John W. Mellor

# MACAULAY INSTITUTE FOR SOIL RESEARCH

1943-1944

# ANNUAL REPORT

# THE MACAULAY INSTITUTE FOR SOIL RESEARCH

CRAIGIEBUCKLER, ABERDEEN

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1943–1944

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# THE MACAULAY INSTITUTE FOR SOIL RESEARCH

## ANNUAL REPORT

### 1943–1944

In view of the continued importance of using to the best advantage the supplies of lime and fertilizers available, particular attention has again been given to advisory work and problems of immediate importance in agriculture. Soil survey work has been continued, and has included surveys of areas of immediate interest to the authorities concerned with post-war planning. Spectrographic and X-ray investigations have been further extended. The survey of the peat resources of Scotland, which is being undertaken in collaboration with H.M. Geological Survey, has been continued: an introductory pamphlet has been published, and data on the north-eastern area collected for a second pamphlet.

As in previous years, there has been very useful collaboration with various other institutions, including the North of Scotland College of Agriculture, the Animal Diseases Research Association, H.M. Geological Survey and the Forestry Commission.

The Institute is represented on Agricultural Research Council conferences which are considering mineral, including trace element, deficiencies affecting either plant or animal health, fertilizer placement, and differences in feeding values for cattle of different pastures.

Dr. W. G. Ogg took up his duties as Director of Rothamsted Experimental Station in October, 1943, but has continued to act as Honorary Director with Dr. A. B. Stewart as temporary assistant. During the year, Dr. R. C. Mackenzie joined the Survey staff, and Mr. W. G. C. Forsyth and Mr. V. C. Farmer were appointed on special grants from the Agricultural Research Council. Mr. Forsyth is carrying out investigations into the nitrogenous compounds of soil organic matter, and Mr. Farmer is working on the trace element contents of soils, plants, and materials of agricultural importance.

The Institute is fortunate in having the services, as scientific consultant, of Dr. V. M. Goldschmidt, Professor of Mineralogy and Geology and Director of the Geological Museum of the University of Oslo. Professor Goldschmidt has been taking a particular interest in trace element distribution.[8, 9, 10]

*September*, 1944.

## Advisory Work

During the year, approximately 4,100 samples of soil have been tested and advisory reports issued on the treatment likely to be most suitable for the areas in question. Most of these samples have been drawn from ordinary agricultural land, but work has also been undertaken on Forestry Commission nurseries, horticultural soils, Air Ministry landing grounds, etc. In addition, analyses have been made of various materials such as limestones, shell sands, by-product limes, flue dusts and other industrial by-products likely to be of value on the land.

Most of the soil sampling has been done by a member of the Women's Land Army, who has for almost two years been acting as a whole-time sampler on the staff of the Institute.

Several short articles on problems of practical importance, e.g. placement of fertilizers, liming, etc., have been contributed to the agricultural press.

From advisory results obtained during the years 1940-43, a comparison has been made of the lime, phosphate and potash contents of the soils of arable rotation land and old grassland in the North of Scotland. On the basis of their contents of these plant food substances the soils have been grouped as satisfactory, slightly low or low in relation to the needs of a rotation of crops of cereals, turnips, potatoes, hay and pasture which is common in the area. A separate grouping of the soils has also been made according to their parent rocks and the results are given in Table I. The numbers of samples in the quartz-rich and peat groups, and particularly the latter, are too small to permit of generalization, but have been included to give some idea of the deficiencies to be expected in such soils. The main conclusions from the results in Table I may be summarized as follows (page 7).

*Lime.* Deficiency in lime is widespread in both arable rotation land and old grassland and is particularly pronounced in soils derived from slates and shales and from quartz-rich rocks. Although few of the soils of basic igneous origin have satisfactory lime contents, the percentage figures for soils of this group which are low in lime are appreciably lower than for the other soils of mineral origin. In the arable rotation soils derived from Old Red Sandstone the lime status is also relatively more satisfactory than in the others, but even in these the great majority of the soils would be improved by the application of lime.

*Phosphate.* The figures for the percentages of soils in the different groups are very similar to those obtained in previous years. As with lime deficiency, the phosphate position is least unsatisfactory in soils of basic igneous origin. Practically all the peat soils examined have been low in phosphate, and soils from slates and shales and quartz-rich rocks are also very liable to be phosphate-deficient. From the table of results it will also be seen that phosphate shortage is much more widespread in old grassland than in arable rotation soils.

*Potash.* As has been found in previous years, the position in regard to potash supplies in the soils of the North of Scotland is relatively much more satisfactory than it is in respect of either lime or phosphate. From the results it will be seen that the old grassland soils have more satisfactory potash contents than the soils from arable rotation land, and that the potash supplies are more satisfactory in soils derived from slates and shales

TABLE I

GROUPING OF ADVISORY SOIL SAMPLES ACCORDING TO THEIR CONTENTS OF LIME, PHOSPHATE AND POTASH. THE FIGURES UNDER THE VARIOUS HEADS ARE PERCENTAGES OF THE SAMPLES EXAMINED

| Geological origin. | No. of samples examined. | | Lime. | | | | | | Phosphate. | | | | | | Potash. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S.† | | S.L. | | L. | | S. | | S.L. | | L. | | S. | | S.L. | | L. | |
| | R.* | G. | R. | G. | R. | G. | R. | G. | R. | G. | R. | G. | R. | G. | R. | G. | R. | G. | R. | G. |
| All formations excluding peat . | 9196 | 1550 | 4 | 3 | 59 | 63 | 37 | 34 | 16 | 9 | 48 | 32 | 36 | 59 | 14 | 37 | 72 | 55 | 14 | 8 |
| Acid igneous rocks . . . | 3723 | 729 | 3 | 3 | 55 | 63 | 42 | 34 | 14 | 7 | 57 | 35 | 29 | 58 | 15 | 36 | 70 | 57 | 15 | 7 |
| Acid sandstones (O.R.S.) . . | 2420 | 318 | 8 | 6 | 65 | 61 | 27 | 33 | 21 | 8 | 51 | 35 | 28 | 57 | 11 | 34 | 74 | 55 | 15 | 11 |
| Slates and shales . . . | 1618 | 219 | 1 | 0 | 48 | 55 | 51 | 45 | 2 | 3 | 26 | 14 | 72 | 83 | 18 | 49 | 74 | 47 | 8 | 4 |
| Basic igneous rocks . . . | 1107 | 210 | 1 | 2 | 76 | 76 | 23 | 22 | 32 | 27 | 44 | 36 | 24 | 37 | 13 | 26 | 72 | 61 | 15 | 13 |
| Quartz-rich rocks . . . | 302 | 74 | 4 | 3 | 45 | 61 | 51 | 36 | 7 | 4 | 32 | 22 | 61 | 74 | 13 | 46 | 72 | 47 | 15 | 7 |
| Peat . . . . . | 145 | 53 | 7 | 8 | 72 | 75 | 21 | 17 | 4 | 2 | 4 | 2 | 92 | 96 | 6 | 11 | 33 | 49 | 61 | 40 |

† S. = satisfactory ; S.L. = slightly low ; L. = low or very low.
* R. = arable rotation land ; G. = old grassland being ploughed for cropping.

than from other geological formations. The basic igneous soils and the peats are the most liable to be deficient in potash.

The above general findings regarding the lime, phosphate and potash supplies in soils of the North of Scotland are well borne out in practice. Under the acid-soil conditions obtaining throughout the area it is probable that nothing like full benefit is being derived from the plant food substances which are either present in the soil or added in manures. There is certainly need for a bold policy of expansion in the liming of the land.

## Soil Fertility Investigations

*General Experiments with Lime and Phosphate.* Field, pot and laboratory studies of factors affecting the growth of plants have been continued and further information is being obtained on the residual effects of varying dressings of lime and phosphate on different soils. Further experiments have also been laid down with the general aim of comparing the liming values of a wide range of materials, including limestone of varying grades, magnesian limes, dried paper works lime and calcareous shell sand.

*Phosphate Fixation.* This long term investigation has been continued and an account of the work done on a soil of the acid igneous group, referred to in last year's report, has been published.[1] This deals with the recovery of added phosphate by different methods and the results indicate that fixation takes place very rapidly. At least 25 per cent. of the total phosphate exists in organic form. The extraction of phosphate in acid solutions is markedly affected by the nature and concentration of the anions present. Of the methods tried, Egner's lactate method and a two-hour extraction with a 2·5 per cent. acetic acid provide the best reflection of the field behaviour, 1 per cent. citric acid being the least satisfactory. Normal dressings of lime had no appreciable effect on the amounts of readily soluble phosphate, and during the year attention has been confined mainly to a detailed examination of the effects of incremental dressings of lime on the fixation and extraction of phosphate under varied conditions. Further work on specific anion effects is also in progress.

The comprehensive examination of samples of soil from experimental plots at Craibstone, the North of Scotland College of Agriculture farm, has also been continued during the year, with particular reference to the determination of the proportions of phosphate present in inorganic and organic combination. From the data so far available it appears that differences due to manurial treatment are reflected mainly in the phosphate present in inorganic or mineral form.

*Experiments with Blast Furnace Slags and with Fertilizers in Granular and in Concentrated Forms.* As a supplement to the general study of phosphate fixation, a considerable amount of experimental work is meantime in progress to study :

(*a*) the effects on phosphate availability of lime and other basic materials such as various blast furnace slags and crushed serpentine rock ;

(*b*) the relative manurial value of granular and powdered forms of steamed bone flour compared with other phosphatic fertilizers ;

(*c*) the relative manurial values of a concentrated granular compound, ammonium phosphate, and equivalent amounts of nitrogen and phosphate in the form of a mixture of sulphate of ammonia and superphosphate.

*Ammonium Nitrate.* Experiments are also being carried out to test the storability and drillability of different forms of ammonium nitrate and their availability to plants. This work was undertaken on behalf of the Ministry of Supply, to whom a progress report on the results to date has been submitted.

*Fertilizer Placement.* As part of a general study of the response of crops to fertilizers applied in different ways, a series of experiments was commenced in 1943 with the aid of a special grant from the Agricultural Research Council. Most of these experiments have been done with cereals on texturally differing soils in order to compare the effects of drill placement and broadcast application of superphosphate at light and medium rates. A few experiments have also been carried out on potatoes to compare the effects of band placement and ordinary broadcast application of a fertilizer mixture. A report on the results of these experiments has been prepared and submitted to the Agricultural Research Council and the main preliminary findings may be summarized as follows :

*Cereals.* With light dressings of superphosphate of about 1-1½ cwt. per acre drilling of the phosphate along with the seed is likely to be more effective than broadcast application. With heavier dressings of the order of 3 cwt. per acre the difference is likely to be less pronounced but still in favour of drilling. Of special interest is the observation that in these experiments the yields obtained with light dressings drilled were on the whole as good as those with the heavier dressings broadcast.

*Potatoes.* In these experiments a comparison has been made of the following treatments : (1) control—no fertilizer, (2) fertilizer mixture applied broadcast before planting, (3) fertilizer mixture applied in two bands, one on each side of and on the same level as the tuber, each band being approximately 2 inches from centre of tuber, (4) fertilizer mixture applied in two bands 2 inches either side of the tuber as in (3) but 2 inches below level of tuber, and (5) fertilizer mixture applied in two bands 4 inches and 2 inches respectively below the level of the tuber. At each centre there has been a marked response to the fertilizer mixture, but there have been no differences attributable to the method of application of the fertilizer.

Further experiments have been laid down during the year for the comparison of :

(*a*) broadcast and drill applications of superphosphate, sulphate of ammonia and various fertilizer mixtures on cereals ;
(*b*) broadcast and drill applications of seed and various fertilizers on land which is being reseeded direct to grass without a nurse crop ;
(*c*) broadcast and drill applications of a fertilizer mixture on potatoes using both whole seed and cut seed.

*Crushed Biotite Schist as a Source of Potash.* As mentioned in previous reports, an investigation of the manurial value of crushed biotite schist was commenced in 1940. Experimental data for a third hay crop have been obtained during the year ; the results to date show that a worth while response can be obtained over a period of years, especially if the initial dressing is at a rate sufficient to supply an appreciably greater amount of potash than is normally applied in the form of a soluble potassium salt such as the sulphate.

## SOIL SURVEY

Considerable demands have been made on the services of the Survey staff this year, with the result that it has not been possible to carry out a systematic survey of any one area. For instance, detailed surveys of some individual farms have been made, including two demonstration farms of the North of Scotland College of Agriculture, and a detailed survey of a lake marl deposit in Caithness has been carried out.

### ABERDEENSHIRE

*(a) 6-inch Primary Survey*

An area of 26 square miles around Aberdeen in the parishes of Aberdeen, Peterculter, Newhills, Dyce and Banchory Devenick (Kincardine) were surveyed on the scale of 6 inches to 1 mile.

Topographically the area is in general smooth and broadly rolling, but locally it is hilly to moundy. The drainage of the northern part of the area falls to the River Don and of the southern to the River Dee.

The district is underlain by granitic and gneissic rocks, which are covered by glacial drift, consisting of boulder clay and sand and gravel spreads. Within this area the Rivers Don and Dee are bordered by wide spreads of recent alluvium.

The higher ground around Beans Hill (451 ft.), Gairn Hill (579 ft.), King's Seat (707 ft.), Tyrebagger (800 ft.) and Hill of Marcus (700 ft.) has very thin stony soils on rock or thin rubbly drift, with occasional areas of bare rock. Similar areas are to be found on the higher ground on the south side of the Dee. A large part of this rocky ground is under plantation and the soils are podzolized.

The freely drained arable soils of the main area are brown to dark brown loams to heavy loams, with medium loams predominating. They are occasionally stony and overlie a stony sandy drift, which is frequently compacted. A thin iron pan is often present. The fields in this area are all surrounded by stone dykes, the stones having been removed from the fields. *Consumption dykes* are quite common. The poorly drained soils have a grey brown surface of medium to heavy loam texture with a cloddy structure, on a grey iron-mottled subsurface, having a texture similar to that of the surface layer.

An intermediate type between the well-drained and the gleyed is found on gently sloping ground northwest of Aberdeen extending to Bucksburn and to the northwest of Dyce. Its profile characteristics are a dark brown medium loam surface of 8-12 inches, overlying a brown slightly iron-mottled and organic stained B horizon of the same texture and slightly more compacted. The C horizon is a khaki-coloured, slightly iron-mottled and indurated, coarse sandy drift.

Between Oldmill and Bucksburn there is an area in which a black horizon of organic matter occurs below the cultivated surface layer. This is thought to be a relic of the former Calluna turf of the moorland which was turned down when the land was brought under cultivation by hand trenching.

In the wetter hollows peaty gley types are found. There are no extensive areas of peat within the district, the Moss of Rotten being the largest, and it is now cut over.

The association into which these soils are grouped is provisionally named *Countesswells.*

On both sides of the Rivers Dee and Don there are extensive spreads of sands and gravels, giving rise to gravelly sandy loams, sometimes with a hard pan and all tending to be too freely drained to withstand drought. Similar soils on mounds of sands and gravels are found in the valley of the Silver Burn, in the area north of Murtle and in the valley between the Rowett Institute and Craibstone Farm.

The soils developed on these sand and gravel areas are similar to those previously described, e.g. Pitcaple and Fyvie (*Ann. Rep.* 1942-43). Since extensive gravel areas are to be found in many localities in Aberdeenshire, with apparently the same soil profile characteristics, a general association name will be required after further survey.

In the area between Sheddocksley House and Upper Mastrick Farm there is a broad channel in which water-sorted drift occurs, giving rise to soils similar to those of the drift areas.

The River Dee is bordered by a wide haugh filled with recent alluvium, which is formed of fine sand and is practically stone free. Deep soils of a loamy texture occur. There are areas of gravel due to recent flooding. Alongside the River Don to the east of Dyce there is a narrow strip of alluvium of sandy loam texture.

(*b*) *Reconnaissance Survey*

An area of 80 square miles extending from a line running east and west through Ellon south to Aberdeen, and bounded on the west by the River Don at Kemnay, has been covered.

The soil associations mapped in this area are :

1. Cruden.
2. Fraserburgh.
3. Belhelvie.
4. Tarves.
5. Old Machar.
6. Links.

1. *Cruden Association.* This association, described in *Ann. Rep.* 1942-43, has been found to continue down the coast towards Aberdeen. From Ellon south there extends a belt of the red-brown clay loam to clay boulder clay generally found on the lower ground. Locally there are areas of red sandy clays and red sands and gravels. The higher ground in this area is formed of local patches of gneissic drift (Tarves Association). To the south of Ellon there is an area of fluvioglacial sands and gravels, surrounded by the red clay drift. The soils in the red clay drift area are cloddy clay loams in general with fair to poor drainage. Several areas of red lacustrine clays occur, notably at Tipperty and Esslemont, where they have been worked for brick-making. East of Ardo House and also about Balmedie, similar deposits are found. The latter appears to be extensive to the south. Red clay underlies the sand and gravel deposits just north of Aberdeen, and is exposed to a depth of 20 feet in a clay pit at the Blackdog. The soils developed on these clays are frequently reddish brown in colour, and are cloddy and very heavy in texture. Within the Balmedie red clay area

there are localized deposits of red sand to very fine sand giving rise to soils of free to slightly impeded drainage.

2. *Fraserburgh Association.* From about Menie House and continuing to Blairton Farm, Balmedie, an area of raised beach deposits of sand occurs. Similar small occurrences are found on both sides of the estuary at Newburgh. The soils are deep fine sandy loams to heavy sandy loams. They appear identical with those of Fraserburgh and occur on a similar smooth, gently sloping topography.

3. *Belhelvie Association.* This association extends from Skellyhill Wood south across Beauty Hill and Wester Craigie Wood, east beyond Harestone Moss as far as Belhelvie. The underlying rocks are basic and ultrabasic in composition. The topography of the area is rugged with many rock outcrops and large erratics. The hollows are generally wet and are peat-filled. The soils tend to be brown to dark brown in colour, of heavy loam to medium loam texture, on a creamy fine sandy and stony iron-mottled drift. The farms on this association tend to be small and agriculturally poor.

4. *Tarves Association.* The soils of this association are found in the district extending east from Pettymuck to the boundary of the Cruden Association and south beyond New Machar. The freely drained soils are generally deep heavy loams on a light khaki-coloured fine sandy and stony drift which may overlie a heavier clay loam drift. The poorly drained soils are heavy loams to fine loams on a sandy clay drift with much iron mottling. The normal topography is smoothly rolling but about New Machar and towards Parkhill it becomes that of the typical hummocky ground moraine.

5. *Old Machar Association.* This association extends from Aberdeen north to the Millden Burn and Belhelvie, and is bounded on the west by a line extending roughly from Parkhill of Dyce to the Bridge of Don. The topography is diverse, comprising sharply defined ridges, smooth slopes and also hummocks. The area is underlain by sands and gravels appearing to be horizontally bedded. At numerous places throughout the area red clay underlies the gravel deposits. The soils vary from excessively drained to excessively wet and texturally vary from loams to medium loams, often underlain by an indurated layer, sometimes with an iron pan. These deposits have been extensively worked for sand and gravel for building purposes. Rabbit infestation is common in the uncultivated parts of this area.

Within the area of this association in the vicinity of Crosby Farm, on a relatively smooth topography, a mixed drift area occurs in which red boulder clay has been found.

6. *Links Association.* From the estuary of the Ythan to the mouth of the River Don there is an extensive development of sand dunes. At their widest part they extend approximately 1½ miles inland, but generally they are only ¼ to ½ a mile broad. The dunes proper have thin immature oromorphic soils, often overlying buried horizons, and associated with these soils are extensive blown-out areas. *Psamma arenaria* is the dominant plant of the stabilized areas. There are smooth areas behind the dunes which have a loamy sand texture and are cultivated. The soils are phytomorphic to phytohydromorphic in drainage. This smooth area is either used as a sheep walk and has a poor grass and herb cover, or is cultivated, when the crops grown are rye or potatoes.

KINCARDINESHIRE

*Glensaugh Experimental Farm*

A soil survey has been made of the farm of Glensaugh, Kincardineshire, on the scale of 6 inches to 1 mile. It covers about 4 square miles in extent and is mainly hill land, apart from about 100 acres of arable ground. Geologically the farm is divided into two parts by the Highland Boundary Fault. To the north of the fault line there is a series of schistose rocks, intruded into which are quartz porphyry and felsitic rocks. On the south side of the fault the rocks are sandstones and conglomerates of the Old Red Sandstone formation. The whole area has been glaciated and a deep deposit of glacial drift covers the lower slopes up to about 700 feet with a thinner drift on the higher ground. There are spreads of sands and gravels extending south and east from the Clattering Brig, and they also occur locally in the vicinity of Loch Saugh.

On the uncultivated hill land the highest ground on the north side of the farm is occupied by deep peat with banks up to 12 feet deep. A thin peat forms a transition zone on the steeper hill slopes to the main area of podzolized soils. These have dominantly a Calluna-Vaccinium-Hypnum vegetation with lesser amounts of Juncus and Sphagnum. Flush gley soils of variable profile character occur associated with the drainage systems on the hill slopes. Surrounding the wet flush areas there is usually a zone of bracken infestation, associated with a brown earth soil type. The very steep slopes are covered by scree and there are extensive areas of colluvial downwash, on which there is a Calluna vegetation but with little development of a Calluna turf.

There are several fairly extensive areas of formerly cultivated land, some of which are now rebroken. These have well-drained soils overlying a fine sandy textured quartz schist drift. Very shallow stony soils with rock outcrops are also found.

The sand and gravel spreads give rise to excessively drained light textured soils.

The lower slopes of Strathfinella Hill on the south side of the farm have soils developed on a deep drift derived mainly from rocks of the Old Red Sandstone formation. The vegetation is a Calluna-Vaccinium-Hypnum association and the soils are podzolized. Areas of former cultivation occur, where the soil type appears to be of the brown earth variety under a grass, bracken and Calluna vegetation, and it would seem that much of the smoother uncultivated slopes up to an altitude of 700 feet could be cultivated and reseeded. On the higher slopes of the hill the Calluna turf is deeper and on the flat top there is a complex of podzol and gleyed podzol soils.

The arable soils are developed on a mixed drift, with subangular stones of schist, quartz porphyry, granite, felsite and Old Red Sandstone pebbles, and are stony to medium stony loams with free or slightly impeded drainage on a fine sandy stony drift, sometimes compacted. An area of deeper freely drained soil is found around Glensaugh Lodge. There are also areas of heavy textured poorly drained soils, with a grey brown heavy loam surface horizon overlying an iron-mottled stony clay loam on a stiff cloddy boulder clay.

CAITHNESS

*Hoy Demonstration Farm*

A detailed soil map of this farm has been made. The area is underlain by flagstones of the Old Red Sandstone formation which are covered by a till derived predominantly from these rocks.

The farm is divided almost equally between soils with free drainage and soils with poor drainage. The freely drained areas tend to occupy the convex slopes while the wet areas occur in the flats and concave slopes. Silt loam is the dominant soil texture over the area as a whole; the freely drained soils are medium brown in colour, friable throughout, on drab khaki very fine sandy and stony drift. Merging through a transitional soil of slightly impeded drainage on a greyer slightly cloddy subsoil, the poorly drained soils are creamy grey at the surface, and cloddy throughout, with a gun-metal grey silty clay subsurface containing manganese and iron staining round the root pores. The uncultivated and abandoned soils conform to the above types, but differ in their surface horizons which are more highly humose due to lack of cultivation.

MIDLAND VALLEY

A reconnaissance survey of an area of some 200 square miles in the counties of West Lothian, Stirling, Clackmannan and Fife has been made. The ground examined is underlain by sedimentary and igneous rocks, mainly of carboniferous age, the area of sediments predominating. The superficial deposits include boulder clays derived from the sediments and the igneous rocks, sand and gravel of fluvioglacial and marine origin, and the carse silt-clays of marine origin. The area bordering the carse is partically complex on account of former marine erosion.

The largest area is occupied by soils derived from the boulder clays of which it is possible to distinguish four types, each of which is closely related to one or more of the solid formations. The internal drainage of these soils, while being definitely a function of texture and climate, seems to depend to a considerable extent on the standard of farming. The largest areas of ill-drained soils occur in the high-lying area south of Bonnybridge and west of Torphichen, where the drift is heavy and the rainfall high. In the stretch between Bonnybridge and Falkirk, however, there is a fairly large area of ill-drained soils overlying lightish drift derived from Millstone Grit.

The area bordering the Forth would appear to be particularly valuable as agricultural land because of the variety of soils it contains and the suitability of these for a wide range of crops. The carse land is remarkably uniform in texture and drainage, the soils being of a silt-clay texture and on the whole well-drained. The highest marine terrace consists of sand and gravel which is practically identical with the great stretch of gravel running from Camelon to east of Linlithgow. These deposits carry excellent, light, well-drained soils locally known as "dry field".

The river alluvium varies considerably in texture from heavy clay to gravelly loam. Drainage is on the whole satisfactory, although the lower-lying tracts are liable to flooding, particularly in parts of the valleys of the River Devon and Bonny Water.

## Laboratory Investigations

Chemical studies of the soils collected during the survey have been continued. Differences between the various types, to which reference has previously been made (*Ann. Rep.*, 1942-43), have been confirmed in soils from other areas. The study of the basic igneous soils of Central Aberdeenshire has now been published.[2] Further analysis of coniferous needles has been carried out in connection with die-back in Forestry Commission plantations (cf. *Ann. Rep.*, 1941-42).

## Soil Mineralogy

The mineralogical examination of the fine sand fractions of soils and their parent materials collected during soil surveys has been continued. The soil parent materials examined were largely glacial drifts of varied lithological composition and the examination was carried out to determine the nature of the fine material of the drifts.

A number of samples were examined from drifts in an area of granitic gneissic rocks and the results showed a high proportion (15-18 per cent.) of ferromagnesian silicate minerals and iron oxides with about 10 per cent. of the orthoclase group, the remainder being quartz. These results agree with those found for similar areas in other parts of Aberdeenshire.

In samples from drift areas, where schists of varied composition underlie the drift, the content of ferromagnesian silicate minerals was found to be much lower (about 8 per cent.). An occurrence of a pebbly quartzite drift with flints was also investigated. Much flint material was found in the fine sand fraction and micas were found to be common in the ferromagnesian silicate group.

Samples were examined from an area in north-eastern Aberdeenshire where a red drift, influenced by rocks from the Old Red Sandstone formation, occurs. Considerable variation in the proportion of the various minerals present was found, with a very high percentage (15 per cent.) forming the ferromagnesian silicate fraction. This is in marked contrast to the proportion (5 per cent.) found in samples taken from a drift directly overlying rocks of the Old Red Sandstone formation in central Aberdeenshire. It is due to the drift being influenced by igneous and metamorphic rocks.

In northern Aberdeenshire there are tracts of fluvioglacial sands and gravels and of light sands. These on examination showed a high proportion of quartz and a varying proportion of ferromagnesian silicate minerals with a small proportion of feldspar.

The soils from the profiles from which these basal samples were taken were also examined and the mineral composition determined.

Samples from an area surveyed in Easter Ross (cf. *Ann. Rep.*, 1941-42) were investigated. This area is underlain by rocks of the Old Red Sandstone formation, which are overlain by glacial drift, fluvioglacial sands and gravels, and by raised beach deposits. In a sample of basal material from the drift area the ferromagnesian silicate content was low (4·7 per cent.), while the orthoclase fraction was 8·9 per cent., the remainder being quartz. In samples from the fluvioglacial and the raised beach areas the ferromagnesian silicate mineral content was variable, but in general low, as also was the orthoclase group fraction.

## PEAT SOILS AND SOIL ORGANIC MATTER

### Peat Survey

The introductory pamphlet covering the peat survey has now been published [3] as Geological Survey Wartime Pamphlet No. 36. The survey of the north-eastern area has been completed and the survey data submitted to the Geological Survey for incorporation in the second pamphlet of the series. The survey has been extended to the Morayshire-Inverness section.

### Peat and Compost Investigations

*Growth tests using peat or potting composts made up with peat.* These have been continued as before but have given no results of particular interest; previous generalizations have been confirmed.

*Tests on a commercial growth-promoting medium.* The extensive tests carried out last year on this material gave no evidence of increased growth resulting from the material under test. This was used both under exact control at the Institute and under market garden conditions on a commercial scale, both under glass and in the open.

*The use of coarse carbonate of lime for maintaining the pH of soil under horticultural conditions.* It was found that, although shell sand gave improved growth of tomatoes as compared with coarse-ground limestone, this was not due to maintenance of *p*H value. It is proposed to repeat this series of experiments in glass instead of earthenware flower pots so as to eliminate any residual effects of previous soils. Further pot experiments have been carried out on the movement of lime in the soil under heavy horticultural watering. The assessment of these has not been completed.

*Composting experiments.* A single large scale composting experiment was carried out with a view to obtaining some information on nutrient losses which occur under ordinary practice. In general terms it appears that under our climatic conditions with rich garden refuse allowed to rot down under cover, as much as two-thirds of some nutrients may be lost in drainage from the rotting heap. Under open conditions but with a considerable admixture of peat to retain early outrun of liquid, losses may be reduced to half this amount. On composting under cover with peat interlayered at the rate of 1 part peat to 4 of refuse by volume, no losses of nutrient could be detected.

*Investigations into the replacement of farmyard manure by peat fortified with artificial manures.* The experiments previously laid down continue to give the same result as before and from further experiments the same conclusion has been reached, namely, that within the past few years at least the crop results obtained from applications of farmyard manure can be duplicated more or less exactly by the use of peat fortified with artificials up to the same nutrient level as that of the dung applied. Under the more intensive treatments given in an allotment at the Institute, both peat with artificials and artificials alone appear to be inducing a higher soil acidity than does dung supplemented with artificials in the usual way.

### Laboratory Work

(*a*) Routine analyses of peats have been continued as before.

(*b*) Investigations of the methods of examination of soil organic matter were, in the earlier part of the year, concerned chiefly with the application

of the methods used for determining polyuronides in plant materials to soil organic matter and peat, and to the modification of these methods for this specific purpose. It may be said that very considerable doubt is thrown on estimations of polyuronides in complex mixtures by the methods commonly used. Even when rate of carbon dioxide evolution is measured against time (under carefully standardized conditions) a simple interpretation of the results obtained is impossible. A very considerable amount of data has been obtained by the application of a new conductimetric method to the measurement of the $CO_2$ evolution taking place.

Studies have been commenced on the "humic acid" fraction of the organic matter and its preparation from various sources in a more or less homogeneous form. It has been found that when prepared by the usually adopted methods, the fraction obtained invariably contained 15-25 per cent. of easily hydrolysable proteins and hemicelluloses, which are co-precipitated with the humic acid fraction proper. Various methods of fractionation have been used. A method of obtaining homogeneous fractions has been applied to soil, peat and compost. The chemical examination of these fractions is now proceeding.

(*c*) Standard pure humus preparations are being made with a view to their use in soil studies.

(*d*) The determination of the ionic exchange properties of typical peats has been continued.

## SPECTROGRAPHIC INVESTIGATIONS

### The Cathode Layer Arc Method

During the past year the technique employed in the spectrographic determination of constituents present in amounts ranging from 5 to 5,000 parts per million in soils, plant ashes, and concentrates of these has been developed further. Accuracy in such determinations depends on the rigid standardization of procedure, control of purity of reagents and electrodes, and cleanliness and care of equipment. When working at the lower limit of sensitivity, the adjustment of the spectrograph itself assumes increased importance, and it is essential to ensure that lenses and masks are in proper register. For estimations by a visual semi-quantitative method, it is essential that electrode dimensions are exact, so as to ensure correct burning time and content of substance under investigation. A small lathe with a tool which can simultaneously cut and bore electrodes to standard dimensions—boring 0·8 mm. diameter and 8 mm. deep in a 2·8 mm. diameter carbon rod, cut down from 5 mm.—has been installed and has produced a great improvement in the quality of the electrodes previously made by a local firm, and has at the same time improved their purity, especially in freedom from copper, lead and tin. Standards used should conform closely in major chemical composition to the unknowns, or at least it should be known that for the elements being determined, any differences are not of importance.

Variations have been noted in the quality of different batches of the best available reagents; as instances, substantial amounts of chromium and nickel respectively have been found in some batches of acetic acid and ammonia, although other consignments had sufficiently low contents for direct use in concentration methods. In such cases purification by distillation is a simple and effective remedy. More difficulty has been experienced in the purification of ingredients of standard mixtures, but by selection of samples containing these impurities which are easiest to remove, sufficiently pure samples of such materials as $CaCO_3$, $Al_2O_3$, $Fe_2O_3$, $K_2SO_4$ and $KH_2PO_4$ have been produced. In some cases quite large amounts of impurities, such as sodium, potassium or magnesium, may be permissible if the standards are required for heavy metal determination.

In the evaluation of results of analyses by a step-sector method involving an internal standard and background correction, details of which have now been published [4] and for which a table of gaussian logarithms was included in last year's report, it has now been found that, where the lines (e.g. Co 3453·5 and Fe 3451·9) have a common background intensity, further simplification can be achieved by the use of a modification of the table. Table A in last year's report gave values of $\gamma$ for values of $\delta$ where $\log (A + B) - \log B = \delta$ and $\log (A + B) - \gamma = \log A$. Calculation of two values $A_1$ and $A_2$ in order to obtain $\log A_1/A_2$ involved two complete operations, values of $\log (A_1 + B)$, $\log (A_2 + B)$ and $\log B$ at the appropriate density being read off from the blackening curves. When a table of $\delta$ against $\delta - \gamma$ is employed it is necessary only to measure the distances of $\log (A_1 + B)$ and $\log (A_2 + B)$ from $\log B$. These values are taken as $\delta_1$ and $\delta_2$ and from the table $(\delta - \gamma)_1$ and $(\delta - \gamma)_2$ are obtained, whence $(\delta - \gamma)_1 - (\delta - \gamma)_2$ gives $\log A_1/A_2$ directly. A suitable table of values is given in the appendix to this report (p. 25).

## Determination of Trace Constituents in Soils and Plants

The lines along which investigations of trace constituents in soils and plants are being carried out are indicated in a recent publication.[5] More detailed work on cobalt and nickel is described in a paper which is in preparation.[11] These elements are of interest in view of the occurrence of cobalt deficiency in sheep in several areas of Scotland and also of areas of infertile soils with large contents of nickel. The results for cobalt so far available suggest that, for arable soils, extraction with 2·5 per cent. acetic acid and determination of the cobalt so extracted is a better diagnostic technique than the determination of the total cobalt content of the soil. Pining of sheep due to cobalt deficiency generally occurs on soils with less than 0·25 p.p.m. cobalt soluble in acetic acid, whilst in a healthy area such, for instance, as Aberdeenshire, it is exceptional to obtain values below 0·30 p.p.m. As far as the content of the herbage is concerned, in areas where pining is widespread, values of less than 0·05 p.p.m. cobalt are common in the critical summer months, although up to 0·08 p.p.m. may be found. The values for pasture herbage are subject to influence from several factors, such as time of sampling, botanical composition of pasture and effect of stock, particularly in respect of soil contamination. It is probably best on heavily stocked areas to sample an area from which the stock has been excluded for a few weeks. More information has been obtained on the uptake of different species, both in pots and in the field, substantiating the value of clover in increasing cobalt uptake.

Further information is being gathered on the normal contents of such elements as barium, strontium, lithium, lead, copper and vanadium in pasture herbage, without so far any significant relationship between the values obtained and the incidence of as yet unexplained animal diseases.

The study of the behaviour of trace constituents during the processes of soil formation, in particular podzolization, has been commenced, and the investigation of the trace contents of different minerals from igneous rocks has been continued.

## The Lundegardh Flame Emission Method

The Lundegardh method has again been used mainly for routine determinations of the alkalis, alkaline earths, and manganese, in connection with the soil advisory service and investigations on plant contents, exchangeable cations, and composts. The number of such determinations made has been of the same order as in previous years. The results obtained are referred to in the reports of the appropriate departments.

It has been possible, in addition, to carry out a considerable amount of work on the interference effects of various salts in the solutions which are sprayed into the flame, and as a result of this it has already been possible to modify methods of determination in order to take advantage of the knowledge so gained. As an example, the results for the effects of calcium and ammonium salts on the determination of the alkalis have shown that the total alkalis in soils can be determined directly in the leachate from the Lawrence Smith fusion without prior removal of calcium. All elements which it is desirable to investigate have not yet been covered, and the work is continuing.

## X-RAY WORK

During the year there has been a change of emphasis in this work, in favour of a rather more fundamental approach to the problem of the mineral constitution of soil clays. This was as a result of experience gained in the investigation of a number of soil colloids of the Insch association, mentioned in last year's report. Most of the clays were mineralogically fairly complicated, and there were a number of features of the photographs obtained which obviously needed further clarification before the maximum amount of information could be said to have been obtained. For this reason, it was thought that before beginning with an extensive programme, involving investigation of clays from a large number of soils, it was desirable to do some work on the pure clay minerals, so as to get more information on the behaviour which might be expected in various circumstances, and to examine a few selected soil clays in detail.

A considerable amount of work has been done on the mixed structures which montmorillonite forms with alcohols, as it is thought that these may have a bearing on the mechanism of binding water in montmorillonite, as well as on the question of possible mixed structures involving montmorillonite and amorphous sesquioxides or organic material. Photographs have been taken of montmorillonite which has been treated with various normal and branched-chain alcohols, and also with a number of polyhydric alcohols. With the latter, the effect of the state of hydration on the basal spacing has also been investigated.

In co-operation with Dr. Emödi of the Fuller's Earth Union Ltd., a series of photographs has been made of several natural and "activated" montmorillonites at various stages of hydration, approached both from the high-moisture and the low-moisture side. It was hoped that this might throw some light on the effects accompanying the occurrence of amorphous constituents between the montmorillonite layers, a phenomenon whose existence was suspected in certain soil clays. The possible connection of this with similar effects obtained with alcohol-saturated montmorillonite is now being investigated.

As a result of the alcohol absorption work, a new and apparently useful method for the positive identification of the montmorillonite minerals by X-rays has been devised, based on the fact that glycerol treated montmorillonite gives a sharp reflection at 17·7 A.[12]

## SPECIAL INVESTIGATIONS

### Joint Work with the Animal Diseases Research Association

(*a*) *Cobalt manuring and pining in stock.* This investigation, to which reference has been made in previous years' reports, has been continued and further areas have been treated with manurial dressings of cobalt salts. Particular attention is being paid to the determination of the residual effects of dressings of cobalt in different soils.

(*b*) *Other stock disease problems.* In connection with the study of various stock diseases, where mineral particularly trace element deficiency or excess is suspected as a causal agent, an examination is being made of samples of soil and produce in order to find out if there is a relationship between soil properties and incidence of the disease. Analyses have been carried out on a considerable number of samples from areas in which the following diseases occur: Solway Pine, Swayback in lambs, Lactation or Grass Tetany, and Abortion in ewes.

### Differences of Feeding Values for Cattle of Different Pastures

As mentioned in last year's report the Institute, at the request of the Agricultural Research Council, is co-operating in a long-term joint investigation of the differences of feeding values for cattle of the produce from different farms where there is no obvious soil or other factor to account for such differences. Comprehensive examination of the soils and determinations of the mineral, especially trace element, contents of the produce from 16 farms in Aberdeenshire have been made during the year.

### Survey of Scottish Limestones

A further small number of limestones have been analysed in connection with the survey of Scottish limestones. The last two pamphlets (Areas I and VIII) have been published by H.M. Geological Survey,[6, 7] and new editions for Areas V and VI have been issued.

A detailed survey of the marl deposit in Westfield Loch, Caithness, has been made. From the contour map prepared the deposit was estimated to contain about 700,000 tons of marl with a moisture content of 60 per cent. The tonnage of marl of 3 ft. thickness and over is about 500,000 tons. The average $CaCO_3$ content (oven dry) is about 90 per cent. The marl is being dug for agricultural use to some extent.

### Studies on Soil Drainage Water

Analytical work on the composition of the drainage waters from the Craibstone lysimeters has been continued during the year.

Turnips were grown as the crop for 1943, lysimeters 2 and 3 each being given, per acre, dung 12 tons, sulphate of ammonia 1½ cwt., superphosphate 5 cwt., muriate of potash 1½ cwt. Ground lime at the rate of 22½ per cwt. CaO per acre was applied to lysimeter 3.

The crop when lifted gave the following weights, per acre :—

| | *As lifted* | | *Dry matter* | |
|---|---|---|---|---|
| | *cwt.* | *lb.* | *cwt.* | *lb.* |
| Lysimeter 1 | 30 | 13 | 2 | 97 |
| ,, 2 | 97 | 93 | 9 | 9 |
| ,, 3 | 105 | 57 | 9 | 111 |

Rainfall, including snow, during the year 1st October, 1943, to 30th September, 1944, totalled 25·42 inches, of which from 45 to 50 per cent. appeared as drainage.

## PUBLICATIONS

*Issued during the year—*

1. "Studies on Phosphate Fixation in Scottish Soils. Part I. The Recovery of Added Phosphate from a Soil of the Acid Igneous Group." By E. G. Williams and A. B. Stewart. (*J. Agric. Sci.*, **33**, 179-89, 1943.)
2. "Studies on the Soils developed on Basic Igneous Rocks in Central Aberdeenshire." By R. Glentworth. (*Trans. Roy. Soc. Edin.*, **61**—Part I—(No. 5), 149-70, 1944.)
3. "Peat Deposits of Scotland. Part I. General Account." By G. K. Fraser. (Geological Survey Wartime Pamphlet No. 36, 1943.)
4. "Background Interference in Spectrographic Analysis and its Correction at a Constant Blackening Value." By R. O. Scott. (*J. Soc. Chem. Ind.*, **63**, 25-9, 1944.)
5. "The Distribution of Trace Elements in Soils and Grasses." By R. L. Mitchell. (*Proc. Nut. Soc.*, **1**, 183-89, 1944.)
6. "Limestones of Scotland. Area I. Southern Scotland." By J. B. Simpson (Geological Survey), A. Muir and H. G. M. Hardie. (Geological Survey Wartime Pamphlet No. 13, 1944.)
7. "Limestones of Scotland. Area VIII. Orkney and Shetland." By D. Haldane (Geological Survey) and H. G. M. Hardie. (Geological Survey Wartime Pamphlet No. 13, 1943.)
8. "Crystal Chemistry and Geochemistry." By V. M. Goldschmidt. (*Chemical Products*, March-April, 1944.)
9. "The Occurrence of Rare Elements in Coal Ashes." By V. M. Goldschmidt. (*Coal Research*, June, 1944.)

*In preparation—*

10. "The Geochemical Background of Minor-Element Distribution." By V. M. Goldschmidt. (To appear in *Soil Sci.*)
11. "Cobalt and Nickel in Soils and Plants." By R. L. Mitchell. (To appear in *Soil Sci.*)
12. "Identification of the Montmorillonite Group of Minerals by X-rays." By D. M. C. Macewan. (To appear in *Nature.*)

# APPENDIX

## Logarithmic Tables for use in Quantitative Spectrographic Analysis

### C. Table of $(\delta - \gamma)$ for values of $\delta$, where $\gamma$ is the subtraction logarithm of $\delta$.

In Table A (*Ann. Rep.*, 1942-43) was given a table of Gaussian or Subtractive Logarithms, which simplified the calculation of the logarithm of the intensity of a spectral line, knowing the values of the logarithm of the intensity of line + background and of the background itself. Thus

$$\log (I_{T.E.} + I_{Bg1}) - \log I_{Bg1} = \delta_1$$

and

$$\log I_{T.E} = \log (I_{T.E.} + I_{Bg1}) - \gamma_1,$$

where $\gamma_1$ for the corresponding value of $\delta_1$ is obtained in the table. A further simplification is possible by elimination of $\log (I_{T.E.} + I_{Bg1})$ from the above. Then

$$\log I_{T.E.} = (\delta_1 - \gamma_1) + \log I_{Bg1}$$

and for a corresponding internal standard line

$$\log I_{I.S.} = (\delta_2 - \gamma_2) + \log I_{Bg2},$$

hence $\log (I_{T.E.}/I_{I.S.}) = (\delta_1 - \gamma_1) - (\delta_2 - \gamma_2) + (\log I_{Bg1} - \log I_{Bg2})$,

and where the lines can be taken to have the same background intensity the last term disappears, so

$$\log (I_{T.E.}/I_{I.S.}) = (\delta_1 - \gamma_1) - (\delta_2 - \gamma_2).$$

Table C consists of a table of values $(\delta - \gamma)$ for values of $\delta$, and has been derived from Table A.

To obtain $\log (I_{T.E.}/I_{I.S.})$ it is necessary only to measure the separations of the blackening curves of the lines from the background at the appropriate density,* these giving $\delta_1$ and $\delta_2$, and to find the difference of the corresponding values of $(\delta - \gamma)$ read from the table.

Where the backgrounds of the two lines differ, the separations to their respective backgrounds are read, and to the difference of the $(\delta - \gamma)$ values the separation between the backgrounds must be added directly. The rule of sign is analogous to that used for $\delta$, i.e. positive for $I_{Bg1} > I_{Bg2}$.

* See Davidson, A. M. M. and Mitchell, R. L. *J. Soc. Chem. Ind.*, **59**, 213 (1940), and Scott, R. O. *J. Soc. Chem. Ind.*, **63**, 4 (1944).

## C. Table of $(\delta - \gamma)$ for Values of $\delta$.

| $\delta$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0·00 | $\bar{6}$·000 | $\bar{3}$·363 | $\bar{3}$·664 | $\bar{3}$·841 | $\bar{3}$·966 | $\bar{2}$·064 | $\bar{2}$·143 | $\bar{2}$·211 | $\bar{2}$·269 | $\bar{2}$·321 |
| 0·01 | $\bar{2}$·367 | $\bar{2}$·409 | $\bar{2}$·447 | $\bar{2}$·483 | $\bar{2}$·513 | $\bar{2}$·546 | $\bar{2}$·574 | $\bar{2}$·601 | $\bar{2}$·627 | $\bar{2}$·651 |
| 0·02 | $\bar{2}$·673 | $\bar{2}$·695 | $\bar{2}$·716 | $\bar{2}$·735 | $\bar{2}$·754 | $\bar{2}$·773 | $\bar{2}$·790 | $\bar{2}$·807 | $\bar{2}$·823 | $\bar{2}$·839 |
| 0·03 | $\bar{2}$·854 | $\bar{2}$·869 | $\bar{2}$·883 | $\bar{2}$·897 | $\bar{2}$·911 | $\bar{2}$·924 | $\bar{2}$·937 | $\bar{2}$·949 | $\bar{2}$·961 | $\bar{2}$·973 |
| 0·04 | $\bar{2}$·985 | $\bar{2}$·996 | $\bar{1}$·007 | $\bar{1}$·017 | $\bar{1}$·028 | $\bar{1}$·038 | $\bar{1}$·048 | $\bar{1}$·058 | $\bar{1}$·068 | $\bar{1}$·077 |
| 0·05 | $\bar{1}$·086 | $\bar{1}$·096 | $\bar{1}$·104 | $\bar{1}$·113 | $\bar{1}$·122 | $\bar{1}$·130 | $\bar{1}$·139 | $\bar{1}$·147 | $\bar{1}$·155 | $\bar{1}$·163 |
| 0·06 | $\bar{1}$·171 | $\bar{1}$·178 | $\bar{1}$·186 | $\bar{1}$·193 | $\bar{1}$·201 | $\bar{1}$·208 | $\bar{1}$·215 | $\bar{1}$·222 | $\bar{1}$·229 | $\bar{1}$·236 |
| 0·07 | $\bar{1}$·243 | $\bar{1}$·250 | $\bar{1}$·256 | $\bar{1}$·263 | $\bar{1}$·269 | $\bar{1}$·275 | $\bar{1}$·282 | $\bar{1}$·288 | $\bar{1}$·294 | $\bar{1}$·300 |
| 0·08 | $\bar{1}$·306 | $\bar{1}$·312 | $\bar{1}$·318 | $\bar{1}$·323 | $\bar{1}$·329 | $\bar{1}$·335 | $\bar{1}$·340 | $\bar{1}$·346 | $\bar{1}$·351 | $\bar{1}$·357 |
| 0·09 | $\bar{1}$·362 | $\bar{1}$·368 | $\bar{1}$·373 | $\bar{1}$·378 | $\bar{1}$·383 | $\bar{1}$·388 | $\bar{1}$·393 | $\bar{1}$·398 | $\bar{1}$·403 | $\bar{1}$·408 |
| 0·10 | $\bar{1}$·413 | $\bar{1}$·418 | $\bar{1}$·423 | $\bar{1}$·429 | $\bar{1}$·432 | $\bar{1}$·437 | $\bar{1}$·442 | $\bar{1}$·446 | 1·451 | $\bar{1}$·455 |
| 0·11 | $\bar{1}$·460 | $\bar{1}$·464 | $\bar{1}$·469 | $\bar{1}$·473 | $\bar{1}$·477 | $\bar{1}$·482 | $\bar{1}$·486 | $\bar{1}$·490 | $\bar{1}$·494 | $\bar{1}$·499 |
| 0·12 | $\bar{1}$·503 | $\bar{1}$·507 | $\bar{1}$·511 | $\bar{1}$·515 | $\bar{1}$·519 | $\bar{1}$·523 | $\bar{1}$·527 | $\bar{1}$·531 | $\bar{1}$·535 | $\bar{1}$·539 |
| 0·13 | $\bar{1}$·543 | $\bar{1}$·547 | $\bar{1}$·550 | $\bar{1}$·554 | 1·558 | 1·562 | $\bar{1}$·566 | $\bar{1}$·569 | $\bar{1}$·573 | $\bar{1}$·577 |
| 0·14 | $\bar{1}$·580 | $\bar{1}$·584 | $\bar{1}$·587 | $\bar{1}$·591 | $\bar{1}$·595 | $\bar{1}$·598 | $\bar{1}$·602 | $\bar{1}$·605 | $\bar{1}$·609 | $\bar{1}$·612 |
| 0·15 | $\bar{1}$·615 | $\bar{1}$·619 | $\bar{1}$·622 | $\bar{1}$·625 | $\bar{1}$·629 | $\bar{1}$·632 | $\bar{1}$·636 | $\bar{1}$·639 | $\bar{1}$·642 | $\bar{1}$·646 |
| 0·16 | $\bar{1}$·649 | $\bar{1}$·652 | $\bar{1}$·655 | $\bar{1}$·658 | $\bar{1}$·662 | $\bar{1}$·665 | $\bar{1}$·668 | $\bar{1}$·671 | $\bar{1}$·674 | $\bar{1}$·677 |
| 0·17 | $\bar{1}$·680 | $\bar{1}$·684 | $\bar{1}$·687 | $\bar{1}$·690 | $\bar{1}$·693 | $\bar{1}$·696 | $\bar{1}$·699 | $\bar{1}$·702 | $\bar{1}$·705 | $\bar{1}$·708 |
| 0·18 | $\bar{1}$·711 | $\bar{1}$·714 | $\bar{1}$·716 | $\bar{1}$·719 | $\bar{1}$·722 | $\bar{1}$·725 | $\bar{1}$·728 | $\bar{1}$·731 | $\bar{1}$·734 | $\bar{1}$·737 |
| 0·19 | $\bar{1}$·740 | $\bar{1}$·742 | $\bar{1}$·745 | $\bar{1}$·748 | $\bar{1}$·750 | $\bar{1}$·753 | $\bar{1}$·756 | $\bar{1}$·759 | $\bar{1}$·762 | $\bar{1}$·764 |
| 0·20 | $\bar{1}$·767 | $\bar{1}$·770 | $\bar{1}$·772 | $\bar{1}$·775 | $\bar{1}$·778 | $\bar{1}$·781 | $\bar{1}$·783 | $\bar{1}$·786 | $\bar{1}$·788 | $\bar{1}$·791 |
| 0·21 | $\bar{1}$·794 | $\bar{1}$·796 | $\bar{1}$·799 | $\bar{1}$·801 | $\bar{1}$·804 | $\bar{1}$·807 | $\bar{1}$·809 | $\bar{1}$·812 | $\bar{1}$·814 | $\bar{1}$·817 |
| 0·22 | $\bar{1}$·820 | $\bar{1}$·822 | $\bar{1}$·824 | $\bar{1}$·827 | $\bar{1}$·829 | $\bar{1}$·832 | $\bar{1}$·834 | $\bar{1}$·837 | $\bar{1}$·839 | $\bar{1}$·842 |
| 0·23 | $\bar{1}$·844 | $\bar{1}$·847 | $\bar{1}$·849 | $\bar{1}$·851 | $\bar{1}$·854 | $\bar{1}$·856 | $\bar{1}$·858 | $\bar{1}$·861 | $\bar{1}$·863 | $\bar{1}$·866 |
| 0·24 | $\bar{1}$·868 | $\bar{1}$·870 | $\bar{1}$·873 | $\bar{1}$·875 | $\bar{1}$·877 | $\bar{1}$·880 | $\bar{1}$·882 | $\bar{1}$·884 | $\bar{1}$·887 | $\bar{1}$·889 |
| 0·25 | $\bar{1}$·892 | $\bar{1}$·894 | $\bar{1}$·896 | $\bar{1}$·898 | $\bar{1}$·900 | $\bar{1}$·902 | $\bar{1}$·905 | $\bar{1}$·907 | $\bar{1}$·909 | $\bar{1}$·911 |
| 0·26 | $\bar{1}$·914 | $\bar{1}$·916 | $\bar{1}$·918 | $\bar{1}$·920 | $\bar{1}$·923 | $\bar{1}$·925 | $\bar{1}$·927 | $\bar{1}$·929 | $\bar{1}$·931 | $\bar{1}$·933 |
| 0·27 | $\bar{1}$·935 | $\bar{1}$·938 | $\bar{1}$·940 | $\bar{1}$·942 | $\bar{1}$·944 | $\bar{1}$·946 | $\bar{1}$·948 | $\bar{1}$·951 | $\bar{1}$·953 | $\bar{1}$·955 |
| 0·28 | $\bar{1}$·957 | $\bar{1}$·959 | $\bar{1}$·961 | $\bar{1}$·963 | $\bar{1}$·965 | $\bar{1}$·967 | $\bar{1}$·970 | $\bar{1}$·972 | $\bar{1}$·974 | $\bar{1}$·976 |
| 0·29 | $\bar{1}$·978 | $\bar{1}$·980 | $\bar{1}$·982 | $\bar{1}$·983 | $\bar{1}$·985 | $\bar{1}$·987 | $\bar{1}$·989 | $\bar{1}$·992 | $\bar{1}$·994 | $\bar{1}$·996 |
| 0·30 | $\bar{1}$·998 | 0·000 | 0·002 | 0·004 | 0·006 | 0·008 | 0·010 | 0·012 | 0·014 | 0·016 |
| 0·31 | 0·018 | 0·020 | 0·022 | 0·024 | 0·026 | 0·028 | 0·030 | 0·031 | 0·033 | 0·035 |
| 0·32 | 0·037 | 0·039 | 0·041 | 0·043 | 0·045 | 0·047 | 0·049 | 0·050 | 0·052 | 0·054 |
| 0·33 | 0·056 | 0·058 | 0·060 | 0·062 | 0·064 | 0·066 | 0·067 | 0·069 | 0·071 | 0·073 |
| 0·34 | 0·075 | 0·077 | 0·078 | 0·080 | 0·082 | 0·084 | 0·086 | 0·088 | 0·089 | 0·091 |
| 0·35 | 0·093 | 0·095 | 0·097 | 0·098 | 0·100 | 0·102 | 0·104 | 0·106 | 0·107 | 0·109 |
| 0·36 | 0·111 | 0·113 | 0·114 | 0·116 | 0·118 | 0·120 | 0·122 | 0·123 | 0·125 | 0·127 |
| 0·37 | 0·128 | 0·130 | 0·131 | 0·133 | 0·135 | 0·136 | 0·138 | 0·140 | 0·142 | 0·144 |
| 0·38 | 0·146 | 0·148 | 0·149 | 0·151 | 0·153 | 0·154 | 0·156 | 0·158 | 0·159 | 0·161 |
| 0·39 | 0·163 | 0·165 | 0·166 | 0·168 | 0·170 | 0·171 | 0·173 | 0·175 | 0·176 | 0·178 |
| 0·40 | 0·180 | 0·181 | 0·183 | 0·185 | 0·186 | 0·188 | 0·190 | 0·191 | 0·193 | 0·195 |
| 0·41 | 0·196 | 0·198 | 0·200 | 0·201 | 0·203 | 0·204 | 0·206 | 0·208 | 0·209 | 0·211 |
| 0·42 | 0·213 | 0·214 | 0·216 | 0·217 | 0·219 | 0·221 | 0·222 | 0·224 | 0·225 | 0·227 |
| 0·43 | 0·229 | 0·230 | 0·232 | 0·233 | 0·235 | 0·236 | 0·238 | 0·240 | 0·241 | 0·243 |
| 0·44 | 0·244 | 0·246 | 0·248 | 0·249 | 0·251 | 0·252 | 0·254 | 0·255 | 0·257 | 0·258 |
| 0·45 | 0·260 | 0·261 | 0·263 | 0·265 | 0·266 | 0·268 | 0·269 | 0·271 | 0·272 | 0·274 |
| 0·46 | 0·275 | 0·277 | 0·278 | 0·280 | 0·281 | 0·283 | 0·284 | 0·286 | 0·287 | 0·289 |
| 0·47 | 0·291 | 0·292 | 0·294 | 0·295 | 0·297 | 0·298 | 0·300 | 0·301 | 0·303 | 0·304 |
| 0·48 | 0·306 | 0·307 | 0·309 | 0·310 | 0·312 | 0·313 | 0·314 | 0·316 | 0·317 | 0·319 |
| 0·49 | 0·320 | 0·322 | 0·323 | 0·325 | 0·326 | 0·328 | 0·329 | 0·331 | 0·332 | 0·334 |
| 0·50 | 0·335 | 0·336 | 0·338 | 0·339 | 0·341 | 0·342 | 0·344 | 0·345 | 0·347 | 0·348 |
| 0·51 | 0·349 | 0·351 | 0·352 | 0·354 | 0·355 | 0·357 | 0·358 | 0·360 | 0·361 | 0·362 |
| 0·52 | 0·364 | 0·365 | 0·367 | 0·368 | 0·370 | 0·371 | 0·372 | 0·374 | 0·375 | 0·377 |
| 0·53 | 0·378 | 0·380 | 0·381 | 0·382 | 0·384 | 0·385 | 0·387 | 0·388 | 0·389 | 0·391 |
| 0·54 | 0·392 | 0·394 | 0·395 | 0·396 | 0·398 | 0·399 | 0·401 | 0·402 | 0·403 | 0·405 |
| 0·55 | 0·406 | 0·408 | 0·409 | 0·410 | 0·412 | 0·413 | 0·415 | 0·416 | 0·417 | 0·419 |

| δ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| **0·56** | 0·420 | 0·421 | 0·423 | 0·424 | 0·426 | 0·427 | 0·428 | 0·430 | 0·431 | 0·432 |
| **0·57** | 0·434 | 0·435 | 0·437 | 0·438 | 0·439 | 0·441 | 0·442 | 0·443 | 0·445 | 0·446 |
| **0·58** | 0·447 | 0·449 | 0·450 | 0·452 | 0·453 | 0·454 | 0·456 | 0·457 | 0·458 | 0·460 |
| **0·59** | 0·461 | 0·462 | 0·464 | 0·465 | 0·466 | 0·468 | 0·469 | 0·470 | 0·472 | 0·473 |
| **0·60** | 0·474 | 0·476 | 0·477 | 0·478 | 0·480 | 0·481 | 0·482 | 0·484 | 0·485 | 0·486 |
| **0·61** | 0·488 | 0·489 | 0·490 | 0·492 | 0·493 | 0.494 | 0·496 | 0·497 | 0·498 | 0·500 |
| **0·62** | 0·501 | 0·502 | 0·504 | 0·505 | 0·506 | 0·507 | 0·509 | 0·510 | 0·511 | 0·513 |
| **0·63** | 0·514 | 0·515 | 0·517 | 0·518 | 0·519 | 0·521 | 0·522 | 0·523 | 0·524 | 0·526 |
| **0·64** | 0·527 | 0·528 | 0·530 | 0·531 | 0·532 | 0·533 | 0·535 | 0·536 | 0·537 | 0·539 |
| **0·65** | 0·540 | 0·541 | 0·543 | 0·544 | 0·545 | 0·546 | 0·548 | 0·549 | 0·550 | 0·551 |
| **0·66** | 0·553 | 0·554 | 0·555 | 0·557 | 0·558 | 0·559 | 0·560 | 0·562 | 0·563 | 0·564 |
| **0·67** | 0·566 | 0·567 | 0·568 | 0·569 | 0·571 | 0·572 | 0·573 | 0·574 | 0·576 | 0·577 |
| **0·68** | 0·578 | 0·579 | 0·581 | 0·582 | 0·583 | 0·585 | 0·586 | 0·587 | 0·588 | 0·590 |
| **0·69** | 0·591 | 0·592 | 0·593 | 0·595 | 0·596 | 0·597 | 0·598 | 0·600 | 0·601 | 0·602 |
| **0·70** | 0·603 | 0·605 | 0·606 | 0·607 | 0·608 | 0·610 | 0·611 | 0·612 | 0·613 | 0·615 |
| **0·71** | 0·616 | 0·617 | 0·618 | 0·620 | 0·621 | 0·622 | 0·623 | 0·624 | 0·626 | 0·627 |
| **0·72** | 0·628 | 0·629 | 0·631 | 0·632 | 0·633 | 0·634 | 0·636 | 0·637 | 0·638 | 0·639 |
| **0·73** | 0·641 | 0·642 | 0·643 | 0·644 | 0·645 | 0·647 | 0·648 | 0·649 | 0·650 | 0·652 |
| **0·74** | 0·653 | 0·654 | 0·655 | 0·656 | 0·658 | 0·659 | 0·660 | 0·661 | 0·663 | 0·664 |
| **0·75** | 0·665 | 0·666 | 0·667 | 0·669 | 0·670 | 0·671 | 0·672 | 0·673 | 0·675 | 0·676 |
| **0·76** | 0·677 | 0·678 | 0·680 | 0·681 | 0·682 | 0·683 | 0·684 | 0·686 | 0·687 | 0·688 |
| **0·77** | 0·689 | 0·690 | 0·692 | 0·693 | 0·694 | 0·695 | 0·696 | 0·698 | 0·699 | 0·700 |
| **0·78** | 0·701 | 0·702 | 0·704 | 0·705 | 0·706 | 0·707 | 0·708 | 0·710 | 0·711 | 0·712 |
| **0·79** | 0·713 | 0·714 | 0·716 | 0·717 | 0·718 | 0·719 | 0·720 | 0·721 | 0·723 | 0·724 |
| **0·80** | 0·725 | 0·726 | 0·727 | 0·729 | 0·730 | 0·731 | 0·732 | 0·733 | 0·735 | 0·736 |
| **0·81** | 0·737 | 0·738 | 0·739 | 0·740 | 0·742 | 0·743 | 0·744 | 0·745 | 0·746 | 0·748 |
| **0·82** | 0·749 | 0·750 | 0·751 | 0·752 | 0·753 | 0·755 | 0·756 | 0·757 | 0·758 | 0·759 |
| **0·83** | 0·760 | 0·762 | 0·763 | 0·764 | 0·765 | 0·766 | 0·768 | 0·769 | 0·770 | 0·771 |
| **0·84** | 0·772 | 0·773 | 0·775 | 0·776 | 0·777 | 0·778 | 0·779 | 0·780 | 0·782 | 0·783 |
| **0·85** | 0·784 | 0·785 | 0·786 | 0·787 | 0·789 | 0·790 | 0·791 | 0·792 | 0·793 | 0·794 |
| **0·86** | 0·795 | 0·797 | 0·798 | 0·799 | 0·800 | 0·801 | 0·802 | 0·804 | 0·805 | 0·806 |
| **0·87** | 0·807 | 0·808 | 0·809 | 0·811 | 0·812 | 0·813 | 0·814 | 0·815 | 0·816 | 0·817 |
| **0·88** | 0·819 | 0·820 | 0·821 | 0·822 | 0·823 | 0·824 | 0·826 | 0·827 | 0·828 | 0·829 |
| **0·89** | 0·830 | 0·831 | 0·832 | 0·834 | 0·835 | 0·836 | 0·837 | 0·838 | 0·839 | 0·840 |
| **0·90** | 0·842 | 0·843 | 0·844 | 0·845 | 0·846 | 0·847 | 0·848 | 0·850 | 0·851 | 0·852 |
| **0·91** | 0·853 | 0·854 | 0·855 | 0·856 | 0·858 | 0·859 | 0·860 | 0·861 | 0·862 | 0·863 |
| **0·92** | 0·864 | 0·866 | 0·867 | 0·868 | 0·869 | 0·870 | 0·871 | 0·872 | 0·873 | 0·875 |
| **0·93** | 0·876 | 0·877 | 0·878 | 0·879 | 0·880 | 0·881 | 0·883 | 0·884 | 0·885 | 0·886 |
| **0·94** | 0·887 | 0·888 | 0·889 | 0·890 | 0·892 | 0·893 | 0·894 | 0·895 | 0·896 | 0·897 |
| **0·95** | 0·898 | 0·899 | 0·901 | 0·902 | 0·903 | 0·904 | 0·905 | 0·906 | 0·907 | 0·908 |
| **0·96** | 0·910 | 0·911 | 0·912 | 0·913 | 0·914 | 0·915 | 0·916 | 0·917 | 0·919 | 0·920 |
| **0·97** | 0·921 | 0·922 | 0·923 | 0·924 | 0·925 | 0·926 | 0·927 | 0·929 | 0·930 | 0·931 |
| **0·98** | 0·932 | 0·933 | 0·934 | 0·935 | 0·936 | 0·938 | 0·939 | 0·940 | 0·941 | 0·942 |
| **0·99** | 0·943 | 0·944 | 0·945 | 0·946 | 0·948 | 0·949 | 0·950 | 0·951 | 0·952 | 0·953 |
| **1·00** | 0·954 | 0·955 | 0·956 | 0·958 | 0·959 | 0·960 | 0·961 | 0·962 | 0·963 | 0·964 |
| **1·0** | 0·954 | 0·965 | 0·976 | 0·987 | 0·998 | 1·009 | 1·020 | 1·031 | 1·042 | 1·053 |
| **1·1** | 1·064 | 1·075 | 1·086 | 1·097 | 1·107 | 1·118 | 1·129 | 1·140 | 1·151 | 1·161 |
| **1·2** | 1·172 | 1·182 | 1·193 | 1·204 | 1·214 | 1·225 | 1·236 | 1·246 | 1·257 | 1·267 |
| **1·3** | 1·278 | 1·288 | 1·299 | 1·309 | 1·320 | 1·330 | 1·341 | 1·351 | 1·362 | 1·372 |
| **1·4** | 1·382 | 1·393 | 1·403 | 1·414 | 1·424 | 1·434 | 1·445 | 1·455 | 1·465 | 1·476 |
| **1·5** | 1·486 | 1·496 | 1·507 | 1·517 | 1·527 | 1·538 | 1·548 | 1·558 | 1·568 | 1·579 |
| **1·6** | 1·589 | 1·599 | 1·609 | 1·620 | 1·630 | 1·640 | 1·650 | 1·661 | 1·671 | 1·681 |
| **1·7** | 1·691 | 1·701 | 1·712 | 1·722 | 1·732 | 1·742 | 1·752 | 1·763 | 1·773 | 1·783 |
| **1·8** | 1·793 | 1·803 | 1·813 | 1·824 | 1·834 | 1·844 | 1·854 | 1·864 | 1·874 | 1·884 |
| **1·9** | 1·895 | 1·905 | 1·915 | 1·925 | 1·935 | 1·945 | 1·955 | 1·965 | 1·975 | 1·986 |
| **2·0** | 1·996 | 2·006 | 2·016 | 2·026 | 2·036 | 2·046 | 2·056 | 2·066 | 2·076 | 2·086 |
| **2·1** | 2·097 | 2·107 | 2·117 | 2·127 | 2·137 | 2·147 | 2·157 | 2·167 | 2·177 | 2·187 |
| **2·2** | 2·197 | 2·207 | 2·217 | 2·227 | 2·237 | 2·248 | 2·258 | 2·268 | 2·278 | 2·288 |
| **2·3** | 2·298 | 2·308 | 2·318 | 2·328 | 2·338 | 2·348 | 2·358 | 2·368 | 2·378 | 2·388 |
| **2·4** | 2·398 | 2·408 | 2·418 | 2·428 | 2·438 | 2·448 | 2·458 | 2·469 | 2·479 | 2·489 |
| **2·5** | 2·499 | 2·509 | 2·519 | 2·529 | 2·539 | 2·549 | 2·559 | 2·569 | 2·579 | 2·589 |

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