

CHEMICAL STUDIES in SOME WOODLAND  
SOILS from NORTH-EAST SCOTLAND.

C O N T E N T S.

	<u>page.</u>
I. Aim of Investigation .....	1.
II. General Aspects of Podzolisation ....	2.
III. The Teindland State Forest .....	7.
IV. Morphology of the Teindland Soils ....	16.
V. Chemical & Textural Properties of the Soils .....	41.
VI. General discussion of results .....	73.
VII. Appendices:-	
A. Field methods .....	84.
B. Laboratory Methods .....	85.
C. Literature cited .....	86.



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I. AIM of INVESTIGATION.

The aim of this investigation was to study the properties of the soils of the State Forest of Teindland, near Elgin. For comparison, data for a soil from near Aberdeen have been introduced.

For a number of years experimental afforestation has been carried out on the Teindland Forest, but no data on the nature and composition of the soils had been obtained. It was therefore considered desirable to make a rough survey of the soils and to collect typical specimens for laboratory investigation.

Since the soils examined all fall into the great group of podzol soils, it is desirable to preface the account of the investigation with a brief description of the main morphological features of podzol soils, and the processes giving rise to these features.

## II. GENERAL ASPECTS of PODZOLISATION.

Podzol soils owe their name to the presence of an ashy-grey layer which underlies the surface layer of dead vegetation and plant roots, "zola" in Russian meaning ashes. The presence of this grey layer in woodland and heath soils had long been known but it was not until the beginning of the present century that a proper explanation of its formation was given.

The general appearance of a strongly podzolised soil is as follows, the horizons being given the conventional letters which are later explained.

1.  $A_0$  Consists largely of decaying organic remains.
2.  $A_1$  An intimate mixture of completely decayed organic residues and mineral matter, dark grey in colour.
3.  $A_2$  Ashy-grey to whitish in colour, low humus and clay content.
4. B Sharply differentiated from  $A_2$  in colour and texture; is rusty or yellowish brown in colour but may be almost black; contains more clay than  $A_2$ ; is usually more compact and may be indurated. This layer is usually subdivided into  $B_1$ ,  $B_2$ , etc.
5. C Parent material.

A straightforward ultimate analysis of the various layers of a podzol soil shows that, in the grey layer silica/

silica largely preponderates over the other constituents, these, e.g. the sesquioxides, being rather low. On the other hand when the layers underlying the grey layer are considered, an immediate increase in the amounts of sesquioxides is at once observed, while the percentage of silica is correspondingly lower. As a rule the clay content of these lower layers is also higher.

These facts suggest that there has been at work in the soil a leaching process, carrying down sesquioxides, bases and clay while the silica is left behind.

On examination of the climatic data for the regions in which podzols occur - the cold temperate region - it is observed that atmospheric precipitation always exceeds evaporation. Thus, the cause of the leaching of the soil constituents from the upper to the lower layers is at once apparent. The rain soaking into the soil dissolves or carries down the various constituents in the colloidal state. Bases, e.g. lime, magnesia, etc. will be carried down in true solution or as adsorption compounds with the colloids, while the sesquioxides will be removed in the colloidal state. Some of the iron, of course, may be leached as ferrous ion.

These/

These constituents are not leached entirely out of the soil. The sesquioxides and some part of the bases being deposited at quite a short distance from the grey layer, imparting a rusty tinge to the soil. The boundary between these two layers is usually very sharp. On account of this deposition of sesquioxides etc., this layer is known as the illuvial horizon (designated B), the leached layer above being known as the eluvial horizon (designated A<sub>2</sub>).

The above gives in a general way the chief features of a podzol soil and the method of its formation. A more detailed explanation of the processes at work in the leached layer has been given by Gedroiz (10) as a result of his experiments on the soil adsorbing complex. This may be summarised as follows.

Under the climatic conditions prevailing in the podzol zone there is a constant leaching of bases from the upper, or eluvial layers of the soil and since under coniferous forest and heath, the organic remains are very poor in bases, hydrogen becomes the predominant cation in the adsorption complex.

Gedroiz found that a soil adsorbing complex when saturated with hydrogen became very unstable in contact/

contact with water and tended to break up into its main component parts, e.g. silica and the sesquioxides. These are set free in the colloidal state and since the sesquioxides are readily peptised by humic substances, they are quickly removed from the seat of decomposition. Silica is only soluble to a very slight extent in acid solution and so for the most part is left in situ. Data for the mineral constituents of river water show that silica is present in very small amount (6). It is interesting to note that the analyses for the Rivers Dee and Don show that the waters of these rivers contain much more silica than sesquioxides.

The precipitation of the sesquioxides in the illuvial horizon has not yet been fully explained and numerous theories have been propounded. The first to study the problem in a quantitative manner was Aarnio (1,2). On the basis of his experiments he put forward the view that an increase in concentration above a certain limit brings about a flocculation of sesquioxide sols. He also found that silica and humus colloids could precipitate iron and alumina sols especially the iron sols.

A fact of importance in this connexion has been brought out in the literature recently - that is/

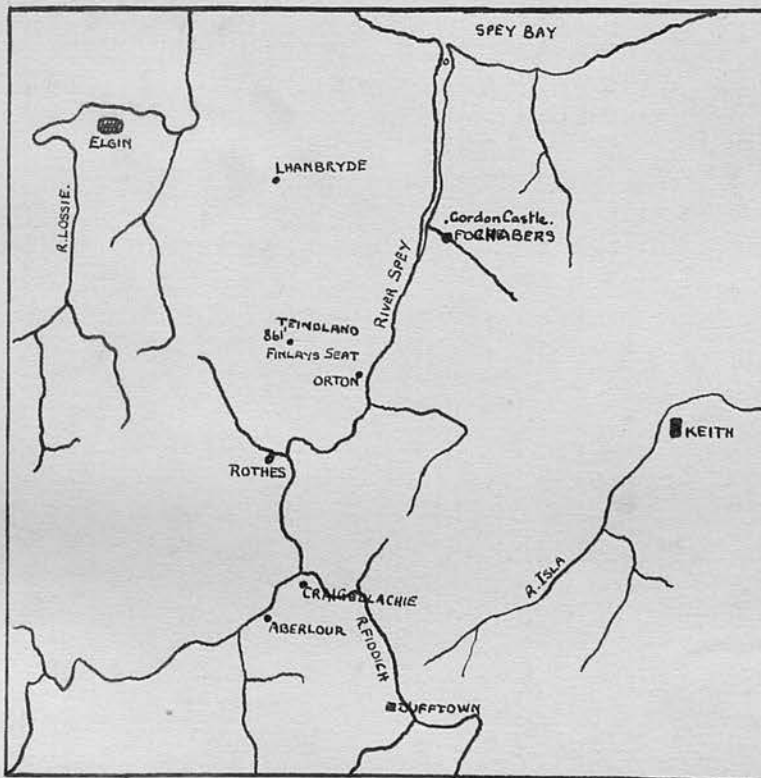
is, the pH of the illuvial layer of podzols tends to approximate to a value of 4.7 (27, 25, 22, ) This would appear to show that the base status of the illuvial horizon also plays an essential part in the precipitation of the sesquioxides. Joffe (15) as a result of a study of American podzols in conjunction with Mattson's theories of soil colloid behaviour comes to the conclusion that "the electrostatic forces causing the movement of the anionic constituents (i.e.  $R_2O_3$  etc.) is regulated by the pH of the medium and the presence of electrolytes." (15).

In the above description of podzolisation it has been assumed that drainage was quite normal. If, however, drainage is impeded in any way the soil acquires quite different characteristics and properties, although it may retain some of the normal podzol features. This will be the case if the impedance is of a temporary or intermittent character and the conditions are otherwise favorable for podzolisation. The features of these soils will be considered later (pp. 29 ff. ) when the morphology of the Teindland soils is being considered.

### III. THE TEINDLAND STATE FOREST.

#### Situation.

The Teindland forest is situated about 7 miles from Elgin on the Elgin-Orton road and occupies the North-East portion of Finlay's Seat, a hill of some 860 feet in height (see map 1). The area of the forest is about two sq. miles.



Map 1. Sketch map of Lower Strathspey.

Physical Features and Surface Geology.

Finlay's Seat rises very gently from the surrounding undulating plain and has all the characteristics of a well glaciated hill.

According to Bremner ( 5 ) three great ice movements have taken place in North-East Scotland and it is to the last of these that the present surface form of the country is largely due. During its advance the ice sheet modified the results of former glaciations, laying down new deposits and further rounding off contours. When the ice retreated it did so by stages and many of the minor features of the present surface are due to the melt water flowing from and along the edge of the ice-sheet.

That part of the hill occupied by the forest can be divided into three distinct geomorphological elements with which are associated very closely both soils and vegetation.

The three elements are:-

(1) The upper slopes (above 700 feet) which do not seem to have suffered any fluvio-glacial action.

(2) The fluvio-glacial channel margins which are found on the northern face of the hill, and run almost parallel to the Red Burn.

(3)/

(3) The over-flow channels which are found up to a height of about 700 feet.

The second and third elements are of great importance for the purpose of elucidating the development of the surface form and will yield valuable evidence on the retreat of the third ice-sheet.

As far as the hill itself is concerned there seem to have been several stoppages of the ice-sheet during its retreat. The first would appear to have been about the 600 ft. contour when the melt-water cut out the deep channel which is now occupied by Ladies Moss (see map 2). The next must have been just a little to the North of Cushley Moss, the upper part of the Red Burn being part of the overflow channel cut at this stage. To the east of the burn there is a deep channel which would appear to have been at one time part of the course of the burn. The third stoppage would appear to have been just about Altonside farm when the series of channel margins on the northern part of the forest would be laid down. The actual retreat of the third ice-sheet must have been a more complicated process than here outlined for there are other smaller features which must belong to this period but which do not seem to fit into this general scheme.

The/

The deposits on the channel margins are quite distinct from those in the overflow channels and on the upper part of the hill. The main drift in this area is a purplish red boulder till - the colour indicating its origin from the Old Red Sandstone rocks which it presumably overlies. There are no exposures of solid rock in the immediate neighbourhood. This red till is of considerable depth; on Teindland itself there is an exposure of some 4 metres without any marked change being noted. Near Rothes a depth of 7 to 8 metres for the ground moraine of the third ice-sheet has been recorded (5, 17), while a total depth of drift of some 60 metres has been recorded at various places in the district (17). The till is extremely stony and many of the stones are pebbles from the Old Red Conglomerate rocks. It is not particularly compact and certainly much less so than the boulder till in the neighbourhood of Aberdeen. Occasionally small pockets and bands of a light fawn compact silty material are found interspersed in the red till. These bands are probably due to small streams running under the ice. This red till is found over the whole of the upper part of the hill and at the bottom of the overflow channels.

On the channel margins and on the eastern lower slopes the drift is of a sandy gravelly nature and of a fawn to pinkish fawn colour. There is no definite indication of banding in these deposits but there is a great variation in these gravels. Two pits dug about 50 yards apart shewed up very marked differences in the gravels. One was extremely stony, the stones being well compacted while the other contained only a moderate amount of stones and the whole deposit was quite loose.

These fluvio-glacial deposits gradually thin out with increasing height until at about 600 feet on the West side and at about 450 feet on the East side of the hill, they disappear. Profile 27 (see p. 23 ) shows only about 50 cm. of the sandy drift.

As can be seen from the map there is a long narrow belt of river alluvium on either side of the Red Burn.

The area of peat is not large being confined to the overflow channels. It is of no great depth, 70 cm. being recorded in Cushley Moss and about 100 cm. in part of Ladies Moss. The peat appears to consist largely of heather and deer-grass remains, but a small area of rush peat was seen in one of the channels.

Climate.

Climatic data for the Teindland itself are not available so we have to make use of those for Gordon Castle and Lhanbryde since these are the nearest places at which weather records are kept. Gordon Castle lies about 4 miles to the North-East, while Lhanbryde is 4 miles to the North of Teindland (see map 1.)

The following table gives the data for rainfall and temperature for the two periods 1881-1915 and 1924-1932. Rainfall data for Lhanbryde are not available in the "Book of Normals" (4), while there are no temperature records at all. Soil temperature records for Craibstone are the only ones available for the N.-E. Scotland, but for comparison these are given.

Period.	Rainfall.		Temperature.	
	Gordon Castle 101 ft.	Lhanbryde 310 ft.	Air at Gordon Castle.	Soil at Craib- <sup>*</sup> stone.
1881-1915	29.77 in.	-	46.6° F.	-
1924-1933	28.52 in.	31.05 in.	47.1° F.	45.9° F.

\* For the period 1925-1933. The thermometer is at 1 ft. below the surface.

The/

The rainfall figures are both within the average for the East coast of Scotland which is about 30 ins. As is seen the difference in height between the two stations makes quite an appreciable difference to the rainfall values and since the Teindland lies at an average height of about 600 ft. the rainfall there will be still higher. From the Book of Normals it is seen that the first six months of the year are much drier than the second six. February and April are the driest months of the year.

The air temperature values are reduced to sea level by the application of the conventional factor of 1° F. for each 300 ft. so that the temperature of the Teindland will be about 2° lower than the values given in the table. July and August are the warmest months, the coldest being December and January.

#### Vegetation.

As was mentioned in the section on the physical features of the area, the vegetation is closely connected with the three geomorphological elements into which the hill can be divided; we thus have three main vegetation areas.

(1) On the lower slopes and on the channel margins where the nature of the drift gives rise to good drainage conditions the vegetation consists mainly of Calluna/

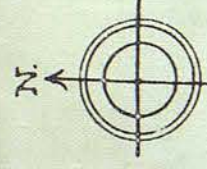
*Calluna vulgaris* and a few mosses of the *Hypnum* and *Dicranum* species, while *Erica cinerea* is often encountered.

(2) The fluvio-glacial overflow channels are usually filled with peat of no great depth. The vegetation here consists largely of *Calluna vulgaris*, *Scirpus caespitosus*, *Eriophorum vaginatum*, mosses of the *Sphagnum* group and *Cladonia* sp. (see phot. 8, p. 39 ).

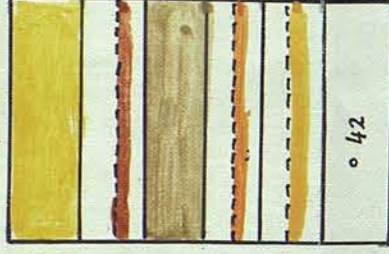
(3) On the upper slopes of the hill drainage is poor owing to the presence of a very impervious hardpan with the result that the vegetation has deteriorated. *Calluna* and *Scirpus* are found here as co-dominant species with a very strong growth of the lichen *Cladonia*. Pine scrub of about 70 years old is present (see phot. 6, p. 31 ).

This *Calluna-Scirpus* association has covered the whole of the upper slopes but is now being eradicated by ploughing and the application of basic slag.

According to the Ordnance Survey map of 1887 the entire hill was covered with trees at that date but judging by the age of the relics seen in the photographs these must just have been planted. On the lower slopes all the former trees have been cut down but from the stumps it is seen that the sands and/



**LEGEND:**



ALLUVIUM

FLUVIO-GLACIAL CHANNEL MARGINS

PEAT MOSSES.  
BOUNDARY OF BOULDER  
TILL AND SANDS.

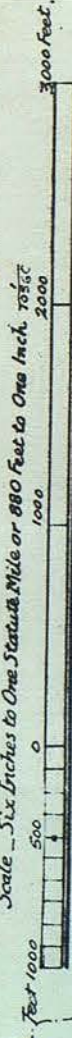
Boundary of Schists and  
Old Red Conglomerate

POSITION OF PROFILES

UNCOLOURED PORTION - SANDS AND GRAVELS.



Scale - Six Inches to One Statute Mile or 880 Feet to One Inch. 1857



# TEINDLAND FOREST

COUNTY OF ELGIN  
PARISHES OF ROTHES & SPEYMOUTH

REE  
R. 30. / No. 21.  
Invd. B.

#### IV. MORPHOLOGY of the TEINDLAND SOILS.

##### A. General.

The soils all fall into the great group of podzol soils and may be subdivided into three main types:

- (1) Normal podzols on fluvio-glacial sands and gravels;
- (2) Humus podzols with hardpan on boulder till;
- (3) Peat gley soils on boulder till.

Each soil, of course, shows a certain amount of variation from the standard, but on the whole, the morphology of each is so characteristic that it can be placed without any hesitation into one of these three types.

Vegetationally each type shows a marked difference from the others. *Calluna* is common to all the types but the plants associated with it allow the soils to be determined very readily. Thus, on the normal podzols in addition to the heather mosses of the *Hypnum* and *Dicranum* species are found; *Plagiothecium undulatum* was very abundant around profile 44. These mosses are not observed on the other soil types. *Scirpus caespitosus* and mosses of the *Sphagnum* species characterize the peat gley soils, while the abundance of *Cladonia rangiferina* on the upper slopes is very characteristic.

The/

The three soil types are closely connected with the three geomorphological elements into which the hill can be divided, although it is doubtful if the surface form by itself has played any definite part in the development of these soils except in the case of the peat gley soils. In the case of these last, the impidence of drainage at the bottom of the overflow channels has been caused by their relative flatness, there being insufficient slope to ensure a rapid run-off of the water collecting at the bottom.

The normal podzols owe their good drainage to the nature of the underlying drift and not the form of the relief of the channel margins. Indeed in some cases these margins are almost closed shallow basins and if it were not for the presence of a porous sand underneath the soils would no doubt have acquired the characteristics of water-logged soils.

On the upper part of the hill where the humus podzols are found it is evident that surface form alone has played very little part in the development of the soil. The slope is sufficient to provide a good run-off of surface water. The depth to which the March Ditch has been cut - 10 to 15 feet in places - is a good indication of the run-off available. The boulder till is not particularly compact and is not high in clay so that it is to other factors that we/

we must turn in order to find an explanation of this type of soil formation. These factors will be considered in detail when the morphology of the soils is discussed.

B. Description of Soil Profiles.

1. Normal Podzols. Four profile descriptions of this type will be given. The methods used in describing these and the subsequent profiles are given, appendix A (p.84 ). The pits dug were at wide intervals over the hill so that they give a good picture of the soils of the lower slopes. The numbers of these profiles are marked on map 2.



Phot. 1. Vegetation at Profiles 42 and 43.

PROFILE 42.

Pit dug on one of the fluvio-glacial channel margins. Height ca. 400 ft.

Vegetation: *Calluna vulgaris* dominant; *Hypnum cupressiformae*, *Hypnum schreberei*, *Dicranum scoparium*, planted pines. See phot. 1.

A<sub>0</sub>-A<sub>1</sub> O - 4(14)cm. Dark brown layer of organic remains with strong root system. In places there is a thin A<sub>1</sub> layer noticeable.

A<sub>2</sub> 4(14)-9(19) cm. Grey, fine sandy layer with slight pinkish tinge, stony, structureless. Many roots.

B 9(19)-55 cm. Rusty brown with slight humus staining in upper centimeter or so. Black humus patches occasional throughout layer. Sandy, stony; roots common. Coarse crumb structure.

C 55 - 90 cm. Pinkish fawn fluvio-glacial gravelly sand. Loose and structureless.



Profile 43.

PROFILE 43.

Pit dug on wide shallow fluvio-glacial channel. Height ca. 400 ft.

Vegetation: *Calluna vulgaris*, *Hypnum cupressiforme*, *H. schreberei*, *Dicranum scoparium*. Young pines (planted). See Phot. 1.

- A<sub>0</sub> 0 - 5(9) cm. Black *Calluna* peat, containing main root mass.
- A<sub>1</sub> 5(9)-7(9) cm. Dark grey humose sand. Coarse crumb structure.
- A<sub>2</sub> 7(9)-14(20) cm. Light grey sandy layer with slight humus staining; suggestion of platy structure; pebbles numerous.
- B<sub>1</sub> 14(20)-16(22)cm. Dark grey-brown sandy, with discontinuous thin iron pan underneath.
- B<sub>2</sub> 16(22)-26 cm. Mottled dark brown and rusty brown sandy layer; many pebbles (mostly small); roots frequent, free and friable.
- B<sub>3</sub> 26 - 50 cm. Rusty fawn fine sand, free, friable, structureless, many small pebbles; roots frequent.
- C 50 - 120 cm. Fawn, pebbly sand, loose and free.



Phot. 3. Group planting experiment.  
Profile 44.

PROFILE 44.

Pit dug on eastern lower slopes; height  
ca. 400 ft.

Vegetation: *Calluna vulgaris*, Mosses, mainly  
*Plagiothecium undulatum*. Group planting experiment  
Phot. 3.

- A<sub>0</sub> 0 - 6 cm. Surface root mat with slightly  
decomposed material in lower portion.
- A<sub>1</sub> 6 - 7 cm. Dark grey humose sand, friable and  
free, stony.
- A<sub>2</sub> 7 - 23 cm. Light grey, in places almost white  
sand. Somewhat variable in depth.  
Coarse platy structure; roots  
numerous.
- B<sub>1</sub> 23-45 cm. Dark grey-brown sandy stony layer,  
slight rusty mottling; loose; roots  
penetrate.
- B<sub>2</sub> 45/

- B<sub>2</sub> 45-55 cm. Rusty brown slightly cemented  
gravelly sand. Stones numerous;  
roots occasional.
- C 55-70 cm. Gravelly sand with occasional  
pockets of pure sand. Loose and  
free.



Phot. 4. Vegetation at Profile 27.

PROFILE/

PROFILE 27.

Pit dug on gentle slope (angle of slope  $2^{\circ}$ ); height ca. 500 ft.

Vegetation: Calluna, with a few mosses, and pine scrub (35 years). See Phot. 4.

- A<sub>0</sub> 0 - 4 cm. Partially decomposed organic remains bound together by calluna roots.
- A<sub>1</sub> 4 - 5 cm. Greyish black layer, specks of silica. Thick root system.
- A<sub>2</sub> 5 - 11 cm. Greyish white fine sandy layer with marked platy structure. Passes imperceptibly into -
- B<sub>1</sub> 11-18(20)cm. Light olive brown fine sand with coarse platy structure in upper portion. Humus colour becomes more intense with depth. Passes sharply into -
- B<sub>2</sub> 18(20)-28cm. Rusty brown fine sand with numerous small black humus spots. Structureless.
- C 28-40 cm. Yellowish fawn fine sand of fluvio-glacial origin. Varies somewhat in depth.
- C' 40-100 cm. Purplish red boulder till, fairly compact but apparently quite permeable to water.

These four profiles all show the typical features of a strongly podzolised soil. There are minor differences, but that is to be expected since, as has been stated earlier, the drifts are not perfectly uniform and in addition the position of the/

the soils in relation to the relief is not the same in each case. There is no doubt that the relief -<sup>1.</sup> both mezzo- and micro-relief - plays quite a large part in the development of the various horizons. It was observed in the pit for profile 43, that the leached layer was slightly thicker at the lower end of the pit than at the higher end. The actual difference in height is no more than a few centimetres.

Considering these four profiles horizon by horizon it is to be noted that the  $A_1$  layer is not developed to any marked extent in profile 42. Where it was present it was never more than a few millimetres in thickness. According to Glinka (12) the absence of this  $A_1$  layer is a characteristic feature of the podzols of the Northern Province of the Russia. The  $A_2$  layer follows immediately after the surface organic layer.

The  $A_2$  layers of all four profiles are very similar in every respect except in structure. The leached layer of profile 42 showed no structure whatever, even when dry, while profiles 44 and 27 showed very marked platy structure. The leached layer of profile 43 had only a suggestion of platiness. This platy/

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1. A term introduced by Neustruev (18) for intermediate forms of relief.

platy structure is a common feature of podzols in general and especially of those formed from clayey or loamy deposits. In sandy soils the lack of clay prevents the cohesion of the coarser particles into structural elements.

Small iron concretions which are common in the A<sub>2</sub> horizons of podzols in Russia were not observed at all in any of these profiles.

The humus accumulation layer (B<sub>1</sub>) is found in all profiles but only in one, profile 43, was there any sign of iron pan below this layer and here it was discontinuous and very thin (2-3 mm.) The lower portion of the illuvial horizon is only cemented in one case (profile 44) and even here it is not very strong.

Occasional spots and patches of humus are found in this lower part of the illuvial/<sup>horizon</sup>are common to all these profiles. In some cases this is due to the decomposition of old roots. Structure is almost entirely absent from the illuvial horizon as a whole, at the most a coarse crumb structure is all that can be observed. This lack of structure again is, no doubt, due to the sandy nature of the parent material.

Underlying these horizons is the parent material in this case a sandy gravelly drift. This drift is of a loose friable nature and show no structure whatsoever.

For/

For purposes of comparison a podzol profile from the Hazlehead Policies, near Aberdeen.

PROFILE. No. 3.

Pit dug on flat part of ridge between two glacial overflow channels. Height, ca. 400 ft.

Vegetation: Open coniferous wood consisting of *Pinus sylvestris*, *Larix europaea*; *Sorbus aucuparia*; *Pteris*, *Deschampsia flexuosa*, *Oxalis acetosella*.

Parent material: Boulder till over granite.

1.  
A<sub>0</sub> (0 - 8 cm. Layer of grass and forest litter thick root system.  
(2.  
(8 - 10 cm. Coffee brown well decomposed organic matter, roots abundant.  
(3.  
(10-15 cm. Black well decomposed organic matter; may represent former calluna peat; very little mineral matter: friable.
- A<sub>2</sub> 4. 15-18 cm. Grey with brownish tinge, silty, sandy texture, friable and porous.
- B<sub>1</sub> 5. 18-23 cm. Brown-grey gritty sandy loam friable and porous; slightly more compact than preceding layer.
- B<sub>2</sub> 6. 23-46 cm. Ochrous-brown loam, gritty with many small stones, fairly compact, few black-brown spots of humus.
- B<sub>3</sub> 7. 46-61 cm. Altered boulder-till, lighter in colour than previous layer with pinkish spots of probably unaltered till. Gritty loam in texture, many stones, porous, few roots.
- C. 8. 61-70 cm. Pinkish fawn boulder till, extremely compact and stony.

This area was probably covered with heather before the present vegetation was introduced and so we find that the lower part of the A<sub>0</sub> horizon consists/

consists of heather peat. The  $A_1$  horizon appears to be absent. The  $A_2$  layer is darker than that of the Teindland podzols, due no doubt to the grassy surface vegetation; it is, however, well leached as will be seen from the chemical data to be presented. No structure is shown whatsoever.

The illuvial horizon is fairly well compacted but shows no structure. It passes gradually into the unaltered boulder till.

Thus, we see that on a granitic drift the soil forming processes at work are of the same type as those which are active at Teindland. The surface mineral layer is deprived of its sesquioxides which are deposited lower down imparting a rusty tinge to the soil.

Podzolised soils are classified by the Russian school into subgroups on the basis of the degree of development of the leached layer. When this layer is not developed morphologically but can only be determined by chemical analysis or by deduction from the position of the soil in relation to climate, vegetation, etc., then the soil is said to be a concealed podzol. As leaching proceeds morphological evidence of podzolisation becomes apparent in the form of small bleached spots and narrow bands. This type of soil is known as a slightly podzolised soil.

According/

According to Tamm (25) it takes about 100 years for podzolisation to become apparent. In some cases it may take much less. The writer was shown a soil at Drumtochty, Kincardineshire which had formerly carried a forest nursery. The ground has been allowed to become overgrown with Scots Pine some 20 years ago and at the present moment a very marked leached layer of about  $\frac{1}{2}$  in. is already visible. Since the soil was periodically cultivated while used for nursery work, the processes of podzolisation would never have a chance to produce any such layer.

When leaching has proceeded to such an extent that a definite grey or whitish layer has been formed the soils are known as medium or strongly podzolised soils.

The term podzol is applied to soils "in which the whitish horizon begins near the surface and attains a considerable thickness, whereas the humus horizon  $A_1$  is hardly developed." (18)

On the basis of these definitions it can be said that the soils described above all belong to the group of strongly podzolised soils.

In Scandinavian countries the above classification does not appear to be used. Under the scheme in use there, these soils would all be grouped as iron podzols (9, 3).

2. Humus Podzols with Hardpan.

As has been mentioned in the introduction to this section the humus podzols are found exclusively on the upper slopes where the red till comes to the surface. The main characteristic of these soils is the presence of an extremely hard and almost continuous iron pan. The formation of this pan has led to an impedence in the drainage of the layers above it with the result that the eluvial layer is no longer of the customary grey tint but tends more to an olive grey tone, and the ground has been invaded by a very inferior type of vegetation. As can be seen from the photographs tree-growth is extremely poor.

Three profiles will be described.

PROFILE 41.

Pit dug on upper slopes of hill; height ca. 700 ft. Old peat hags are very common on this part.

Vegetation: *Calluna vulgaris*, *Erica tetralix*, *Scirpus caespitosus*, Mosses and *Cladonia* spp.; poor pine scrub.

A<sub>0</sub> 0 - 3 cm. Mat of heather and other plant roots.

A<sub>1</sub> 3 - 13 cm. Black spongy peat, full of roots, with old tree roots occasional. Passes sharply into -

A<sub>2</sub>-G 13-45 cm. Olive grey silty fine sand, some rusty mottling; structureless, stony, roots penetrate.

B<sub>1</sub>/

- B<sub>1</sub> 45-46 cm. Hard pan of varying thickness. Appears to be quite impervious, and water seeped into the pit from above the pan. The layers underneath were almost dry.
- B<sub>2</sub> 46-56 cm. Boulder till with some rusty streaking and mottling. Occasional dead roots. Stony and compact.
- C 56-70 cm. Purplish red till; patches of a bright red, stiffer clay.



Photo. 5. Vegetation at Profile 41.



Photo. 6. Vegetation at Profile 23.  
The staff in photo. is 4 ft. high.

PROFILE 23.

Pit dug on gentle slope near top of hill.  
Height ca. 800 ft.

Vegetation: Mainly Calluna and Scirpus,  
with very poor pine scrub. (Phot. 6).

- |                     |            |   |
|---------------------|------------|---|
| A <sub>0</sub>      | (0 - 5 cm. | Mat of Calluna and Scirpus roots.   |
|                     | (5 -11 cm. | Well decomposed peat, with many live roots; spongy when wet, but cracks on drying.                  |
| A <sub>2</sub> '-G  | 11-17 cm.  | Gray sandy layer, structureless; contains many stones which are somewhat bleached. Roots penetrate. |
| A <sub>2</sub> ''-G | 17-27 cm.  | Dirty olive brown, silty fine sand in texture; structureless; many stones; slight signs of gleying. |
| B <sub>1</sub> /    |            |   |

- B<sub>1</sub> 27-27.5 cm. Iron pan, not quite continuous but extremely hard.
- B<sub>2</sub> 27.5-40 cm. Purplish red with slight iron staining, especially along old root channels; very compact.
- C 40-90 cm. Purplish red boulder till, looser than previous layer.



Photo. 7. Vegetation to Profile 40.

PROFILE 40.

Pit dug on hummock on upper slopes at a height of about 700 feet. This part very hummocky.

Vegetation: Calluna, Scirpus, Erica tetralix, Carex spp., Cladonia spp., Sphagnum compactum in wet hollows. Stunted pine scrub. Photo. 7.

A<sub>0</sub>/

- A<sub>0</sub> 0-7(10) cm. Surface root mat over black well decomposed peat. Stones occasional.
- A<sub>2</sub>-G 7(10)-17 cm. Dark grey, sandy; humus staining throughout. Stony and free; many roots.
- B<sub>1</sub> 17-23 cm. Brownish black humus accumulation layer, sandy and stony, roots numerous. Underlain by discontinuous hardpan which is quite thin.
- B<sub>2</sub> 23-38 cm. Iron stained sandy, stony, roots occasional, structureless, slightly compacted yet appears free. Slight humus staining.
- B<sub>3</sub> 38-53 cm. Lighter in colour than previous layer, no humus staining visible. Fairly compact, stony and structureless.
- C 53-80 cm. Purplish red till, stony, structureless; slightly compacted.

✕

The term humus podzol has been applied to these soils on the authority of Tamm (26), who in this paper describes a soil very similar to the above except that the hardpan is of much greater thickness.

The formation of humus podzols is the result of periodical swamping with the result that instead of the usual dry surface layer of "raw humus," there is formed a layer of peat of some thickness. The swamping may be a result of one or other of two causes: (1) the ground water level rises fairly high during/

\* It might be better to apply the Russian term peaty gley-podzolised to these soils.

during the wet seasons, waterlogging the surface layers giving rise to conditions of bad aeration and so to peat formation; (2) the presence of a layer in the soil which is impermeable to water. The rain water in this case cannot pass through the soil but lies on the surface until it evaporates or flows away, if there is sufficient slope to permit this. In either case there is a general diffusion of humus through the upper layers.

The soils here considered belong to the second class - the hardpan being the impervious layer.

Two explanations of the development of this type of soil may be put forward.

(a) It may be assumed that the soil developed first as a normal podzol with the formation of hardpan underlying the layer of humus accumulation. That this is possible is seen from Profile 43 which has this feature. As the hardpan increased in thickness so did its impermeability to water increase until in the end, no water could pass through. This is the case in Profile 41. Thus surface waterlogging was made possible and peat formation set in. The presence of a slight platy structure in one profile examined would seem to lend weight to this argument. If the second explanation is assumed then this platy structure would not be present. The  $A_2$  horizon of humus/

humus podzols is normally quite structureless.

(b) Due to the compact layer of heather, remains which have a high absorption capacity for water, the surface layers of the mineral soils would be kept in a wet condition for fairly long periods. Under these conditions iron compounds would be reduced to the ferrous state and as such leached out into the lower layers. These would be in a drier state and the iron would then be reoxidised and precipitated, eventually forming the hardpan.

That the boulder till is sufficiently porous to carry off any excess water was shown by the following. One of the pits had become well filled with water after heavy rain yet it only required two or three days for the water to soak away. There is no evidence at all of a high ground-water level on the upper slopes.

That the iron forming the pan comes from the upper layers is not in doubt. The layers above it are most obviously leached and the fact that the pan consists of a series of thin bands is certain evidence for if the iron were brought from below there would be no chance of sufficient evaporation to enable the sesquioxide gels to pass into the irreversible form. The chemical analysis to be given in the next section also point to the eluvial horizon as the origin of the iron/

iron. The manner of its removal in the early stages of the development of the soil cannot be proved, but at the present time it would appear to be carried down in the ferrous state since the conditions of poor aeration would tend to this. The greenish tint is a good indication of the state of the iron.

The surface organic horizon of these humus podzols takes the form of a layer of peat of no great depth. The  $A_1$  horizon which is found in some of the normal podzols is entirely absent, the peat lying directly on the bleached mineral layer. The leached layer has lost its usual colour and has acquired a greenish tint, i.e. it is gleyed to some extent. This colour is common to many Scottish moor soils especially when a layer of hardpan is present.

The waterlogging which these soils undergo has also the effect of preventing a proper expression of the humus accumulation layer which is usually found under the horizon of eluviation. In these Teindland soils, however, it is very often possible to differentiate two fairly well defined layers above the hardpan, the lower being usually distinctly darker in colour than the upper layer. An example of this feature is seen in profile 23. Whether the darker colour is due to the deposition of dark coloured humus substances alone, or partly to less leaching/

leaching having taken place, it is impossible to state without laboratory investigation. The ignition of samples from each of the layer shows at once that both are strongly leached, the humus alone accounting for the more intense colour of the lower layer.

Similar results have been recorded by Pronevich (21) in his study of the eluvial horizons of a number of Russian podzols.

The hardpan in these soils is remarkable for its continuity and its compactness. In thickness it is fairly variable, ranging from 0.5 cm. to 10 cm. in places, but whatever its thickness it seems to be quite impermeable to water as has been noted in connexion with profile 41. It invariably has a thin matting of fine roots on its upper surface and in none of the profiles in which it was continuous were any live roots found below it. The pan consists of a series of thin bands (1-2 mm.) strongly cementing together grains of sand and small stones. It fluctuates remarkably in depth from the surface, variations of 15-20 cm. over a distance of 1 metre being quite common. The cause of these fluctuations is not quite clear yet but they are probably connected in some way with slight textural differences in the boulder till.

There/

There lies below the hardpan a layer of about 10 cm. in thickness which is somewhat limonite stained. In this layer old root channels are very common, showing that at one time it was possible for the vegetation to draw supplies of nutrients from the lower illuvial horizon. There is no sign of gleying below the pan in any of these profiles and indeed the lower layers were usually fairly dry, indicating that the ground water table must lie at some distance.

At the bottom of each of the profiles we have the purplish red boulder till. It is loamy to silty sand in texture and shows no structure whatsoever. It is not very compact and allows water to percolate through very readily.

### 3. Peat Gley Soils.

The example of this type was taken on the Cushley Moss. The Moss lies in a slight hollow between the 600 and 700 feet contours and is connected with Ladies Moss by two narrow but fairly deep channels. Ladies Moss itself lies mainly in an outflow channel. Cushley Moss is drained by the Cushley Burn.



Photo. 8. Vegetation on Cushley Moss.

PROFILE 25.

Pit dug about 50 yards from the Cushley Burn and about the middle of the moss. Height ca. 600 ft.

Vegetation: Calluna, Eriophorum, Scirpus, Sphagnum mosses, Cladonia spp., pine scrub and planted spruce. See photo. 8.

1. 0 - 5 cm. Matting of mosses, heather and other plant roots.
2. 5 - 70 cm. Black peat, full of roots; sodden.
3. 70 - 120 cm. Bluish-grey sandy compact layer; very stony, structureless; sodden; many decayed roots.
4. 120-150 cm. Mottled blue-grey and purplish red boulder till, sandy and very stony but extremely compacted.
5. 150 + cm. Purplish red boulder till.

The profile appears to be typical for the various mosses found in the forest as far as can be judged from exposures in ditches. The actual depth of peat is variable but the features of the gleyed <sup>are common</sup> horizon/to all the peat mosses. The blue-grey colour of the mineral horizons is due to the reduction of iron compounds to the ferrous state under conditions of permanent water-logging. That the water-logging is actually permanent is seen from the fact that no signs of reoxidation along root channels or pores are visible. The gleyed horizon and patches are more sandy than the unaltered till. It might be expected that with water continually flowing through the moss, a certain amount of mechanical leaching might take place.

V. CHEMICAL and TEXTURAL PROPERTIES of the SOILS.

Under this heading it is proposed to consider the mechanical and chemical composition of the soils investigated. Since the soils of each type show such similarity it is not considered necessary to submit detailed analyses for every soil. The analyses given bring out the main features of the soil types and enable us to confirm the deductions made in the section on the morphology of the soils.

It is convenient to consider the soils in three groups as before. The methods used in the laboratory investigations are given <sup>in</sup> appendix B. (p. 85).

NORMAL PODZOLS.

Mechanical Composition.

The mechanical analyses of this type bring out very clearly the removal of the clay complex from the upper and its deposition in the lower layers. It does not, however, indicate any chemical changes which may have taken place.

In profile 42 it is seen that there is a very marked accumulation of sand in the A<sub>2</sub> layer while the clay content is extremely low. The latter rises

TABLE 1.

MECHANICAL ANALYSIS of PROFILE 42.

Depth. Fraction.	A <sub>2</sub> 4-9 cm.	B <sub>1</sub> 9-19 cm.	B <sub>2</sub> 20-30 cm.	B <sub>3</sub> 45-55 cm.	C 55-65 cm.
Coarse Sand	53.85	41.30	39.96	50.38	53.13
Fine Sand	33.20	26.60	24.67	26.10	34.90
Silt	8.45	5.97	11.77	5.15	3.07
Clay	4.80	13.53	10.13	4.70	3.68
Loss by soln.	0.15	1.78	1.59	1.15	0.58
Moisture	0.66	4.34	4.14	4.34	1.57

Values expressed as percentages of oven-dry  
fine earth (< 2 mm.)

sharply in the succeeding layers while the sand content falls off. With further increase in depth the sand content rises again while the clay content decreases. This feature is also shown by profile 43, but here this soil appears to be to some extent abnormal, the B<sub>3</sub> horizon having a much higher fine sand content than would be expected. This feature is no doubt due to a certain amount of coarse banding in the sands although the bands are not visible.

TABLE 2.

MECHANICAL ANALYSIS of PROFILE 43.

Depth. Fraction.	A <sub>2</sub> 7-14 cm.	B <sub>1</sub> 14-16 cm.	B <sub>2</sub> 16-26 cm.	B <sub>3</sub> 30-40 cm.	C 60-70 cm.
Coarse Sand	30.08	22.46	26.12	19.94	54.83
Fine Sand	53.76	42.38	43.56	54.45	33.92
Silt	10.87	9.06	9.63	9.50	4.17
Clay	4.75	12.32	10.12	9.25	4.58
Loss by soln.	0.20	1.80	1.60	1.97	1.00
Moisture	0.65	5.41	4.72	4.12	1.46

From the colour of the mechanical fractions and from the appearance of the precipitate obtained in determining the loss by solution strong evidence is obtained of the destruction of the adsorption complex. The fractions from the leached layer are in every case almost white and the precipitate appears to contain very little iron. The illuvial horizon fractions on the other hand, are strongly coloured with iron and the precipitate appears to consist largely of that constituent. This evidence is purely qualitative but when we consider the chemical analysis of the clay fraction we obtain very definite quantitative evidence of the degree of destruction of the adsorption complex.

The/

The mechanical analysis of the Hazlehead profile (No. 3) is given in Table 3. The soil as a whole has a much higher clay content than any of the Teindland podzols and it is very evident that there has not been such a loss of clay from the upper horizons. In fact the A<sub>2</sub> horizon contains slightly more clay than the B<sub>1</sub> horizon. In the B<sub>2</sub> horizon, however, there is a definite increase in the clay content.

TABLE 3.

MECHANICAL ANALYSIS of PROFILE 3.

Horizon.	A 10-15 cm.	A <sub>2</sub> 15-18 cm.	B <sub>1</sub> 18-23 cm.	B <sub>2</sub> 23-46 cm.	B <sub>3</sub> 46-61 cm.	C 61-70 cm.
Coarse Sand	16.02	35.33	37.89	36.81	38.82	38.38
Fine Sand	28.28	20.98	25.12	26.08	26.27	26.79
Silt	15.60	16.67	12.65	13.95	17.50	13.80
Clay	9.80	11.25	10.10	11.30	14.02	16.50
Loss by soln.	1.77	0.67	1.83	2.07	1.22	1.45
Moisture	11.29	3.12	6.38	4.63	2.26	2.18

Analysis/

Analysis of the Clay Fraction.

In the characterisation of the main soil types it has become the practice to make use of the ratio of silica to sesquioxides in the clay fraction of the soil (21). That this ratio can render great service in the classification of the major soil groups is a well proved fact. The statistical analysis of a large number of data carried out by Crowther (7) has shown that for American soils, at any rate, there exists a definite correlation between temperature, rainfall and the silica sesquioxide ratio. As an indicator of the relation movements of the silica and sesquioxides in a soil profile this ratio is very useful.

TABLE 4.

CLAY ANALYSIS of PROFILE 42.

Horizon.	A <sub>2</sub> 4-9 cm.	B <sub>1</sub> 9-19 cm.	B <sub>2</sub> 20-30 cm.	B <sub>3</sub> 45-55 cm.	C 55-65 cm.
SiO <sub>2</sub>	52.46%	39.65%	37.62%	28.83%	36.25%
TiO <sub>2</sub>	2.13%	2.05%	1.84%	1.08%	1.00%
Al <sub>2</sub> O <sub>3</sub>	23.23%	27.72%	35.24%	47.39%	44.40%
Fe <sub>2</sub> O <sub>3</sub>	7.80%	27.67%	21.42%	18.23%	11.80%
SiO <sub>2</sub> /R <sub>2</sub> O <sub>3</sub>	2.58	1.47	1.30	0.82	1.03
SiO <sub>2</sub> /Al <sub>2</sub> O <sub>3</sub>	3.03	2.41	1.80	1.03	1.38
SiO <sub>2</sub> /Fe <sub>2</sub> O <sub>3</sub>	17.90	3.80	4.66	4.20	8.17

The  $A_0$  and  $A_1$  horizons of the soils were rejected since they contain practically no mineral matter.

Considering the percentage composition of the clay fractions it is evident that there has been considerable leaching of both iron and alumina from the upper layer and deposition of these substances in the lower layers. It is of interest to note that iron appears to have been carried down, in profile 43, much farther than alumina, the reverse being usually the case. The more normal distribution is shown by the other profiles. The general decrease in the silica-sesquioxide ratio is not affected by this since the increase in iron is offset by the decrease in alumina. When this fact was noted it was resolved to calculate the silica-ferric oxide ratio as well as the silica-sesquioxide and silica-alumina ratios which are usually given alone. In this way a much better conception of the relative movements of iron and alumina is obtained.

On the whole there has been a much more rapid removal of iron than of alumina from the eluvial horizon. This is brought out well by the  $SiO_2-Fe_2O_3$  and  $SiO_2-Al_2O_3$  ratios. In this case of profile 43 there is a decrease from 17.9 to 3.8 for  $SiO_2/Fe_2O_3$  while  $SiO_2/Al_2O_3$  has only decreased from 3.03 to 2.41.

TABLE 5.

CLAY ANALYSIS of PROFILE 43.

Horizon	A <sub>2</sub> 7-14 cm.	B <sub>1</sub> 14-16 cm.	B <sub>2</sub> 16-26 cm.	B <sub>3</sub> 30-40 cm.	C 60-70 cm.
SiO <sub>2</sub>	59.02%	46.28%	31.73%	33.80%	35.20%
TiO <sub>2</sub>	3.59%	1.19%	1.82%	1.50%	1.00%
Al <sub>2</sub> O <sub>3</sub>	24.20%	29.92%	38.36%	31.62%	24.56%
Fe <sub>2</sub> O <sub>3</sub>	4.18%	14.36	20.42	21.71	18.80%
SiO <sub>2</sub> /R <sub>2</sub> O <sub>3</sub>	3.71	2.00	0.95	1.26	1.63
SiO <sub>2</sub> /Al <sub>2</sub> O <sub>3</sub>	4.12	2.61	1.03	1.80	1.92
SiO <sub>2</sub> /Fe <sub>2</sub> O <sub>3</sub>	37.50	8.56	4.13	4.14	4.98

That the upper part of the eluvial horizon is more strongly leached than the lower is brought out in Table 6 in which the analyses of the clay fractions from profile 44 are given.

TABLE /

TABLE 6.

CLAY ANALYSIS of PROFILE 44.

Horizon	A <sub>2</sub> <sup>1</sup> 8-15 cm.	A <sub>2</sub> <sup>1</sup> 15-23 cm.	B <sub>1</sub> 23-43 cm.	B <sub>2</sub> 45-55 cm.	C 60-70 cm.
SiO <sub>2</sub>	50.11%	46.80%	25.50%	24.50%	27.75%
TiO <sub>2</sub>	1.83%	n.d.	0.94%	0.68%	0.41%
Al <sub>2</sub> O <sub>3</sub>	37.95%	39.77%	49.30%	57.41%	53.65%
Fe <sub>2</sub> O <sub>3</sub>	5.16%	8.75%	18.42%	13.31%	12.04%
SiO <sub>2</sub> /R <sub>2</sub> O <sub>3</sub>	2.06	1.75	0.71	0.63	0.77
SiO <sub>2</sub> /Al <sub>2</sub> O <sub>3</sub>	2.24	2.00	0.88	0.72	0.88
SiO <sub>2</sub> /Fe <sub>2</sub> O <sub>3</sub>	25.80	14.20	3.68	4.87	6.19

It is seen that there is quite a sharp decrease in the SiO<sub>2</sub>-R<sub>2</sub>O<sub>3</sub> ratio in passing from the upper to the lower part of the A<sub>2</sub> horizon while there is only a small decrease in the SiO<sub>2</sub>-Al<sub>2</sub>O<sub>3</sub> ratio. In the succeeding layers the SiO<sub>2</sub>-Al<sub>2</sub>O<sub>3</sub> ratio for profile 44 continues to decline whereas the SiO<sub>2</sub>-Fe<sub>2</sub>O<sub>3</sub> rises in the B<sub>2</sub> horizon. The alumina, on the whole seems to be carried down much farther than the iron.

These conclusions are in accord with the results obtained by Tamm in his investigations of Swedish forest/

forest soils (25, 26). Tamm concluded that iron was the first to be removed while silica and alumina were only removed after podzolisation had proceeded for some time.

In Table 7 are given the results of the clay analysis for profile 27. As has already been mentioned this profile was taken quite near to the upper limit of the sand and gravel region where it was found possible to reach the boulder till which underlies these fluvio-glacial deposits. The results for the sand contrast very strongly with those for the boulder till.

TABLE 7.

CLAY ANALYSIS of PROFILE 27.

Horizon	A <sub>2</sub> 5-11 cm.	B <sub>1</sub> 11-18 cm.	B <sub>2</sub> 20-28 cm.	B <sub>3</sub> 30-40 cm.	C 40-48 cm.	Boulder till 90-100 cm.
SiO <sub>2</sub>	57.80%	38.50%	35.10%	33.90%	44.20%	53.76%
TiO <sub>2</sub>	2.33	1.66	1.26	0.83	0.81	0.68
Al <sub>2</sub> O <sub>3</sub>	23.15	45.99	42.51	46.57	41.08	28.66
Fe <sub>2</sub> O <sub>3</sub>	7.47	10.80	18.95	11.63	8.46	14.16
SiO <sub>2</sub> /R <sub>2</sub> O <sub>3</sub>	3.05	0.82	1.12	1.07	1.61	2.42
SiO <sub>2</sub> /Al <sub>2</sub> O <sub>3</sub>	4.24	1.42	1.40	1.24	1.83	3.18
SiO <sub>2</sub> /Fe <sub>2</sub> O <sub>3</sub>	20.57	6.67	4.92	7.75	13.30	11.07

In Table 8 is given the clay analysis of profile 3. As in the other soils there is a definite leaching of iron and alumina from the A<sub>2</sub> horizon. This leaching does not appear to have proceeded very far, however, and the point of maximum deposition of these constituents has only reached the B<sub>1</sub> horizon. In the Teindland soils it was noted that the alumina had been carried much farther down the profile.

TABLE 8.

CLAY ANALYSIS of PROFILE 3.

Horizon.	A <sub>2</sub>	B <sub>1</sub>	B <sub>2</sub>	B <sub>3</sub>	C
SiO <sub>2</sub>	46.60	38.43	40.28	44.83	45.76 %
TiO <sub>2</sub>	2.43	3.50	1.10	1.0	1.0
Al <sub>2</sub> O <sub>3</sub>	32.15	44.60	28.46	30.09	31.64
Fe <sub>2</sub> O <sub>3</sub>	12.31	20.14	23.01	17.40	12.61
SiO <sub>2</sub> /R <sub>2</sub> O <sub>3</sub>	1.98	1.13	1.58	1.85	1.87
SiO <sub>2</sub> /Al <sub>2</sub> O <sub>3</sub>	2.40	1.46	2.40	2.53	2.45
SiO <sub>2</sub> /Fe <sub>2</sub> O <sub>3</sub>	10.07	5.07	4.65	6.83	9.65

From/

TABLE 9.

ULTIMATE ANALYSIS of PROFILE 43.

Horizon.	A <sub>1</sub> 5-7 cm.	A <sub>2</sub> 7-14 cm.	B <sub>1</sub> 14-16 cm.	B <sub>2</sub> 16-26 cm.	B <sub>3</sub> 26-50 cm.	C 60-70 cm.
SiO <sub>2</sub>	89.43	91.05	82.49	78.86	76.40	83.12
TiO <sub>2</sub>	0.14	0.12	0.24	0.21	0.21	0.11
Al <sub>2</sub> O <sub>3</sub>	6.11	5.81	10.10	10.30	11.08	8.56
Fe <sub>2</sub> O <sub>3</sub>	0.89	0.55	2.71	3.59	3.32	2.19
CaO	0.63	0.45	0.52	0.68	0.94	0.59
M <sub>9</sub> O	0.30	0.54	0.40	0.22	0.71	0.46
Undeter- mined residue	2.50	1.78	3.54	6.14	7.34	4.87
Total	100.00	100.00	100.00	100.00	100.00	100.00
Loss on ignition	38.73	1.77	7.87	5.66	3.92	1.63
Moisture (105°)	12.02	0.65	5.41	4.72	4.12	1.46

Silica: This constituent is at its maximum in the A<sub>2</sub> horizon and shows a decrease in the succeeding horizons, reaching a minimum in the lowest part of the illuvial horizon. It increases again in the parent material. The decrease observed is, of course, only

a relative one, being caused by the increase in the amounts of the other constituents in the illuvial horizon. The actual decrease in the amount of silica present must be considerably less.

Sesquioxides: In the eluvial horizon these constituents are at a minimum as has already been shown by the analyses of the clay fractions. In the lower layers the relative movement of the sesquioxides is not the same as judged by these two methods. The ultimate analysis indicates the B<sub>3</sub> horizon as the point of maximum accumulation of alumina while according to the clay analysis this occurs in the B<sub>2</sub> horizon. In the case of iron there is also some divergence. The B<sub>1</sub> horizon is the point of maximum accumulation of iron by the clay analysis whereas according to the ultimate analysis this occurs in the B<sub>2</sub> horizon.

Calcium and Magnesium: The contents of these constituents vary inversely through the profile, the calcium increasing with depth while magnesium decreases. In the B<sub>3</sub> horizon they both reach a maximum. The high content of magnesia in the A<sub>2</sub> horizon may be associated with the presence of garnets which are extremely resistant to weathering. Hendrick and Newlands (13) reported a relatively high garnet content/

content in a drift formed from Old Red Sandstone rocks near Nairn.

Potash and soda were not determined, but it may be assumed that the bulk of the undetermined residue consists of these substances. Thus it is seen that like calcium and magnesium they are accumulated to the greatest extent in the B<sub>3</sub> horizon.

This fact that according to the ultimate analysis most of the main constituents are at a maximum in the lower part of the illuvial horizon is in sharp contrast to the results of the clay analyses which shows the maxima occur in the upper and middle parts of the illuvial horizon. This difference makes possible an interesting field for further investigation.

Rodé (23) as a result of his investigations of the mechanical fractions of podzolised soils came to the conclusion that "the B horizon of podzolised soils is not only a horizon of accumulation but also a horizon of transformation." It is thus possible that a certain amount of recombination has taken place among the various constituents giving rise to secondary minerals which may be removed from the colloidal state by the intense drying to which these sandy soils are subjected.

Polynov (19) recorded the presence of a magnesium/

magnesium alumo-silicate paligorskite in illuvial horizon of some Russian soils. According to Fersman ( 8 ) the formation of paligorskite in sandy soils is due to the interaction of colloidal alumina, silica and magnesium carbonate. This is quite a reasonable explanation since the soil solution percolating down must contain a certain amount of these substances, even in very small quantity.

#### Adsorbed Bases and Acidity.

Except in the organic horizons the content of exchangeable bases is extremely low and in many cases so small that this determination is difficult. This is found to be the case in most Scottish forest soils formed from non-basic rocks. Table 10 gives the amounts of exchangeable calcium and magnesium found in profile 43 together with the pH of each horizon. From the pH value it is evident that hydrogen must be the predominant cation in the adsorption complex.

The high exchangeable Ca and Mg in the  $A_0$  and  $A_1$  layers is probably partly due to the lower volume weight of these horizons. There is a slight increase in exchangeable Ca in the B horizon but when dealing with such small quantities sampling errors may be sufficient to account for any small differences found.

TABLE 10.

ADSORBED BASES and pH for PROFILE 43.

Horizon	A <sub>0</sub>	A <sub>1</sub>	A <sub>2</sub>	B <sub>1</sub>	B <sub>2</sub>	B <sub>3</sub>	C
Calcium	$\frac{0.14\%}{7.0 \text{ m.eq.}}$	$\frac{0.06\%}{3.0 \text{ m.eq.}}$	$\frac{0.015\%}{0.8 \text{ m.eq.}}$	$\frac{0.021\%}{1.1 \text{ m.eq.}}$	$\frac{0.01\%}{0.5 \text{ m.eq.}}$	$\frac{0.016\%}{0.8 \text{ m.eq.}}$	$\frac{0.015\%}{0.8 \text{ m.eq.}}$
Magnesium	n.d.	$\frac{0.032\%}{2.6 \text{ m.eq.}}$	$\frac{0.012\%}{1.0 \text{ m.eq.}}$	$\frac{0.012\%}{1.0 \text{ m.eq.}}$	$\frac{0.011\%}{0.9 \text{ m.eq.}}$	$\frac{0.01\%}{0.8 \text{ m.eq.}}$	$\frac{0.01\%}{0.8 \text{ m.eq.}}$
pH	3.75	3.92	4.34	4.48	4.54	4.83	5.15

In Table 11 are given the amounts of exchangeable Ca and Mg found in profile 3. They follow the same course as those found in profile 43. The larger amount of Ca found in the A<sub>2</sub> horizon may be due to the fairly high humus content of that layer. Except in the A<sub>0</sub><sup>3</sup> horizon the amount of magnesium was extremely small.

The pH values for some of the other soils are given in Table 12. From these it is seen that there is a general decrease in pH with increasing depth. The pH of the illuvial horizon generally approximates to a value of 4.5, this being about the point of complete precipitation of iron from solutions of its salts. The value, however, is liable to vary on account of interference from any humus substances present.

TABLE/

TABLE 11.  
ADSORBED BASES IN PROFILE 3.

Horizon.	A <sub>0</sub> <sup>3</sup>	A <sub>2</sub>	B <sub>1</sub>	B <sub>2</sub>	B <sub>3</sub>	C
Calcium	$\frac{0.067\%}{3.35 \text{ m.eq.}}$	$\frac{0.25\%}{1.25 \text{ m.eq.}}$	$\frac{0.016\%}{0.8 \text{ m.eq.}}$	$\frac{0.013\%}{0.63 \text{ m.eq.}}$	$\frac{0.014\%}{0.7 \text{ m.eq.}}$	$\frac{0.032\%}{1.6 \text{ m.eq.}}$
Magnesium	$\frac{0.054\%}{4.42 \text{ m.eq.}}$	1 m.eq.	...	...	...	...

TABLE 12.  
PH OF NORMAL PODZOLS.

Horizon.	A <sub>2</sub>	B <sub>1</sub>	B <sub>2</sub>	B <sub>3</sub>	C
Profile 42.	4.22	4.54	4.56	4.62	4.92
" 44.	4.27	4.80	5.22	-	5.22
" 27.	4.56	4.77	4.99	5.04	5.12
Boulder till in No. 27.	5.13	-	-	-	-

2. Humus Podzols.

In Tables 13, 14 and 15 are given the results of the mechanical analyses of profiles 41, 23 and 40 respectively. It is seen from these tables that the clay content of the eluvial horizon is always very low and usually rises sharply on passing into the illuvial horizon. In the case of profiles 23 and 41 in which the eluvial horizon was divided it is observed that the lower of the two layers is somewhat richer in clay.

Table 13.

MECHANICAL ANALYSIS of PROFILE 41.

Depth Fraction.	A <sub>1</sub> <sup>'</sup> -G 12-23 cm.	A <sub>2</sub> <sup>''</sup> -G 35-45 cm.	B <sub>2</sub> 46-56 cm.	B <sub>3</sub> 60-70 cm.
Coarse Sand	48.34	46.30	44.86	45.83
Fine Sand	32.23	29.67	28.68	28.47
Silt	7.6	12.10	15.15	12.38
Clay	7.9	10.80	10.53	11.75
Loss by soln.	0.65	0.62	0.61	0.15
Moisture	1.79	1.78	1.08	0.65

Expressed as percentage of air-dry fine earth  
( 2 mm.)

TABLE /

TABLE 14.

MECHANICAL ANALYSIS of PROFILE 23.

Depth Fraction.	A <sub>2</sub> <sup>i</sup> -G 11-17 cm.	A <sub>2</sub> <sup>ii</sup> -G 17-27 cm.	B <sub>2</sub> 30-40 cm.	B <sub>3</sub> 40-50 cm.	C 80-90 cm.
Coarse Sand	60.73	30.00	36.02	45.03	45.26
Fine Sand	15.50	44.40	35.60	30.40	24.94
Silt	7.05	6.65	12.15	12.15	17.70
Clay	4.25	7.75	7.30	9.10	11.70
Loss by Soln.	0.38	1.21	1.17	0.81	0.13
Moisture	2.24	5.49	2.14	1.43	0.64

This is probably due to the mechanical washing down of clay from the upper layer, the hardpan preventing its removal to the lower horizons. In the case of profile 41 there is no difference in the clay contents of the lower A<sub>2</sub> and B<sub>2</sub> horizons. It is probable, however, that a mechanical analysis of the hardpan would show a sharp increase in clay. It could not be carried out owing to lack of material.

TABLE /

TABLE 15.

MECHANICAL ANALYSIS of PROFILE 40.

Depth. Fraction.	A <sub>2</sub> -G 7-17 cm.	B <sub>1</sub> 17-23 cm.	B <sub>2</sub> 23-33 cm.	B <sub>3</sub> 40-50 cm.	C 70-80 cm.
Coarse Sand	58.29	48.70	48.91	48.69	46.08
Fine Sand	29.65	24.53	27.84	32.63	34.90
Silt	6.75	8.30	7.55	8.55	9.82
Clay	3.75	8.50	8.75	8.75	8.88
Loss by Soln.	0.15	1.52	1.36	0.50	0.45
Moisture	1.10	5.10	4.34	1.40	0.92
Loss on ignition	4.70	13.53	9.36	2.80	2.59

In profile 41 the same general features are observed, the clay content being low in the eluvial horizon and rising sharply in the B horizon. An interesting feature of this soil is the large amount of humus which has been washed down into the lower layers. This is a very characteristic feature of the humus podzols as originally described by Frosterus (9).

As was observed in connexion with the normal podzols the mechanical fractions of the eluvial horizon/

horizon are very light in colour and evidently have had a large portion of their iron content leached out. The fractions of the illuvial horizon are quite strongly coloured.

It is of interest to note that the red colour of the till is entirely due to the silt and clay fractions; the sands contribute the purplish tinge.

#### Analysis of the Clay Fraction.

From the analyses given in the following tables it is seen that the humus podzols have undergone leaching just as strong as the normal podzols. In the case of profile 41 this is not brought out very well by the clay analysis owing to the absence of an analysis of the hard pan. The analyses of the other two profiles do bring out this leaching. It is especially marked in profile 40, there being a very abrupt fall in the  $\text{SiO}_2/\text{R}_2\text{O}_3$  ratio. After this decrease the ratio gradually rises again.

In the discussion of the morphology of the soils it was mentioned that there appeared to be two well defined layers above the hardpan, but whether these were both eluvial horizons or not could not be proved without recourse to chemical analysis. The results/

results for both profiles 23 and 41 definitely show that these two layers are eluvial, the lower one in 23 being slightly less leached than the upper. In profile 41, the reverse is the case, but the difference is slight.

TABLE 16.

CLAY ANALYSIS OF PROFILE 41.

Horizon	A <sub>2</sub> <sup>1</sup> -G 13-23 cm.	A <sub>2</sub> <sup>2</sup> -G 35-45 cm.	B <sub>2</sub> 46-56 cm.	B <sub>3</sub> 60 - 70 cm.
SiO <sub>2</sub>	46.01	45.45	41.90	48.68 %
TiO <sub>2</sub>	1.52	0.91	0.70	0.52
Al <sub>2</sub> O <sub>3</sub>	37.44	36.51	39.97	37.28
Fe <sub>2</sub> O <sub>3</sub>	10.84	9.84	15.03	10.50
SiO <sub>2</sub> /R <sub>2</sub> O <sub>3</sub>	1.75	1.87	1.44	1.86
SiO <sub>2</sub> /Al <sub>2</sub> O <sub>3</sub>	2.08	2.18	1.78	2.19
SiO <sub>2</sub> /Fe <sub>2</sub> O <sub>3</sub>	11.30	12.80	7.42	12.20

A possible explanation of this is that under the conditions associated with water-logging there is a tendency for silica to pass into the colloidal state and to be leached out (23a). This would lead to the relatively higher sesquioxide content in the upper part/

part of the eluvial horizon.

TABLE 17.

CLAY ANALYSIS of PROFILE 23.

Horizon.	A <sub>2</sub> -G 11-17 cm.	A <sub>2</sub> -G 17-27 cm.	B <sub>2</sub> 30-40 cm.	B <sub>3</sub> 40-50 cm.	C 80-90 cm.
SiO <sub>2</sub>	45.12	42.98	40.05	45.23	45.77%
TiO <sub>2</sub>	2.30	1.50	1.40	1.00	1.00%
Al <sub>2</sub> O <sub>3</sub>	41.17	42.95	41.54	36.95	36.51%
Fe <sub>2</sub> O <sub>3</sub>	6.63	6.53	9.72	14.30	9.17%
SiO <sub>2</sub> /R <sub>2</sub> O <sub>3</sub>	1.68	1.63	1.42	1.66	1.83%
SiO <sub>2</sub> /Al <sub>2</sub> O <sub>3</sub>	1.85	1.99	1.63	2.06	2.12%
SiO <sub>2</sub> /Fe <sub>2</sub> O <sub>3</sub>	18.10	17.50	10.95	8.40	13.27%

TABLE /

TABLE 18.

CLAY ANALYSIS of PROFILE 40.

Horizon.	A <sub>2</sub> -G 7-17 cm.	B <sub>1</sub> 17-23 cm.	B <sub>2</sub> 23-33 cm.	B <sub>3</sub> 40-50 cm.	C 70-80 cm.
SiO <sub>2</sub>	44.50	31.67	34.66	38.50	44.26%
TiO <sub>2</sub>	0.50	1.27	0.80	0.60	0.60%
Al <sub>2</sub> O <sub>3</sub>	33.50	28.72	32.65	44.07	37.90%
Fe <sub>2</sub> O <sub>3</sub>	10.03	24.87	22.30	13.07	12.00%
SiO <sub>2</sub> /R <sub>2</sub> O <sub>3</sub>	1.89	1.15	1.25	1.25	1.65
SiO <sub>2</sub> /Al <sub>2</sub> O <sub>3</sub>	2.25	1.75	1.80	1.48	1.98
SiO <sub>2</sub> /Fe <sub>2</sub> O <sub>3</sub>	11.80	3.38	4.13	7.84	9.81

In the illuvial horizon of profile 40 there is a very marked increase in the sesquioxide content. As in the case of the normal podzols the alumina is carried much farther down the profile than the iron. In the case of profiles 41 and 23 the B<sub>2</sub> horizon has not been enriched to any extent in either iron or alumina. The conditions in the case of these soils seem to have favoured the accumulation of iron in the form of hardpan. Why this should be is not at all clear.

Although/

Although no signs of a high water table were observed the  $\text{SiO}_2\text{-Fe}_2\text{O}_3$  ratio for the  $\text{B}_3$  horizon of profile 23 indicates the possibility of its presence. It appears that slight leaching has taken place from the layer immediately below the hardpan, redeposition taking place in the next layer. It is always possible, however, that the enrichment is from below as has been suggested by Tamm (26).

Ultimate Analysis of Profile 41.

The results of an incomplete ultimate analysis of profile 41 are presented in Table 19. Potash and soda were not determined.

TABLE /

TABLE 19.

ULTIMATE ANALYSIS of PROFILE 41.

(As percentages of ignited fine earth).

Horizon.	A <sub>0</sub> 3-13 cm.	A <sub>2</sub> <sup>I</sup> -G 13-23 cm.	A <sub>2</sub> <sup>II</sup> -G 35-45 cm.	B <sub>1</sub> 45-46 cm.	B <sub>2</sub> 46-56 cm.	C 60-70 cm.
SiO <sub>2</sub>	77.56	86.40	81.94	81.58	81.34	82.70
TiO <sub>2</sub>	0.99	0.43	0.40	0.39	0.31	0.31
Al <sub>2</sub> O <sub>3</sub>	13.53	8.07	10.73	7.56	10.63	10.93
Fe <sub>2</sub> O <sub>3</sub>	3.03	2.16	2.55	7.23	3.34	3.04
CaO	1.61	0.37	0.33	0.37	0.21	0.23
MgO	1.65	0.38	0.38	0.54	0.22	0.52
Undeter- mined residue	1.63	2.15	3.67	2.33	3.95	2.27
Total	10.00	100.00	100.00	100.00	100.00	100.00
Moisture (105°)	39.94	1.79	1.78	3.25	1.08	0.65
Loss on ignition	41.88	3.54	3.64	2.66	2.54	2.76

Silica: As in the case of the normal podzols the humus podzols have undergone strong leaching, the eluvial horizon showing a higher silica content than the other layers.

Sesquioxides/

Sesquioxides: It is interesting to note that the alumina appears to have been removed to a very slight extent, especially from the lower part of the eluvial horizon. Iron on the other hand has been strongly leached and redeposited mainly in the form of the hardpan ( $B_1$ ). From the clay analyses it was seen that there was very little difference between the two layers into which the eluvial horizon had been divided. The ultimate analysis also show this to be the case, if anything the upper portion being more strongly leached.

From the analyses there does not appear to be any accumulation of aluminium in the hardpan. It would probably be carried down in the  $B_2$  horizon as is usual. As judged by the loss on ignition the humus content of the pan/ <sup>is low</sup> the cementing of the sand grains must be due almost entirely to precipitated ferric hydroxide and other iron compounds.

Calcium and Magnesium: The high values for these constituents found in the  $A_0$  horizon are probably partly due to the high organic matter content of this horizon and partly to the presence of unweathered coarse sand from disintegrating stones which are very common in the peat. There is really very little change on the whole in the content of these bases throughout/

throughout the profile, but there is a slight increase in the CaO and a sharp rise in the MgO content of the hardpan to be noted. The high magnesia content may be associated with the formation of secondary minerals of the paligorskite type. On the other hand, this higher base content may have been the reason for the precipitation of the iron. That the base status plays an important part in the precipitation is seen from the pH values for the illuvial horizons. In the case of the normal podzols the value was about 4.5. In the humus podzols it is a little higher, ranging from 4.7 to 5.0.

#### Adsorbed Bases and Acidity.

Like the normal podzols these humus podzols are very acid and the content of exchangeable bases is extremely low except in the A<sub>0</sub> horizon. Table 20 gives the content of exchangeable Calcium and the pH of profile 41. The amounts of magnesium were too small for accurate determination.

TABLE 20.

EXCHANGEABLE CALCIUM and pH of PROFILE 41.

Horizon	A <sub>0</sub> 7-13 cm.	A <sub>2</sub> <sup>1</sup> -G 13-23 cm.	A <sub>2</sub> <sup>II</sup> -G 35-45 cm.	B <sub>2</sub> 46-56 cm.	C 60-70 cm.
Calcium	0.1% 5.0m.eq.	0.013% 0.65m.eq.	0.011% 0.55m.eq.	0.008% 0.4m.eq.	0.026% 1.3m.eq.
pH	4.26	4.82	4.88	5.01	-

Peat Gley Soils.

In Table 21 are given the results of the mechanical analysis of the mineral horizons of profile 25.

TABLE 21.

MECHANICAL ANALYSIS of PROFILE 25.

Horizon.	G <sup>I</sup>	G <sup>II</sup>	C
Coarse Sand	39.25	48.16	47.50
Fine Sand	39.33	37.82	25.02
Silt	8.75	11.00	13.52
Clay	12.60	12.50	14.30
Loss by soln.	0.27	0.16	0.17

There/

There is a definite increase in the silt and clay content in passing from the gleyed horizon into the unaltered till. There is a possibility a mechanical loss of the fine fractions, since there appears to be a definite flow of water through the moss.

TABLE 22.

CLAY ANALYSIS of PROFILE 25.

Horizon.	G'	G''	C
SiO <sub>2</sub>	51.31	51.10	50.50%
TiO <sub>2</sub>	n.d.	n.d.	0.57%
Al <sub>2</sub> O <sub>3</sub>	37.77	36.07	40.55%
Fe <sub>2</sub> O <sub>3</sub>	4.71	7.07	8.58%
SiO <sub>2</sub> /R <sub>2</sub> O <sub>3</sub>	2.12	2.12	1.85
SiO <sub>2</sub> /Al <sub>2</sub> O <sub>3</sub>	2.30	2.39	2.10
SiO <sub>2</sub> /Fe <sub>2</sub> O <sub>3</sub>	18.20	12.10	9.80

That there is a decided chemical leaching is seen from Table 22 in which are given the results of the analyses of the clay fractions. Unfortunately these results do not bring out the proportion of ferrous iron in the clay, for, from the colour of the horizons ferrous iron would appear to represent a considerable/

considerable proportion of the total iron present. There is practically no change in the  $\text{SiO}_2\text{-R}_2\text{O}_3$  and  $\text{SiO}_2\text{-Al}_2\text{O}_3$  ratios, the  $\text{SiO}_2\text{-Fe}_2\text{O}_3$  ratio, however, changes very sharply on passing from the G horizon into the till. The iron that is removed does not appear to be deposited in the underlying layers, in fact the iron content of the C horizon in this profile is smaller than that of the till underlying the humus podzols. It would thus appear to be washed completely out of the soil.

As in the case of the humus podzols both the peat and the mineral soil in these mosses are extremely acid, the pH being in every case below 5. Exchangeable bases are likewise very low, in no case did the amount of exchangeable Ca reach 1 milli-equivalent while magnesia was too small to be determined with any accuracy.

DISCUSSION of RESULTS.

It has been definitely established that the soils all belong to the great group of podzolic soils which are subject to strong leaching from the upper mineral horizon with the subsequent deposition of the leached substances at some depth from the surface. As a general rule the bases are leached first, iron next, while alumina and silica are last to be removed. Phosphates usually move with the iron.

Since podzolisation is definitely a destructive process it may be well to consider its implications from the point of view of forestry. The litter which is returned to the soil by coniferous trees and by heath plants such as calluna is very poor in all the essential nutrients and so very little mineral matter is returned to the soil. Thus the soil becomes more and more impoverished and less able to support a good standard of vegetation. In addition to the general impoverishment of the soil there may also be a hardpan present. This impedes the drainage of the soil which might otherwise be quite good and adds to the difficulty of bringing the soils into a suitable condition for good tree growth. The photographs illustrating the vegetation of/

of profiles 40, 41 and 23 show very clearly the results of the two adverse factors, poor drainage and poor soil.

An attempt was made to determine the amounts of "available" potash and phosphate in the Teindland soils by the methods in use in the Macaulay Institute. The quantities obtained were very minute, in most cases being less than 1 mgn. per kilogram of soil. Since this was true of both the normal podzols, on which tree growth is good, and the humus podzols on which growth is poor, it would appear as if the drainage is the determining factor for tree growth in this case. Scots Pine, of course, always prefers a sandy soil while larch and spruce thrive better on loams in which the moisture content is higher.

Since it appears that drainage is the main factor governing tree growth on the humus podzols the removal of the cause of the bad drainage would appear to be the first necessity. The removal of the hardpan presents many difficulties and a number of methods for this have been proposed. Owing to the impossibility of employing chemical methods, reliance must be placed on physical methods. Deep ploughing with breaking up of the hardpan at the same time would appear to be a satisfactory method but/

but it would be limited to soils in which the pan was fairly near the surface. The general nature of the soil itself and the surface of the ground must be taken into consideration. An attempt was made at Teindland to cut some open drains with a Henderson plough but owing to the stony nature of the surface soil the project failed. Ordinary ploughing has been used with marked success in establishing young trees but in addition to ploughing some treatment with artificial fertilizers is necessary, phosphates being chiefly used. By simple ploughing the aeration of the surface soil is improved and the mixing of the peat with the A<sub>2</sub> horizon will improve the texture of the soil. The trees, once they are properly established may be strong enough to penetrate the hardpan and so break it up, but this seems unlikely. The improvement in the aeration of the surface may have a much greater effect in softening the hardpan. It was observed that the hardpan exposed in ditches was much softer than that found in freshly dug pits.

Another method of breaking up the pan which has been used is by means of explosives. The use of an explosive which has a good lateral thrust as well as vertical would certainly soon break up the pan sufficiently to allow root penetration.

After/

After breaking up the pan some measures to preventing its reformation which might take place fairly rapidly under such acid conditions, would have to be considered. The use of basic manures such as basic slag would have the desired effect and in addition would supply a nutrient in which the soil is deficient. Liming would not be so beneficial to coniferous trees as they require fairly acid conditions for best growth.

The improvement of impoverished podzol soils may also be carried out by planting birch. Tamm (25) has described the reversion to brown earth of a podzol which was planted with birch. The litter from birch is much richer in plant nutrients than coniferous litter so that an enrichment of the surface layers of the soil takes place. It might be advantageous to plant birch in mixture with conifers, the base content surface-organic horizon being then kept up.

Up to the present it has been the general practice in forestry to map areas as plantable or otherwise on the basis of surface vegetation, elevation and exposure, without taking into consideration the properties of the soils which underly the/  
the/

the vegetation. This may be quite a successful method in many ways but there are cases in which the ground would be called plantable as judged by the vegetation etc., and yet the soil would not support a vigorous forest. Taking profiles 40 and 41 or 23 as examples, we see that the absence of hardpan in 40 would enable the tree roots to penetrate well into the soil whereas in the case of 40 or 23 the hardpan would very soon hold up tree growth, yet the vegetation is the same for all these soils. A soil survey would indicate fairly accurately the boundaries of the various soil types and when suitable methods have been evolved it will also be possible to make some statement as to the type and amount of manures required. Since this work has only begun in Scotland it will require intensive examination of the various soil types and the conditions of their formation and development before a sound relationship between Soil Science and Forestry can be established.

YOUTH and AGE of SOILS.

Consideration of the degree of development of the various elements of the earth's surface, e.g. river valleys, mountain ranges, etc., led W. M. Davis (28) to propound his theory of the "Geographical Cycle" on the basis of which he was able to classify land forms into young, mature and old stages. This theory can be expressed in a general way as follows:-

$$\text{S.F.} = f(\text{R, T, P})$$

where S.F. = surface form

R. = nature of underlying rocks

T. = time

P. = processes at work.

In the same way we may write a formula for the degree of development of a soil. It will depend on much the same factors as surface form and in addition will include surface form itself.

If we compare two countries whose river systems are of the same age, e.g. Scotland and England, it would appear that this could not be the case for England is, on the whole, a much flatter country than Scotland. It is in a case such as this that the effect of the underlying rock is dominant. In England the rocks are soft and easily worn down, while/

while the rocks of the Scottish Highlands are very resistant to weathering, giving the country a younger appearance.

This factor of the relative resistance to weathering of rocks and minerals is of fundamental importance in soil development. In Scotland the soil parent materials (factor R.) are, for the most part drifts of glacial or fluvio-glacial origin; soils formed directly from solid rock are the most part on hill tops. The drifts formed by glacial action, e.g. ground-moraine, are usually of a loamy or clayey texture while the fluvio-glacial drifts are mostly sands and gravels.

Let us consider two soils, one formed from a sand, the other from a loam, their mineral composition being the same. We will assume that they carry similar vegetation, say coniferous forest and that climatic conditions are the same. It is readily seen that the processes of podzolisation will proceed much more rapidly in the sand than in the loam. In the sand there will be very little clay which will soon become saturated with hydrogen, leading to the disintegration of the adsorption complex and the removal of its constituents to lower layers of the soil where some of them will be deposited.

In/

In addition the great porosity of the subsoil will readily permit mechanical washing down of clay as such. This will lead to a rapid development of the grey eluvial layer.

In the case of the loam, saturation of the exchange complex with hydrogen will not be so rapid with the result that the destruction of the complex will be likewise slow. Mechanical washing down of clay will be very small. The grey eluvial horizon will thus take much longer to develop.

That this is the case is seen from a comparison of two profiles formed from granitic drifts - one a ground moraine, the other a sand and gravel. The heavier soil is that taken in Hazelhead Woods (profile 3) the sandy soil was taken in Torshinach Wood, some 6 miles from Aberdeen. The Hazelhead soil may be described as a medium podzolised soil. There was no great change in the clay content throughout the profile, while leaching has only been moderate. In the Torshinach soil leaching has been as strong as in the Teindland sands. There is a very low clay content in the eluvial horizon and the iron content is likewise low. The geological age of these two soils must be practically the same and there can be no doubt that they have both been covered with heath and forest for a very long time.

It would appear then, that as in Davis's theory/

theory of surface form, the degree of development of the soil profile must be taken as the criterion of youth, maturity and old age.

In this way, taking the degree of development of the leached layer as our criterion, the Teindland sands will be classed as mature soils.

In trying to arrive at some idea of the age of the soils on the upper slopes we must consider the introduction of another factor into the development of the soils. If we assume that these soils had undergone more or less normal development before swamping set in, then they must have reached the stage of maturity. The degree of leaching as judged from the analyses of the clay fractions and the ultimate analysis points to this. The formation of the impervious hardpan introduced a new factor into the development of the soil, viz. water-logging. As soon as water-logging became pronounced new processes set in with the result that the soil acquired new characteristics. Reduction processes, which came into action owing to lack of aeration, changed the colour of the eluvial horizon, while the waterlogging together with the general poverty of the soil made possible the invasion of the ground with an inferior type of vegetation. The rapid decomposition of/  
of/

of plant remains became difficult and practically stopped, with the result that the process of peat formation has set in. The peat will continue to grow unless man, by removing the adverse factors, can produce better conditions for plant growth.

Thus, these soils on the upper slopes are really young soils of the peat-gley podzolised type, the peat having not reached any great depth as yet.



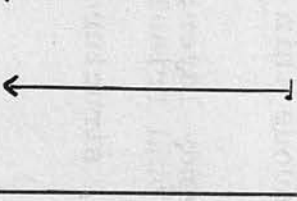
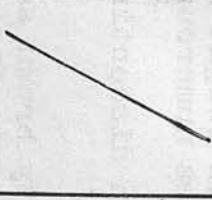

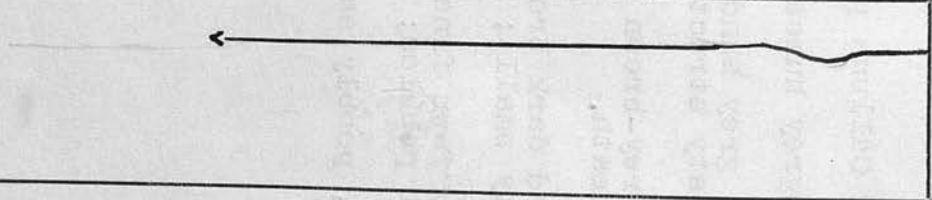
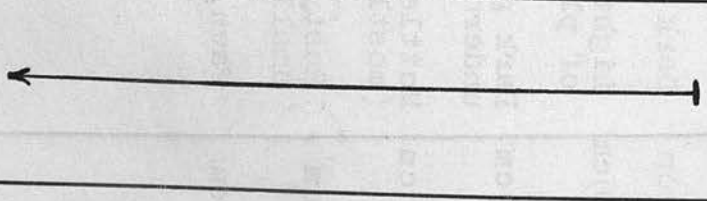
If the minerals composing the drift are of a basic character, the effect will be to slow up or inhibit podzolisation. Soils formed from limestone will not be podzolised even under coniferous forest or heath vegetation. Such soils occur in the neighbourhood of Aberdeen. Soils from basic rocks, e.g. the soils formed on the norite belt in the Inch district of Aberdeenshire are mainly of the brown earth type even when under coniferous forest but one soil has been found (29) in which podzolisation, as judged by the analysis of the clay fraction, has commenced.

An example of the joint effect of relief and parent material is illustrated by some of the brown earths described by Tamm (25). These are formed from calcium rich drifts on well-drained slopes, whereas the normal soils of the district are podzolised.

Thus/

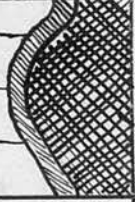

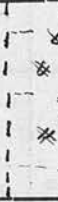




Thus both the Swedish brown earths and those found at Insch may be classed as intrazonal. In such a case as this due weight must be given to the effect of the parent material in judging the age of the soils from the degree of development of the profile.



OCCURRENCE OF ROCK OR ROCK FRAGMENTS.	MECHANICAL COMPOSITION.	FISSURES AND CAVITIES.	SOIL P.A.V.A.	NEW FORMATIONS AND CONCRETIONS	COMPACTNESS.	MOISTURE STATE AT TIME OF OBSERVATION. WATER LEVEL.	NOTES
	<p>Sand.</p> 	<p>Old root channels.</p> 		<p>thin iron pan.</p> 		<p>Damp</p> 	

SOIL FORMING MEDIUM (GEOLOGICAL): FLUVIO-GLACIAL GRAVELLY SAND.



	HUMUS COLOUR.	COLOUR OF PROFILE.	OCHRE SPOTS AND LAYERS.	INDICATION OF PODSOLISATION.	MORPHOLOGICAL INDICATIONS OF GLEYING.	CARBONATE.	STRUCTURE.	ROOT SYSTEM.
5		Black						
10		Dark grey						
20		Light grey Dark grey-brown. Mottled dark brown and rusty brown.						
30		Rusty fawn.						
40								
50								
60								
70								
80		Fawn.						

DEFINITION OF SOIL: Strongly podzolised gravelly sand.

APPENDIX A.

FIELD METHODS.

The methods used in making the pits describing and sampling the soil profiles are based on the methods the writer learned while working in Russia and he would like to put on record his indebtedness to the late Professor. K. K. Gedroiz and to Professor B. B. Polynov for granting him the opportunity to become acquainted with these methods.

A very detailed description of the methods used in Russia has been given by Krasluk (16) and a short description has been issued, in English, by the Dokuchaiev Soil Institute (20). In describing the profiles, forms of the type given in the insert were used throughout. By the use of these forms a much clearer picture of the soil profile is obtained and this aids in the comparison of profiles for classification purposes. These forms are based on those issued by the State Tobacco Institute to their soil expeditions, and were drawn up by Professor B. B. Polynov. The present modification was made by the writer to suit Scottish conditions.

APPENDIX B.

LABORATORY METHODS.

The methods used in the laboratory work are given below.

Ultimate analyses were carried out by the standard methods as detailed in Hillebrand and Lundell (14) and Gedroiz (11). Iron was determined by the iodometric method described by Gedroiz (11).

Mechanical analysis were made by the method proposed in Technical Communication No. 26, except that 20 grams of soil were used.

Exchangeable bases were determined by the Ammonium Acetate extraction method (24). Determinations of pH were made by the standard quinhydrone method.

The separation and analysis of the clay fractions were done as recommended by Robinson (22). Iron, again was determined iodometrically.

APPENDIX C.

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THE SEASONAL FLUCTUATIONS in the  
NITRATE and AMMONIA CONTENTS of  
SOME HILL SOILS from MIDLOTHIAN.

C O N T E N T S.

	page.
I. Introduction:	
1. Nitrification in acid soils .....	89.
2. Seasonal fluctuations in nitrate and ammonia .....	92.
II. Aim of investigation .....	93.
III. Situation & Physical Features of Locality .....	93.
IV. Soils studied .....	94.
V. Experimental .....	101.
VI. Results .....	104.
VII. Laboratory Experiments on Soil Nitrifying capacity .....	107.
VIII. Discussion of Results .....	110.
IX. Summary .....	112.
X. Literature cited .....	113.

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I. INTRODUCTION.

1. Nitrification in Acid Soils.

In 1927 attention was drawn by Professor  
1.  
Hendrick to a misconception prevalent in standard text-books on soil science regarding the process of nitrification in acid soils and he cited a statement from Russell's Soil Conditions and Plant Growth to the effect that nitrification cannot take place in acid media. The results obtained with the lysimeters at Aberdeen showed that this was not the case. The tank which had been regularly manured with ammonium sulphate had become more acid and yet a large proportion of the added manure had been converted into nitrate. A survey of the literature on nitrification, however, brings to light not a few investigations on the influence of acidity on the process. These investigations have been made mostly on the Continent and in America, only two English contributions being found.

During the 19th century and at the beginning of this century it was repeatedly affirmed that nitrification did not take place in sour soils, e.g. woodland and forest soils. This statement was first challenged/

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1. Reference to literature cited on p. 113.

challenged by Weis (2) in 1908 and by Hall and his co-workers (3). Weis showed that quite significant nitrification took place in an acid forest soil, while Hall showed that in bulk nitrification took place slowly in spite of the acidity. Since then a large number of investigations have been made using both soil and solution tests.

Temple (4) in America showed that nitrification could take place in a soil having a "lime requirement" of more than 3000 lbs. About the same time White (5) showed that the process took place in Pennsylvanian soils having a lime-requirement of about 8000 lbs. per acre.

The first systematic study was carried out by Fred and Graul in 1916 (6). They set out to find whether or not the organisms causing nitrification in acid soils were the same as those in neutral soils. Their method was to inoculate sterile neutral soils with an acid soil in which nitrification had been shown to take place. From their results they concluded that acid soils do not contain a special acid-resisting bacterium.

In 1920 Stephenson (7) published an intensive study of the effect of lime on nitrification in which he suggested that the processes may be made possible by bases other than carbonates present in the acid soils/

soils. He also suggested that ammonia which is formed by moulds may neutralize the acidity and thus permit nitrification to take place. It seems hardly likely, however, that these factors taken even together would account for the amount of nitrate that is sometimes formed.

A number of Scandinavian workers have followed up Weis's discovery with some very important results. Hesselman, Olsen, and Gaarder and Hagem have all shown that nitrification can take place even in extremely acid forest soils. Olsen and Weis found that nitrification could take place even at a pH of 3.9. These workers have used mainly solution tests and have worked over a wide range of pH values.

Gaarder and Hagem (8) attempted to show that there exists a series of organisms each species of which has a characteristic pH optimum. By their method, however, there is always a possibility of the bacteria having become acclimatized to the pH of the medium.

Olsen (9) followed these solution tests with a series of experiments on very acid forest soils (pH 3.7). Even at this low pH quite significant nitrification took place. After 22 days incubation at 18-20°C. as much as 100 mg. per kilogram of dry soil had accumulated.

2. Seasonal Fluctuations in Nitrate and Ammonia in Soils.

Numerous investigators have pointed out that seasonal fluctuations are a very marked feature of the numbers of organisms in a soil and it is natural that these fluctuations should show up equally clearly for the products of their activity.

Thus, Russell and Appleyard (10) showed that the production of  $\text{CO}_2$  and  $\text{NO}_3$  is more rapid in spring and autumn, less rapid in winter and sometimes in summer. Similar results for India (11) Russia (12) and parts of America (13) have also been obtained. Such investigations have not only been confined to agricultural soils, a very detailed study of the seasonal fluctuations of the nitrate and ammonia content of forest soils were carried out by Clarke (14) at Oxford.

II. AIM of PRESENT INVESTIGATION.

The soils, vegetation and geology of the Boghall Farm and Glen have been fully studied (15, 16, 17, 18, 19) and in the present investigation the seasonal fluctuations in the nitrate and ammonia contents of some of the main soil types will be presented.

III. SITUATION and PHYSICAL FEATURES of the LOCALITY.

The farm of Boghall is the experimental farm of the Edinburgh and East of Scotland College of Agriculture. It lies to the South West of Edinburgh on the south-east slopes of the Pentland Hills. Of the 600 acres covered by the farm about 250 acres are under cultivation, the remainder being given over to sheep grazing. The grazing ground which lies on the slopes of Caerketton and Allermuir, rises from about 700 feet to about 1,600 feet. The bottom of the Boghall Glen is fairly flat but the hill slopes are on the whole steep.

The geology of the area has been described by Hart (17) who has pointed out that the rocks over the whole area are volcanic in origin and may be divided/

divided into two groups - a basic, consisting of basic andesites and basalts, and an acid, consisting of acid andesites, rhyolitic lavas, trachyte and tuff. The whole of the lower ground and much of the glen is covered by glacial drifts, only on the tops of the hills is there any solid rock exposed.

The rainfall at the farm (645 feet) is about 36 inches per annum and in the glen it will be higher owing to the presence of mists and low clouds. The details of the rainfall for the period of the investigation are given later.

#### IV. SOILS.

The variety of parent materials caused by the mixing of the various rocks by glacial action is reflected in the great diversity of soil types found in the glen. "Marked differences in depth, texture, moisture conditions, acidity and other characteristics are met with and these differences are associated with equally striking differences in the vegetation from place to place." (18)

A brief description of the soil types investigated together with the results of the mechanical analyses, lime requirement, pH and total nitrogen/

nitrogen for the surface layers are given below.

The type numbers employed are those given by Dr. Ogg in his original survey of the area. They have since been modified as a result of later work and names have been applied to the soils in the report of the Soils Correlation Committee.

Type 29 (II)

This type occurs chiefly on the lower slopes of Caerketton where the surface material derived from the basic rocks has been carried down the slopes. The soil is a well drained brown medium loam (Table I) of good depth. The content of organic matter is about the same as that of a normal cultivated loam and there is no peaty layer on the surface. The pH and lime requirement are not greater than are shown by many fertile arable soils.

Ogg and Heddle describe the vegetation as a "bent-fescue" type, being dominated by bent grass and fine-leaved fescues. It is regarded as the most valuable type in the glen from the point of view of sheep grazing, being kept well cropped by the sheep thus preventing the herbage becoming rough.

TABLE I.

Type 29 (II) MECHANICAL ANALYSIS.  
(1925 Method).

-----

Coarse Sand .....	23.74%
Fine Sand .....	26.29%
Silt .....	8.05%
Fine Silt .....	11.73%
Clay .....	10.05%
Lime requirement:	0.55%
pH :	5.30
Total nitrogen :	0.40%

Types 29 (I) and (IV) were formerly considered as varieties of the main type described above, but as a result of more recent work Dr. Ogg has informed me that they should now be given a separate number or name. For the purposes of this work it is sufficient to use the old numbers, references being given throughout to the recent publication of Ogg and Heddle on the vegetation types.

These soils occur on the mounds of glacial sands and gravels which are found towards the bottom of the glen. The surface layer consists of a gritty light loam, greyish brown in colour, powdery, full of grass roots and difficult to wet. The content/

content of organic matter is fairly high yet there is no tendency to peat formation.

The herbage is mainly dominated by whins, much of which have been burned. After burning the ground between the bushes becomes colonized by a grassy vegetation of an essentially "bent-fescue" type (18). Bent grass and sheep's fescue are the dominant grasses although *Nardus* tends to invade the ground. There is also an abundance of heath bedstraw (*Galium saxatile*). Ogg and Heddle call this type "short dry grass."

The dry state of these soils, even after heavy rain is one of their main characteristics, the dense mat of bent and fescues appearing to act like a thatch and tends to run rain water off the surface without wetting the soil at all. The soils are very acid and have a lime requirement ranging from 3 to 5 tons of calcium carbonate per acre (18).

TABLE II.

TYPES 29 (I) and (IV) - MECHANICAL ANALYSES.

	29 (I)	29 (IV)
Coarse Sand . . . .	34.44%	58.00%
Fine Sand . . . . .	23.57%	13.9%
Silt . . . . .	5.83%	3.69%
Fine Silt . . . . .	7.71%	5.58%
Clay . . . . .	8.19%	5.06%
Lime requirement:		0.55%
pH :		4.90.
Total nitrogen :	0.38%	0.613%

Type 32 is characterised by the dominance of *Nardus stricta* in the vegetation association. Blaeberry and wavy hair grass are present in abundance; heather and heath rush are of frequent occurrence.

The parent material of the soil is a boulder clay with a thin covering of downwash from the slopes above. The soil has a dark brown to black peaty surface of varying depth (1-3 in.) The upper mineral horizon consists of a grey-brown loam of fairly high organic matter content. It is very acid and has a high lime requirement.

TABLE III.

TYPE 32. - MECHANICAL ANALYSIS.

Coarse Sand .....	17.44%
Fine Sand .....	25.65%
Silt .....	7.35%
Fine Silt .....	13.68%
Clay .....	15.99%
Lime requirement :	0.67%
pH :	4.90
Total nitrogen :	0.53%.

Type 47. The vegetation of the type is called "Nardus with undergrass" by Ogg and Heddle. *Nardus* is still dominant but is no longer associated with blaeberry/

blaeberry as co-dominant. In place of blaeberry a mixed grassy herbage is found consisting of bent, sheep's fescue, sweet vernal grass and others. Blaeberry is still present but occupies a very subordinate position.

The parent material of the soil is boulder clay, but in places may be overlaid with alluvium. Acid rocks predominate in the boulder clay.

The surface layer of the soil is a dark brownish-grey loam mottled with rusty spots and has a fairly high content of organic matter. It is very acid and is usually very wet, or waterlogged, even in summer.

TABLE IV.

Type 47. - MECHANICAL ANALYSIS.

Coarse Sand .....	13.33%
Fine Sand .....	21.51%
Silt .....	8.73%
Fine Silt .....	13.98%
Clay .....	20.94%
Lime requirement .....	0.85%
pH :	4.80
Total nitrogen :	0.465%

Type/

Type 47 G is a very wet type of soil and the vegetation is characterised by rushes and sedges. The soil is grey in colour and is quite shallow and is fairly stony just below the surface. The organic matter is high but the soil is not so acid as some of the other soils, resembling type 29 (II) in this respect. The lower acidity of these two types may be due to flushing by spring water rich in bases. The vegetation of this soil is called "wet flush pasture" by Ogg and Heddle (18).

TABLE V.

Type 47G. - MECHANICAL ANALYSIS.

Coarse Sand .....	30.93%
Fine Sand .....	23.93%
Silt .....	7.63%
Fine Silt .....	10.15%
Clay .....	10.26%
Lime requirement :	0.22%
pH :	6.0
Total nitrogen :	0.395%.

V.      EXPERIMENTAL.

Selected areas on each soil type were marked out with pegs, each plot having an area of about 100 sq. feet. These plots were visited weekly and samples from the top 9 inches were withdrawn by means of an augur. About 10 samplings were taken from each plot.

On arrival at the laboratory the soils were sieved to remove stones and gravel and portions of the fine earth (< 2 mm.) were weighed out for the determination of the moisture, nitrate and ammonia contents.

The Moisture Content was determined by drying weighed portions to constant weight at 100°C.

The mechanical analyses were made by the A.E.A. 1925 method while lime requirement was determined by the Hutchinson and McLennan method.

The determination of the nitrate content was made by means of the phenoldisulphonic acid method, following the procedure recommended by Gimmingham and Carter (20) except that calcium sulphate was added to assist in the removal of nitrate and to help to clear the solution.

The determination of ammonia content was made by the Carsten Olsen method (21) which may be briefly described/

described as follows:- 50 gms. of soil are weighed out into a 250 c.c. beaker, 100 c.c. distilled water and 2 gm. calcium sulphate are added. The whole is allowed to stand for 1 hour with frequent stirring and the suspension filtered. From each filtrate an aliquot is placed in a distillation flask and about 5 g. magnesium oxide added. The volume of liquid is made up to about 300 c.c. and the ammonia is distilled off into a measured volume of standard acid.

The nitrate content of the extract may be determined in the same aliquot as follows: After completing the ammonia distillation, the volume of liquid is again made up to 300 c.c. and approximately 2.5 g. of Devarda's alloy is added. A fresh flask containing standard acid is placed under the outlet and distillation recommenced. Any nitrate present in the extract is reduced to ammonia which passes over into the standard acid.

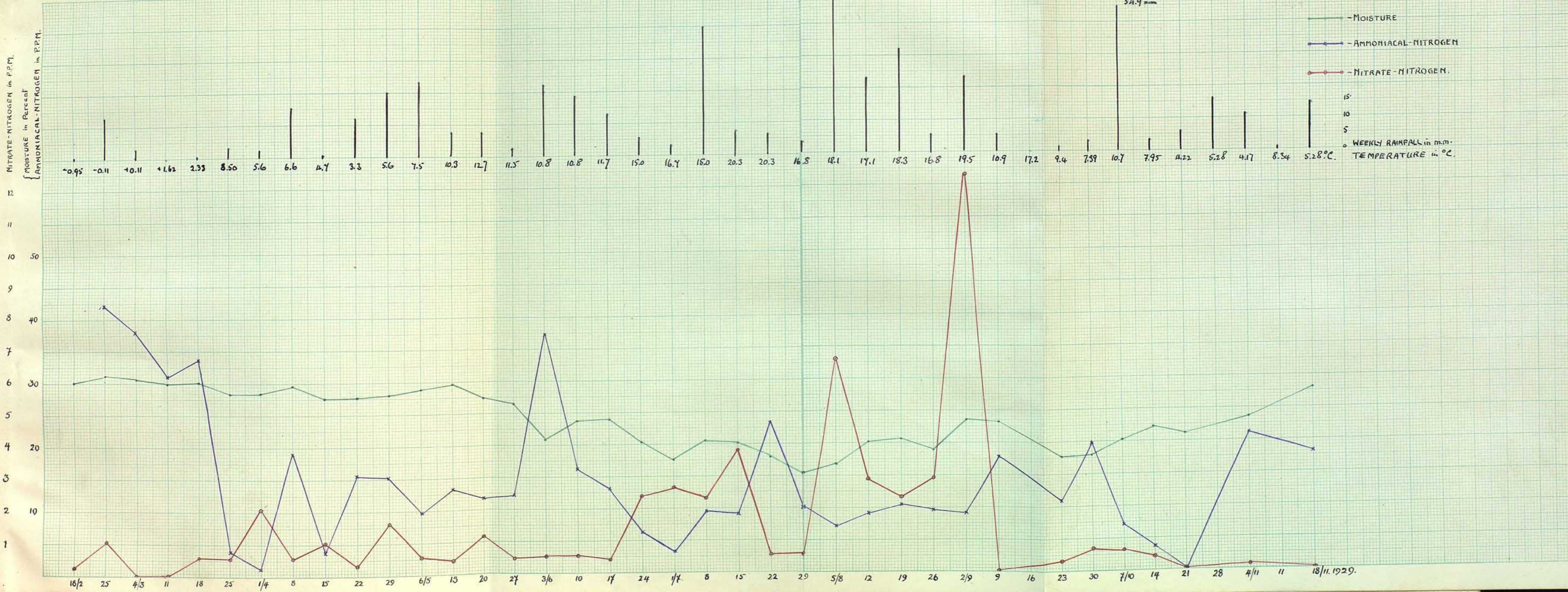
This method was frequently used to check the results obtained by the colorimetric method. When the amounts of nitrate are small the colorimetric method is the more accurate since even with such gentle action there must be a certain amount of decomposition of nitrogen compounds such as amines, amides/

amides, etc.

The total nitrogen was determined by the standard Kjeldahl method. Later determinations showed no variations, the small differences found being covered by the experimental error.

The ammonification and nitrification of the soil organic matter was determined as follows:

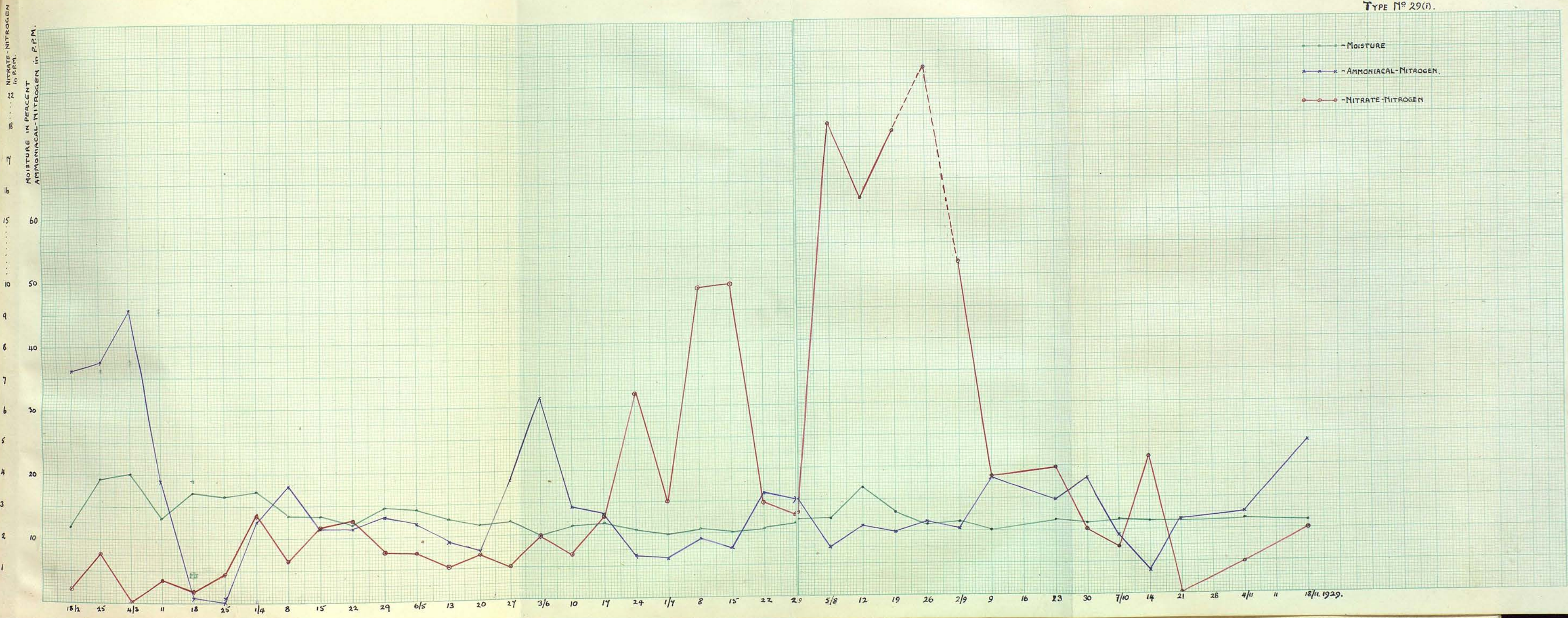
50 g. quantities of soil without addition of organic matter were incubated at 22°C for 30 days. Ammonia and nitrate were determined in the soil before and after the experiment.



VI. RESULTS.

The results of the study of the seasonal fluctuations of nitrate and ammonia in the Boghall soils are presented in the form of graphs since this brings out the fluctuations much more effectively than tabular presentation.

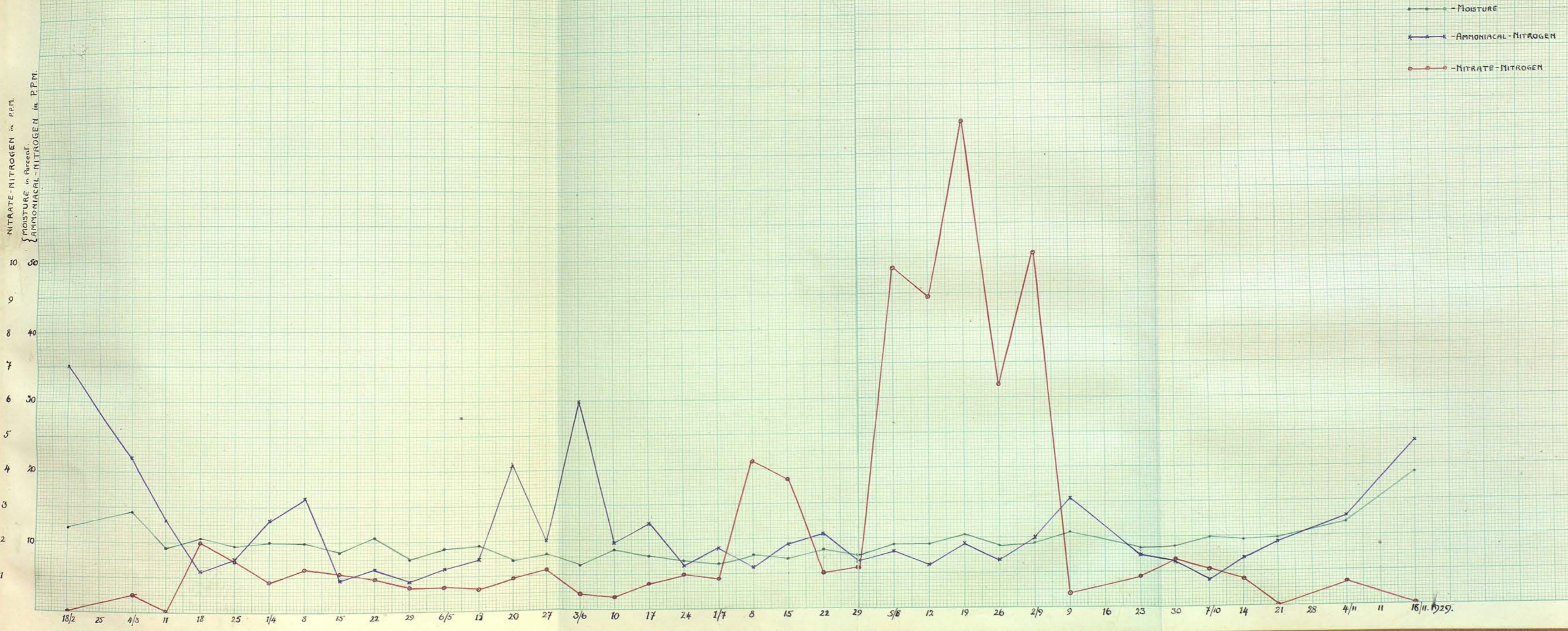
On the first diagram are shown the results obtained for Type 29 (II). It is to be noted that the moisture content of the soil is remarkably constant throughout the year. This would seem to show that the soil must derive a fair amount of its moisture from underground sources. On the whole there is no definite relationship between the moisture content and the amounts of the products of bacterial activity nor is there any marked correlation between weekly rainfall and nitrate and ammonia accumulation. On the whole it would seem that during wet weather ammonia accumulates to a greater extent than nitrate; in drier weather the reverse is the case. There is one very pronounced exception to this generalisation during August when nitrate accumulation was especially great, although this month was extremely wet. This accumulation would appear to be due to the higher temperature prevailing during August. There is only a very slight/



- Moisture  
 - Ammoniacal-Nitrogen  
 - Nitrate-Nitrogen

105

TYPE No 29 (iv).

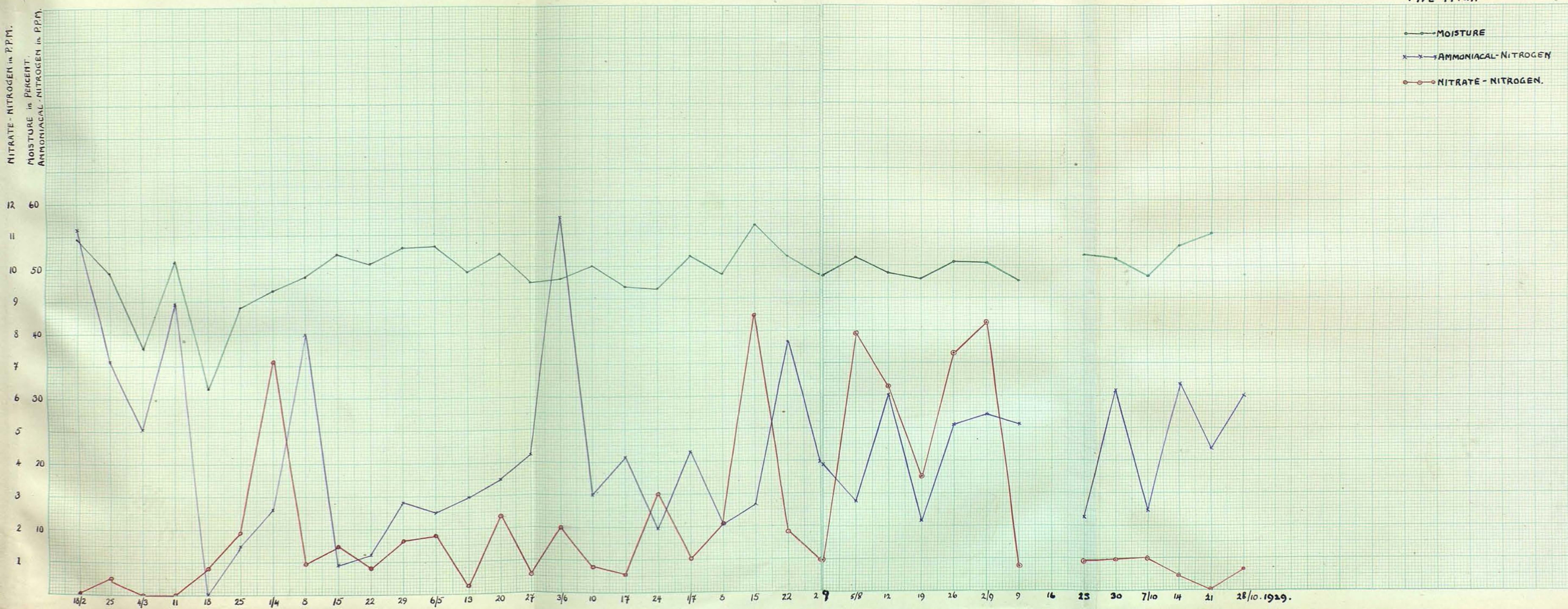


slight increase in the nitrate content in spring, it is fairly constant during summer and then rises to a maximum during late summer and autumn. During late autumn it falls and during the second half of November and December only very minute amounts of nitrate were found.

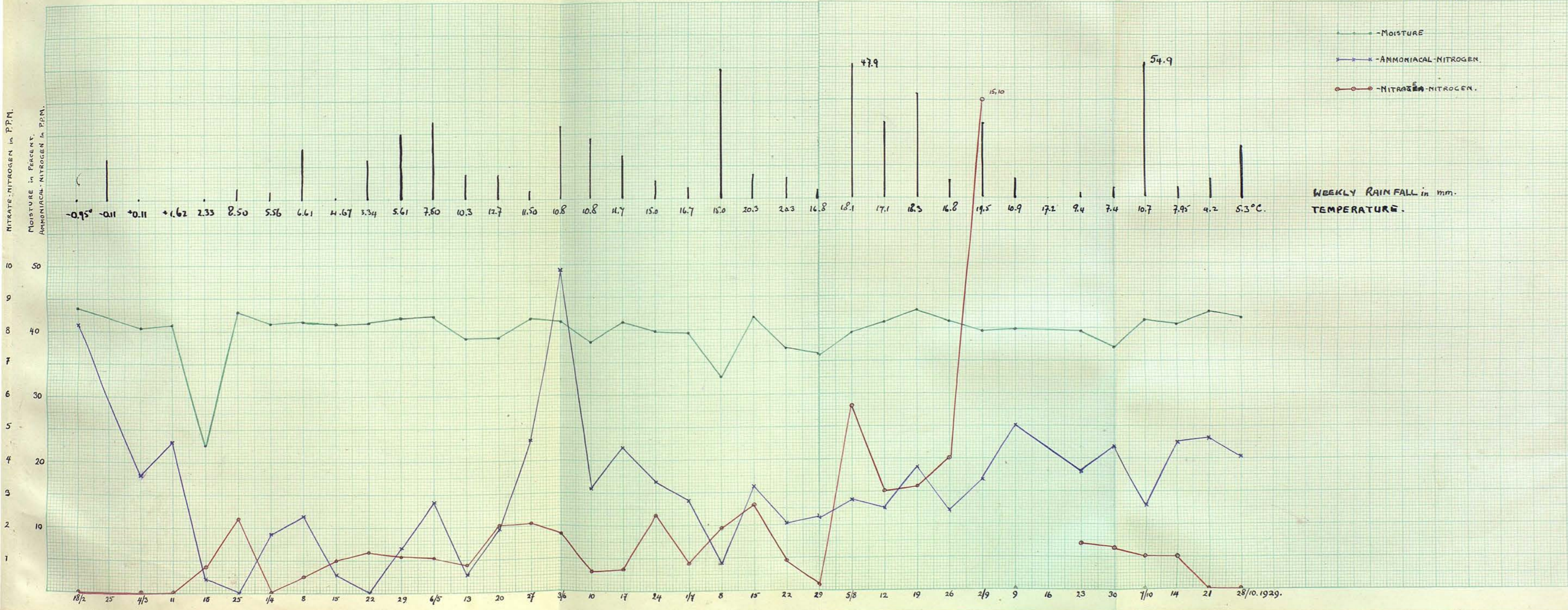
The ammonia content calls for no special remark. The fluctuations do not seem to be connected to any extent with the nitrate content. It appears that in some cases nitrate is high when ammonia is low and vice versa but no generalisation can be made.

Types 29 (I) and (IV) These two types are closely related and show no marked difference in moisture content. In the field they are very similar, being both very dry and fluffy. As in type 29 (II) there is only a very slight increase in nitrate content in spring (diagrams 2 and 3). On the whole the ammonia and nitrate contents of type 29 (I) are much the same as that of 29 (IV). Both types show a very marked increase in the nitrate content in late summer and early autumn after which it falls off rapidly; the increase in the case of 29 (I) being somewhat greater. The ammonia content shows the most marked rise during May and June. In neither case/

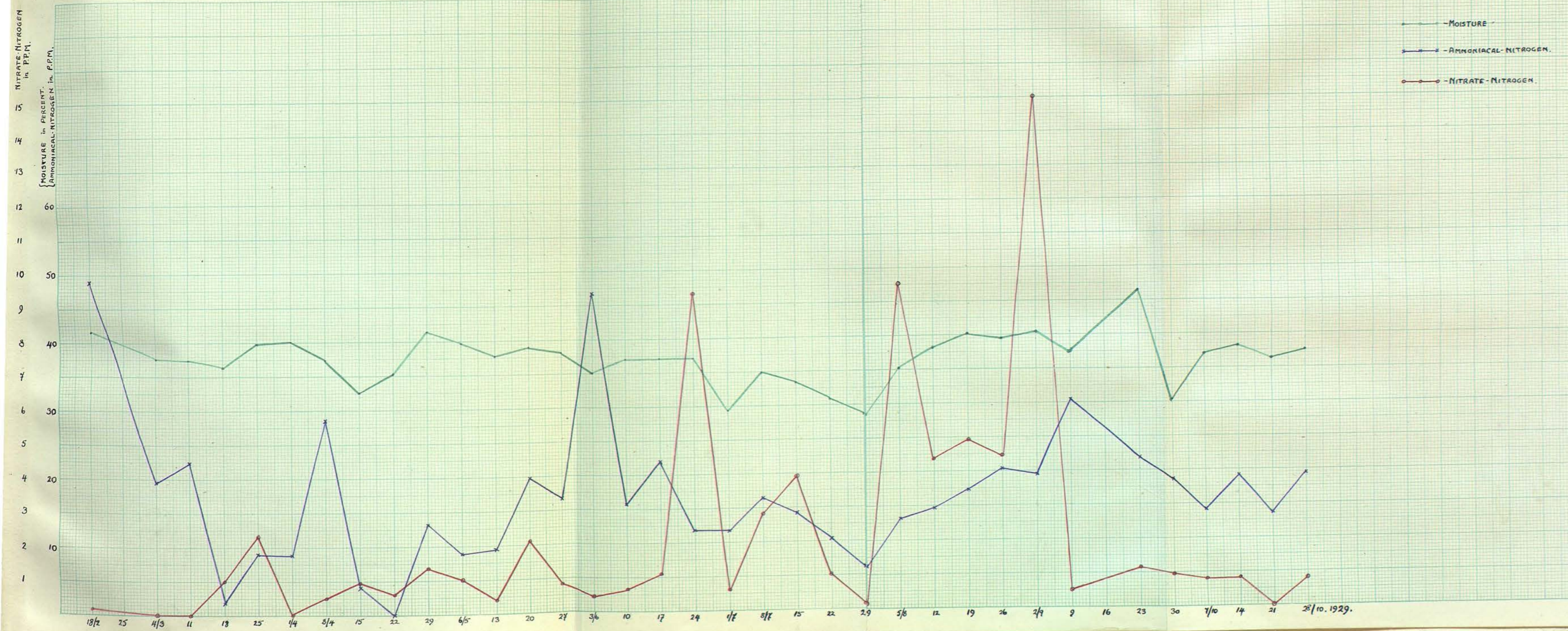
TYPE 47(G).



case of nitrat



WEEKLY RAIN FALL in mm.  
TEMPERATURE.



case of nitrate

case is there any marked relation between the results of bacterial activity and rainfall but as in the case of 29 (II) there is a marked correlation between nitrate ~~xxx~~ accumulation and temperature.

Type 32 and 47. The fluctuations in these types are much more marked than in the three types just considered. This is especially so for the ammonia content which is on the whole much greater than in the varieties of type 29. As in the other soils the accumulation of nitrate is at its maximum during late summer and autumn, after which it falls off rapidly. The ammonia content does not fall off to the same extent as that of nitrate and even in the middle of winter ammonia is always to be found although in small amounts.

Type 47 G. The fluctuations in this type are still more marked than in the last two types. It is possible that the rate of flow of water through this soil may account for these fluctuations. There is a very marked rise in the nitrate and ammonia contents during spring but these fall off rapidly and the nitrate remains low only the ammonia content increasing to any extent in early summer. In July and August, however, both nitrate and ammonia rise very sharply. In the case of nitrate, this falls during September without rising above 1 p.p.m. during the next month.

VII.      LABORATORY EXPERIMENTS on SOIL  
NITRIFYING CAPACITY.

It was hoped that a full series of experiments on the nitrifying power of the soils of the Boghall Glen would be carried out. This work had to be broken off owing to the writer's visit to Russia. Some of the results, however, are very interesting and are presented in the following table.

TABLE /

TABLE VI.  
NITRIFICATION OF SOIL ORGANIC MATTER.

Soil Type.	pH	* L. I.	Nitrate in p.p.m.			Ammonia in p.p.m.		
			at start	at end	formed	at start	at end	formed.
Type 29 ( <u>II</u> )	5.20	14.26	0.32	10.79	10.47	7.03	13.09	6.06
Type 29 ( <u>I</u> )	4.73	13.63	1.35	55.59	54.24	9.75	11.96	2.21
Type 29 ( <u>IV</u> )	5.10	10.50	0.85	59.33	58.48	6.08	13.44	7.36
Type 47 G.	6.01	12.50	0.49	32.14	31.65	12.30	19.40	7.10
Type 47	4.90	14.87	0.50	17.24	16.74	13.09	44.08	30.99
Type 32	5.30	11.36	0.40	8.93	8.53	12.15	39.60	27.45

\* Loss on ignition.

The results given are the means of two separate sets of determinations. The order of nitrifying and ammonifying power was the same in both sets. Types 29 (I) and (IV) show a much greater nitrifying power than any of the other types; type 47 G is also fairly high. Types 29 (II) and 32 show a very low nitrifying power. The amount of ammonia formed in the soils with high nitrate is low while in those with low or medium nitrate it is medium to high.

The power of the soils to nitrify and ammonify added organic matter in the form of dried blood was tested on the three varieties of type 29. The one set of results obtained showed that nitrification hardly proceeded at all, the added organic nitrogen being converted into ammonia. The soils, however, appeared in a different order of activity; types 29 (I) and (IV) are about equally active, while type 29 (I) is decidedly more so.

VIII. DISCUSSION of RESULTS.

From the diagrams of the seasonal fluctuations it is evident that the most marked accumulation of nitrates occurs during the warm weather of late summer and early autumn. The fact that there is no great accumulation in spring may be due to the fact that the temperature rises very slowly and late frosts are very common, the result being that the vegetation is able to assimilate practically all the nitrate formed at these comparatively low temperatures.

The three varieties of type 29 and type 49 G show the greatest nitrifying power in the field, but type 29 (II) lags behind the others in the laboratory tests. As regards ammonification, type 32 is most active both in the field and under the controlled laboratory conditions.

Ogg and Heddle have shown that the vegetation carried by type 29 (II) has the highest grazing value in the glen, yet as judged by these nitrification tests it has a very low activity. On the other hand, type 47 G, which is flushed with basic spring waters, carries a fairly productive type of pasture and shows a fairly high nitrifying power. The vegetation of both types 32 and 47 is of low productive capacity and/

and the soils have relatively low nitrifying powers.

The main factor governing the nitrifying power of the soil would appear to be the moisture content. The drier the soil the more active are the soils when brought into optimum conditions. Since the vegetation is much richer on type 29 (II) than on any of the others it would appear that other factors are at work. According to Ogg and Heddle chemical analyses and conductivity measurements show that the water with which this type is flushed is fairly rich in bases and the "available" potash is about normal. In type 29 (II) conditions are thus very favourable to active nitrification and since the vegetation is rich any nitrate formed would be rapidly removed by the plants, and any which remained would soon be removed by the percolating water. Thus, most of the easily nitrifiable matter is quickly converted by the micro-organisms. From the tests of nitrification and ammonification of dried blood, type 29 (II) was decidedly more active than the other two, although the amounts of nitrate formed were small.

It would appear then, that the better pasture on type 29 (II) is a result of a number of favourable factors and cannot be ascribed to one alone.

In the case of the poorer types of pasture it would appear that poor soil together with lack of drainage/

drainage have contributed to this end. The soils produce more ammonia than nitrate which is a common feature of poor acid soils and may be due to moulds.

The texture of the soil appears to have some effect on the rate of nitrification. E. Domracheva (22) found that nitrification proceeded much more rapidly in sands and light loams than in soils of heavier texture. This would appear to be supported by the results given above.

## IX.            SUMMARY.

1. The seasonal fluctuations in the nitrate and ammonia content of some soils from Boghall Glen have been studied.
2. There is no very marked increase in the nitrate content in spring, but in late summer the increase is very marked.
3. This summer increase in nitrate content appears to be connected with the much higher temperature prevailing in that season.
4. The relation of nitrifying powers to the quality of the pasture is discussed.

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