically continuous hornblende, are abundant. (See Plate VI, Fig. 2, D and E).

Alteration to chlorite proceeded first; it accurately

conforms to the original outlines and encloses residual hornblende.   Chloritisation commenced marginally and tended to follow the cleavages.

Granules and aggregates of epidote are commonly associated with the chlorite.   Occasionally, too, black ores are much in evidence, occurring as euhedral or rounded grains, marginally distributed.

Patchy calcite, with "lobate" margins, replaces both hornblende and chlorite.   Often it follows the original outlines as closely as the chlorite, elsewhere its distribution is less regular.   Epidote tends, however, to remain enclosed and unreplaced.   Some examples of otherwise unaltered hornblende veined with calcite occur.

Rarely albite can be seen irregularly replacing hornblende.

(c).   Unaltered biotite never occurs, but chlorite suspected of pseudomorphing biotite is common.   The evidence that the original mineral was not hornblende, but probably biotite, is as follows:

(i) Chlorite is sometimes found in rectangular sections with the characteristic ragged ends and strong basal cleavage of biotite.   Basal flakes with no cleavage and nearly hexagonal outlines may be seen.

(ii) The general outline and cleavages of these pseudomorphs are quite unlike those of chloritised hornblende.
Traces of cleavage after hornblende, if seen at all, are

always fine, straight and infrequent.   In these pseudo-
morphs, however, the cleavages may be waved or bent; a
feature which is common in biotite.

(iii) Complete "biotite" pseudomorphs are found in one specimen
(95) together with nearly unaltered hornblende.   Their
derivations from hornblende is therefore extremely unlikely.

(iv) The epidote (see pp. 22 - 23) is partly of a fibrous type,
following the cleavages, not found in pseudomorphs after
hornblende.

The matrix, is conveniently considered under three main
headings, according to the relative position in the dyke, which
    each
are∧in turn divided into two sub-headings, describing primary
and secondary constituents.

(A). Marginal Portion of Dyke (e.g. specimens 95 and 96).

Here the matrix is fine-grained and definite crystal
outlines cannot be distinguished.

(a) Primary Constituents:

Between crossed-nicols a mottled effect is seen which is
due to the incipient development of "shadowy" felspars.
These have been "frozen" before assuming more distinct
outlines or clearing themselves of minute inclusions.
Red and black specks of ore and laths of chlorite pseudo-
morphs are abundant.   The general reddish colour is due,
presumably, to a dispersion of hydrated iron oxides.

(b) Secondary Constituents:

Flakes, streaks and tiny fibres of chlorite have been

extensively introduced.   Their distribution is highly
irregular, but tends to be concentrated around phenocrysts
of felspar and pseudomorphs after hornblende and biotite.
Elsewhere, too, in the matrix occur chlorite aggregates and
patches.

Quartz is not uncommon, being usually closely associated
with felted fibres of chlorite and forming colourless patches
with shadowy extinction.   Occasionally, too, grains of clear
secondary albite, showing twin-lamellae occur with, and are
eut-by partly replaced by quartz.   The latter appears to
replace chlorite also, since it cuts across the fibres.

Tiny rounded calcite patches are distributed fairly
uniformly throughout the matrix, together with occasional
irregular replacements of greater extent.   Calcite appears
to be always the latest replacing mineral, penetrating matrix,
chlorite and quartz alike.

The degree of alteration of the matrix bears no apparent
relation to the proportion of secondary minerals in the
matrix.   Thus, although the matrix is identical in specimens
95 and 96, yet in the former the hornblende is fresh, while
in the latter it is entirely chloritised.

(B). Intermediate Varieties (e.g. specimens 99 and 100).

(a) Primary Constituents:

Here the matrix is less obscurely developed.   The
felspars have assumed more or less rectangular outlines with
definite crystal edges.   Even so, under the microscope, the

rock still retains a porphyritic texture.

(b) Secondary Constituents:

A more advanced type of hydrothermal alteration can here be recognised.   The most notable feature is the occurrence of "nests" of quartz and albite, sometimes with other minerals (e.g. epidote, chlorite and calcite) in addition. The albite is frequently untwinned.   Where associated with chlorite, the latter is the replacing mineral, penetrating the albite in fibrous growths and encroaching on its crystal margins.   It is clear, as evidenced by the fact that the chlorite fibres are always cut by quartz, but never cut it, that quartz is a still later mineral.   Replacement phenomena between quartz and albite are well exhibited:

   (i)   Smooth rounded encroachments of quartz into albite
          crystals;

   (ii)   Fingering penetrations of quartz into albite;

   (iii) Partial replacements of quartz after albite, in which
          only a fine network of optically continuous albite
          remains;

   (iv)   Fine intergrowths of quartz and albite.   These
          frequently occur beyond the edges of unaffected albite
          laths or tablets.   They may also form a peripheral
          rim to a felspar which happens to be in the vicinity of
          a quartz-albite nest.

Albite, chlorite and quartz are also dispersed throughout the matrix, always showing evident replacement of earlier

minerals.   Quartz, although tending to occur in the interstices of the matrix felspars, commonly makes lobate penetrations into their margins.

A clear, bright yellow, pleochroic _epidote_ of aggregate-columnar or radiating-fibrous habit, often occupies the middle of quartz-albite nests.   (Plate VI, Fig. 2, A & C).

Calcite occasionally replaces the matrix, primary and secondary minerals alike., forming clear optically-continuous patches with irregular, rounded or angular edges.

(C). _Innermost Varieties_ (e.g. specimens 101 and 102).

(a) Primary Constituents:

These rocks correspond with the "granitic" variety of the field description (see p.11).   The matrix is even coarser than in 99 and 100 and individual felspars have reached the proportions of small phenocrysts.   The even-grained appearance of the groundmass is lost, but the distinctive feature of the rock lies in its secondary characters.

(b) Secondary Constituents:

Intergrowth- textures are here dominant.   The larger felspars are often surrounded by "rosettes" of albite and quartz.   The secondary albite appears to have grown in continuity with the original felspars and to have been partially replaced by quartz.   Where the intergrowths are very fine discrimination is often possible only if the component minerals can be traced to discrete crystals.   The various

fine replacement textures are:

  (i)   Striation type, in which the two minerals are evenly
        streaked together.   The striations are straight and
        parallel.

  (ii) Vermicular type.   The component minerals can here
        be readily distinguished and traced to larger areas.
        This closely resembles myrmekitic textures.

  (iii) "Herring-bone" type.   This usually forms the
        rosettes surrounding felspar crystals.   Each "spoke"
        of a rosette has the appearance of a herring-bone of
        which quartz forms the backbone and ribs and albite
        the intervening spaces.

  (iv) Mesh type, in which the albite remains as a fine
        lattice-like framework.

Frequently these intergrowths become perceptibly resolved
only under high-power.   (Plate VII, Figs. 1 and 2).

      Chlorite may assume a spherulitic habit in quartz-
albite nests; with it are occasionally associated radiating
fibres of what is probably a pale actinolite (see pp. 23-24)

      <u>Chlorite</u> of several varieties is abundant in all the
dyke-rocks.   The mineral occurs as:

(a) Pseudomorphs replacing hornblende and "biotite".

(b) Fibrous aggregates and scattered flakes in the matrix and
    through the felspars.

(c) Constituents of albite-quartz nests, often with spherulitic
    radiating habit.

Penninite (negative):   This, the most abundant variety, pseudomorphs hornblende and occurs through the matrix and felspars.   It is pale green in colour, slightly pleochroic and fibrous or flaky in habit.   Pseudomorphs consist of aggregates of separate flakes.   It has a negative optical sign and shows abnormal prussian-blue interference tints.

Penninite (positive):   Another pale green chlorite occurs in association with a brownish epidote in the "biotite" pseudo-morphs.   The interferemce tints are deep purplish-indigo, sometimes changing to a rusty-brown on rotation.   A further distinction is its positive optical sign.

Colourless Chlorite: Occasionally a colourless radiating fibrous mineral is found associated with positive penninite in biotite pseudomorphs.   It tends to form sheafs of acicular crystals along the cleavage planes of the pseudomorphs, appearing to push aside the epidote granules and penninite. The crystals are commonly length-slow; otherwise optical properties are not determinable.

Epidote is a very widely distributed mineral. Optical properties are usually difficult or impossible to determine, but it is convenient to recognise the following varieties, according to differences in form and mode of occurrence:

(a) Epidote I: Greenish or brownish-yellowish granules occurring in the hornblende pseudomorphs.   The grains have high relief and characteristic birefringence (about 0.030), but their crystal orientation is usually difficult to

determine.   Elongated crystals appear to show typical straight extinctiòn and may be either length-slow or fast. The sign is negative and the greatest absorption is always with the length.

(b) Epidote II: A second variety, brownish, cloudy and often fibrous, is almost exclusively associated with positive penninite in biotite pseudomorphs.   The fibres are more or less parallel to the cleavage of the chlorite, but may occur in lenticular aggregates of sheaf-like habit.   The extinction is usually but not invariably straight.   Under high-power the real colour is seen to be pale yellow, the brown colour being due to the cloudiness, which may obscure the interference tints. The optical properties are the same as those of the first variety, which also occurs in the biotite pseudomorphs.

(c) Epidote III: A bright yellow, aggregate-columnar or radiating-fibrous variety is found in the middle of albite-quartz nests.   Here the epidote is very clear and has strong pleochroism.   The sign is negative, the acute bisectrix at right angles to the length and the elongation usually nearly with the optic normal.   In the aggregates, transverse sections showing acute and obtuse angles are common.

A radiating, fibrous mineral is occasionally associated with chlorite in hornblende pseudomorphs or in the chlorite of quartz-albite nests.   It has the following properties, suggesting actinolite:

(a) Fibrous, pale green in colour, faintly pleochroic and

with brownish clouding arranged in concentric bands in the
sheafs;

(b) Moderately high relief, greater than that shown by quartz,
felspar and chlorite;

(c) Oblique extinction, up to about 20°;

(d) Slow with length;

(e) Negative sign.

Since its needles penetrate the associated chlorite, its
position in the paragenetic sequence appears to be later than
that mineral.   Relations with quartz have not been observed.

Distinction is often difficult between quartz and albite
in the nests and matrix replacements, since:

(a) The albite is frequently clear and free from visible signs
of twinning;

(b) The albite-quartz replacement textures may be so fine that
discrimination is impossible.

Distinction, where possible, has been based on the following
features:

(a) Lamellar twinning, where found, is indicative of albite;

(b) Where albite and quartz occur together without overlapping
the relative refractive indices may be determined;

(c) If the orientation is suitable a clear uniaxial or biaxial
figure can sometimes be found.   An albite section, in which
the twinning is not seen, is often nearly perpendicular to
the acute bisectrix;

(d) Where the intergrowth textures are very fine the component

minerals may be sometimes traced to larger crystals, the
identification of which are possible.

Evidence of Veins.

A few thin veins occur in the central portions of the
dyke.   The vein material varies from place to place,
containing sometimes quartz, elsewhere albite, and occasionally
chlorite or calcite.   Quartz and albite, both of which are
colourless, are most readily distinguished when passing thrôugh
albite phenocrysts.   The clear albite of the vein is sharply
contrasted to the cloudy albite of the phenocrysts, but both
have the same refractive index.   Quartz, however, to has
a relief perceptibly higher than either.

Accessories:

Accessories are apatite and zircon.   Apatite is a
relatively abundant mineral, occurring as euhedral inclusions
in the mafic or felspathic constituents or scattered through
the matrix.   The crystals are not infrequently acicular in
form, suggesting a direct magmatic source.   This variety
contrasts with the squat, rounded crystals from the dyke
margin and the slates, the forms and restricted occurrence of
which suggest a sedimentary origin (see below, p. 26).

At least one or two isolated crystals of zircon have been
recorded from every dyke section.   In a section from the
margin no fewer than five were found within a few square
millimetres.   The outlines are always much rounded and the

similarity of their form to those found in the slates suggests a sedimentary origin.

Relations with Slates.

At its southern end the dyke can be seen making a sharp, though irregular contact with the slates.   Under the micro-scope igneous material is observed to have penetrated the sediments, irregular offshoots containing phenocrysts of of hornblende, felspar and pseudomorphous chlorite in a chilled matrix.

The slates consist of irregualr quartz grains of varying size, togehter with much finely disseminated green chloritic material and black ore.   Occasional albite porphyroblasts occur, and, here and there, nearly colourless flakes of mica, showing high interference tints.

Rounded crystals of zircon and apatite were observed in the slates, apatite being by far the more abundant.

In the margins of the igneous rock, too, apatites occur, often rounded, larger and in greater abundance than in the rest of the dyke.   Rounded zircons were also found in the marginal rock and, as already mentioned (p. 25), in most of the slides of the dyke similar rounded zircons can be found. The detrital appearance of the apatite and zircon and their general similarity to those in the slates suggest their derivation from the latter.

MINERAL SUMMARY: TYPE II.

A.   PHENOCRYSTS.

Primary Minerals:	Secondary Minerals:

Albite:
 	
Form: euhedral tablets;
  "fragmentary" crystals or
  aggregates; re-entrants
  common; angles may be
  rounded; sometimes matrix
  inclusions.
Lamellar Twinning.
No Zoning.
Extinction Angles:
         $17° - 18°$.
Refractive Indices:
         α 1.528
         γ 1.537
Optic Sign: Positive.
	Alteration and replacement:
	
	  "Kaolin" clouding.
	
	Extensive saussuritisation:
	  "Sericite", rarer Chlorite,
	  clear secondary Albite -
	         as flakes;
	Quartz and Calcite -
	         irregular patches.

Hornblende:
 	
Form: small euhedral crystals.
Colour: brownish-green.
Simple Twinning.
Extinction Angle: $Z_{\wedge}c$ $23°$.
Birefringence: 0.023.
Optic Sign: Negative.
Optic Angle: Moderate.
Pleochroism: $X<Y<Z$
         (mod. to strong).
	Often entirely pseudomorphed:
	
	  Negative Penninite and
	  Epidote granules;
	  Black Ores;
	  Rare Actinolite;
	  Calcite;
	  Rare Albite.

Biotite:
 	
Entirely pseudomorphed.
Form: rectangles with ragged
  terminations; hexagonal
  flakes.
	Positive Penninite and much
	  fibrous Epidote.

Accessories:

Rounded Apatite near dyke margins;
Acicular Apatite internally;
Rounded Zircons - especially near margins.

B.   MATRIX:

Primary Minerals:	Secondary Minerals:
Albite: In finest types; light-coloured patches - incipient crystals. **Hornblende:** Needles and laths; more or less chloritised. **Ores:** Dispersion of hydrated ores gives general red coloration Black specks and granules.	**Chlorite:** Flakes dispersed through groundmass - concentrations round pseudomorphs. **Nests** of Chlorite, clear Albite Quartz and Calcite, together with sheafs of clear yellow Epidote. **Quartz-Albite** intergrowths; intricate and finely textured; often margining felspar phenocrysts; most important where non-porphyritic.

TYPE III: ALBITOPHYRE   (ALBITISED PORPHYRITE).

This is the most widespread of all the "porphyrite" types.   Owing to its wide variations in texture and degree of alteration it cannot be briefly defined.   Most of the dykes between Kirkcudbright and Castle Douglas and the extensive sheet-like expanses round Culdoach Hill and from Bentudor to Black Stockarton Moor are of this type.   At intervals intrusions of the more massive red albite-porphyry are assoc- with those of Type III, but good contacts between the two types have not been found.

In the field it is evident that the rocks of Type III are always more or less intensely altered.   They are grey,

purplish-brown, dull- green or reddish-brown in colour and, though not markedly porphyritic, they all contain numerous green chloritic clots up to several millimetres in diameter.

Most of the varieties are excellently exposed in the southern dyke of the Tongland road-cutting (see Pl.III), which is taken for convenience as the type example.   This is the smaller of the two dykes exposed in the cutting and has a width of approximately thirty yards.

The slates may be seen to the south of the dyke and again between the two dykes.   Close to the contact they are somewhat baked but otherwise they are but little affected by the intrusion.   The cleavage dips at about 65° and strikes in the characteristic N.E. - S.W. direction.

The southern contact of the dyke is sharp, with irregular injections into the slates.   The contact is interrupted by a V-shaped shatter-system of jumbled slates and dyke-rock and is charged with calcite veins.

The "porphyrite" near the contact has a dark greenish-grey or purplish colour, with a flaky surface and well-jointed structure.

Beyond the shattered zone is a jointed rock of a reddish colour with chlorite clots.   This is succeeded by a more massive "porphyrite" of similar colour, having strong rectangular joints, the planes of which are coated with calcite and chlorite.   In turn, this variety passes sharply into well-jointed red rock, which, for the next twenty yards,

becomes progressively more massive.

The dyke at its northern end makes a sharp penetrating contact with the slates, irregularly truncating the cleavage planes.

Petrography:

The microscope shows that the field variations are purely mechanical, and that, conversely, the wide textural variations disclosed in thin section are in no way reflected in the appearance of the rocks in the hand-specimen.

The specimens of which slides have been made can be classified into the following groups:

(a) 78}: Porphyritic Variety: fine-grained matrix containing
    81}
                        felspar microlites.

(b) 77: Variety with matrix intermediate between (a) and (c).

(c) 80} Coarse-grained Variety: "cracked" orthophyric felspars;
    83}:
    92}   characterised by biotite.

(d) 76}: Variety intermediate between (c) and (e).
    87}

(e) 88}: Variety with saussuritised, brown felspars;
    89}
                    characterised by chloritisation of all mafics.

There is a general relationship between these varieties and their position in the dyke.   Variety (c) occurs on either side of (e), which is more or less central in position and the most extensive.   Variety (d) is intermediate between these two, both (d) and (a) are, however, practically suppressed on the northern limb of the dyke.   (Plate III)

<u>Variety</u> (<u>a</u>):

This has a characteristic porphyritic texture, with phenocrysts of plagioclase and more or less chloritised biotite (Pl.VIII fig. 1).

The <u>felspar</u> phenocrysts, though occasionally showing nearly euhedral outlines, are generally grouped as irregular aggregates. Angles and edges may have rounded outlines, suggesting resorption. Crystal margins frequently grade into the matrix, with no sign of a definite edge.

Irregular patchty inclusions in the phenocrysts, having crenulate or smoothly rounded margins are common; a general tendency towards concentration in the crystal centres being observed (cf. p. 12). The magins are always clear. In composition the patches resemble the matrix, with which, it is presumed, they are to be identified. This interpretation suggests that some of the phenocrysts were unable to clear themselves of matrix inclusions; perhaps because they separated from a highly viscous magma.

The felspars always have an appearance of being highly altered. All the larger and many of the smaller crystals are nearly opaque, apart, as a rule, from a narrow marginal zone. This is only in part due to the development of a kaolin type of mineral. Under high magnification a confused mass of "sericite", chlorite, clear albite and epidote is revealed. The clear margins are occupied by clear albite, which sends penetrating processes into the opaque products of

the interior of the crystals.   Those felspars which are clear

throughout have refractive indices lower than that of balsam

and are entirely made up of unzoned albite.   The alteration

processes appear to be., therefore, saussuritisation (responsible

for the opaque products), succeeded by marginal or complete

replacement by albite.

No original felspar can be found; hence the original

composition can be inferred only from that of the felspars of

the internal varieties of the dyke.

A greenish biotite, more or less pseudomorphed by chlorite,

is relatively abundant.   The replacing chlorite has the same

bright green colour and can be distinguished only by its low

interference colours.   Granules of epidote are associated

with the chlobite.   Frequently the chlorite develops beyond

the original outlines of the biotite.   Replacement of the

biotite by another colourless mica, has, in some cases, also

occurred.   The later mica is probably more closely related

to sericite as it forms tiny flakes making an angle with the

original cleavage.

Certain dirty, brownish, flaky aggregates showing

variable birefringence may be partly micaceous, partly chloritic.

Similar patches, having approximately hexagonal outlines, may

represent former basal sections of mica.   They show an

undulose extinction, resembling that often seen in biotite

flakes.   The extreme alteration of the rock, however, makes

identification impossible.

There is no evidence suggesting the original occurrence of hornblende in the rock.

In addition to the chlorite which partially pseudomorphs biotite, a pale green _penninite_ occurs.   Occasionally it has sharp polygonal margins; more generally it sends off penetrating fibres and irregular proccesses into the matrix.   Enclosed mesh-works of black ore are common, suggestive of derivation from an earlier mineral.

The characters of certain albite-chlorite "clots" are of considerable interest.   Plate X, fig. 1 illustrates a typical example.   Here there are areas of pale green chlorite partially or completely enclosing crystals of clear albite. The albite is penetrated by chlorite flakes and fibres; the former is evidently the earlier mineral.

The matrix is fine-grained with an abundance of tiny felspar laths and needles, forming a characteristic criss-cross pattern.   The background of the matrix is partly felspathic, but contains, in addition, much disseminated chloritic and black ore material.

Little "nests" of quartz aggregates are scattered through the matrix.   The latter is evidently replaced, since the felspar microlites are abruptly truncated.

Variety (_c_):   (Plate VIII, Fig. 2).

This is a coarser-grained rock than the last described; all the constituent minerals are visibly crystalline and the

porphyritic texture is correspondingly less conspicuous.

The dominant mineral is a relatively clear, often nearly euhedral _felspar_.   All gradations in size occur.   The felspars, especially the smaller ones, tend to occur in squat-rectangular or lath-like forms.   The grain-size and dominant form of the felspars controls the appearance of the rock, giving it an orthophyric texture.

The sharp edges, emphasised cleavages and cracks, and streaky grey clouding are features whicha are characteristic of the felspars of this variety.

Lamellar twinning is usual and slight marginal zoning not uncommon in larger crystals.

	Centres of zoned crystals:	Smaller crystals and marginal zones:
Extinction Angles:	$14°$	$7°$
Reffactive Indices:	α 1.545	1.540
	γ 1.553	1.548
Optic Angle:	Large – approaching $90°$.	
Optic Sign:	Negative.	

The felspar therefore varies in composition from $Ab_{70}An_{30}$ to $Ab_{74}An_{26}$.

The slight clouding, presumably due to a _kaolin_ type of mineral, is usually concentrated along streaks isolating clear areas of felspar.

Flakes of a colourless _mica_, showing high birefringence, are abundant.   It appears to be an early replacement, since with "kaolin" it occurs in otherwise unaltered felspars.

Clear Albite, usually untwinned, develops along the margins and twinning planes of the oligoclase crystals. Smaller laths may become completely albitised. The albite is recognisable by its low refractive index and positive sign.

Chloritisation apparently occurs in two stages. The earlier chlorite forms tiny flakes in the more altered-looking felspars. Where the felspar is clear albite little or none of this chlorite occurs. Later chlorite chlorite forms fibrous streaks and veinlets which penetrate the albite along cleavages and otherwise.

Granules of epidote, smaller than those in pseudomorphous chlorite are relatively common. Frequently they are associated with streaks of albite, thereby suggesting derivation from the anorthite part of the felspar.

Quartz effects an indiscriminate type of replacement. Commonly it occupies interstices, from which it replaces neighbouring crystals. Lobate encroachments into felspar margins and penetrations along cleavage planes are frequent. With albite, however, quartz forms more complex intergrowths. Occasionally quartz replaces and partly isolates portions of albite crystals, leaving rounded margins. Elsewhere quartz penetrates albite in fine striae or vermicules, which can often be traced back to recognisable discrete crystals. Sometimes albite tablets have been almost entirely pseudomorphed, leaving only a fine albite mesh.

The biotite is identical with that occurring in the

marginal variety (a).   It is green or brownish-green in colour and has a fibrous structure.   Chloritisation has proceeded along the margins and cleavages, associated with the deposition of granules of epidote and black ore.

Aggregates of chloritised biotite often enclose mesh-works of black ore and relatively large epidote crystals.   The chlorite is paler in colour and the biotite and shows grey interference tints.   From larger masses fibrous processes pass into adjacent felspars.   Quartz, however, always cuts the chlorite fibres and is therefore later.

The biotite and chlorite are often nearly opaque, owing to a brownish-grey clouding, probably due to a fine dispersion of hydrated ores.   Definite characters are therefore impossible to determine.

Epidote is always of a cloudy, brown, granular variety. The true yellow colour and pleochroism can only be recognised under high-power.   Optical properties are difficult to determine.

Apart from the flaky chlorite pseudomorphing biotite, chlorite occurs as fibrous patches, having a replacing habit towards the surrounding matrix minerals.   Sometimes these form marginally on biotite-chlorite clots.   Occasionally plumose, fibrous aggregates of a plae green penninite are found.

Calcite is uncommon in this variety.   Its importance increases through the intermediate variety (d) to a maximum

in (e).

Tiny needles and basal sections of apatite are abundant.
They are especially frequent in biotite or chlorite-chlobite
clots, but are unusual in the felspars.

Variety (e):   (Plate IX, Fig. 1).

This is characterised by brown felspars, without sharp
edges, cleavages or cracks, as in variety (c).   The texture
is typically orthophyric.   No original biotite remains; ~~the~~
chlorites are clear and pale green in colour and calcite is
abundant.

The felspar is all either saussuritised or nearly entirely
albitised.   The final albitisation has developped along
twinning planes or slightly winding channels, evidently
replacing the confused "saussurite".

The chlorite is a clear, pale-green penninite with
abnormal blue interference tints and negative optical sign.
Often it has definite rectangular outlines, but if it be a
pseudomorph there is no evidence as to the identity of the
original mineral.   It is noteworthy that chloritisation
is not complete im the intermediate variety (d).

Epidote granules are abundant, both as an alteration
product of the felspars and as an associate of chlorite.

Calcite has a characteristically grey, cloudy appear-
ance; it is genmeally pseudomorphous after felspar, biotite
or chlorite.   In the intermediate variety (d) there are
calcite pseudomorphs in which residual fibres of biotite

and still remain.

Irregular grains and aggregates of quartz are abundant.
Often they appear to have apurely interstitial disposition,
but closer examination reveals lobate extensions into the
felspars or chlorite, transgressions across felspar laths and
penetrations along the cleavage planes in the felspars.
Calcite, however, is never affected by the quartz and is
therefore presumably of contemporaneous or later development.

Colourless needles of <u>apatite</u> are common throughout the
rock, enclosed by both felspars and chlorite.

The "Red Spot".

This is a patch of reddish material occurring in variety
(e) with a calcite-quartz infilling towards one side.   It
was in no way connected with vein material, since, when found,
the spot was entirely surrounded by normal dyke rock.

The spot shows striking replacement phenomena by albite
and quartz.   All the original felspar has been albitised
and radial sheafs of albite are common.   The spot is rimmed
by these sheafs, which often enclose lath-shaped pseudomorphs
of original felspar.   Quartz has also been an active
replacing mineral, occurring both interstitially and as
penetrations into the felspar laths.   Frequently, too, zig-
zag fingerings of quartz cut across the albite sheafs.

The infilling itself (see Pl. XI, fig. 1) consists of
chlorite, quartz and calcite, developed in that order from the
margins to the centre.   These minerals are surrounded by a

series of albite sheafs.   Each of these ~~the~~ minerals in turn shows replacement relations towards the earlier mineràl on the outer side and normal growth features towards the interior of the infilling.

The evidence for the order of replacement is as follows:

(i)   Calcite is latest, since it replaces both chlorite and quartz with development in each case of similar marginal textures.   The quartz appears to have straight edges inwards; actually, under high magnification, they are found to be minutely ragged and indented by calcite.   Towards the margins of the infilling (that is , where development was possible only by replacement), the calcite ceases to be optically continuous and is formed of patchy granules.

(ii)   Quartz is later than the chlorite and generally occurs between chlorite and calcite.   Inwards it has developed in tooth-shaped crystals; towards chlorite, however, it forms irregular patchy replacements which truncate the chlorite fibres.

(iii) Albite is replaced by chlorite and quartz, both of which cut across the albite sheafs.

Thus the order of mineral replacement is established:

I) Albite, ii) Chlorite, iii) Quartz, iv) Calcite.

The Significance of the Internal Modifications of Type III.

As regards the differences between varieties (a), (b) and (c) the controlling factor appears to have been distance from the margin, the effect of which on the course of crystal-

lisation has been a corresponding change from a porphyritic to a coarse-grained equigranular type of rock.

The relation between (c) and (e) is of quite a different nature, despite the fact that there is every gradation from one to the other. The main features distinguishing the extremes are:

(i) Marked differences in the felspars as regards degree of "definition", colour and intensity of alteration. The colour-change — from grey in (c) to reddish-brown in (e) — is probably due to hydration of disseminated iron-ores in (e). Moreover, original oligoclase remains only in (c), whereas in (e) a more advanced stage of alteration and replacement has been reached.

(ii) No original biotite remains in variety (e).

(iii) Variety (e) shows a much greater development of calcite.

It is therefore clear that variety (e) has suffered more severe hydrothermal alteration than (c). Nor can its position in the dyke be without significance. Just as (c) approaches nearer to the contact on the northern than on the southern limb of the dyke, so does the more altered variety (e). The latter thus occupies what may be termed the "genetic centre" of the dyke.

The process of hydrothermal alteration in this example is considered to be autolytic (see pp. 65-71). It is convenient at this juncture to summarise the implications of this hypothesis.

As the magma crystallised, water and carbon dioxide,

together presumably with some excess of soda, would become
concentrated in the still fluid portions, particularly in the
"genetic" centre of the dyke.   Eventually aqueous solutions,
containing sodium and carbonate ions and silica would remain.
First the silica and sodium assisted in the breakdown of the
plagioclase into albite and epidote, (Na Si) driving out (Ca Al).
At the same time hydration led to chloritisation of biotite
with release of iron-oxides, together with potassium.   The
latter would facilitate production of "sericite".   Later,
residual silica was deposited as quartz, initially in the
interstices and afterwards as replacements of such neighbouring
minerals as obstructed its crystal development.   Finally,
"carbonate" with released calcium formed the latest replacing
mineral, calcite.

The absence of any fine network of veins supports this
hypothesis of auto-alteration by residual solutions, since the
latter would already be widely dispersed throughout the
interior of the dyke.

The evidence of the "Red Spot" is also of significance,
since it appears to have been a centre of intense hydrothermal
alteration.   The red igneous material is probably only the
normal dyke-rock which has suffered extreme alteration and
replacement, the encircling rim of albite sheafs representing
the "fore-front" of this localised activity.   The calcite-
quartz-chlorite area is partly an infilling, towards the centre;
partly a replacement, towards the margins.   The order of
replacement in the "spot" and the order of infilling of the

cavity, both agree with the observed order of replacement throughout the dyke.

The "spot" therefore represents a centre of unusual concentration of volatile material, which, after the rock had crystallised, reacted with the primary minerals in the manner already outlined for the dyke as a whole.

Von Eckermann (1928) describes similar quartz or calcite infillings in a lamprophyre ("hamrongite") from near Gavle in northern Sweden.   Both these minerals also occur interstitially.

Miss Reynolds (1931) figures a drusy cavity, closely analogous to the "red spot", in a kersantite from the Ards Peninsula, Co. Down.   Here, calcite,the final infilling material, replaces both quartz and felspar.

It is significant, too, that it is the interior of the northern dyke (Type II), that shows the greatest alteration features.   Here again, veins along which hydrothermal solutions could have travelled from an external source, are extremely rare.   Quartz-albite nests, however, which appear to have the same significance as the "red spot", are common, and in the interior of the dyke are the centres of intense hydrothermal activity.

The analyses of varieties (c) and (e) shown on p. 44 serve to emphasise the soda-rich character of these rocks. The close similarity between the two analyses suggests that a molecular rearrangement would largely account for the mineralogical differences observed under the microscope.

MINERAL SUMMARY: TYPE III.

Primary Minerals:	Secondary Minerals:

Plagioclase: (Ab_xAn_y - Ab_wAn_{25})
 	
 Form: euhedral with sharp
 edges; smaller crystals
 rectangular.
Lamellar Twinning.
 	
Marginal Zoning occasionally.
 	
Extinction Angles:
      margins   centres
       7°   14°
Refractive Indices:
   α 1.540   1.545
   γ 1.548   1.553
Optic Sign: Negative.
	Alteration and replacement:
	
	 Frequently original felspar
	 remains unreplaced.
	"Kaolin" not abundant; cloudy
	               patches.
	"Sericite"; abundant flakes.
	Chlorite; greenish flakes and
	            fibres.
	Albite; clear, often untwinned;
	 frequently effects complete
	 replacement.
	Epidote; tiny granules.
	Quartz; irregular areas of
	        replacement.

Biotite: Green or brown colour. Ragged and fibrous; sometimes in clotted aggregates with ores. Often nearly opaque owing to clouding.	Extensive chloritisation together with granules of epidote and calcite. Quartz and calcite - indiscriminate replacement.

Accessories:
 	
      Black Ores;
      Apatite needles.	

Matrix: (where porphyritic) - contains abundant tiny felspar laths.	

(Analyses)

NO: 80.	CHEMICAL ANALYSIS:		NORMATIVE COMPOSITION:		CALCULATED MINERAL COMPOSITION:	
SiO_2	58.20	Quartz	8.39	Quartz	9.93	
Al_2O_3	17.08	Albite	52.27	Albite	55.53 } 56.87	
Fe_2O_3	3.07	Anorthite	3.26	Anorthite		
FeO	1.94	Corundum	3.94	Corundum	1.34	
MgO	4.82	Orthoclase	9.73	(Orthoclase)	9.73 } 27.96	
CaO	1.96	Hypersthene	10.29	Chlorite*	15.00	
Na_2O	6.18	Dolomite	3.13	Calcite	3.13	
K_2O	1.65	Magnetite }	4.34	Ores	4.24	
$H_2O^{-105°}$	0.40	Haematite				
$H_2O^{+105°}$	2.36	Ilmenite	1.74	Apatite	0.64	
CO_2	1.54	Apatite	0.64	Water	0.91	
P_2O_5	0.27	Water	2.76		100.46%	
TiO_2	0.92		100.49%			
MnO	0.15	SYMBOL:- II.(4)5.2.4.		†Quartz largely intergrown hence low modal value.		
	100.54%					

NO: 89.	CHEMICAL ANALYSIS:		NORMATIVE COMPOSITION:		CALCULATED MINERAL COMPOSITION:	
SiO_2	58.10	Quartz	7.28	Quartz	9.39	
Al_2O_3	17.38	Albite	51.02	Albite	57.70 } 68.74	
Fe_2O_3	2.49	Anorthite	6.68	Anorthite		
FeO	2.76	Corundum	3.14	Corundum	0.80	
MgO	4.10	Orthoclase	10.24	(Orthoclase)	10.24	
CaO	2.26	Hypersthene	10.84	Chlorite*	13.42	
Na_2O	6.03	Dolomite	1.90	Calcite	1.90	
K_2O	1.73	Magnetite	3.61	Ores	4.84	
$H_2O^{-105°}$	0.40	Ilmenite	1.96	Apatite	0.60	
$H_2O^{+105°}$	2.81	Apatite	0.60	Water	1.43	
CO_2	0.90	Water	3.21		100.32%	
P_2O_5	0.25		100.48%			
TiO_2	1.03	SYMBOL:- II.(4)5.2.4.				
MnO	0.19					
	100.43%					

‡Calcite largely as partial hence high modal value.

*Chlorite calculated as Penn formula:- $FeO.4MgO.3SiO_2.Al$

Analyst: A. Huddleston.

NO: (34. RED ROCK DYKE.

CHEMICAL ANALYSIS:

SiO_2	67.32
Al_2O_3	16.04
Fe_2O_3	0.41
FeO	0.98
MgO	1.48
CaO	2.02
Na_2O	5.06
K_2O	1.98
H_2O-	0.70
H_2O+	2.20
CO_2	1.38
TiO_2	0.32
P_2O_5	0.18
MnO	trace
	100.07%

Quartz	26.60	
Orthoclase	11.73	
Albite	42.76	}59.24
Anorthite	4.75	
Corundum	3.81	
Hypersthene	3.05	
Magnetite	0.60	}1.21
Ilmenite	0.61	
Apatite	0.34	
Calcite	2.89	
Water	2.90	
	100.04%	

SYMBOL:- I.4.2.4.

Analyst; W. H. Herdsman.

NO: 80.

CHEMICAL ANALYSIS:		NORMATIVE COMPOSITION:		CALCULATED MINERAL COMPOSITION:		MODAL (VOL.) COMPOSITION:	
SiO_2	58.20	Quartz	8.39	Quartz	9.93	†Quartz	3.3
Al_2O_3	17.08	Albite	52.27	Albite 55.53 }56.87		Felspars	65.0
Fe_2O_3	3.07	Anorthite	3.26	Anorthite		Biotite	
FeO	1.94	Corundum	3.94	Corundum	1.34	Chlorite }26.3	
MgO	4.82	Orthoclase	9.73	(Orthoclase) 9.73		Calcite	
CaO	1.96	Hypersthene	10.29	Chlorite* 15.00 }27.96			
Na_2O	6.18	Dolomite	3.13	Calcite 3.13		Ores, etc.	5.4
K_2O	1.65	Magnetite	4.34	Ores	4.24		100%
H_2O-	0.40	Haematite }					
H_2O+	2.36	Ilmenite	1.74	Apatite	0.64		
CO_2	1.54	Apatite	0.64	Water	0.91		
P_2O_5	0.27	Water	2.76		100.46%		
TiO_2	0.92		100.49%				
MnO	0.15	SYMBOL:-					
	100.54%	II.(4)5.2.4.					

†Quartz largely intergrown with Felspars, hence low modal value.

NO: 89.

CHEMICAL ANALYSIS:		NORMATIVE COMPOSITION:		CALCULATED MINERAL COMPOSITION:		MODAL (VOL.) COMPOSITION:	
SiO_2	58.10	Quartz	7.28	Quartz	9.39	Quartz	6.4
Al_2O_3	17.38	Albite	51.02	Albite 57.70 }68.74		Felspars	73.9
Fe_2O_3	2.49	Anorthite	6.68	Anorthite			
FeO	2.76	Corundum	3.14	Corundum	0.80	Chlorite	13.2
MgO	4.10	Orthoclase	10.24	(Orthoclase) 10.24		Calcite‡	6.6
CaO	2.26	Hypersthene	10.84	Chlorite*	13.42		
Na_2O	6.03	Dolomite	1.90	Calcite	1.90	Ores	3.6
K_2O	1.73	Magnetite	3.61	Ores	4.84		103.7%
H_2O-	0.40	Ilmenite	1.96	Apatite	0.60		
H_2O+	2.81	Apatite	0.60	Water	1.43		
CO_2	0.90	Water	3.21		100.32%		
P_2O_5	0.25		100.48%				
TiO_2	1.03	SYMBOL:-					
MnO	0.19	II.(4)5.2.4.					
	100.43%						

‡Calcite largely as partial pseudomorphs, hence high modal value.

*Chlorite calculated as Penninite, having formula:- $FeO.4MgO.3SiO_2.Al_2O_3.4H_2O$.

Analyst: A. Huddleston.

TYPE IV: (LEUCOCRATIC) ALBITE-PORPHYRY.

This type forms large, wall-like dykes, sometimes over 10 feet inwidth, always with well-defined straight margins. They are intruded parallel to the strike of the country rocks and their relations to the cleavage-planes are always discordant The large dykes at Red Rock near Balmae (south of Kirkcudbright) and on the eastern foreshore of Brighouse Bay, and several other strike dykes near Kelton Hill (three miles south-west of Castle Douglas) are typical examples.

The dyke at Red Rock has a width of approximately 30 feet and is well-exposed on the foreshore.   Inland, within 60 yards it is displaced south-eastwards by two small faults.   The displacement in each case is about the same as the width of the dyke.

The rock is homogeneous in appearance, of a pink or cream colour and has a flaky fracture.   Fine jointing, parallel to the dyke margins, is especially marked towards the contacts. Weathered surfaces show numerous small felspar phenocrysts. Calcite veins are common, sometimes penetrating the slates.

Petrography:

The rock is an interesting type inasmuch as almost all its recognisable constituents are albite.

The felspar phenocrysts occur as rectangular tablets, irregular or indented crystals, or glomero-porphyritic aggregates.   Genefally the degree of alteration is not

considerable; slight clouding and scattered flakes of a sericitic mica being usual.   Occasionally calcite has replaced patches of the felspar.

    Extinction Angles: $17° - 19°$.

    Optic Sign: Positive.

    Refractive Indices:

                    α 1.526

    (measured $\perp$ Y)

                    γ 1.536

Evidently the composition approximates closely to that of albite.

Mafic minerals are rare.   Original biotite has not been observed, but chlorite-"sericite"-calcite aggregates, having a form suggestive of pseudomorphs after biotite, are present.

The **matrix** is as pale as the felspar phenocrysts and its dem dominant constituent has a low refractive index.   It can largely be resolved even under the low power and consists principally of angular albite crystals, together with calcite, "sericite", and some chlorite.

Though there is nothing in the mode which can be identified as **Quartz**, the latter mineral forms no less than 26.6 per cent of the normative composition of the rock.

The **accessories** are a lustrous, pale yellow metallic sulphide, sometimes as relatively large crystals, and tiny needles of apatite.

MINERAL SUMMARY: **TYPE IV.**

Phenocrysts:	Matrix:
Albite: Form: euhedral tablets; angular fragments and aggregates. Extinction Angles: 17° - 19°. Refractive Indices: α 1.526 γ 1.536 Optic Sign: Positive. Alteration: slight - "Kaolin" mineral; "Sericite".	Dominantly Felspathic. Pale colour. Constituents: Micro- and cryptocrystalline Albite; Calcite, Chlorite and "Sericite".
Mafic Minerals: (rare) Chlorite-"Sericite"-Calcite pseudomorphs; (? after Biotite) Rare Epidote granules with chlorite.	

Accessories:
     Opaque yellow Sulphide Ores;
     Tiny Apatite needles.	

TYPE V: **PLAGIOPHYRES.**

These were encountered at Portling Bay, in the Rockcliffe district. Except for a relatively narrow belt, widening eastwards, in the neighbourhood of the high-water mark, the foreshore at Portling Bay consists of Carboniferous basement beds. A number of irregular dykes occur in the Silurian. In the central part of the bay, just below the road, there are outcrops of two plagiophyre dykes and one of xenocrystic type,

the latter being east of the others.

The plagiophyres have a dark, green or grey colour, with scattered pinkisk felspars and numerous fine joints.   Specks of pyritic ore are freely disseminated.   Felspathic veins and streaks are common, as well as irregular veins and impregnations of carbonates.

Petrography:

The dyke and veins will be described separately:

(a) Main-Dyke Plagiophyre:

The rock consists of about equal proportions of light and dark coloured minerals, with an evenly medium-grained texture and no groundmass.

The felspars are usually euhedral in form, ranging from rectangular tablets 1.0 to 1.5 mm. in length, down to small laths.   All crystals tend to be arranged in a decussate pattern, modified somewhat by the mafic minerals,   Whilst sometimes the "hornblende" pseudomorphs interrupt the regular form of the felspars, elsewhere laths of felspar penetrate the pseudomorphs or "control" their outlines.

Where not obscured by alteration, the felspars show excellent zoning and lamellar twinning.

The central zones have extinction angles of $18° - 19°$ and a refractive index higher than that of balsam, corresponding to sodic andesine ($Ab_{65}An_{35}$).   The margins have a lower refractive index than balsam and are evidently near albite in composition.

The cores of the crystals are often nearly opaque as a result of clouding by alteration products; marginally they may be nearly or completely fresh.   The alteration is of the saussuritic type, with abundant flakes of sericitic mica, rarer chlorite, clear albite and a dispersed brownish material, presumably a clay mineral.   Often, too, the central zones contain disseminated flakes of calcite, resulting in a grey clouding which"twinkles" on rotation in polarised light.

The _mafic_ minerals have been entirely replaced by chlorite. According to their form, pseudomorphs after hornblende and biotite can be recognised.   These diagnoses are supported by the fact that the chlorite replacing presumed hornblende differs from that after biotite.   The former always occurs as small green flakes and fibres, with an approach to parallel orient-ation; has a prussian-blue interference tint; and is associated with numerous tiny granules and granular aggregates of epidote and sparse ores.   The flakes are too small and felted for determination of the optic sign.

The chlorite after biotite has a clear emerald green colour, with rarer epidote and ores, and preserves the biotite cleavage.   It shows a rusty-brown or indigo interference tint, gives a positive optic sign and has an absorption formula $X=Y>Z$. These properties agree with those for positive penninite. Frequently it forms irregular patches with winding processes cutting indiscriminately across the felspars.   Here replace-ment has occurred at a late stage.

Accessories are _apatite_, inacicular needles, and sulphide

ores in numerous grains; both are included by all the other minerals.

Besides the minerals already mentioned, others occur which are characteristic of a hydrothermal assemblage; their development is probably related to the alterations which have affected the primary constituents.

Clear <u>albite</u>, distinguished by its refractive index, often free from twin-lamellae, is frequently moulded irregularly on the outer plagioclase zones; it may also enter into dentate intergrowths with quartz.   In one slide a thin albite vein (up to about 0.02mm. in width) replaces all the primary minerals in its course.   Occasionally calcite fills the vein for short distances.   When it passes through the hornblende pseudomorphs only some of the chlorite fibres disappear and those left have lost their ubiquitous epidote granules. Significant, too, is the fact that the clear patches of penninite cut across the vein and were therefore relatively later.   This is concordant with the relative order established between penninite and albite in Types II and III.

<u>Quartz</u>, though in part occupying the interstices of the felspar mesh-work also embays and sends fingering processes into the felspar laths.   Irregular crystals of quartz may lie right across the felspars or entirely within them.   As calcite alone is unaffected by the quartz it is presumably of later development.

Apart from the diffuse flakes in the felspars, <u>calcite</u>

forms clear, discrete crystals exhibiting replacement relations towards the earlier-formed minerals. Association with quartz and chlorite is common.

A micrometric measurement of one section (No. 27) gave the following mode (proportions by volume):

Hornblende pseudomorphs............29.1

Penninite, including
  pseudomorphs after biotite........18.3

Plagioclase....;.....................47.1

Quartz.............................. 2.8

Calcite............................. 4.0
                                    ─────
                                    101.3 %

(b) <u>Leucocratic Vein</u>: <u>Quartz-Plagiophyre</u>: (Pl. XII, Fig. 1).

The felspathic veins show a rather coarser and more even grain than the main rock. Felspars range in size up to about 2.5 mm. in length and the smaller crystals often have nearly square outlines. They exhibit characteristic euhedral outlines and show marked zoning. The central zones have extinction angles (about 15°) corresponding with calcic oligoclase.

The chlorite is all of the emerald-green, positive penninite variety, with associated epidote granules and black ore. Much of it is evidently pseudomorphous after biotite, the cleavage and general form of which are still preserved. Occasionally the chlorite occurs as elongated, straight or twisted crystals up to a millimetre or so in length and a small fraction of a millimetre in width. Penninite also occurs as irregular flakes and aggregates, with frequent fibrous processes

replacing surrounding minerals.

Albite forms irregular outgrowths from the plagioclases. Interstitial quartz embays the felspars, just as in the main dyke rock.   Calcite is frequent, usually in association with quartz.

The mineral composition and textures of this variety are thus very similar to those of the main dyke.   The relative proportions of the constituents are, however, widely different. Hornblende pseudomorphs are absent and penninite constitutes only about 9per cent.   Quartz has increased considerably, to approximately 10 per cent, whilst plagioclase, constituting most of the remainder, is also much higher.

Conclusions:

(a) Genesis of the Magmas.

The close similarity between the main dyke and its more leucocratic veins, in texture,and mineral composition and type of hydrothermal alteration, indicates an intimate relation between their respective magmas.   In each case the magma was endowed with the same tendencies during crystallisation, both as to the production of minerals and the development of textures. Crystal-sinking of the mafic constituents in situ to form the residual magma of the felspathic veins can scarcely be invoked, but the possibility must not be overlooked that the veining magma was the squeezed or drained out residual liquid from the main dyke after the latter had practically consolidated, the process taking place moree or less in situ.   The complete absence of former hornblende, reduction in the proportion of

"biotite" and increase of quartz seem favourable to this view. Against this mechanism may be cited the following points:

(i)   A residual liquid produced after most of the main magma had consolidated would be unlikely to deposit zoned plagioclase with central zones nearly as calcic as the crystals of the parent.

(ii) Although there is considerably more quartz in the leucocratic veins, albite has not increased in corresponding proportion.   A late magmatic liquid would theoeetically contain a higher ratio of albite to calcic felspar than that found.   Hence it is extremely unlikely that any process of crystallisation-differentation in situ could account for the proved facts.

It is presumed, therefore, that the leucocratic vein magma was differentiated by some mechanism operating in depth or by some syntectic-metasomatic process operating nearly in situ.   Of neither process is there any evidence and it would serve no useful purpose to speculate further.

(b) Hydrothermal Activity.

Both the dykes and the vein systems show identical hydrothermal textures, which are characteristic of the type, and in marked contrast to those of Types II and III.

It is quite evident that the group of hydrothermal minerals —— albite, chlorite, quartz and calcite — were most actively developed after the magma had practically consolidated. For even albite, the earliest hydrothermal mineral, forms veins with

sharp margins, pointing definitely to development in a solid medium.

Such activity is frequently regarded as having been effected by low temperature aqueous solutions, arising from some source in depth, after an indefinite pause succeeding complete consolidation.

If such were here the case it seems difficult to explain why the development of hydrothermal quartz, for example, is much greater in the veins than in the main dyke.

The facts suggest that the hydrothermal agencies were inherent in each initial magma and that early crystallisation gradually increased the concentration of "volatiles". (See further pp.65-71).

(c) <u>Nomenclature</u>.

Tyrrell (1912 - 13) suggested the term "plagiophyre" for rocks with the texture and appearance of orthophyres. Most of the features of the examples he described accord closely with those of the type here under discussion. "The rock consists essentially of euhedral plagioclase in short laths, with diverse, non-fluidal arrangement". The plagioclases are similarly "highly zonal" and have the same composition, whilst "chloritic decomposition products" and "iron-ores" occupy the interstices.

He also records a quartz-plagiophyre with an abundance of "interstitial euhedral quartz" and notes that the chlorite "has probably overspread its original euhedral boundaries" and "sends processes into the felspars".

The terms "plagiophyre" and "quartz-plagiophyre" appear, therefore, to be quite appropriate for the dyke-rock and the leucocratic veins, respectively.

MINERAL SUMMARY: TYPE V.

Primary Minerals:	Secondary Minerals:

Plagioclase: $(Ab_{65}An_{35})$
 	
  Form: often euhedral; laths
    and rectangles.
  Lamellar Twinning.
  Strong Zoning.
  Extinction Angles:
            18° - 20°.
  Optic Sign: Negative.
	Brownish clouding of "Kaolin"
	            mineral.
	Also;
	        "Sericite",
	        Rarer Chlorite,
	        Clear Albite, (moulded
	          on to outer zones)
	        Some Calcite.

Hornblende:
 	
  Pseudomorphs with hornblende
                form.
  (Absent from felspathic veins).
	Flakes and fibres of Chlorite
	  (prussian-blue int. tints)
	Much granular Epidote,
	Rarer Ores.

Biotite:
 	
  Pseudomorphs with biotite
              form.
	Clear green Penninite
	  (indigo-blue int. tints)
	  (positive sign).
	Rarer Epidote granules.

	Positive Penninite also oversteps "biotite" margins - and as irregular patches.

	Quartz: interstitial and
	  encroaching on felspars.
	
	Calcite: similar distrib-
	                (ution.

Accessories:
            Apatite needles;
            Black Ores and Pyrite.	

TYPE VI: XENOCRYSTIC VARIETIES.

A number of dykes occur in which the phenocrysts have an appearance and composition quite incompatible with their having crystallised directly and completely from the same magma as that forming the matrix.   The most striking occurrence is a dyke from the eastern end of Portling Bay, nine miles south-south-east of Dalbeattie.

The rock is markedly porphyritic in texture, with large phenocrysts of quartz, felspar and biotite in a fine-grained matrix.

Most common are large rounded tablets of or_t_hoclase , with a lower refractive index than that of balsam; many of these show simple twinning and somewhat wavy extinction.   Perthitic replacement by albite is frequent, and in some cases albitis-ation has proceeded until little orthoclase remains.   Large plagioclases, showing strong oscillatory zoning, occur in aggregates; the most calcic component ranges up to oligoclase-andesine in composition.

The quartz shows very striking resorption phenomena. Optically continuous, rounded relics of formerly continuous quartz crystals are now surrounded and penetrated by the matrix.   The matrix itself becomes modified against the resorbed margins, resulting in "apectral" zoning following the outlines of each individual.   (See Pl. XI, fig. 3).

Biotite also exhibits rounded outlines.   It is of a fawn-brown colour with a woody, fibrous cleavage and strong

pleochroism.   Partial or complete alteration to chlorite is
frequent.   Some chlorite-calcite pseudomorphs are, however,
more probably after hornblende.

The **matrix** has an indefinite, microfelsitic texture.
The poorly-formed felspars occasionally show lamellae and
always have refractive indices lower than that of balsam.
The presence of **albite** is therefore indicated.

Patchy **calcite**, oacasionally occupying vein-like channels,
has been a late replacing mineral, affecting biotite, felspar
and matrix alike.

Accessories are apatite and ores; both of which are
frequently included in the biotite.

The following features suggest that the rock is a
mixture of partly resorbed xenoliths and xenocrysts in a magma
which broke through a pre-existing plutonic or pegmatitic rock:
(a) The occurrence of xeno-porphyritic aggregates;
(b) The strong resorption xhmwx which shows that marked
   instability existed between phenocrysts and liquid;
(c) The occurrence of perthite, the crystallisation of which
   from a magma under hypabyssal conditions, such as doubtless
   controlled the consolidation of the matrix, would be unlikely;
(d) The occurrence of orthoclase, a mineral not found in any of
   the other types and therefore suspected to be foreign to the
   type in question.

In the Dalbeattie "granite" the following minerals have
been described, (M. MacGregor, 1936):
(i)   Plagioclase, with oscillatory zoning and composition

of oligoclase-andesine (average);

(ii) Microperthite;

(iii) Biotite: ragged crystals, often in clots with
hornblende and containing inclusions of apatite and
iron-ores;

(iv) Hornblende: common variety.

The similarity between these and the xenocrysts suggests that
the Dalbeattie granite or a similar rock might be looked to
as a source for at least some of the xenocrysts.[*]

The following order of degree of resorption can be
clearly made out in the rock under discussion:

1) Quartz - most;

2) Biotite;

3) Orthoclase and Perthite;

4) Plagioclase - least.

The matrix corresponds closely to a normal albitophyre.
Since it would naturally deposit albite, the above order can
be readily explained.   The outer zones of plagioclase would
be little affected, but orthoclase would tend to be replaced.
It seems not unlikely that at least some of the perthite was
formed in this manner.   To an even greater degree would
quartz depart from equilibrium, whilst biotite and hornblende
naturally became chloritised.   There would also be a quantity
of calcite replacing these minerals indiscriminately.

Original + Xenolithic ⟹ Matrix + Corroded and
  Magma   Material   Altered Xeno-
                                         liths and Xenocrysts

[*](Cf. Fenner 1933).

TYPE VII: LAMPROPHYRES.

A number of lamprophyres were briefly examined.   All those encountered form narrow, irregular dykes, a few feet in width, usually with intricate indented margins, and accompanied by numerous short apophyses and embayments into the slates.

In appearance they are all dark grey or greenish, fine-grained, compact rocks with abundant glistening flakes of mica. Calcite veins are always common.

All are mica-bearing, but under the microscope many show an extreme type of carbonate alteration, whereby their original characters are largely obscured.

Petrography:

A brief description will be given of one relatively fresh dyke from the right bank of the Dee estuary near Nun Mill. This is the southernmost of three lamprophyres intruded into Silurian grits and volcanic agglomerate.

In texture the rock is strikingly porphyritic with abundant phenocrysts of biotite and carbonate pseudomorphs after olivine.   The biotite is of a yellowish colour, but with a strong absorption parallel to X, of a deep fawn-brown. Hexagonal basal flakes are common, usually showing a number of concentric zones of deeper colour and giving a wavy extinction. Calcite filled veins and channels often penetrate the crystals. Silicified patches along the margins of the flakes are common.

Euhedral pseudomorphs, having the form of olivine, are

frequent (see Pl.XII,fig. 2). The edges are generally delineated by black ores, with carbonates occupying the interior. A staining test indicated that the carbonate is not calcite, but an iron- or magnesium-rich variety. Most of the carbonate has developed in minute flakes, having a general brownish coloration, but in places larger, colourless crystals are found.

The **matrix** is dark and cryptocrystalline, but shows numerous tiny shadowy laths of felspar. The latter are always too small and obscure to be determined optically.

Relations:

H. H. Read (1926) has shown, in Wigtownshire, that the mica-bearing dykes are restricted to the country south-east of a line from the Mull of Galloway to the neighbourhood of Creetown. A continuation of this line eastwards would leave the similar dykes of the Kirkcudbright area also to the south-east; they evidently belong to the same swarm.

CONCLUSIONS: AFFINITIES AND HYDROTHERMAL AGENCIES.

A characteristic and significant feature of Types II, III and V, especially as compared with Type I, is the striking evidence they exhibit of intense hydrothermal alteration and replacement. Although the altered types are distinguished among themselves by certain significant differences of texture, which, to some extent, correspond with differences of composition, they have, nevertheless, been afected by later agencies

which have produced a similar assemblage of minerals.

1).   Replacement Textures.

Gilluly (1932) adduces strong textural, mineralogical
and chemical evidence in favour of a replacement origin for the
albite in granites near Sparta, Oregon.   He shows that much
of the present albite has replaced original andesine and that
the rock as a whole is an albitised diorite.   Quartz has in
turn replaced albite, with development of textures which are
identical with those of the same two minerals in Types II and
III.   The following comparable observations by Gilluly may
be noted:

(i)   General saussuritic alteration of the felspar is
       characteristic.

(ii)   Clear albite replaces andesine as marginal coatings,
       penetrative veins and scattered patches.

(iii) Quartz replacements of albite vary from simple embay-
       ments to intricate pseudomorphs, in which only a mesh of
       albite remains.

(iv)   Rosettes and myrmekitic intergrowths of quartz and
       albite frequently surround albite crystals.

Gilluly cites a wealth of literature in which other examples
are described of replacement of plagioclase by albite and of
the origin of myrmekitic textures by replacement.

Gilson (1929) has shown replacement of plagioclase by
orthoclase and microcline in the Plioche District of Nevada.

Bailey and Grabham (1909) described albite replacement

of plagioclase in basaltic lavas of Carboniferous and Permo-Carboniferous age.

Fenner (1936) has recently described cases where replacement of plagioclase by orthoclase is actually being effected at the present day.   Dacites are being transformed into rhyolites by geyser emanations in Yellowstone Park.   Bore-hole evidence shows it to be a dynamic process in the course of which soda, displaced by potash in depth, is redeposited at higher levels, whilst steam alone escapes at the surface.

2). Mineral Assemblages.

The production of the final assemblage of minerals (albite, chlorite, epidote, quartz and calcite) is of such widespread occurrence as to suggest that it represents a stable, low-temperature mineral-facies.   It is highly signifiaant that this assemblage is frequently encountered in schists as well as in igneous rocks.

Eskola (1925) has listed characteristic series of assemblages in certain Fennoscandian schists.   The final changes under low-temperature metamorphism involves the transformations:

$$\text{Albite - Epidote - Actinolite,}$$
$$\downarrow$$
$$\text{Albite - Epidote - Chlorite - Calcite.}$$

In the schists of central and western Otago, New Zealand, Turner (1935) has observed the following change:

$$\text{Augite - Hornblende - Plagioclase,}$$
$$\downarrow$$
$$\text{Actinolite - Albite - Epidote - Chlorite.}$$

He concludes that such transformations are only possible at low grades in the presence of sufficient water and, when calcite occurs, upon the presence of an adequate concentration of carbon dioxide to combine with the lime set free during the chloritisation of amphiboles.   The occurrence in the hornblende pseudomorphs of Type II of actinolite (see pp. 23-24) is of interest in view of the assemblages cited above.

3). Mineral Transformations.

Some idea of the nature of the hydrothermal agencies may be gained from an analysis of the mineral transformations which have taken place in the breakdown of original constituents.

Brammall (1936) has demonstrated that such changes are more realistically shown by an atomic, rather than a molecular scheme.

One of the most characteristic changes of the types is the replacement of a plagioclase (oligoclase-andesine) by albite.   This involves the replacement of (Ca Al) by (Na Si). Since only about one-fourth of the original felspar was anorthite and, since sericite, kaolin (?) and, to a smaller extent, chlorite, epidote and calcite result from the mineral transformations, removal of Ca by the incoming of Na is not so complete as might appear at first sight.

The change hornblende→chlorite involves the release of Ca, Si and some Na and requires the addition of (HO) and, possibly some Al.   Chloritisation of biotite releases Si, K and possibly Al, and requires (HO).   The frequent association

of iron-ores with chlorite suggests that the Fe/Mg ratio may also be altered during the destruction of the original minerals.

Of the other new minerals formed, epidote takes up Ca and Al; sericite K, Al and (HO); and calcite Ca and (CO_3).
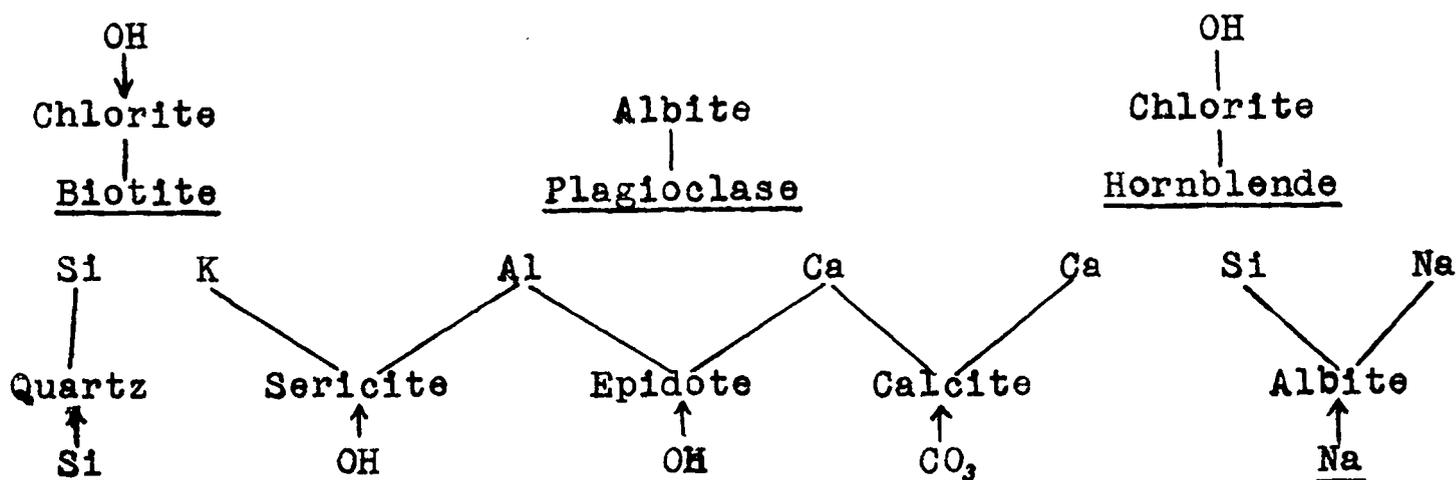
It appears probable, therefore, that to effect the breakdown of the original constituents and the production of many of the later minerals only HO and CO_3 were required. The compositions of the rocks are, however, all more than normally rich in Na and it is quite evident that for the considerable development of hydrothermal albite and quartz extra Na and Si must have been derived from a source other than that provided by the destruction of early-formed minerals. This aspect will be considered later in relation to the magmatic history of the intrusions (see pp. 65 - 72).

4). Order of Replacement.

From a detailed examination and comparison of the mode of occurrence of the replacing minerals a general order has been established (q.v. under separate descriptions). The following order has been found to hold, more or less consist-

PLATE IV.

Diagram illustrating Petrogenetic
Sequence, with particular reference to
Types III and V.

PLATE IV.
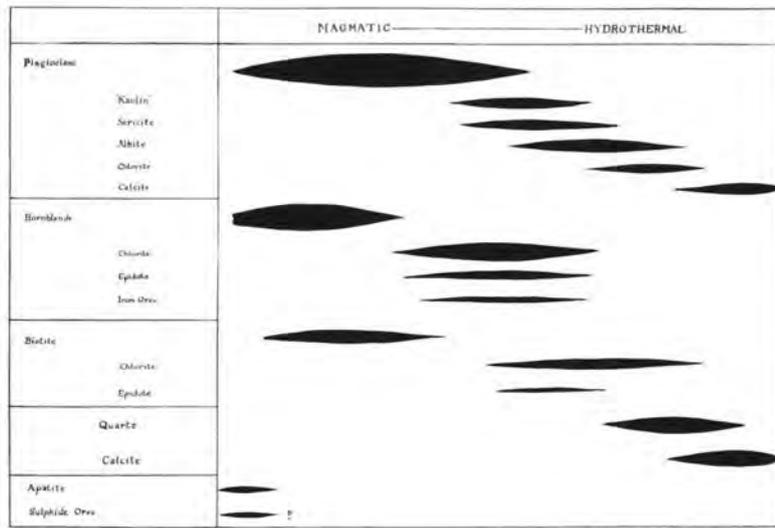
ently, throughout (a) individual dykes; (b) all dykes of one type; and (c) all the different types which show hydrothermal alteration:

(i)   Chloritisation of hornblende and biotite (epidote);

(ii) Albitisation (epidote);

(iii) Second period of chloritisation (probably continuous with the first);

(iv) Development of quartz; nests with albite;

(v)   Calcite replacements.

Considerable overlapping of the successive stages has undoubtedly occurred.   Thus albite entering into felspar replacements is earlier than that occurring in nests with quartz.   Similarly chloritisation commenced by pseudomorphing the original mafic minerals and then proceeded to develop more irregularly.   The hydrothermal sequence is represented diagramatically in Plate 1V.

5). The Spilite-Keratophyre Problem.

A close similarity exists between these rocks and those of the more acid members of the spilite suite.   The following characters are common to both:

(i)   A high content of soda;

(ii) The occurrence of albite as the dominant felspar, often showing clear signs of a late replacement origin;

(iii) Chlorite as dominant mafic mineral;

(iv) Abundance of epidote, associated with both chlorite and albite;

(v)   Abundance of calcite.

There has been, and is still, much controversy as to the source and nature of the albitising agents.

Eskola (1925) and more recently Gilluly (1932) have summarised the conflicting opinions relating to this problem, the main features of which will be indicated here.

Bailey and Grabham (1909) considered that albitisation was the work of residual solutions, that is , a process of auto-metasomatism. They contended that the original magma was abnormally rich in soda, carbon dioxide and water.

Dewey and Flett (1911), working on pillow-lavas, suggested that spilites were a distinct suite, associated with periods of subsidence without considerable folding. They conceived the albite to be often primary in the keratophyric types, but more generally due to "pneumatolitic emanations", rich in water, soda, silica and probably carbon dioxide.

Sundius (1915), from his work on the Kiruna greenstones, contended that alteration was due to "regional metasomatosis"; more recently (1930), he suggested that the spilites should be "distinguished as a special rock type", and maintained that the albite is of primary origin.

Wells (1922 and 1923) discussed the spilites and their associates and considered the "suite" to be established as a petrogenetic concept, particularly as these rocks are not commonly associated with basalts.

Eskola (1925) considered the albitisation as due to late residual fluids, rich in soda and silica, permeating

and replacing the consolidated magma.   More recently he has cooperated in an experimental investigation of the "spilite reaction" (Eskola, Vuoristo and Rankana 1935).   A generalised equation competent to represent the transformation is:

$$Na_2CO_3 + CaAl_2Si_2O_8 + 4 SiO_2 \longrightarrow CaCO_3 + 2 NaAlSi_3O_8.$$
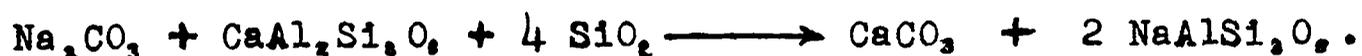
The problems are, therefore; (a) whether the albite and other characters are primary or due to later replacement; (b) whether the parental magma is distinct from the normal calc-alkali (basaltic) types or not; and (c) whether the chemical and mineral assemblages are essential features determined by the initial composition of the magma.   The possibilities may be summarised thus:

    1). Albite may be of primary origin;

    2). Albite may be due to later replacement, by the action of material from:-

        either (i) an internal source, i.e. from the immediate magma of the rock concerned, with or without extensive internal migration;

                (ii) an external source, i.e. from a regional deep-seated source.

In the case of Types II and IV there is no trace of an original, more calcic felspar, and all the available evidence suggests that the albite of the phenocrysts and the incipient crystals of the matrix were of primary origin.   At the same time clear albite, quartz and chlorite, all of obvious hydrotherma origin,are much in evidence.

The phenomena of Types III and V, on the other hand,

raise the question of the source of the albitising agencies, whether 2 (i) or 2 (ii).

On the triangular diagram (Pl.XIII) points have been plotted to represent the relative proportions of mafic oxides, alkalies and lime for representative spilites, albite-diabases and keratophyres.   Points representing various basalts, porphyrites and andesites are added for comparison.   Significant fields have been enclosed by lines.   A continuous gradation is demonstrable from basalts to spilites and albite-diabases, and from andesites and porphyrites to keratophyres.   Similarly spilites and albite-diabases clearly grade into keratophyres. It should be noted, however, that a marked overlap occurs between the fields of the latter groups; this was also disclosed when alkalies and lime were plotted against either silica or the ferromagnesian ratio.   Clearly then some confusion has occurred in the discrimination between spilites (and albite-diabases) and keratophyres, and the ranges of the two appear to require more exact definition.   From the diagram it is also evident that the sodic character of the spilite-keratophyre rock group is both marked and fundamental.

Gilluly (1932) has criticised the method adopted by Sundius (1930) of selecting analyses to establish a hiatus between spilites and more normal basalts.   It is difficult to understand why so much emphasis should be laid on the presence or absence of such a hiatus as evidence for or against the indepence of the spilites as a group.   All gradations exist between boys and men, yet their individuality remains

unquestioned.   Whether spilites were produced from normal
basalts by albitisation or consolidated from distinct magmas,
intermediate types would be expected.   In the one case
$Na-H_2O-CO_2$ emanations are added to magmatic material after its
consolidation; in the other they were present in the magmatic
material before its consolidation.   The real problem is the
source of these "emanations".

Gilluly (1935) has advanced a number of arguments with which
an autolytic explanation has to contend.   He casts doubt upon
the contention that "although the aggregate magma was more than
usually sodic, it did not make the primary felspar as sodic as
possible, but retained the alkalies in solution to low temper-
atures".   Surely if this were impossible, zoned plagioclases
could never be produced during the course of a crystallising
magma.

A more important, but purely theoretical criticism lies
in what Gilluly calls "the quantitative difficulty".   He
demonstrates that the volume of "residual self-contained
solutions" required to alter an original more calcic rock,
would be out of all proportion to the volume of the original
magma, and that, "if entirely indigenous", such solutions
"would be expected to be revealed by vugs, comby cavities and
other evidences of the volume they occupied while the rock was
consolidating".   To support this view, he compares the
composition of a "pre-spilite" (basalt) with an albite-diabase,
and shows that, assuming normal solubilities in an aqueous
medium, that the solutions required would occupy 50 per cent

of the volume of the rock.   By employing the analysis of a
basalt to represent the "pre-spilite" of his calculations, he
makes the implicit assumption that crystallisation of the rock
would have led to the formation of basaltic minerals before the
residual solutions had affected it.   Moreover, there is
no justification for the explicit assumption that the active
agents were aqueous solutions of laboratory type.   The
existence of residual solutions commences with the beginning
of crystallisation and their reaction with the early-formed
crystals is not restricted merely to one definite stage
towards the end of consolidation of the rock.

As regards the albitic rocks of Kirkcudbrightshire, it
has been shown (pp. 63 - 64) that no drastic amounts of intro-
ductions in solution would be necessary to alter the original
constituents.   These, in fact, could readily be altered by
the continued solvent and subsequent precipitating action of
relatively small quantities of water and carbon dioxide,
together with some silica and soda.   It is the quartz, albite
and calcite of the "nests" and interstices that exhibit the
most striking display of hydrothermal crystallisation, and
where, moreover, there is every reason to regard the develop-
ment of these minerals from residual solutions as almost
certain.

It has perhaps been too readily assumed by many
petrologists that the nature of hydrothermal solutions is
entirely different from that of the original magma.   A
sudden and drastic change, from magmatic to post-magmatic

conditions, is often inherently implied.   It is, therefore,
especially noteworthy that particularly in the case of the
plagiophyres (Type V), it is extremely difficult to decide
where a distinction is to be drawn between late-magmatic and
"post-magmatic" (hydrothermal) activity.   (Cf. Krokstrom, 1936,.

Against the application to the present rocks of the
hypothesis of wide-spread hydrothermal solutions permeating
the rocks after consolidation, and derived from some hypo-
thetical source in depth, are ranged the following points:

(i)   Apart from occasional calcite veins, which extend for
short distances from the dykes, the country rocks are
unaffected by hydrothermal agencies, beyond the usual
modifications for a few inches outside the dyke-margins.

(ii)   Examples of both relatively fresh and intensely altered
dykes may occur within a few feet of each other.

(iii) The unaltered dykes invariably xkmmx have textures quite
distinct from those showing hydrothermal alteration.
This suggests that the latter are not merely modified
varieties of a normal type.

(iv)   The larger dykes which have been examined in detail
disclose evidence of a definite relationship between
distance from the dyke-margin and degree of hydrothermal
alteration.   This strongly suggests that hydrothermal
agencies were inherent in the magma of each individual dyke.

The evidence thus consistently suggests that a process of
"autolysis" (auto-metasomatism) was responsible for the
characteristic hydrothermal features of the altered types of

intrusives in the Kirkcudbright area.

ACKNOWLEDGMENTS.

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ANALYSES EMPLOYED IN PLATE XIII.

Andesites:	Analyst:	Reference:
1. Hornblende andesite, O. R. S. lava, Cheviots.	J.S.Grant Wilson	Guppy, Eileen M., "Chem. Analyses of Igneous Rocks, Metamorphic Rocks and Minerals". Memoirs of the Geological Survey. 1931, p. 45. No. 169.
2. Andesite, O. R. S. lava, Cheviots.	J.S.Grant Wilson	Guppy, Eileen M., idem. p. 46. No. 171.

Porphyrites:

3. Hornblende porphyrite, O. R. S. dyke, Argyllshire.	E.G.Radley	Guppy, Eileen M., idem. p. 38. No. 142.
4. Q-diorite-porphyrite, Pre-Cambrian(?) intr. Leicestershire.	E.G.Radley	Guppy, Eileen M., idem. p. 38. No. 146.

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6. Basalt, Tertiary lava, Mull.	E.G.Radley	Guppy, Eileen M., idem. p. 65. No. 244.

Keratophyres, etc.

7. Average Keratophyre		Johannsen, A., idem. ,p. 511.
8. Keratophyre, Pre-Devonian (?) sill, Cornwall.	W. Pollard	Guppy, Eileen M., idem. p. 85. No. 326.
9. Keratophyre, Pre-Devonian sill, Cornwall.	E.G.Radley	Guppy, Eileen M., idem. p. 85. No. 327.
10. Albite-trachyte, Ordovician lava, Skomer Is., Pembroke.	E.G.Radley	Guppy, Eileen M., idem. p. 85. No. 328.
11. Q-albite-granophyre, Carrock Fell.	H.F.Harwood	Holmes, A., Geol. Mag. Vol. IV. 1917., p. 406. No. 639.
12 Albitophyre, & 13. Tongland, Kirkcudbrightshire.	A. Huddleston	(Present Work, p. 44).

Spilites:

14. Spilite, Pre-Camb. lava, Argyllshire.	E.G.Radley	Guppy, Eileen M., idem. p. 83. No. 315.

15. Spilite,
    Pre-Camb.(?) lava,
    Argyllshire.
	E.G.Radley	Guppy, Eileen M., idem.
		p. 83. No. 316.

16. Spilite,
    Ord. lava,
    Cornwall.
	E.G.Radley	Guppy, Eileen M., idem.
		p. 83. No. 318.

17. Spilite,
    Ord. lava,
    Ayrshire.
	J.J.H.Teall	Guppy, Eileen M., idem.
		p. 84. No. 320.

18. Spilite,
    Lava,
    Aunus.
	P. Eskola	Eskola,P. "On the Petrology
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		Basic Rocks in the Karelian
		Formations." Fennia, Vol. 45.
		N:o 19. 1925. p. 13.

19. Spilite,
    Intrusion,
    Aunus.
	P. Eskola	Eskola, P. idem. p. 19.

20. Spilite,
    (Albite-Hornblende
           Rock)
    Aunus.
	P. Eskola	Eskola, P. idem. p. 24.

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23. Albite-diabase,   B.E.Dixon   Guppy, Eileen M., idem.

    Palaeozoic intrusion,   p. 81.   No. 309.

    Cornwall.

24. Albite-diabase,   W. Pollard   Guppy, Eileen M., idem.

    Palaeozoic intrusion,   p. 81.   No. 310.

    Cornwall.

25. Albite-diabase,   E.G.Radley   Guppy, Eileen M., idem.

    Palaeozoic sill,   p. 81.   No. 313.

    Devonshire.

26. Albite-porphyry   W. Herdsman (present work p. 44).

PLATE V.

Fig. 1.   Diorite-porphyrite (Type I) illustrating
Plagioclase, Hornblende and Biotite
phenocrysts: matrix conventional.
(Diameter of field - 2.25 mms.)

Fig. 2.   Albite-porphyrite (Type II) illustrating
texture of porphyritic variety.
(Diameter of field - 2.25 mms.)
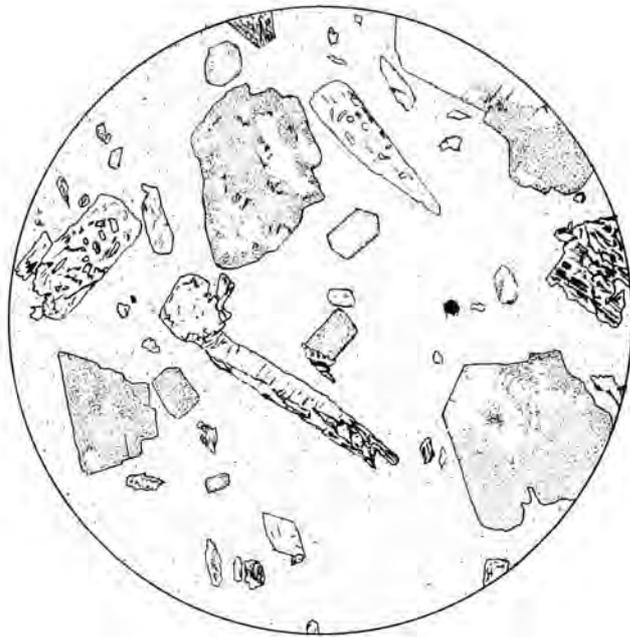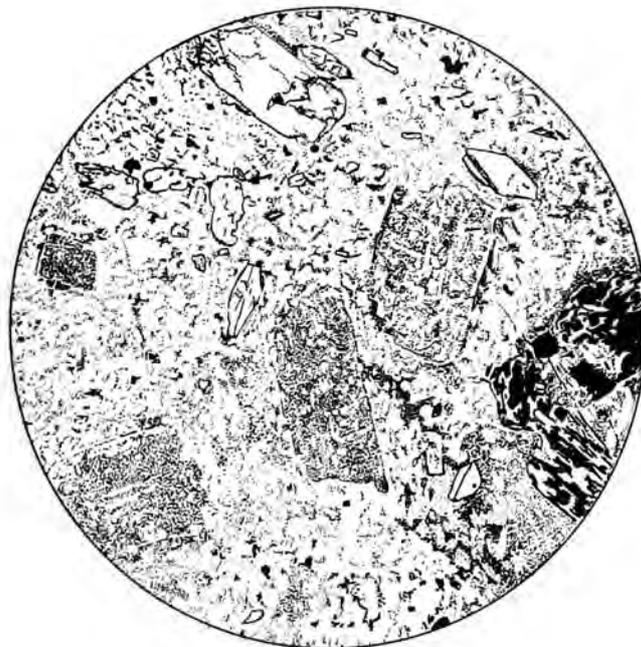
PLATE V.

Fig. 1.

Fig. 2.

PLATE VI.

Fig. 1.   Albite-porphyrite showing outlines of
Albites in marginal variety.
(Diameter of field - 2.25 mms.)

Fig. 2.   A,B and C are Quartz-Albite "nests":
A and C show radiating-fibrous Epidote.

D is an Epidote (fibrous) and Chlorite
pseudomorph after Hornblende.

E is a partial pseudomorph in Chlorite
showing residual, optically-continuous
Hornblende.

PLATE VI.
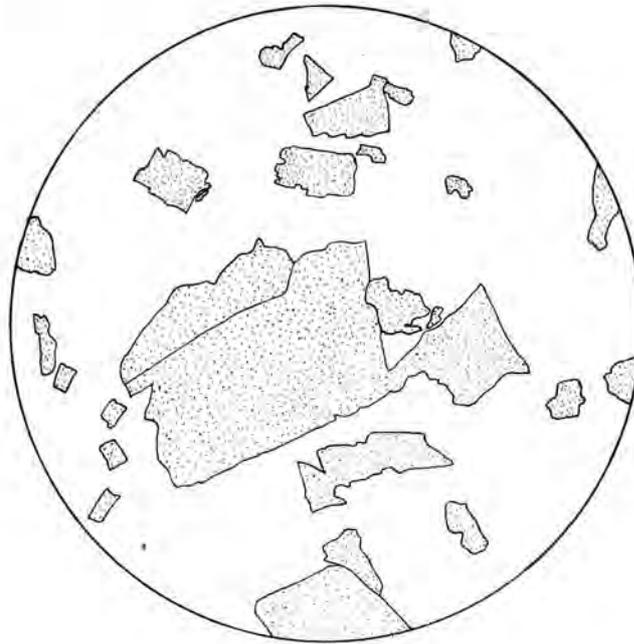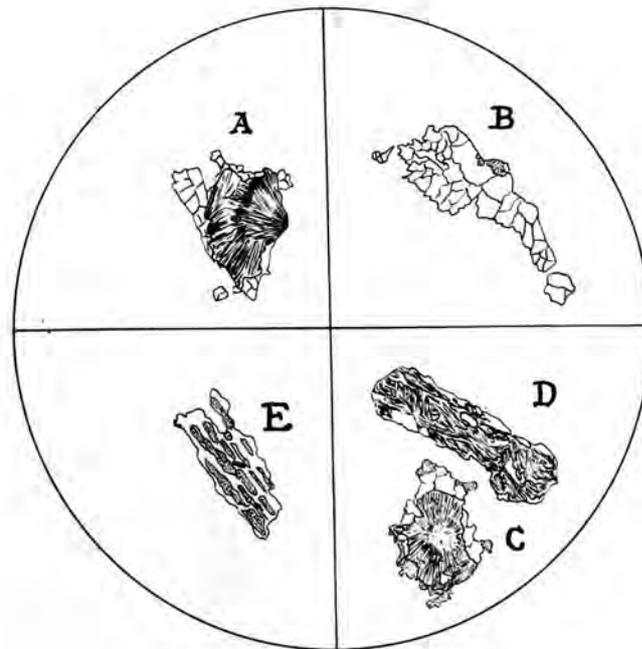
Fig. 1.

Fig. 2.

PLATE VII.

Fig. 1. Typical "Myrmekite" in Albite-porphyrite
          (slide 102).   Micro-photograph.
          (Diameter of field - 0.70 mm.)

Fig. 2.   As above: (diameter of field - 0.35 mm.)

PLATE VII.

Fig. 1.

Fig. 2.

PLATE VIII.

Fig. 1.   Albitophyre (Type III) showing texture.
    (Diameter of field - 2.25 mms.)
        Variety (a).

Fig. 2.   Albitophyre (Type III) showing texture:
    (Diameter of field - 2.25 mms.)
        Variety (c).

PLATE VIII.
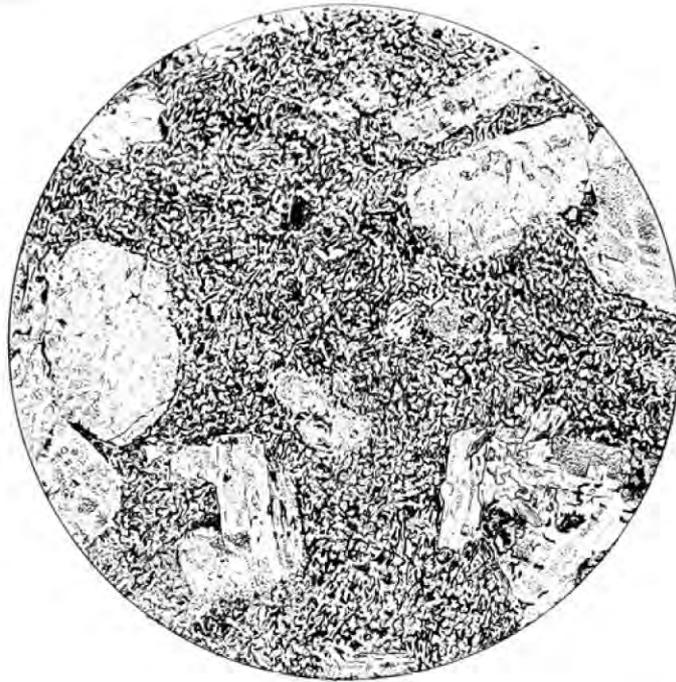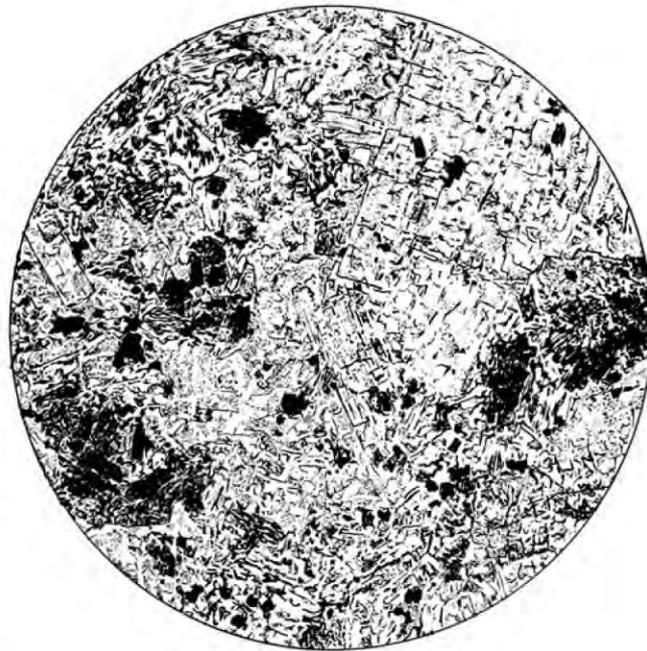
Fig. 1.

Fig. 2.

PLATE IX.

Fig. 1.   Albitophyre; variety (e) showing texture:

colourless areas are of pale green penninite.

(Diameter of field - 2.25 mms.)

Fig. 2.   Albite-porphyrite (Type 11) from near

Argrennan Mains, showing "riddled" felspars.

(Diameter of field - 2.25 mms.)

PLATE IX.
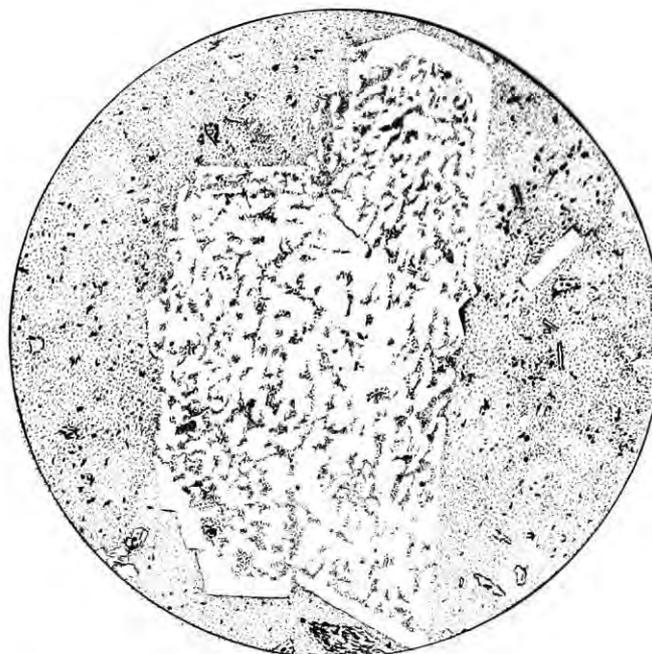
Fig. 1.

Fig. 2.

PLATE X.

Fig. 1.   Chlorite-Albite "Clot":

    A: Diameter of field - 2.25 mms.)

    B: Diameter of field - 0.40 mms.

Fig. 2.   Albite (unshaded) and Epidote replacing

Oligoclase-Andesine.   Much "sericite"

and Chlorite (both as minute flakes)

omitted.

(⅛th. inch objective employed).
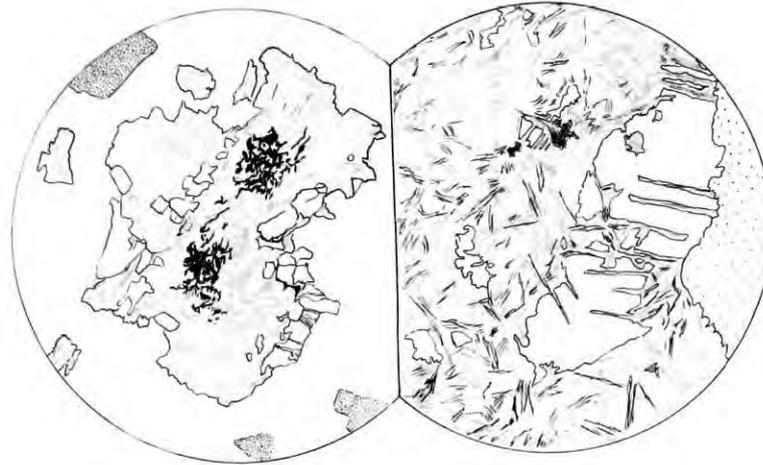
PLATE X.

Fig. 1.

A.   B.

Fig. 2.
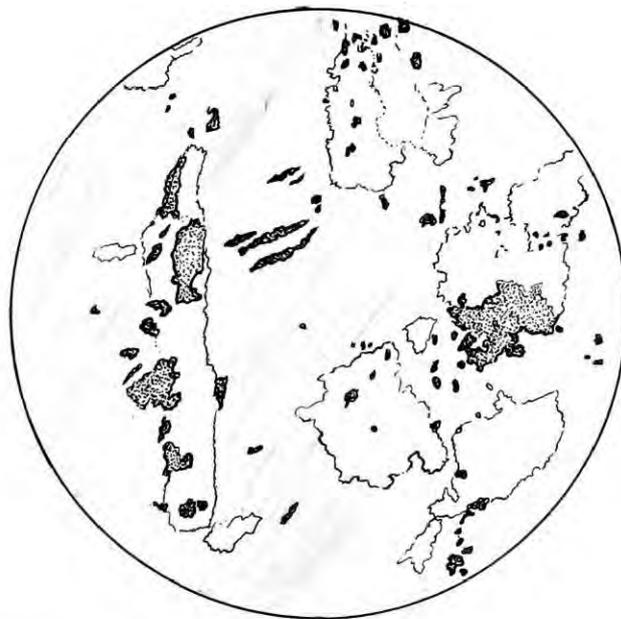
PLATE XI.

Fig. 1.   A: Minerals of Infilling: (diameter of
           field - 2.25 mms.)
           (a) Albite (near margins of field), with
               "sheaf" habit;
           (b) Chlorite (dark and flaky);
           (c) Quartz (unshaded or even grey), with
               "toothed" habit;
           (d) Calcite - final infilling.

           B: Albite (with sheaf habit) penetrated by
           Quartz (unshaded). (Diameter of field
           - 0.40 mm.)

           C: Calcite (unshaded) replacing Quartz
           (light shading) and Chlorite (fibrous).
           (Diameter of field - 0.40 mm.)

Fig. 2.   A: Albite (unshaded) replacing Oligoclase-
           Andesine: chlorite and epidote also indicated.

           B: Quartz (light stippling) replacing Albite
           and Chlorite (darker shading).

           C: Quartz (unshaded) replacing Albite with
           "myrmekite" texture. Partial pseudomorph of
           Albite by Quartz shown.   Epidote, Chlorite
           and "Sericite" stippled.

Fig. 3.   A: Strongly resorbed crystal of Quartz.

           B: Rounded Biotite crystal: margins are
           chloritised and flakes of chlorite have
           developed beyond rounded margins of Biotite:
           Calcite has effected replacement along
           cleavage-traces.

           C: Outline drawing of portion of a xeno-
           porphyritic aggregate of Plagioclase crystals.
           (Diameters of fields - 2.25mms.)
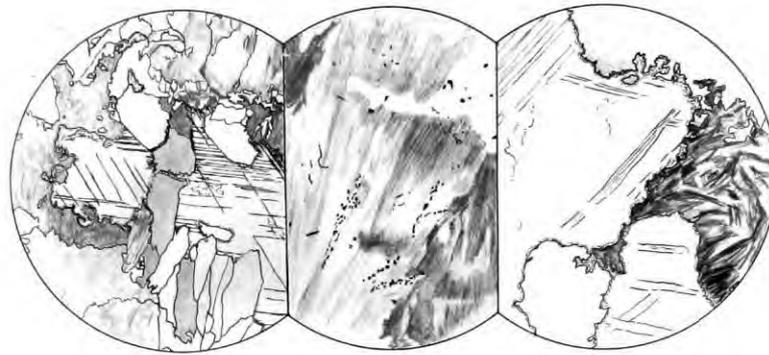
PLATE XI.

Fig. 1.
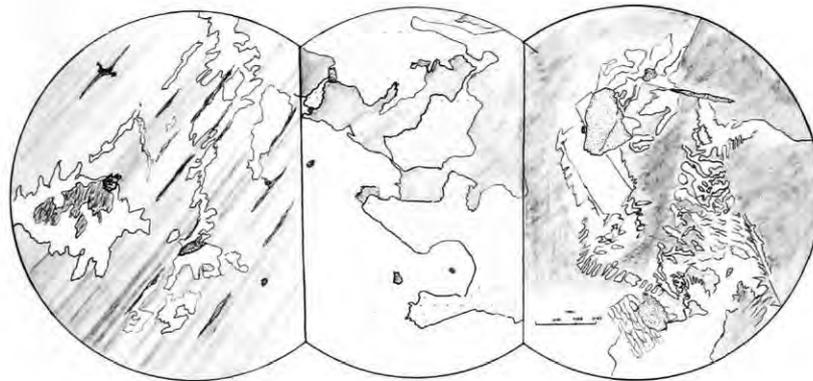

A.   B.   C.

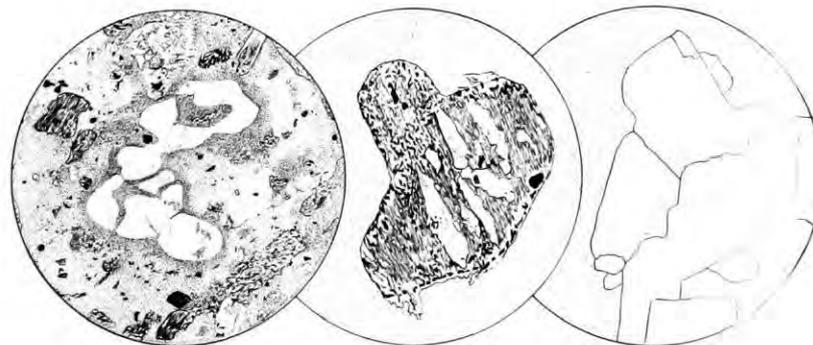Fig. 2.

A.   B.   C.

Fig. 3.

A.   B.   C.

PLATE XII.

Fig. 1.   Quartz-plagiophyre (Type v):

Quartz (Qu) and Albite (Ab) are indicated.

(Diameter of field - 2.25 mms.)

Fig. 2.   Large basal flake of Biotite, showing

slight marginal zoning, and carbonate

pseudomorph after olivine.   From

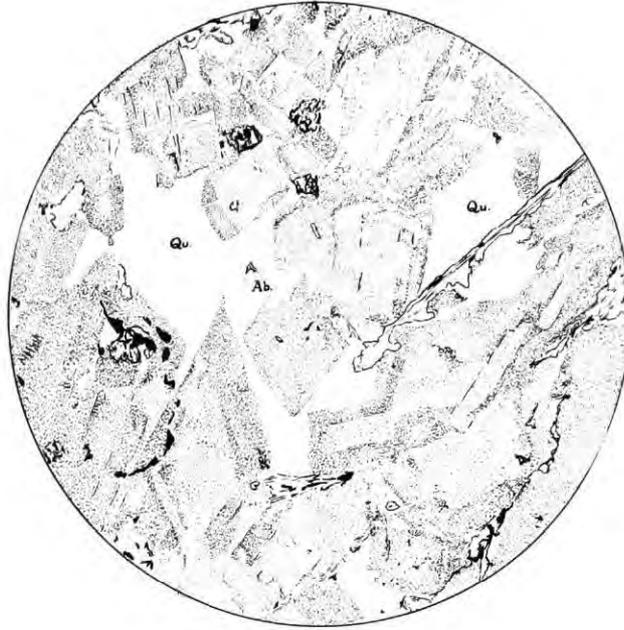Lamprophyre (near Nun Mill).

(Diameter of field - 2.25 mms.)

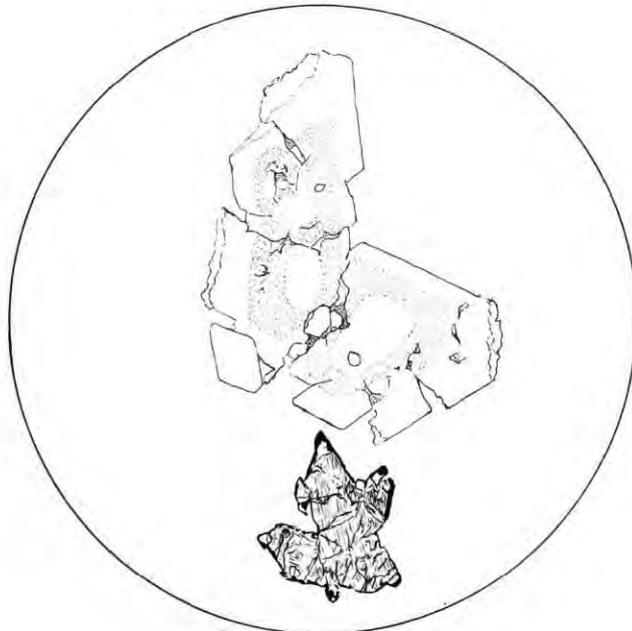PLATE XII.

Fig. 1.

Fig. 2.

PLATE XIII.

Triangular Composition Diagram illustrating
relations of Spilite-Keratophyre suite to
corresponding calcic rocks (Basalts, Andesites,
etc.,).

12 and 13 are from the analyses of
Albitophyres shown on p. 44 (Type III).

26 is from the analysis (p. 44) of the
Albite-porphyry (Type IV) at Red Rock.

References to the other analyses employed
are given in the Appendix, p. 76.

PLATE XIII.