THE GEOLOGY OF THE HIGHLAND BORDER

FROM TAYSIDE TO NORANSIDE.

by

DOUGLAS ALEXANDER ALLAN, B.Sc., Ph.D.

VOLUME II.

SECTION IX.

GENERAL ACCOUNT of the SEQUENCE and STRUCTURES.

Having described the nature and arrangement of the different varieties of rocks and the major disloca--tions to which they have been subjected, it is now possible to consider the sequence and general structures along the Highland border. The rocks fall into three groups; the Dalradian phyllites, schistose grits, and quartzites; the Highland Border Rocks, graphitic shales and grits, probably including the serpentine--schalstein complex; and the Lower Old Red Sandstone sandstones, conglomerates, and lavas. Scanty evidence has been obtained of a discontinuity between the first and second named groups in the Prosen section and further to the north-east they are probably bounded by faults. The junction between the Old Red Sandstone rocks and those of the Highland Border Series is apparently a reversed fault, while the younger series lies with a strong unconformability on the Dalradian schists wherever the boundary is not a plane of disloca--tion. The two older groups having been implicated in the Caledonian folding movements, it is with the/

the structures of the Lower Old Red Sandstone rocks
that this investigation is most concerned.

The lowest beds are the phyllite conglomerates
of the upper Ericht, (Pl. VIII., fig. 3.), which are
overlain locally by other conglomerates of a more
mixed Highland assemblage, by thin micaceous, red
sandstones, and bedded, fine-grained tuffs.   These
pass upwards into a microporphyritic olivine-basalt
seen on the Ericht below Old Milton of Drimmie and in
the outlier among the Dalradian schists in the Burn of
Watersheal, which is proof of an originally much wider
spread of lavas than remains to-day.   What is possibly
the same flow is exposed south of Balintore where,
however, it is underlain by a porphyritic pyroxene-
-andesite not found in the other sections, but which
may not have extended so far to the south-west.   The
succeeding beds as exposed appear to be fine-grained
biotite-andesites with some conglomerate bands and
occasionally beds of sandstone.   The next outstanding
horizon is formed by the Lintrathen type dacite which
outcrops at Craighead and again at Pitewan, showing
the repetition also found in the underlying acid
andesites and due to the N. E. - S. W. fault, which
runs/

runs from Craighall on the Ericht to the neighbourhood of Balintore, the beds dipping to the south-east while the fault, which is a normal one, throws down to the north-west. The highest bed exposed is an olivine--basalt overlying the dacite.

The boundary of this northerly area of Lower Old Red Sandstone rocks starts from the neighbourhood of Bridge of Cally and can be traced with a general north-east direction to the valley of the R. Prosen, where it apparently fuses with the more northerly thrust described in Section VIII of this paper. While the mapping and also occasional references to the district in Sir A. Geikie's "Ancient Volcanoes of Great Britain" suggest that this junction is an unconformity, a detailed petrological examination of the rocks to the south has demonstrated an abrupt truncation of different members of the lower lava flow sequence which is only compa--tible with the presence of a line of fault. As brecciation of any kind is conspicuous by its absence, it is probable that we have here a normal fault with the downthrow to the south-east.

In the district between the two thrust planes the main structure is a syncline elongated parallel to the/

the lines of dislocation, and rising to the north-east.
The lowest beds are sandstones underlying the dacite,
exposed in the Isla section and again above the Prosen
near Pearsie.   While the dacite is in the main confined
to the lower parts of the syncline in the north-east, it
is again met with at Tamhingan near the Tay, where only
a short distance separates it from a higher pyroxene-
-andesite group.   The porphyritic biotite-andesite
overlying the dacite is seen in the Isla section.   The
exposures of olivine-basalt associated with these two
acid rocks are curiously irregular in their development,
being seen in the north near Garlow, in the Isla gorge,
near Fyall, and also north-east of Tàmhingan.   Above
is the widespread conglomerate charged with boulders of
highly acid volcanic rocks as well as basic ones.
Towards the south-west the higher horizons show an in-
-creasing percentage of basic igneous rocks and inter-
-calated among them is a group of microporphyritic
pyroxene-andesites and olivine-basalts.

In the vicinity of the Ericht a secondary
anticlinal fold has been truncated by the dip fault
already mentioned leaving a greater extent of lava out-
-crops on the upthrow side to the east while on the
downthrow/

downthrow side the overlying conglomerates are exposed.
These beds, which contain more basic igneous material
than the underlying ones, constitute the highest group
of rocks seen on the north side of the main Highland
Boundary Fault.   On the south side of that line the
sequence opens with a group of porphyritic pyroxene-
andesites capped by one or more flows of olivine-basalt.
While to the south-west of the Isla these rocks are lost
against the Boundary Fault, a small faulted area occurs
south of Blairgowrie, and they reappear at Stenton on
Tay.   North of the Isla, for a large part of their
outcrop they show a steep anticlinal fold between the
main Strathmore syncline and the Highland Boundary
Fault.   Although they are lost against this fault yet
again in the vicinity of the S. Esk they reappear in a
somewhat attenuated form along the south side of the
Den of Ogil, being there represented by olivine-basalt
only.

The succeeding basic volcanic conglomerate
can be traced for sixteen miles north-east of the Isla,
and the sandstone which overlies it can be followed for
an even greater distance, several quarries marking the
outcrop./

outcrop.   The highest conglomerate with quartzites
and schistose grits gives rise to a ridge from the south
of Blairgowrie to the Hill of Ogil, a distance of some
twenty-five miles.   These beds all dip south-east into
the Strathmore syncline, the centre of which is occupied
by a series of well-bedded, red sandstones, overlying
the last mentioned conglomerate.   The dips near the
Highland Boundary Fault are about 70°;   a mile-and-a-
half away the dip is barely 40°.   In the highest sand-
-stones the dip approaches, but is rarely less than,
20°.   As the strata on the opposite side of the syncline,
often barely a mile to the south-east, are inclined at
an angle of 5° - 10° the fold has a steeper limb on the
west than on the east, as has been described from
Kincardineshire to the north.[*]

It is unfortunate that there is no strati-
-graphical horizon on the north side of the main High-
-land Boundary Fault which can be compared directly
with any on the south side, for there is thus a gap in
the sequence reconstructed above.   The highest lavas
to the north are pyroxene-andesites as are the lowest
ones/

* R. Campbell, Trans. Roy. Soc. Edin., Vol. XLVIII.,
    (1913), p. 958.

ones to the south of the fault, but the northern ones
are microporphyritic while the southern ones are
strongly porphyritic. The conglomerates on the north
side contain acid as well as basic volcanic rocks, while
those to the south are practically devoid of anything
but basic rocks.   As the lower conglomerate horizons
on the north side are increasingly acid, the general
trend in the direction of an increasingly higher con-
-tent of basic igneous rock boulders is continuous across
the fault line.   The olivine-basalts associated with
the pyroxene-andesites are similar on the opposite
sides of the fault.

The only feature of the tectonics still
calling for attention is the development of a series of
strike faults with a general N. - S. orientation.   The
most important one, running from Craighall to Balintore
has been mentioned already.   There are others,
apparently extending for much shorter distances, in the
vicinity of Bridge of Cally, Lintrathen Loch, and the
Knock of Cortachy.   They are probably of later forma-
-tion than the major S.W. - N.E. dislocations, and as
they seem to be normal faults they may represent the
phase/

phase of tensional relief subsequent to that of
compression.

The interpretation of the major vertical
variation is a comparatively straightforward one.   The
lowest conglomerates indicate the denudation of a
region of Highland schists and over them spread flows of
acid andesites together with a few olivine-basalts.   The
succeeding conglomerate represents the wastage of a
district of volcanic rocks presumably overlying a Dal-
-radian schist floor, and the variety of igneous material
must reflect a corresponding variety in the composition
of the lava flows from which it was derived.   Had the
fragments come from one or more intrusions the ratio of
pebbles of non-igneous country-rock to those of igneous
origin would have been very much greater than is the
case.   It is not certain that these highly acid lavas
were of Old Red Sandstone age, but if they occurred in
Pre-Old Red Sandstone times it is curious that no frag-
-ments of them are present in the lower conglomerates.

The succeeding lava flows of andesites and
basalts are associated with conglomerates in which the
acid igneous rock content steadily diminishes, until in
the/

the highest volcanic conglomerate only basic rocks are represented. The basic material in these boulder beds is closely akin to that of the intercalated lava flows from the northward continuation of which in all proba--bility it was derived. On account both of this affinity between the lavas and the waterworn pebbles, and the general freshness of the material of these con--glomerates, it is suggested that the later denudation of the basic igneous rocks indicates the removal of a group of flows poured out after the underlying acid volcanic rocks had been completely eroded away, and not that the processes of weathering had cut down to a horizon underlying that of the acid rocks. Practically conclusive evidence to this effect lies in the absence, so far as is known, of similar basic andesites from the lower conglomerates.

The highest conglomerate with its scanty igneous content and its abundant quartzites and schis--tose grits suggests the almost complete removal of the lava cap with the re-exposure of the Dalradian basement. The upward passage of the conglomerates into sandstones is in keeping with the increasing distance of the area from/

from the shore-line and the diminishing speed and
erosive power of the rivers, which would attend the
subsidence of the area of deposition and the extensive
denudation of the hinterland.

An interpretation of this kind demands sub-
-stantial evidence of contemporaneous erosion.   The
removal of so great a mass of material to form extensive
conglomerates is indeed shown by the incomplete sequen-
-ces which to no small degree rendered difficult the
mapping and interpretation of the rocks.   Certain ex-
posures reveal eroded surfaces — at, for example, the
old quarry south of the Knock (Cortachy), (Pl. II.,
fig. 3.), where a massive conglomerate rests on an
uneven floor of dacite.   A closely similar phenomenon
is exposed at the north end of Tamhingan near Dunkeld.

On the other hand a search among the boulders
of conglomerates at the same or at slightly higher
horizons has yielded good results and enabled broken
sequences to be reconstructed and compared with more
complete ones.   A few examples will serve to illustrate
this.

At the Hill of Ascreavie the lavas above the
dacite are missing, but in the overlying conglomerate
occur/

occur pebbles of a fairly coarse olivine-basalt iden-
-tical with that which occupies the corresponding posi-
-tion in the Fyall section.   In Aucharroch Wood the
dacite is exposed, and in the conglomerate above are
pebbles of a porphyritic biotite-andesite similar in
every way to that which in the Isla section lies a
little above the dacite.   North of Meams Hill the
dacite is exposed but there are no overlying lavas.
In Meams Quarry, however, the most striking feature of
the conglomerate, which is high up in the sequence, is
the huge roughly angular masses of porphyritic biotite-
-andesite.   In the Knock quarry, Cortachy, the dacite
is exposed, and in the overlying conglomerate the same
rock occurs as a boulder.   Pebbles of the porphyritic
biotite-andesite, while not conspicuous in this bed,
are common in the conglomerate fringing the south side
of the Den of Ogil, at a horizon which is a little
lower in the sequence than that at the Knock quarry —
which is worthy of note as the biotite-andesite overlies
dacite.   Pebbles of the biotite-andesite occur in the
conglomerate at the top of the Reekie Linn, while the
same rock is present in its proper position a little
downstream./

downstream.   Two miles to the north, on the other side
of the syncline, the dacite is exposed in the bed of
the Melgam Water, but the andesite is missing, so that
the pebbles may have travelled from the denuded outcrop
to the north.   The biotite-andesite appears at the
surface north of the Loch of Clunie in its proper
place in the sequence.   To the south of the loch, frag-
-ments of the same andesite are present in a conglome-
-rate at a higher horizon at Craigiewallace.   At
Dunmore and at Craig of Stenton further south, the
biotite-andesite occurs only as pebbles in a conglomerate
overlying the dacite.   Below the Foghouse, Craighall,
on the Ericht, both the dacite and the andesite are
present as pebbles in a conglomerate.

No volcanic necks have been found anywhere
and as so many of the exposures in the area are strike
sections there is available little evidence to show
from what direction the lava flows came.   In the micro-
-porphyritic olivine-basalt associated with the lowest
lava group — the mica-andesites — there are present
amygdules as large as hens' eggs, one end of which is
hemispheroidal while the other is tapered to a very fine
edge/

119.

edge, approximately parallel with the surface of the flow.   On the assumption that the walls of the cavities bounded originally approximately spherical vapour bubbles, the distortion of which by the flow of the surrounding mass would be most marked in the parts last consolidated, and also that those portions of the flow most distant from the focus of dispersion would solidify earliest, the hemispherical ends of the vesicles must represent the "forward" direction of the flow.   The amygdules present their rounded ends towards a direction 125° Mag--netic, so that it would appear reasonable to assume the orifice or orifices from which the lava came lay to the W. N. W.   If this is true for the entire group of acid andesites, in Perthshire and Forfarshire, they fall into line with those of Kincardineshire where, from a com--parison of the lavas on both sides of the northern con--tinuation of the Strathmore syncline, R. Campbell advocated a Highland source for the more acid rock types.*

    With regard to the source of the stratigraphi--cally higher pyroxene-andesites and olivine-basalts there is no evidence within the area, but compared with the corresponding groups in Kincardineshire there is a marked attenuation towards the west, suggestive of an eastern origin for the lavas.

* "The Geology of South-Eastern Kincardineshire", Trans. Roy. Soc. Edin., Vol. XLVIII,, 1913, p. 950 -951.

COMPARISON with the LOWER OLD RED SANDSTONE
SEQUENCE in KINCARDINESHIRE.

In Kincardineshire R. Campbell has establish-
-ed a sequence for the Lower Old Red Sandstone rocks
with which it is useful to compare that derived from the
Perthshire and Forfarshire ones.   He divides the
sequence into five groups named Dunnottar, Crawton,
Arbuthnott, Garvock, and Strathmore respectively.   The
conglomerates show a main threefold subdivision, a
lower Highland one, a middle volcanic one, and an
upper Highland one, a general variation which holds good
also in the southern area.

Near the base of the Crawton Group, he records
a dacite of the Lintrathen type, succeeded by a por-
-phyritic biotite-hornblende-andesite, which is in turn
overlain by a conglomerate containing a high percentage
of strongly acid volcanic rocks.   As this succession
only occurs at one horizon in Kincardineshire and at one
in Forfarshire it seems reasonable to regard them as
representing the same stratigraphical horizon.   Below
it, in both areas, there is an essentially Highland
conglomerate, which belongs to the Dunnottar Group.
With/

* Trans. Roy. Soc. Edin. Vol. XLVIII., 1913, p. 923.

With this conglomerate there is on the western side of
the Strathmore syncline in Kincardineshire towards the
Highland Boundary Fault only a limited exposure of an
acid andesite, but in Forfarshire there is between
3,000 - 4,000 feet of strata, mainly compact acid
andesites, below the dacite horizon, and most of this
apparently should be considered as belonging to the
Dunnottar Group.   In both districts there is a por-
phyritic augite-andesite near the base of the division.

          Above the Crawton Group, which in the
southern area may be taken to include the dacite, the
porphyritic biotite-andesite, together with some
olivine-basalts and the overlying acid volcanic conglo-
-merate, the next subdivision of the Kincardineshire
rocks is the Arbuthnott Group, characterised by a wide
spread of pyroxene-andesites and olivine-basalts on the
southern limb of the syncline and a volcanic conglo-
-merate on the northern one.   In Perthshire there is
a similar series of pyroxene-andesites, olivine-basalts
and a basic volcanic conglomerate partially represented
on each side of the Highland Boundary Fault, which
taken together would seem to be closely equivalent to
the/

the Arbuthnott Group.

The succeeding Garvock Group in Kincardine-
-shire consists of sandstones and Highland conglomerates
associated in the eastern limb of the syncline with
basaltic lavas.   In Perthshire and Forfarshire there
are sandstones and Highland conglomerates but lava
flows are absent.   The Strathmore Group of flagstones
and sandstones appears to be similar in both districts.

While no fossils have been found in the Old
Red Sandstone rocks along the northern limb of the
Strathmore syncline, a fairly numerous plant assemblage
comes from the quarries at Myreriggs, two- and-a-quarter
miles south-east of Blairgowrie.   In a well-bedded
series of fine grey sandstones occur many fragments of
stems and branches of Psilophyton princeps, less com-
-monly portions of the stems of Psilophyton robustus and
of Arthrostigma gracile.   The strata have a gentle
north-westerly dip and appear to be about a thousand
feet below the highest beds along the centre of the
synclinal axis.   From this axis northward the first
thousand feet of strata have been referred to the red
Strathmore Sandstone Group, while below lies the
quartzite conglomerate provisionally placed in the
Garvock/

Garvock Group, and which would thus appear to be at the
same horizon as the plant-bearing grey sandstones.
This is strictly in accordance with the fact that in
Kincardineshire abundant fossil plants characterise the
Garvock Group, while no organic remains have been recor-
-ded from the succeeding division.[*]

In his book on "The Geology and Scenery of
the Grampians", P. Macnair places these plant-bearing
beds near the summit of the (Lower) Old Red Sandstone
series,[**] and, in order to account for their proximity
to certain "basal conglomerates" in the Ericht, invokes
the aid of a strike fault, illustrated in the section
shown on p. 16.   In the first place the "basal conglo-
-merates" are the quartzite conglomerates of the
Garvock Group, at least sixteen thousand feet above the
local basement of the Lower Old Red Sandstone Series.
Secondly the steady upward succession from these con-
-glomerates into red sandstones, with a diminishing
dip towards the south-east, can be demonstrated in the
Ericht and in many other exposures.   Thirdly, if his
section/

* Trans. Roy. Soc. Edin. Vol. XLVIII., 1913, p. 949.
** Ibid, p. 9.

124.

section is drawn to scale, the centre of the Strathmore synclinal axis is shown to be $2\frac{1}{2}$ miles south-east of Blairgowrie while it is only half-a-mile away in that direction, and the fault is placed half-a-mile south-east of Blairgowrie and yet shown to truncate beds along the north-west limb of the fold.   The only field exposures where anything suggestive of a fault is to be seen are about a mile to the south-east of the axis, where what may be a dip fault has tilted up some of the sandstones.   Other sandstones not far away show little signs of any disturbance.

To group the higher sandstones and conglomer--ates along the northern limb of the Strathmore fold with the Garvock beds is to regard as contemporaneous two lithologically different rock types.   In so doing, however, we have again a parallelism with the same stratigraphical group in Kincardineshire, for there the conditions which favoured the formation of a Highland conglomerate to the north-west apparently precluded the deposition of the sandy limestone, which in Forfarshire and Kincardineshire occupies a position near the top of the Garvock Group on the south-eastern limb/

limb of the fold.   To explain this limitation of the
sandy limestone to the south-east of the synclinal axis
by the presence of a long strike fault would demand
considerable field evidence at present entirely lacking.

.The application of Campbell's subdivisions
to the Perthshire and Forfarshire Lower Old Red
Sandstone Series does no violence to the natural group-
-ing of the rocks and thus avoids any further addition
to stratigraphical nomenclature.   On the following
table the thickness of the two sets of groups can be
compared.

Sequence in	Perth and Forfar.		Kincardine.	
Sandstone	? 550ft. 550ft.+		1500ft.	Strathmore Group.
Quartzite Conglom. Sandstone	2200ft. 1300ft. } 3500ft.		4000ft.	Garvock Group.

Basic Volc.
  Conglom.
Pyroxene-
-Andesites.
 	
*
 	
Basic Volc.
  Conglom.
Pyroxene-
-Andesites.
	2200ft.
	
	1100ft. }
	
	7200ft.+
	
	3000ft.
	
	900ft. }
			5000ft.	Arbuthnott
				
				Group.

Acid Volc. Conglom. Biotite- -Andesite. Dacite	2000ft. (?) 600ft. } 3400ft. 800ft.		1600ft.	Crawton Group.
Biotite- -Andesite. Highland Conglom. Augite- -Andesite.	4000ft. } 4700ft.+ 700ft. ?		6900ft.	Dunnottar Group.

* Break in sequence owing to Highland Boundary Thrust.

The MAGNITUDE of the THRUSTS.

From a consideration of the average thickness
of the different groups it is possible to obtain some
idea of the magnitude of the major dislocations which
have affected the rocks.   The sequence on both sides
of the more northerly thrust plane contains stratigraph-
-ical horizons common to both, from the comparison of
which it would appear that in the vicinity of Balintore
the vertical displacement is fully five thousand feet.
Near Derryhill it seems to be about three thousand five
hundred feet, while further south at Parkneuk the
dislocation is nearly four thousand feet.

In attempting to estimate the displacement
of the more southerly thrust plane, where it is not
complicated by the presence of rocks of the Serpentine
Belt, only a minimum value can be given owing to the
unknown extent of the gap in the sequence already men-
-tioned.   The fact that such a hiatus exists is signi-
-ficant probably of the importance of the movement.
Near Stenton on Tay the vertical displacement is over
three thousand five hundred feet; north-east of the
Loch of Clunie it is seven thousand feet; in the
Ericht/

Ericht at Blairgowrie it is over five thousand feet;
near Fyall Mill it may be nine thousand feet; in the
Isla it is fully seven thousand five hundred feet, and
at Kinclune it is over seven thousand feet.

The average value for the vertical displace-
-ment in this important fault zone is thus over seven
thousand feet.   The low figure from Stenton is due to
the presence, to the east, of a second fault with its
upthrow side to the west, so that for comparison with
the displacement along the Highland border elsewhere the
values at Stenton ought to have added to them the
amount of the downthrow of this subsidiary fault, which
it has not been possible to obtain so far.   That the
northern thrust is the less important of the two is
further emphasised by the fact that the average extent
of its displacement is four thousand five hundred feet.
Therefore, on account of its greater vertical displace-
-ment and its striking continuity from south-west to
north-east, the southern thrust is considered to be
the main line of dislocation, the Highland Boundary
Fault.

SECTION X.

INTRUSIONS.

A. Field Occurrence.

The district is similar to others in Scotland where a wealth of superficial volcanic rocks is accom--panied by intrusions on a very small scale. The re--mapping of the Lintrathen type dacite as a lava flow has removed from the map the most considerable "intru--sion". Only one sill remains, that at Corriefodly near Bridge of Cally, the rest of the rocks being in the form of rather narrow dykes.

On the banks of the R. Ardle, immediately upstream from Bridge of Cally, is exposed a series of schistose grits standing almost vertically with their strike direction E.N. E. On the left bank upstream, below the grounds of Corriefodly, the lowest exposures are of a conglomerate containing an almost exclusively Highland assemblage of boulders, which presumably rests on a floor of schistose grits although the contact is not visible. Overlying the conglomerate are thin--bedded sandstones and mudstones, and along their bedding--planes has been intruded a dolerite, its outcrop making/

making a steep cliff face among the trees for a distance
of about a hundred yards, (Pl. IX., fig. 1.). Above
this scarp no further exposures were found. The
dolerite, which is characterised by very irregular
jointing, is often vesicular and is veined with calcite.
It exhibits locally transgressive junctions on a small
scale among the sandstones and contains fragments of the
same rock, but the most convincing evidence of its in-
-trusive nature lies in the contact alteration of the
underlying sediments which have been indurated to such
an extent that they resist weathering almost better than
the sill itself, and project boldly for fully two feet
in some cases beyond the eroded unaltered sandstones
below.

The previous mapping of the sill on Sheet 56
of the Geological Survey of Scotland shows its extension
on the south bank of the Ardle. No exposures of
igneous rock indubitably in situ were found, but one
small Knob, which may be a boulder, occurring in the
west bank of the small tributary burn immediately east
of the old Cattle Market, yielded a dolerite identical
with that of the sill. In the higher reaches of the
"Cairns"/

"Cairns" burn, another tributary of the Ardle, thin-
bedded red mudstones, sandstones, and tuffs were found.
For three hundred and fifty yards downstream there are
no exposures, and finally, just before the Ardle is
reached, the Highland conglomerate, described from the
opposite bank of the main river, forms steep banks for
some seventy yards.   It is unfortunate that the inter-
-vening stretch, where one would expect to locate the
sill, is covered thickly with glacial sands and gravels.

Before describing the field disposition of
the majority of the dykes, that at the extreme north-
eastern end of the area calls for mention on account of
its distinctly different lithological characters. Below
the west gate of Auchnacree, in the stream bed which
forms a deep gully running south-eastwards, is exposed
a narrow (6 feet) dyke of igneous rock, truncating a
group of bedded Lower Old Red Sandstone tuffs. A little
to the south-west, what is apparently the same dyke rises
through Margie Grits, and still further in the same
direction it is occasionally exposed among Lower Old Red
Sandstone rocks in the bed of the Noran Water below
Glenley.

The most extensive development of dyke rocks
follows/

follows very closely the Highland Boundary Fault from
Tayside to Noranside.   In practically every exposure
of the serpentine belt there is a dolerite dyke, and in
many cases the chilling of the latter against the former
is so obvious as to render unnecessary the use of a
lens.   The dykes have a general S. W. - N. E. orienta-
-tion, and with one exception, that at Pictfield, keep
to the northerly limb of the Strathmore syncline.   It
is possible, however, that the scanty record of such
rocks from the level portions of Strathmore reflects
rather the presence of widespread sands and gravel than
the absence of intrusions.   The dykes, which generally
show good columnar jointing, are usually single, but
sometimes two run alongside each other a little distance
apart.   They show violent transgression with regard to
the country rock, truncating sandstones, conglomerates,
and lavas with equal ease, and seem to follow rather
the main line of steep folding and dislocations.   As
certain of the dykes rise through the Strathmore Sand-
-stones, some if not all of them must be of post Lower
Old Red Sandstone age.   They are a remarkably uniform
assemblage petrographically and belong to the group of
"East-and-West Dykes" so well developed throughout the
Central/

Central Valley of Scotland, which are now usually re-
-garded as of late Carboniferous age.   A summary of

the evidence with regard to the age of these dykes is

given on pp. 150 - 151 of the Glasgow District

Memoir (1925).

In many cases the dyke rocks have been quar-
-ried extensively for the supply of road metal, and

these undertakings have left available for inspection

the contacts of the intrusions.   In nearly every case

the outstanding feature of the country rock walls,

whether of sandstone or of conglomerate, is the marked

development of smoothed and slickensided surfaces, show-
-ing that the dyke occupies a fracture plane, (Pl. IX.,

fig. 2.).   That these fractures do not represent fault

lines with any considerable vertical displacement is

evidenced by the fairly close continuity of the bedding

planes across the break and by the fact that convex

portions of the one wall are found to be nearly opposite

similar but concave parts on the other in certain cases.

It is clear, however, from the generally steep inclina-
-tion (60° - 90°) of the slickensides scoring that

whatever movement there was took place in a nearly ver-
-tical direction.   The actual directions of the scores

have/

have been mapped but as yet they are too conflicting to yield results.   The inclination of the dykes varies from the vertical to 30° from it on either side.

B.   Petrology.

The Corriefodly Sill.

The rock is porphyritic with large serpen--tinised olivines often nearly idiomorphic, and at other times resorbed.   The serpentine is bright green in colour, fibrous in texture, and it retains the charac--teristic curved cracks of olivine.   Closely associated with it are numerous small specks of black iron oxide. There are also many large tabular crystals of fresh plagioclase — zoned labradorite — which are in most cases devoid of resorption on the rim although they are occasionally spongy further in.   Twinning on all three laws is sometimes seen, and there is a tendency for the crystals to develop in clusters.

The groundmass consists of smaller laths of labradorite which are moulded on clots of tiny granular augite.   The interstices are occupied by dark glass with apatite needles, iron oxide microlites and rods. The last stage in the history of the rock apparently was the infilling of any cavities and possibly the re--placement of/

of some of the glass by bright green chlorites, and a
minute quantity of quartz.

Apart from the serpentinised olivine, the
constituent minerals are absolutely fresh, (Pl. XX.,
fig. 1.).

The rock is a coarse-textured olivine-
-basalt.

The Auchnacree Dyke.

This rock is strongly porphyritic with large
tabular plagioclase felspars usually with idiomorphic
outlines, although inside they display bands of honey-
-comb structures and often contain inclusions of brown-
-ish glass.   Although it is highly decomposed in every
section examined, the felspar was most probably labra-
-dorite.   Slightly less conspicuous in size and number
are elongated, slightly resorbed, crystals now replaced
by aggregates of chlorites and calcite, the general
appearance of which suggests that they are pseudomorphs
after hypersthene and possibly augite as well.   Of
smaller size and more scanty development are pseudo-
-morphs after olivine with the characteristic shapes
and cracks still retained.

The/

The groundmass consists of small stout felspar crystals, granular calcite probably after augite, iron oxide, and brownish-black glass with microlites. The general appearance of the rock recalls most strongly the porphyritic pyroxene-basalts of the Arbuthnott Group, but that we are dealing with an intrusion is shown by the narrow extent of the dyke and the marked chilling towards the contacts where the phenocrysts are small slender felspars set in a groundmass of glass with radiating aggregates of minute felspar needles, in many respects similar to the chilled edges of the dolerite dykes to be described next.   The absence of fluidal arrangement of the minerals of this dyke is in contrast to the usual behaviour of those in lava flows, (Pl. XX., fig. 2.).

The rock appears to be a <u>Porphyritic olivine-hypersthene-basalt</u> with definite affinities with certain of the latest lavas of Lower Old Red Sandstone age, and it may well be the product of a late stage of that vulcanicity.

The N. E. - S. W. Dykes.

The dyke rocks are essentially aggregates of plagioclase, pyroxene, olivine, ilmenite, with quartz, apatite and a varying proportion of dark glassy residue.

The most abundant constituent is fresh, water-clear, tabular plagioclase. In coarse-grained rocks the crystals tend, where anything approaching idiomor--phism is seen, to have a rather squat habit; in the finer-textured equivalents the felspar occurs as elon--gated slender laths. It is invariably strongly zoned, the major and central portions being labradorite while the surrounding parts are progressively more acid to--wards the rim. Twinning on the Carlsbad and Albite laws is prominently developed, and cross and stellate clusters are common. The felspar is on the whole remarkably free from inclusions. Some strings of rather oval or globular dark glass, obviously following cleav--age planes, have been noted, together with apatite needles, although this last named mineral was most abun--dantly crystallised towards the close of the cooling history of the rocks. In addition some small inter--stitial areas of orthoclase are present.

The/

The pyroxene is a very pale grey-green augite
with well marked cleavage.   Lamellar twinning is fre-
-quent but zoning and hour-glass structures are absent.
Very occasionally a dark brownish resorption rim is
seen, but on so small a scale that it was not possible
to be certain that it is hornblende, although it is
probably so.   Orthorhombic pyroxene is very scantily
represented.

Olivine, or rather its decomposition material,
is of widespread occurrence in all the sections exam-
-ined.   It is in the form of rather small lozenges,
often approaching idiomorphism and frequently display-
-ing resorption bays, the periphery being marked with
black iron oxide,which also occupies the characteristic
ramifying cracks throughout the mineral.   It is re-
-placed by either fibrous green serpentine or pleo-
-chroic reddish-brown to green iddingsite.

Iron oxide is the most abundant accessory and
appears in two distinct habits.   In one it has the
form of complex skeletal crystals, often of fairly
large size;   in the other it occurs as narrow rods.
While the structures are most suggestive of ilmenite,
the/

the oxide is magnetic and is regarded as titaniferous
magnetite.   Apatite is represented by tiny colourless
acicular crystals.

Quartz occurs only interstitially or in
ocelli, and in very small quantity.   It is usually
surrounded by greenish and brownish decomposition pro-
-ducts in the interstices or by calcite or chlorites in
the ocelli.

The mesostasis is of dark brownish glass
bounded by idiomorphic felspars.   Within it are numer-
-ous tiny rods of iron oxide, a few minute felspar laths,
some augite microlites, and abundant apatite needles.

An examination of the coarse-textured rocks
from the centre of the dykes throws light on their con-
-solidation history and the structures produced, (Pl.XX.,
fig. 3.).   The earliest formed mineral was olivine
which, apart from irregularities due to subsequent re-
-sorption, presents idiomorphic outlines to all the
other constituents, and upon which all the other minerals
can be seen to be moulded.   Then followed resorption
of the crystals, but only to a slight extent.   The next
mineral to crystallise was iron oxide, skeletal forms
not infrequently being embedded on the olivine.

Labradorite/

Labradorite came next in the sequence, followed closely by the pyroxene, for the commonest structure of all the dyke rocks is that most conveniently described as an hour-glass shaped felspar held between jaws of augite. The crystallisation of the augite came to an end before that of the plagioclase which often envelops rounded and idiomorphic edges of the pyroxene. The closing stages of cooling are represented by the formation of glassy mesostasis between the crystalline constituents, but during this time, and slightly before it, the long narrow rods of iron oxide were growing, for they are most widely developed in the glass and penetrate the surrounding plagioclase only to a very slight extent. In many cases they stop short against the pyroxene; in a few they penetrate it, but to an even less extent than in the case of the felspar. The coarse-grained rocks are thus non-porphyritic and strongly ophitic, with comparatively little interstitial mesostasis.

The portions of the dykes nearer the country rock show a progressively finer texture and an increas--ing percentage of glassy residue, which tends to emphasise the earlier-formed minerals, producing por--phyritic structure, (Pl. XX., fig. 4.). The phenocrysts/

phenocrysts are either labradorites, with idiomorphism in the longer pair of sides and a dentate structure in the other two, or labradorite-augite clusters.   Nearer the centre of the dyke these clusters show ophitic relationships between the felspar and the fairly large plates of augite, but towards the margin of the intru- -sion the plates of augite tend to be replaced by clots of granular or hypidiomorphic pyroxenes. With a great- -er amount of undifferentiated base the chance of find- -ing different minerals in contact is correspondingly lessened, but nowhere was there any evidence of a variation in the order of crystallisation.   The plagio- -clase phenocrysts, even in the finest textured "chilled edge", envelop augites, in a glassy matrix containing abundant small idiomorphic pyroxenes and skeletal titaniferous magnetite, and rather less widespread olivine.

Circular ocelli are frequently developed in the marginal portions of the dykes, and are bounded by tangentially disposed plagioclase.   Where the infilling material is glassy mesostasis there is a general radiate arrangement of the microlites.   In others, quartz has crystallised/

crystallised inwards from the bounding surfaces, devel-
-oping regular faces, and the interstices are occupied
by calcite in most cases, with or without an interven-
-ing layer of sheaf-like green chloritic material. The
amount of free quartz present increases towards the
margins of the dykes.

A last feature of the dyke rocks, arising
from a study of them in thin section, is worthy of men-
-tion. The felspars are frequently broken across and
rejoined rather imperfectly. The augite in many cases
shows marked bending of the cleavage lamellae, with the
production of wavy extinction. Both phenomena suggest
dislocation and compression of the cooling magma, pro-
-bably not unconnected with the movements evidenced by
the slickensiding of the bounding walls of the intrusion.

From their mineral composition and textures,
these rocks can best be described as olivine-tholeiites
of the Salen Type, so abundantly represented among the
dykes of Mull. An analysis of a good coarse-grained
specimen is appended, and for comparison, one from
Mull. The similarity is obvious.

* Mem. Geol. Survey of Scotland, "Tertiary and Post-
    Tertiary Geology of Mull, Loch Aline, and Oban,"
    1924, p. 370.

Chemical Analyses of Tholeiites.

	A.	B.
SiO_2	46.65	47.35
Al_2O_3	16.76	13.90
FeO	3.01	8.96
Fe_2O_3	10.58	5.87
MgO	5.67	5.97
CaO	9.45	10.65
Na_2O	2.33	2.73
K_2O	0.59	0.54
H_2O at $105°C.$	0.95	1.04
H_2O above $105°C.$	1.13	1.16
TiO_2	2.04	1.75
P_2O_5	0.38	0.24
MnO	0.40	0.23
Ni & Co	Traces	Not found
S.	do	0.23
CO_2	do	0.32
Total	99.94	100.94

A. Dyke cutting Serpentine Belt at Kinaird on the Melgam Water, Lintrathen.

B. Dyke on short $\frac{1}{4}$-mile S.S.E. of Kintallen and $2\frac{1}{2}$ miles N.N.W. of Salen, Mull. (p. 17 of the Mem. Geol. Survey of Scotland, "Mull, etc." 1924.

The N. E. - S. W. dykes are a remarkably
fresh group of rocks, and so is that of the Corriefodly
sill.   There is much in common between the two although
the sill contains much more olivine.   The felspars and
the pyroxene are closely akin to each other, and the
dark glassy mesostasis is identical to the development
of the long streaks of black iron oxide, which penetrate
the groundmass felspars only slightly.   It is probable
that they represent different manifestations of the
same phase of vulcanicity.   In their general develop-
-ment and characters, they show the closest resemblance
to the intrusions of late Carboniferous times.   If that
be their age it is quite comprehensible why the
Auchnacree dyke rock with its Lower Old Red Sandstone
affinities should be so highly decomposed while they
are so strikingly fresh.

SECTION XI.

NOTES on GLACIAL HISTORY.

The Pleistocene ice sheets have left many
indications of their presence in the peculiarities of
topographical relief seen in the northern districts of
Perthshire and Forfarshire.   The major evidence lies
in the rounded features of every mountain and valley,
and is too well known throughout Scottish highland areas
to call for particular description.   The less conspicu-
-ous traces of ice work in the form of roches mouton-
-nées, glacial grooves, and striations were noted and
considerable additions have been made to the number
already recorded on the maps of the Geological Survey,
(See Map 2.).

In the Dalradian Schist country, at altitudes
generally over 1,000 feet above sea level, the striae
are with a few exceptions orientated in a south-east
direction parallel to the main river valleys.   The
exceptions occur in the south-west near the southern
margin of the Highland rocks.   In the Old Red Sandstone
belt to the south, at altitudes from 850 - 500 feet,
both striae and roches moutonnées occur, mainly on
lava-form/

lava-form rocks although a few were located on conglo-
-merates, (Pl. IX., fig. 3.).   Their orientation varied
from E. S. E. to E., but in two cases the direction was
well north of east.   In Strathmore the striae are
either easterly or north-easterly, and on the north-
-western flanks of the Sidlaws, 400 feet higher up, the
ice markings show the same easterly trend.   The general
interpretation of the striae would seem to be that the
main Strathmore glacier moving, in its lower parts,
towards the north-east had a more easterly direction
forced upon it by the advance of powerful tributary
ice streams coming from the Highland gathering grounds.

The transport of erratic blocks has left in
exposed positions numerous large boulders to which in
many cases local names and traditions have been attri-
-buted.   It is probable that the many "Standing Stones",
cairns, etc., which abound in the higher parts, reflect
a prodigality of material which attracted the attention
of the prehistoric architects.   The blocks are almost
invariably of Highland and metamorphic origin.   The
huge "Devil's Stone", below Cortachy Bridge, is a mass
of synthetic gneiss.   In the Isla above the Reekie
Linn there are boulders of a speckled epidiorite more
than/

than fourteen feet in diameter.

The most striking relics of glaciation, however, are associated with retreat phenomena. Ter--minal moraines occur in the upper reaches of most of the valleys in the schist country, barriers of rock debris stretching from side to side and breached only where the present stream passes through. There is a very well preserved terminal moraine in the valley of the S. Esk near Gella Bridge and another on the Back Water below Over Scithie. While variations exist, it is on the whole true that these moraines occur at 750 - 800 feet above sea level.

Drift extends over most of the area up to these altitudes but considerable differences in thick--ness have been noted. In the valleys of the Prosen and the Carity there is fully 130 feet of boulder clay, but the more common depth probably lies between 30 and 50 feet in more open situations along the north-western flank of Strathmore. On the schist country immediate--ly north of the present Old Red Sandstone boundary it is usual to find drift along the river banks to a depth of over ten feet.

While an examination of the nature of the boulders in the drift would make a special investigation of/

of its own, it was noted that generally Highland material
predominates along the Highland boundary, except towards
the north in the Prosen and the S. Esk valleys where a
fairly high proportion of Old Red Sandstone material
occurs in a till overlying a Pre- Old Red Sandstone
floor.   ¹his would indicate either the removal of an
Old Red Sandstone outlier such as that which remains in
the Burn of Watersheal or the encroachment of the
Strathmore ice upon the higher ground along its northern
margin.   In keeping with the latter hypothesis is the
occurrence of striae with a south-north orientation at
Balloch (Ascreavie), a mile-and-a-half to the south-west.

As the ice sheets diminished in thickness,
ridges of rock were uncovered and, along the exposed
margins, torrents of melt-water found their way to lower
levels, carving channels in the process and sweeping
away morainic and other debris to be deposited in Kame-
-like mounds along their banks.   Many such piles of
irregularly bedded sands, gravels, and pebbles have
been noted.   There are several elongated hummocks
parallel to, but above, the present bed of the Carity,
(Pl. XI., fig. 3.).   Much more conspicuous masses occur
higher/

higher up the same stream east of Auldallan, where the
most striking marginal drainage channel in the district
debouches on to an old lake bed.   At Dykends, Glenisla,
the road cuts through a good example of a Kame parallel
to the valley of the Back Water, and near Bellaty is
another lying alongside the Isla.   Between Alyth and
Blairgowrie, and parallel to the north-western flank of
Strathmore, are long mounds of a similar character and
presumably associated with drainage streams,which were
forced to keep to the slopes above the central depres-
-sion by the presence of ice.   The best example in the
neighbourhood is that south of Pictfield.   In the val-
-ley of the Ericht there is a long gravel mound, rough-
-ly parallel to the stream about a mile-and-a-half
above Craighall Bridge.   Further to the south-west
there is an elongated gravel pile at Concraigie, a
little west of the Loch of Clunie.   It is at right
angles to the Lunan Burn there and was probably associ-
-ated with a tributary stream coming down the valley
from the Craig of Clunie to the south.

The marginal drainage channels with a
general parallelism to the fringe of the Grampians
form a striking group of valleys linking together the
main/

main glens.   In some cases they contain diminutive
streamlets, in others except for an artificial drainage
ditch they are dry.   They are generally accompanied by
a group of topographic features which may be described
briefly.   To the south-west these valleys terminate
high up on the left banks of some of the principal
rivers coming from the Highlands.   The dry valleys may
be simple, or they may have feeders, or they may occur
in groups at different levels.   To the north-east each
system passes into a triangular shaped depression in
the course of a less important Highland river, commonly
occupied by sand and gravel banks.   Beyond the hollow
another dry channel leads in a north-easterly direction
to the next Highland valley.   It is suggested that
this arrangement of surface features, which is duplica-
-ted several times between the Tay and the N. Esk, may
be interpreted in the following way.   For the first
part of the dry valleys to be operative, the major river
valley to the south-east must have been filled with ice
to a height slightly greater than that of the overflows,
by means of which the melt-water followed a north-east-
-erly direction seeking an opportunity to flow down
into Strathmore, but prevented by the ice sheet lying
there,(Pl. XIII., fig. 3.).   When/

When the water encountered the remains of a smaller
Highland valley, the glacier occupying which had retrea-
-ted north-westward, a small lake was formed in which
sediment carried by the stream from the south-west and
the other one from the north-west was deposited.   If
the Strathmore ice was about the same height above sea
level as that in the major Highland valleys, or even
fifty feet less in some cases, the water in the small
lake would be enabled to flow still further to the
north-east until it reached a south-west flowing stream
which entered Strathmore beyond the ice margin.   At
Glenley on the Noran Water there are two dry valleys,
one about 700 feet and the other a little lower, which
unite a short distance to the north-east forming a well
rounded, fairly broad valley till the Cruick Water
coming down from the Highlands is reached.   If the gap
there were barred by Strathmore ice to a height of 700
feet a small lake would be formed, the overflow of
which would pass north-eastward along the fine dry
valley,below Trusta,to the alluvial flats which indicate
an old loch at Balfield (400 feet), through which the
present West Water flows to join the N. Esk.

       Above/

Above the left bank of the S. Esk at Cortachy
there are two sets of overflows with tributaries, one
set passing north of the Knock Hill at 700 feet, and
the other along the south side at 650 feet, (Pl. XII.,
fig. 1.).   At present, what drainage there is joins
the White Burn, a Highland stream, and plunging through
a steep pile of sands and gravels at Newmill of Inshewan
descends to Strathmore.   A barrier at 650 feet,
however, would divert this drainage through the Den of
Ogil — now a reservoir — to feed into the Noran Water
about a mile downstream from Glenley.

East of Lintrathen Loch there is a dry valley,
associated with fairly broad alluvial flats, and running
north-east to Kirkton of Kingoldrum at a height of about
600 feet.   The present drainage from it turns right
back upon its course there and flows south-west to join
the Isla, but a barrier at 650 feet would have diverted
the water still further north-eastward to discharge into
the Loch of Kinnordy — now almost completely dried up.

Above the Alyth Burn near Bamff House are two
dry valleys (650 feet and 640 feet) which join to form
a broad rounded valley running north-east along the
Serpentine/

153.

Serpentine Belt to the Achrannie Burn, a tributary of
the Isla.

There is a conspicuous notch on the north-
-east bank of the Ericht, north of Drimmie Wood, and
truncating a lava with the formation of the cliff called
the Craigies.   Closer inspection shows this to be an
overflow channel (780 feet) with a second a little to
the south (750 feet) which join and then pass across
the Moor of Drimmie to the Alyth Burn beyond.   The fine
deep dry valley known as the Den of the Welton is 850
feet above sea level at its south-western end and runs
along the Highland Boundary Fault to the Alyth Burn.

Finally mention must be made of the finest
dry valley system located, lying to the north of the
series just described.   Immediately to the north of
Lintrathen Loch is a sheet of sand and gravel forming
the floor of a valley which is somewhat broken by elon-
-gated hummocks and mounds terminating southwards in a
broad barrier some fifty feet high, and composed of
roughly bedded yellow sands with occasional layers of
boulders, probably banked up against the Strathmore ice,
(Pl. X., figs. 1 and 2.).   Its base is about 680 feet
above sea level.   Round the margins of this tract
are/

are traces of old terraces, and the general characteris-
-tics are those of an old lake. It was fed by the
Quharity Burn coming from the north and it probably re-
-ceived in addition the Melgam Water, which now dischar-
-ges into Lintrathen Loch, but which may have passed to
the more northerly basin by one or other of the three
hollows below Wester Coul Farm. The outlet of the
lake, the water of which stood at an altitude of about
800 feet, was at its north-eastern corner below Craig of
Auldallan, from which it is proposed to name this old
loch. A striking deep valley, with steep but rounded
sides and a spread of gravel and boulders across its
floor, (Pl. X., fig. 3.), runs eastwards for two miles
along the southern margin of the Dalradian schists, and
debouches on to a second alluvial flat with gravel
mounds and terraced margins, 680 feet above sea level,
(Pl. XI., fig. 1.). The outlet of this loch, the Loch
of Ascreavie, was not at its extreme eastern end but at
its south-eastern corner where it overflowed across a
ledge of dacite and cut back the gorge now known as
Carity Den, (Pl. XI., fig. 2.), the waters then going
eastward to join the Prosen. The speed of the floods
passing/

155.

passing from the Loch of Auldallan to the Loch of
Ascreavie is evidenced by the deeply incised channel,
and by the fact that the detritus was swept to the far
eastern end of the lower loch, where now lie great piles
of sand and gravel.

It is worthy of note that the dry valley
systems, of which a few have been described, lie to the
north-east of each major Highland Valley, a circumstance
in keeping with the fact that the melting of snow and
ice would be more marked along the south-facing slopes
of the valleys.   At certain places, the west banks of
the Highland rivers are occupied by great piles of sand
and gravel heaped against the side of the valley and
often showing cone screes etc., — examples being the
Heuchs o' Mause on the Ericht, (Pl. XIII., fig. 1.),
and also on the Burn of Kilry, west of Kilry.   In all
probability they represent material swept down by the
late glacial floods and deposited wherever a widening
of the channel demanded a diminution of the load.

The last and lowest marginal drainage
channel of importance is now marked by the chain of
shallow lochs, (Pl. XII., fig. 3.), separated by
stretches/

156.

stretches of bog or irregular areas of sand and gravel,
which extends from the Loch of the Lowes, less than a
mile distant from the Tay, through Butterstone, Clunie,
(Pl. XII., fig. 2.), and Marlee Lochs — the last-named
being seven-and-a-half miles E. N. E. of the Tay —
eventually draining into the Isla,which joins the Tay at
Cargill.   The distance from the Loch of the Lowes down
the Tay to Cargill is ten miles; the drainage of the
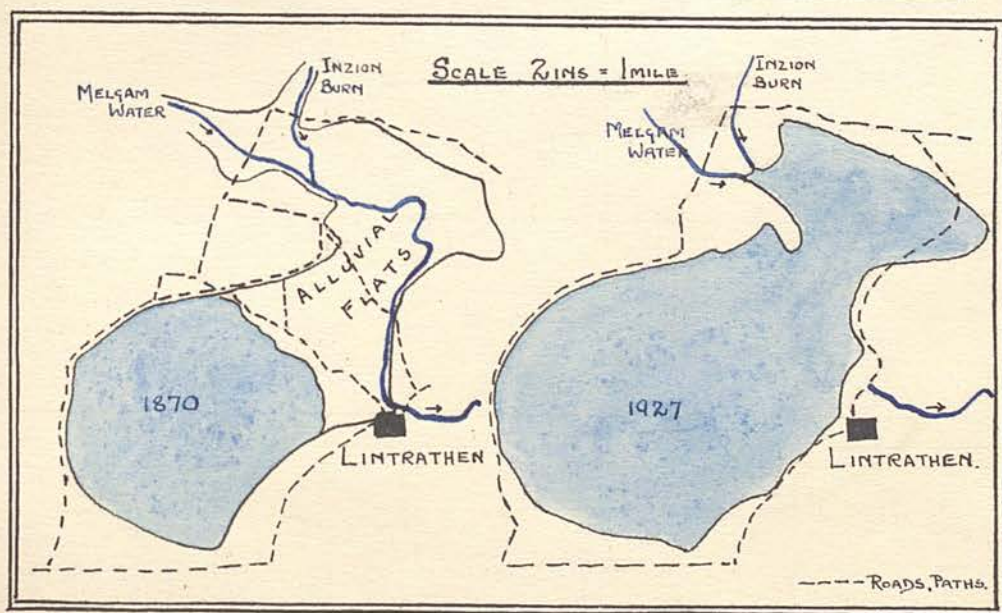lochs follows a course of fifteen miles.

　　　　We can gain some idea of the thickness of the
Strathmore ice sheet, during the halt in its retreat
indicated by the main marginal drainage channels, by a
comparison of the level of their intakes with the
present altitude of the floor of Strathmore opposite to
them.

Drainage Channel.	Intake. Feet above Sea.	Floor. Feet above Sea.	Thickness. Feet.
Glenley	700	200	500
S. Esk	700	180	520
Melgam Water	680	140	540
Alyth Burn	700	110	590
Ericht	780	90	690

The ice apparently thickened from north to
south, the increment being of the order 1 : 465, although
the actual surface was nearly horizontal.   The latest
drainage system through the lochs shows that the ice
barrier sloped downwards in a northerly direction, the
gradient being 1 : 235, and that the corresponding
thickening to the south was as 1 : 222, more than double
that during the earlier stages of retreat.   It is
possible that in the first case the edge of the ice
sheet lay well to the north, while in the second there
was a steep terminal slope somewhere in the vicinity of
Blairgowrie.

The disappearance of the ice sheets left the
river systems to re-establish themselves on an area the
topography of which doubtless had been modified pro-
-foundly.   While in their upper courses the streams
probably followed ice-deepened ancient valleys cut in
the schists, in the area to the south new channels had
to be carved through Old Red Sandstone rocks.   The
shortest route to the floor of Strathmore demanded rock-
-cutting in the direction of dip, and, while in some
cases this was done, in others there is deflection of
the/

The Recent History of the Loch of Lintrathen.

MELGAM WATER · INZION BURN · SCALE 2 INS = 1 MILE · INZION BURN · MELGAM WATER · ALLUVIAL FLATS · 1870 · 1927 · LINTRATHEN · LINTRATHEN · ------ ROADS, PATHS.

the rivers for varying distances along the strike of
the more resistant outcrops.

The general disposition of the outcrops at
right angles to the principal drainage direction pro-
-bably produced the ponding evidenced in different
localities where alluvial flats indicate the earlier
existence of lakes.   The work performed by the consi-
-derable head of water thus conserved is shown in the
deep and narrow gorges found downstream from the old
lake beds, e.g. Craighall Gorge, (Pl. V., fig. 2.),
Keith Falls, (Pl. V., fig. 3.), on the Ericht; Reekie
Linn, (Pl. IV., fig. 2.), Slug of Achrannie, on the
Isla;   together with others on the Prosen and S. Esk.

Lintrathen Loch, (Pl. XIII., fig. 2.), is a
sheet of water on the Melgam drainage system, dammed
behind a resistant mass of dacite.   The erosion of its
outlet channel had in 1870 lowered the water level and
drained the basin to half its earlier superficial
extent.   The reason why it had not shared the fate of
complete drainage suffered by the others is apparently
either because it was the site of an earlier lake, the
outlet of which was at its southern end, or because
ice/

ice action had deepened that end. The Post-Glacial

overflow was towards the south-east, through the Melgam

gorge below Lintrathen Church, and when this was cut

sufficiently low to drain the northern half of the

loch, the south-western deeper basin remained untapped,

separated from the exposed river channel by a belt of

marsh nine hundred feet across. The most recent phase

in the history of this interesting loch has been its

reinstatement over the original extent by the erection

of a dam across the Melgam Water overflow by the

Water Commissioners of the City of Dundee.

SUMMARY.

1. The Highland Border Series.

The rocks previously mapped as Margie Grits
have been examined microscopically and are shown to
resemble very closely those from other localities.
In the R. Prosen there has been found a new group of
fine grits, black shales, and chert, which are devoid
of fossils but probably belong to the older Black
Shale-Jasper Series.

2. The Lower Old Red Sandstone.

A petrological examination of the lava-
-form rocks has shown them to belong to various sub-
-divisions of the andesite and basalt families. The
well-known "Lintrathen porphyry" is found to be a
dacite and also a lava flow with a wide-spread occur-
-rence at one stratigraphical horizon.

An investigation of the conglomerates has
shown their reliability as stratigraphical indices,
and a definite rhythmic variation in their composition
has been demonstrated, upon which an interpretation of
the conditions of their accumulation can be based.
The tuffs and sandstones show a closely similar varia-
-tion in composition.

3./

3.   The Upper Old Red Sandstone.

What may be a remnant of Upper Old Red Sandstone sediments has been found among the Margie Grits near Auchnacree.

4.   The Serpentine Belt.

The rocks of the belt contain the remains of three types of ultrabasic igneous rock, HARZBURGITE, SERPENTINE-PEGMATITE, and DUNITE, and probably represent one plutonic intrusion; together with a smaller quantity of highly decomposed tuffs resembling schalsteins.

5.   Intrusions.

Most of the intrusive igneous rocks are N.E.--S.W. dykes of tholeiitic character, identical with the Salen type tholeiite from Mull.   One sill near Bridge of Cally is probably associated with these rocks, re--presenting a slightly different phase of the vulcanic--ity which may be of Carboniferous age.   The dyke at Auchnacree is a pyroxene-basalt and may be connected with the igneous activity of Old Red Sandstone times.

6.   Sequence.

A stratigraphical sequence of the Lower Old Red Sandstone rocks has been worked out on the field evidence/

evidence, and it has been found that the order and grouping is similar to that derived from the Kincar--dineshire rocks by R. Campbell.   The nomenclature of that author is therefore employed.

7. Tectonics.

The investigation has revealed the existence of a major Highland thrust with a minor one to the north, both of them being steeply inclined upthrusts from the north-west.   Estimates of their magnitude are given.   Beyond is a normal fault with its downthrow to the south-east.   The rocks of the serpentine belt are bounded both to the south-east and to the north-west by planes of dislocation, evidence of contact metamorphism by the serpentine on the country rock being absent.   The serpentine-schalstein complex is therefore thought to be older than the Lower Old Red Sandstone.   There is a second group of dislocations— dip faults — cutting the Highland Boundary area in a direction N.N.E. – S.S.W.

The Old Red Sandstone rocks lie in synclines elongated approximately parallel to the major thrust and fault lines, and in the north-westerly area

overlie/

overlie immediately a denuded Dalradian schist floor.
In the middle and more easterly areas anticlinal folds
occur in close proximity to the main Highland
Boundary Thrust.

8.   The glaciation of the region has left ex-
-tensive relics.   New striae and roches moutonnées
are recorded and various kames are noted.   A series
of marginal drainage channels has been mapped along
the fringes of the Grampians, parallel to the main
valley of Strathmore, and the possibility of their
inter-communication in some cases discussed.
Associated with these are certain lakes, but there are
many others, at intervals along the course of the
present river systems, of probably later date, when
the melting snows followed the shortest route to
Strathmore and cut deep gorges through the conglomerate
ridges.

PLATE I.

Fig. 1. Marginal Drainage Channel north-west of Glenley with outcrops of Margie Grits along hillside to the left.

Fig. 2. Cliff of microporphyritic biotite-andesites on left bank of R. Ericht below Old Milton of Drimmie.

Fig. 3. Folded microporphyritic biotite-andesite immediately north of dolomite-fault-breccia on the Alyth Burn downstream from Craighead.

Plate I.

1.

2.

3.

PLATE II.

Fig. 1. The Devil's Punchbowl on the R. Isla. The waterfall is cut through Lintrathen type dacite. Below the distant crooked tree on the right, the dark shadow marks the hollow where the tuff has been eroded from between the dacite and the overlying olivine-basalt.

Fig. 2. A closer view of the same outcrop. The tuff is immediately above T on the photograph. D = dacite; B = basalt.

Fig. 3. Old Quarry south of the Knock, Cortachy, with conglomerate overlying an eroded floor of Lintrathen type dacite, the line of junction being marked in black.

Plate II.

1.

2.

3.

PLATE III.

Fig. 1. Old Quarry South of the Knock, Cortachy.   Conglomerate
        overlying eroded dacite floor.   To the right above
        the hammer is a large rounded boulder of dacite.

Fig. 2. Tamhingan near Dunkeld.   The hill consists of
        Lintrathen type dacite.   The Highland Boundary
        Thrust runs through the loch, and the camera was
        standing on Dalradian schistose grits.

Fig. 3. The Isla gorge below the Reekie Linn, with cliffs of
        Lintrathen type dacite on the left bank.

Plate III.

1.

2.

3.

PLATE IV.

Fig. 1. The Isla gorge below the Reekie Linn, with cliffs of
porphyritic biotite-andesite on the left bank.

Fig. 2. The Reekie Linn on the R. Isla, the water falling over
a ledge of microporphyritic olivine-andesite.

Fig. 3. The top of the Reekie Linn, with the ledge of micro-
-porphyritic olivine-andesite, showing platy jointing.

Plate IV.

1.

2.

3.

PLATE V.

Fig. 1.   Basement conglomerate of phyllite and vein quartz
          fragments in Lower Old Red Sandstone outlier at
          Strone House on the R. Ardle.

Fig. 2.   Gorge on the R. Ericht cut through Lower Old Red
          Sandstone conglomerates along a line of fault at
          Craighall.

Fig. 3.   Quartzite conglomerate on the R. Ericht at the Keith
          near Blairgowrie.   The erosion of the constituent
          pebbles often gives rise to the formation of
   potholes.

Plate V.

1.

2.

3.

PLATE VI.

Fig.1. Outcrop of serpentine on the R. South Esk immediately above Cortachy Bridge.

Fig. 2. Serpentine exposure on the Carity Burn, which beyond the right angle bend in the foreground flows along the junction of the serpentine with the most northerly infaulted area of Lower Old Red Sandstone mudstones.

Fig.3. Serpentine exposure on the Carity, as above, but showing a great knob of pegmatitic serpentine (P).
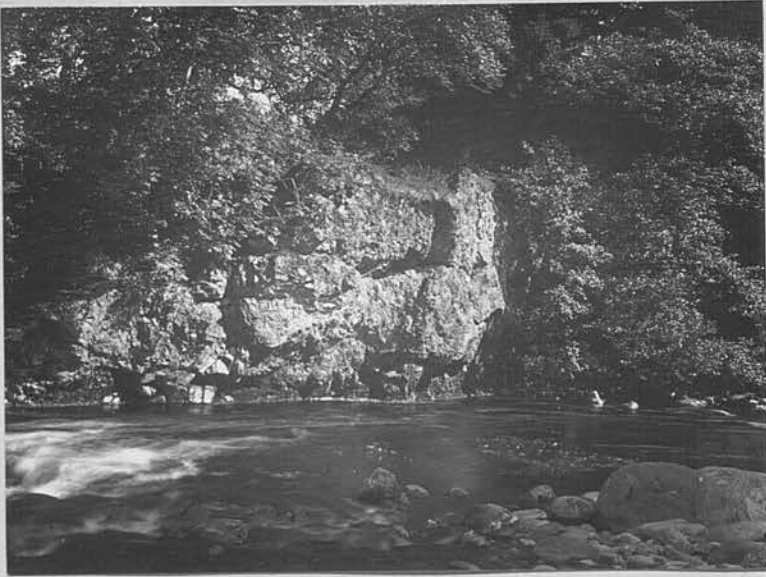
Plate VI.

PLATE VII.

Fig. 1. Carity Den section. Uptilted Lower Old Red Sandstone
    mudstones immediately to the south of the serpentine
    shown in Plate VI., fig. 2. This is the most
    northerly infaulted area of sediments in the
    serpentine belt.

Fig. 2. Carity Den section. Lower Old Red Sandstone conglo-
    -merate faulted into dolomitic serpentine-fault-
    -breccia (F).

Fig. 3. Highland Boundary Fault in the Isla. To the left of
    the line are highly disturbed sandstones; to the
    right a tholeiite dyke.

Plate VII.

PLATE VIII.

Fig.1. Limestone Bank Quarry south-east of Loch of Clunie.
Tholeiite dyke cutting calcareous fault-breccia
along the Highland Boundary Fault.   The large
slickensided surface is possibly associated with the
injection of the dyke, but above the spade on the
left the shear-planes of the breccia can be seen to
lie at a lower angle from the horizontal and most
probably follow the main plane of the original
dislocation.

Fig.2. Fault on the right bank of the R. Ardle above Bridge
of Cally.   The hammer lies on Dalradian schists,
the branch follows the line of fault, and the fore-
-ground is occupied by a Lower Old Red Sandstone
"Highland" conglomerate.

Fig.3. Infaulted Lower Old Red Sandstone outlier at Strone
House on the R. Ardle.   The cliff at the back con-
-sists of vertical phyllites, to the left can be
seen a local basement conglomerate of phyllite
fragments, and to the right under the trees is a
small outcrop of a microporphyritic biotite-andesite.

Plate VIII.

1.

2.

3.

PLATE IX.

Fig.1.   Olivine-basalt sill at Corriefodly on the left bank of
the R. Ardle.   The hornfelsed underlying sediments
stand out as a ridge high up among the trees at the
back.

Fig. 2. Tholeiite dyke at Westfield, Blairgowrie.   Most of the
igneous rock has been quarried away but a small
patch remains in the bottom right corner.   The
slickensided walls of Lower Old Red Sandstone con-
-glomerate can be seen towards the middle.

Fig. 3. Near Dunmore above Stenton on Tay.   Roches moutonnées
of andesite.

Plate IX.

PLATE X.

Fig. 1. View north-east from the Knock of Formal to Cat Law
with the Gorge of Auldallan forming the V on the
horizon and the alluvial flats of the old Loch of
Auldallan in the central portion of the photograph.

Fig. 2. Gravel mounds and alluvial flats of the Loch of
Auldallan with the outlet through the gorge to the
left beyond the two trees.

Fig. 3. The north-eastern end of the Auldallan gorge — a dry
valley with a gravelly bottom.   It is here that it
debouches on to the flats of the old Loch of
Ascreavie.

Plate X.

1.

2.

3.

PLATE XI.

Fig. 1. View from Kame at north-east end of Auldallan gorge
to the old basin of the Loch of Ascreavie. Traces
of terraces can be seen on the right. The wooded
ridge in the central and right background is the
outcrop of Lintrathen type dacite. The outflow was
by the Carity Den, marked with the arrow.

Fig. 2. Carity Den, a dry valley with rocky walls of Lintrathen
type dacite.

Fig. 3. View north-east across the Carity Burn valley. The
hillock marked K is the dacite outcrop at the Knock,
Cortachy. Beyond are Dalradian Schist hills. To
the left along the banks of the Carity are Kames.

Plate XI.

1.

2.

3.

PLATE XII.

Fig. 1. View north-east along dry valley on south side of the
Knock, Cortachy.

Fig. 2. Loch of Clunie.   View from east side showing Dalradian
Schist mass of Benachally beyond.

Fig. 3. View from hill to south-west of Loch of Clunie, showing
the line of the lochs linked up with marshes and
sand-banks.   In the foreground is the Loch of Clunie,
beyond is Marlee Loch.

Plate XII.

1.

2.

3.

PLATE XIII.

Fig.1. Gravel and sand piles at Heuchs o' Mause on the R. Ericht, above Blairgowrie.

Fig.2. The Loch of Lintrathen from the Knock of Formal.

Fig.3. View across Strathmore from the summit of the Heuchs o' Mause, Blairgowrie.
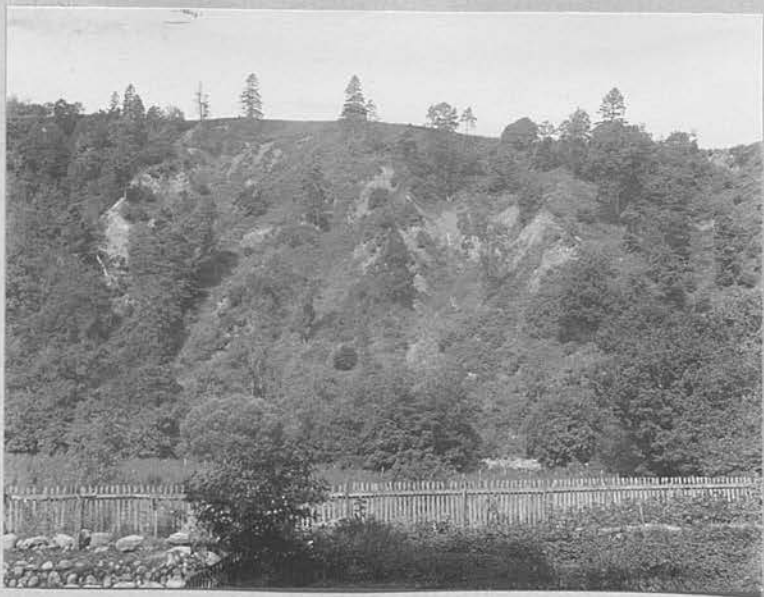
Plate XIII.

1.

2.

3.

PLATE XIV.

Fig. 1. Lintrathen type Dacite.

In the centre a large pheno-
-cryst of quartz showing marked resorption.   On either
side are crystals of oligoclase, while above are several
flakes of biotite.   The groundmass consists of small
fragments of quartz, strips of plagioclase and accessory
iron oxide and apatite set in a glass and together
showing fluidal arrangement.

X 30.   Quarry beside Lintrathen Loch.

Fig. 2. Lintrathen type Dacite.

Phenocrysts of quartz and
biotite, the latter with inclusions of apatite, set in
a glassy groundmass possessing good spherulitic
structure.

X 30.   Hill Quarry beside Lintrathen Loch.

Fig. 3. Porphyritic Biotite-Andesite.

Numerous phenocrysts of
oligoclase-andesine with tabular habit occur to the
right.   On the left is a large crystal of biotite show-
-ing crumpling of the lamellae.   The elongated light
area is composed of pale green chlorites. Apatite
inclusions are present.   The groundmass consists of
small stout laths of oligoclase, clear apatite, iron
oxide, and brownish glass.

X 30.   Isla Gorge, right bank, downstream from Reekie
                                                    Linn.

Plate XIV.

1.
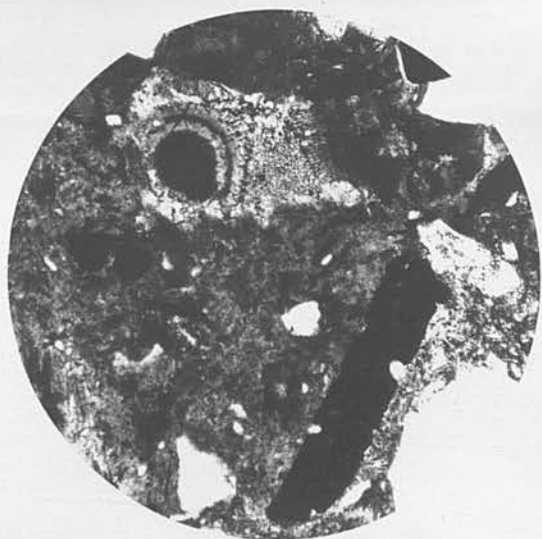
2.

3.

PLATE XV.

Fig. 1. <u>Microporphyritic Biotite-Andesite</u>.
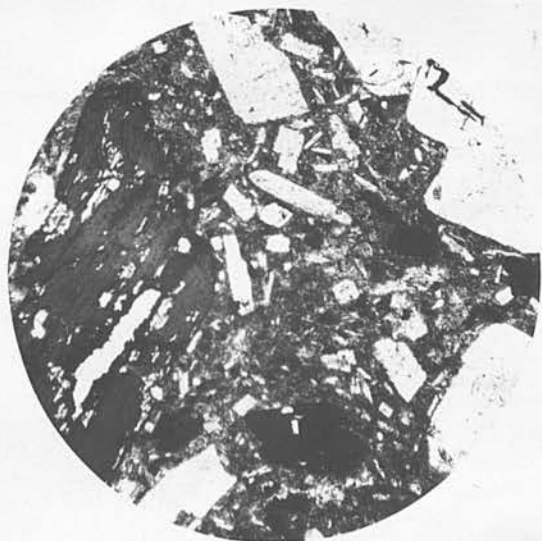A flake of biotite replaced by black iron oxide is seen in the upper part of the field, scattered throughout which are smaller elongated crystals of oligoclase-andesine. The groundmass consists of small felspar laths, biotite, some granular augite, and iron oxide. The dark appearance of the rock is due to the biotite of the groundmass having been replaced by black iron oxide which has tended to spread throughout.

X 30. Burn of Drimmie near Rannagulzion.

Fig. 2. <u>Non-porphyritic Biotite-Andesite</u>.
A very fine-textured rock composed of tiny oligoclase laths, flakes of biotite, and granular calcite probably after augite. There is abundant acicular apatite. The irregular patches of iron oxide seen in the upper half of the field may represent original clots of biotite and are of frequent occurrence.

X 30. Quarry south-west of Wester Derry.
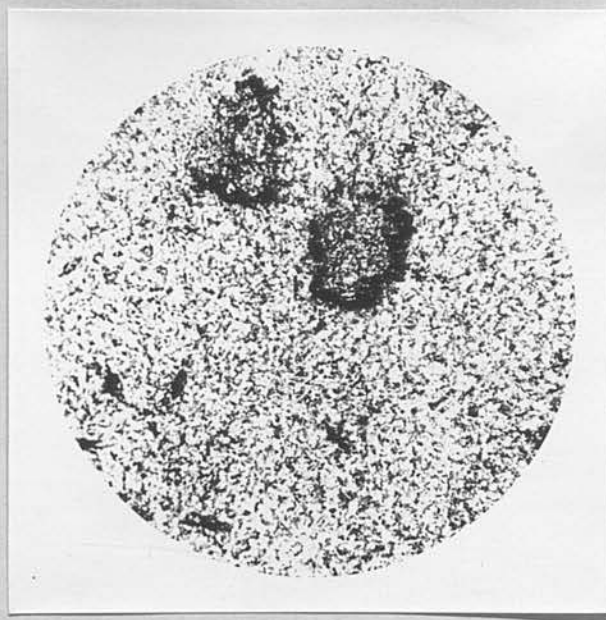

Fig. 3. <u>Porphyritic Andesine-Pyroxene-Andesite</u>.
Near the top is a phenocryst of fresh andesine; to the right is one of hypersthene showing strong transverse cracks and a resorbed rim. The groundmass consists of andesine, augite, apatite, iron oxide, and glass - showing typical hyalopilitic structure.

X 30. Muir Wood, Balintore.

Plate XV.
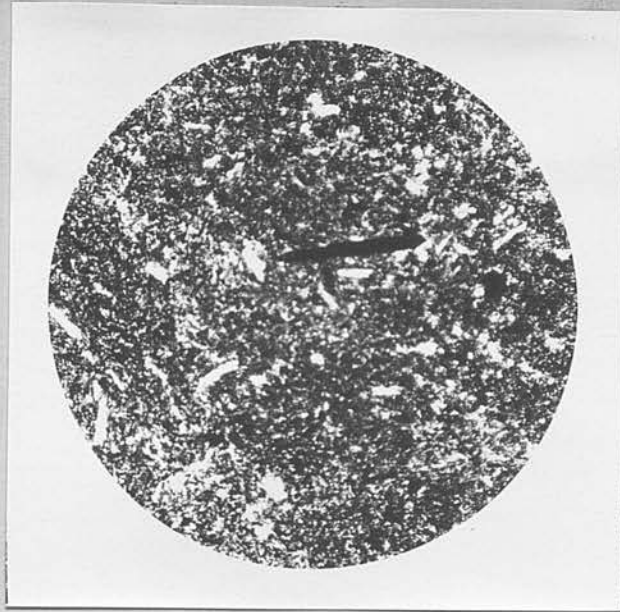
1.

2.
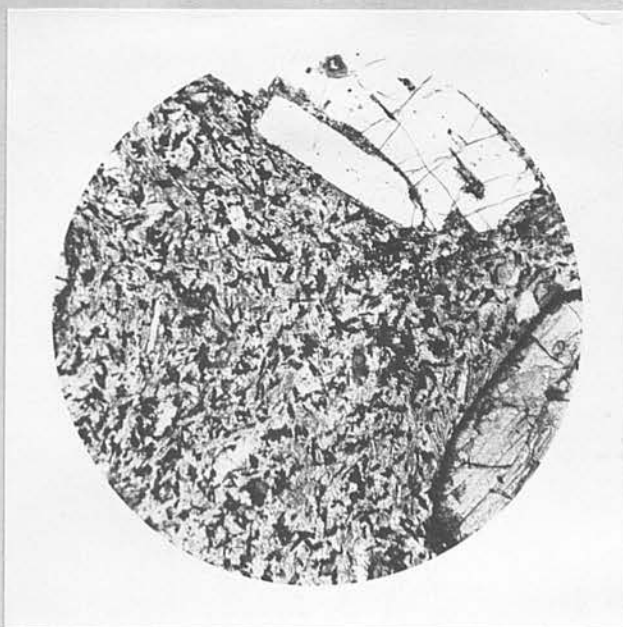
3.

PLATE XVI.

Fig. 1. Porphyritic Labradorite-Pyroxene-Andesite.
                                                    Numerous
phenocrysts of labradorite with abundant glass
inclusions.   To the left is a smaller hypersthene, to
the right an augite.   The groundmass is hyalopilitic
containing tiny laths of andesine, pyroxene, apatite,
and iron oxide.

X 30.   Road floor east of Lintrathen, near Wardend.

Fig. 2. Microporphyritic Pyroxene-Andesite.
                                          Abundant small
crystals of hypersthene set in a groundmass of laths of
andesine and small prisms of both monoclinic and ortho-
-rhombic pyroxene.   The structure is closely akin to
pilotaxitic.

X 30.   Gauldswell Quarry, Bamff.

Fig. 3. Microporphyritic Olivine-Andesite.
                                     At the bottom is a
good idiomorphic serpentinised olivine.   Other smaller
ones are of frequent occurrence.   The groundmass
consists of laths of andesine and small prisms of
augite, and fluxion structure is well developed.   The
accessories are iron oxide and apatite.

X 30.   Top of Reekie Linn, R. Isla.

Plate XVI.

1.

2.

3.

PLATE XVII.

Fig. 1. Porphyritic Olivine-Hypersthene-Basalt.

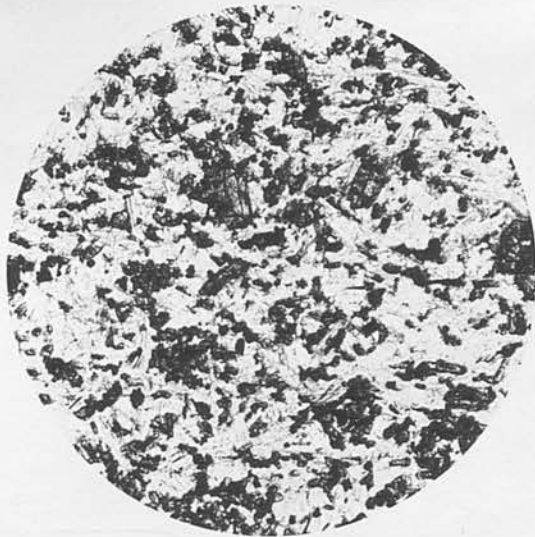In the top left hand quadrant is a resorbed tabular labradorite pheno--cryst, and near it is a good almost idiomorphic serpentinised olivine. The bottom right hand quadrant is occupied by two or three bastite pseudomorphs after hypersthene, growing together. The groundmass con--sists of small but stout laths of labradorite, the remains of probably both hypersthene and augite, apatite and iron oxide. Some of the black represents glass.

X 30.   Lornty Burn, Milton of Drumlochy.

Fig. 2. Porphyritic Olivine-Basalt.

Large idiomorphic serpentine pseudomorphs after olivine, and smaller elongated crystals of labradorite, set in a groundmass of labra--dorite laths, granular calcite after augite, and a little olivine. Iron oxide, apatite, and dark glass fill in the interstices. The rock is exceedingly decomposed but is one of the best examples available.

X 30.   Burn of Watersheal, Nether Drumhead.

Fig. 3. Microporphyritic Olivine-Basalt.

Small porphyritic serpentinised olivines approaching idiomorphism, set in a groundmass of tiny labradorite laths and granular augite, together with apatite, iron oxide, and some glass. Good fluidal banding is seen.

X 30.   Burn of Watersheal outlier.

Plate XVII.

1.

2.
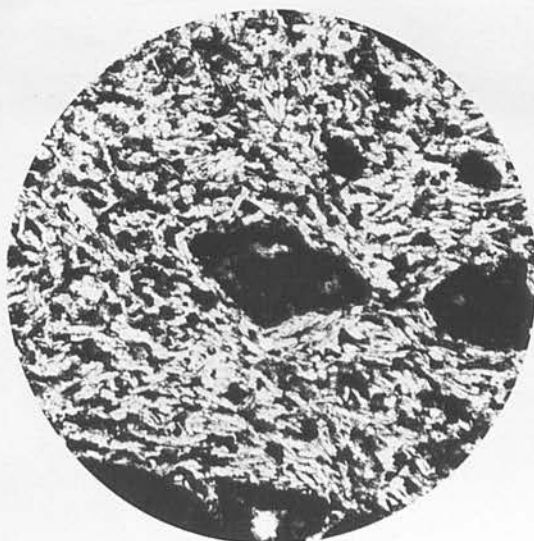
3.

PLATE XVIII.

Fig. 1. <u>Porphyritic Olivine-Enstatite-Serpentine (Harzburgite)</u>.
Unaltered enstatite, with strong cleavage,
embedded in mesh (olivine) serpentine.   Near the top
to the right is a crystal of picotite.

X 30.   Bogside — Bamff ridge, north-west of Alyth.

Fig. 2. <u>Pegmatitic Serpentine</u>.
Fibrous serpentine after
enstatite.

X 30.   Carity Burn.

Fig. 3. <u>Dunite Serpentine</u>.
Serpentine after olivine, with black
iron oxide occupying the mesh-lines.

X 30.   South of Craig, north of Alyth.

Plate XVIII.
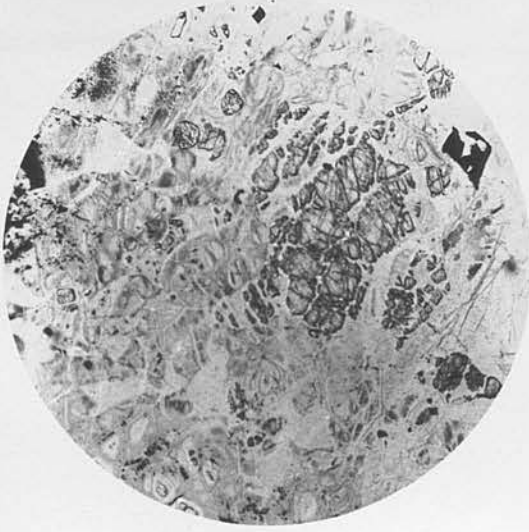
1.
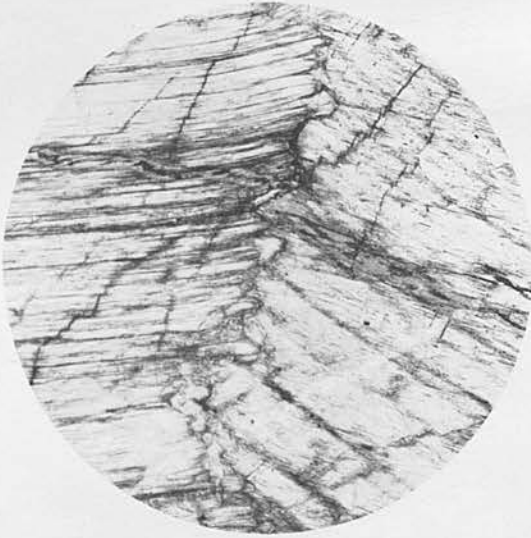
2.
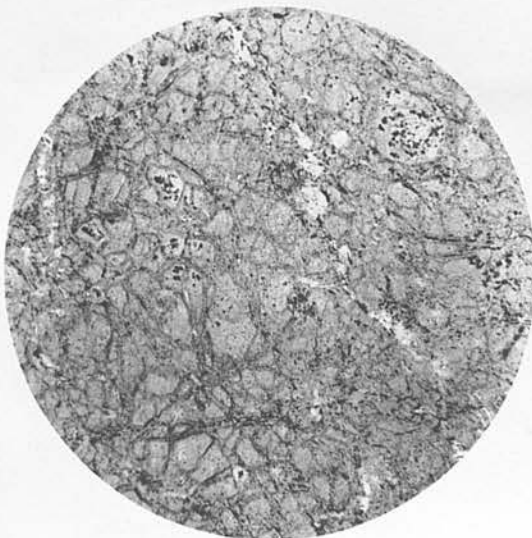
3.

PLATE XIX.

Fig. 1. Schalstein.
               Silicified rock containing igneous fragments and iron oxide, showing "aschen" structure.

X 30.   Melgam Water, Kinaird, Lintrathen.

Fig. 2. Schalstein.
               Similar to Fig. 1 above, but with some quartz grains.

X 30.   Melgam Water, Kinaird, Lintrathen.

Fig. 3. Chert.
      Chert with rhombs of carbonates and specks of black iron oxide.

X 30.   R. Prosen above Prosenhaugh.

Plate XIX.

1.
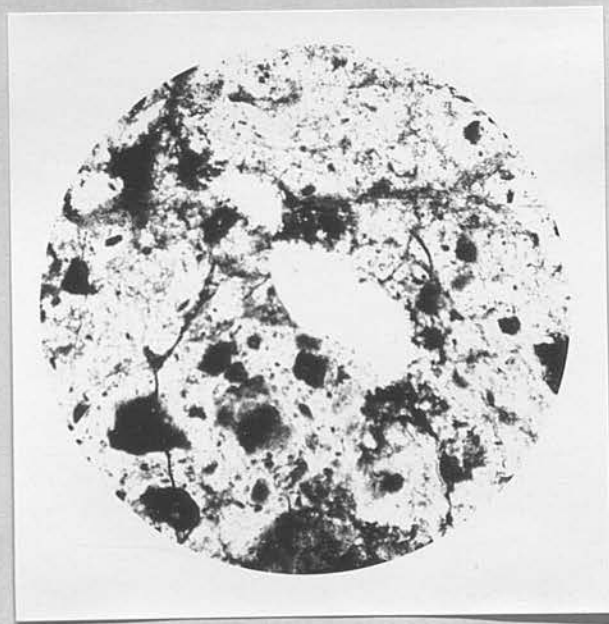
2.
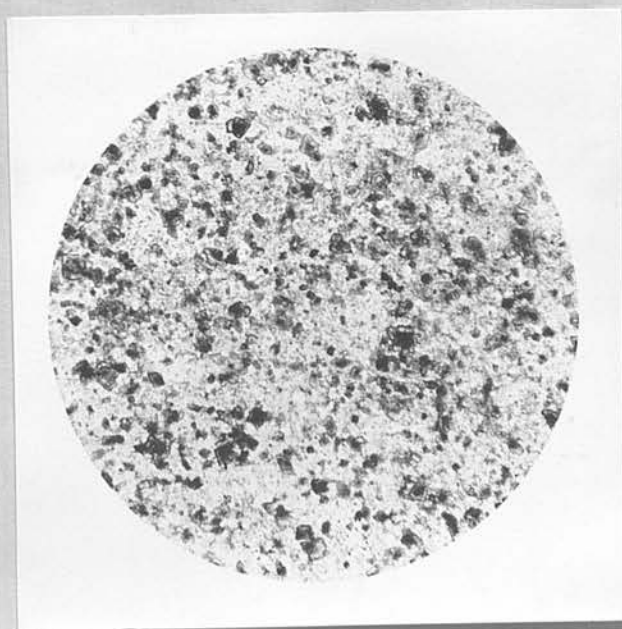
3.

PLATE XX.

Fig. 1. | Olivine-Basalt.
In the centre is a serpentinised olivine, surrounded by tabular crystals of labradorite. The groundmass consists of laths of labradorite and small prisms and granules of augite. The remainder of the field is occupied by dark glass and iron oxide. Long streaks of black iron oxide are of common occurrence throughout.

X 30. Corriefodly Sill, R. Ardle, Bridge-of-Cally.

Fig. 2. | Olivine-Hypersthene-Basalt.
To the left is a bastite pseudomorph after porphyritic hypersthene, and at the bottom is a phenocryst of labradorite. The groundmass consists of small felspar crystals, and some granular calcite probably after augite. The residue is dark glass.

X 30. Dyke in stream west of Auchnacree.

Fig. 3. | Tholeiite. Coarse-textured from centre of dyke. Large tabular labradorites in sub-ophitic to ophitic relationship to the augite occupy most of the field. To the left is a small lozenge-shaped serpentinised olivine on which is moulded black iron oxide. Both are surrounded in part by plagioclase and in part by augite.

X 30. Hill of Ogil, Quarry on south side.

Fig. 4. | Tholeiite. Porphyritic "chilled edge" of dyke. Elongated crystals of labradorite with smaller augites partially embedded in them, set in a dark glassy base containing a felt of smaller plagioclase laths, granular augite, and some iron oxide.

X 30. R. Isla, right bank, near Wester Campsie.

Plate XX.

1.

2.

3.

4.

*1260
CONLAN HILL

*1594
BENACHALLY

LOCH
BENACHALLY

*1315

DRUMDEARG *1383

*1243
HILL OF THREE CAIRNS

*1322
HILL OF FERNYHIRST

BURN OF WATERSHIP

BURN OF NILRY

BACK WATER

*1630 *
CREIGH HILL

BADEN BURN

R. ARDLE

R. BLACKWATER

MAUSE LOCH

R. ERICHT

BURN OF DRIMMIE

LOCH OF DRIMMIE

DIES BURN

R. ISLA

*1272
CRAIGLEA HILL

LOCH OF
AULDALLAN

*18
LOCH

VALLEY
LOCH

LUNAN BURN

*1045
ARLICK

*1394
BALDUFF HILL

MILNA-
CRAIG
LOCH

BUCKNY BURN

LOCH
CRAIGLUSH

LOCH OF
BUTTERSTONE

MORGANSTON BURN

*1221
INCHLEY

*1158
KNOCK OF
FORMAL

*1017
BRANKAM HILL

*1341
MILE HILL

LOCH OF THE
LOWS

GLASCLUNE BURN

*859

LOCH OF
LINTRATHEN

LOCH OF
ASCREADIE

LUNAN BURN

LORNTY BURN

*641

LOCH OF
AUCHRANNIE

MELSAT WATER

996 *
NEWTYLE HILL

*856

*749

R. ISLA

1041 SILVERSIDE

LOCH OF
CLUNIE

*966
HILL OF ALYTH

AUCHRANNIE BURN

*798 SCHURROCH

CULHAWK HILL

*1018

*277

DUNMORE

HEIGHTS o MAUSE

R. ERICHT

*871
LOYAL HILL

*BARRY HILL

ALYTH BURN

CROMIE BURN

1047 CLUNE

MARLEE
LOCH

*398

*556

R. TAY

*200

LUNAN BURN

*250

LOCH OF KINNORD

SCALE 1 IN. = 1 MILE.

*180

*242

HEIGHTS IN FEET.

0   1   2   3

SKETCH MAP SHOWING GLACIAL AND DRAINAGE
FEATURES ALONG THE HIGHLAND BORDER.
PRESENT RIVERS & LAKES IN BLACK.
PAST RIVERS & LAKES IN BLUE.
GORGES IN CONTINUOUS RED LINES: MARGINAL DRAINAGE CHANNELS
IN BROKEN RED LINES.
→ STRIÆ. KAMES.
●→ ROCHES MOUTONNÉES. SANDS & GRAVELS.

BACK WATER
CREIGH HILL 1630
BURN OF NLBY
R. ISLA
CRAIGLEA HILL 1272
LOCH OF AULDALLAN
1466 THE GOAL
NIMRIVE 1180
1788
1863 LONG GOAT
MILNA CRAIG LOCH
HILL
KNOCK OF FORMAL 1158
BRANKAM HILL 1017
LOCH OF LINTRATHEN
MILE HILL 1341
NEW MOSS 1569
TULLOCH HILL 1230
NAKED TAM 1607
ST ARNOLD'S SEAT 1615
PINDERACHY 1682
NCHLEY
LOCH OF AUCHRANNIE
MELGAM WATER
LOCH OF ASCREAVIE
1295
CRAIG OR TRUSTA 1378
1530
CONLAWER HILL 1242
NORAN WATER
PAPHRIE BURN
R. ISLA
CARITY BURN
R. PROSEN
R. SOUTH ESK
KNOCK 922
DEN OF OGIL
AUCHRANNIE BURN
CLUNEHILL 1047
CULHAWK HILL 1018
CASTLE HILL 970
853
DEUCHAR HILL 970
DRUMMORE 1003
TOLLO HILL 1031
871
SCHURROCH 798
390
499
850 DRUMBEG
CRUICK WATER
ROYAL HILL
BARRY HILL
CROMIE BURN
413
NORAN WATER
556
LOCH OF KINNORDY
R. SOUTH ESK
0   1   2   3
SCALE 1 IN. = 1 MILE.
407
242
HEIGHTS IN FEET.

Dunkeld

River Ardle
River Ericht
River Isla
River Tay
Black Water
Alyth Burn
Melgam Water

Drumderg 1383
Broom Hill 1230
Creigh Hill 1630
Bodandere Hill 1757
Tombay 1199
Cat Law 2196
Black Hill 1454
Hill of Three Cairns 1243
Balintore
Auldallan
Craighead
Balduff Hill 1074
Knock of Formal 1168
Inchbey 1221
Bamff
Reekie Linn
Strone Hill 1074
Brankam Hill 1017
Kinclune Hill 1341
Kinclune
Loch of Lintrathen
Lintrathen
Kinnaird
Kinard
Clunehill 1047
Culhawk Hill
Kirkton of Kingoldrum
Cromie Burn
Loch of Kinnordy
Burn of Auchrannie
Newtyle Hill 996
Kincardine
Loch of Clunie
Lunan Burn
Marlee Loch
Craighall
Drumshade
Ruthlaw
Hill of Alyth 960
Loyal Hill
Barry Hill 660
Alyth
Blairgowrie
Rattray
Alcteild
Myrerigg
Caputh
Ruthven
Stenton
Limestone Bank
Lornty Burn
Glenkilrie Burn
Bridge of Cally

A B C D

HILL 454

BROOM HILL 1230

CREIGH HILL 1630

QUARRITY BURN

BALINTORE

BODANDERE HILL 1757

St ARNOLD'S SEAT 1611

BACK WATER

1199 TOMBAY

CAT LAW 2196

1607 NAKED TAM

1178 BLACK HILL

D

RIVER PROSEN

PITEWAN

MELGAM WATER

INZION BURN

AULDALLAN

CARITY BURN

1230 TULLOCH HILL

RIVER SOUTH ESK

F

CONLAWER HILL 1244

BALDUFF HILL

1168 KNOCK OF FORMAL

STRONE HILL 1974

KINCLUNE HILL 1341

T

T

T

T

Σ

T

CORTACHY T AUCHNACREE

1221 INCHLEY

REEKIE LINN

BRANKAM HILL 1017

KINCLUNE

CARITY DEN

PROSENHAUGH

911 KNOCK

DEN OF OGIL

RIVER ISLA

LOCH OF LINTRATHEN

LINTRATHEN

Σ

Σ

CARITY BURN

CORTACHY CASTLE

WHITE BURN

NORAN WATER

KINARDO

CLUNEHILL 1047

CULHAWK HILL 1018

MEAMS HILL 889

E

MELGAM WATER

KIRKTON OF KINGOLDRUM

RIVER SOUTH ESK

BURN OF AUCHRANNIE

CROMIE BURN

AUCHILSHIE BURN

OF ALYTH

LOYAL HILL

BARRY HILL

C

LOCH OF KINNORDY

ALYTH

RIVER ISLA

C

KIRRIEMUIR

RUTHVEN