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# MACAULAY INSTITUTE FOR SOIL RESEARCH



1942-1943

# ANNUAL REPORT

# THE MACAULAY INSTITUTE FOR SOIL RESEARCH

CRAIGIEBUCKLER, ABERDEEN

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1942–1943

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# THE MACAULAY INSTITUTE FOR SOIL RESEARCH

## ANNUAL REPORT

### 1942–1943

DURING the year there have been no major changes in the general work of the Institute, and special attention continues to be given to advisory work and wartime problems. Spectrographic work has been further developed, with particular reference to trace constituents in soils, plants and other substances of agricultural interest, and X-ray investigations have been continued with the aid of a special grant from the Agricultural Research Council. Considerable progress has been made in the survey of the peat resources of Scotland which is being carried out in collaboration with the Geological Survey of Great Britain.

In previous years the soil survey work has been confined to the 6-inch primary survey, but in view of the immediate need for more general information on the distribution of the main soil associations this has been curtailed to some extent in favour of a reconnaissance survey. Some 250 square miles in Aberdeenshire have now been surveyed on the scale of 2·5 inches to 1 mile.

As in previous years, there has been co-operation with various other institutions including the North of Scotland College of Agriculture, the Animal Diseases Research Association, the Geological Survey of Great Britain and the Forestry Commission.

The results obtained in the course of advisory work again emphasize the widespread and pressing need for lime in the great majority of the soils.

Dr. Ogg has been appointed director of Rothamsted Experimental Station, but fortunately he is to continue, for the time being, as honorary director of the Institute.

The Institute is fortunate in having the temporary services of Professor Victor M. Goldschmidt, For.Mem.R.S., of Oslo.

Towards the end of the year Mr. J. W. S. Reith was appointed to assist with advisory work and general soil fertility investigations.

## SOIL FERTILITY AND ADVISORY WORK

### Advisory Work

Particular attention has again been given to advisory work and to problems of immediate practical importance. During the year over 4,000 samples of soils have been examined and advice given on the treatment likely to be most suitable for the areas in question. Most of these samples have been drawn from ordinary arable rotation land and from old grassland which is being ploughed for cropping, and a special study is being made of the manuring of flax, a considerable acreage of which is now being grown in the North. Work has also been carried out on Forestry Commission nurseries, Air Ministry landing grounds, market gardens and allotments. In addition, analyses have been made of various materials such as limestones, shell sands, by-product limes, wood ashes, flue dusts and other industrial by-products likely to be of value on the land.

As in previous years most of the actual soil sampling has been done by members of the staffs of the Institute and the North of Scotland College of Agriculture, and the work has been greatly facilitated by the appointment of a member of the Women's Land Army as a whole-time sampler on the staff of the Institute.

General problems of liming and manuring have been dealt with in several short articles contributed to the Press, the Department of Agriculture for Scotland's "Notes for Farmers" and the *Scottish Journal of Agriculture*.[1] An account of soil advisory work and other soil fertility problems has also been given in a paper in the *Transactions of the Highland and Agricultural Society of Scotland*.[2] In the latter a comparison has been made of the lime, phosphate and potash contents of soils from arable rotation land and old grassland in the North of Scotland, and a separate grouping of the soils has also been made according to their parent rocks. Deficiencies in lime and phosphate are widespread and are much commoner than potash deficiency. Under present conditions the supplies of phosphate available may not be adequate to meet the real need of our soils, but stress has been laid on the need for applying much more lime. It is again emphasized that there are in Scotland abundant supplies of good quality limestone which, if developed and applied to the land, would increase its productivity enormously.

### Soil Fertility Investigations

*General Experiments with Lime and Phosphate.* The main experiments referred to under this head in last year's report have been continued, and further information is being obtained on the residual effects of varying dressings of lime and phosphate on different soils. In addition, field experiments have been laid down with a view to obtaining information on the relative manurial values of superphosphate, a superphosphate reverted with magnesian limestone and a finely ground coprolite. Other work continued during the year includes pot and field experiments for the comparison of the manurial value of different forms of phosphate and for the characterization of the phosphate status of soils on which phosphate fixation studies are being made.

*Phosphate Fixation.* As indicated in previous reports, a long-term investigation is in progress to study phosphate fixation in North Scottish soils with the ultimate objects of improving fertilizer practice and standardizing methods of determining readily soluble phosphate. A general review of the subject has been published.[3]

An account of the work to date on a typical phosphate deficient soil of the acid igneous group has been accepted for publication.[12] This soil has a high capacity for fixing phosphate in difficultly soluble and unavailable form and requires frequent dressings to maintain yields. Fixation takes place very rapidly and is apparently complete in a few days with superphosphate and within seven weeks with basic slag. Both fixation and release of phosphate appear to be functions of colloidal amphoteric complexes, and anion exchange is evidently of considerable importance in the phosphate relationships of the soil. Complete extraction of added phosphate is approached only in very strongly acid and alkaline media and about 25 per cent. is very firmly fixed. In the lower *p*H range phosphate solubility is markedly affected by the nature and concentration of the anions present, sulphate solutions extracting considerably more phosphate than corresponding chloride solutions. For practical purposes buffered acid extractants provide the best characterization of the soil and, of the methods tried, Egner's lactate method and a two-hour extraction with 2·5 per cent. acetic acid give the best reflection of the field behaviour, whilst 1 per cent. citric acid is the least satisfactory. Neubauer and Mitscherlich determinations give results very similar to the lactate method and have no special advantage. None of the methods tried, however, show any marked or consistent effect of lime comparable with the field behaviour, and further work is in progress on this aspect with particular reference to the time of application of lime and its effect on the organic phosphate content of the soil which constitutes at least 25 per cent. of the total present. There are also indications that, initially at any rate, the availability of the fixed phosphate is somewhat greater than would be expected from its solubility, and the possible existence of a category of easily replaceable phosphate is being investigated in conjunction with an extension of the study of specific anion effects to cover anions such as lactate, citrate and acetate which occur in extractants commonly employed for the determination of readily soluble phosphate.

Work on some 250 samples of soil from experimental plots at Craibstone, the North of Scotland College of Agriculture farm, has also been continued. Hydrochloric acid and acetic acid extractions have been carried out on all the samples and the results confirm last year's preliminary finding that, where the soils have been receiving manurial dressings consistently over a period of years, distinct differences can be seen both in the readily soluble phosphate and in the total reserve of phosphate in the soil, due to the varying treatments. With the soils which have received only one or two applications of fertilizer, however, little or no difference is evident. The study of these samples, with particular reference to the organic fraction of the phosphate present in the soils, is being continued.

*Fertilizer Placement.* As part of a general study of the response of crops to fertilizer applications, a series of experiments has been undertaken with the aid of a special grant from the Agricultural Research Council. Most of the experiments are being carried out with cereals on texturally differing

soils in Aberdeenshire and Kincardineshire in order to compare the effects of drill placement and broadcast application of superphosphate at light and medium rates. In addition, preliminary experiments have also been laid down on potatoes at four centres to compare the effects of band placement with ordinary broadcast application of a fertilizer mixture.

*Crushed Biotite Schist as a Source of Potash.* As mentioned in last year's report an investigation of the manurial value of crushed biotite was commenced in 1940. The results obtained in the field during 1940, 1941 and 1942 have been published,[2] and further results for a second hay crop have been obtained during the year. From these it is evident that the heavy biotite schist dressing (250 lb. $K_2O$ per acre) has now supplied a considerable amount of potash to the crops.

## PEAT SOILS AND SOIL ORGANIC MATTER

### Peat Survey

The peat survey commenced last year has been continued. The area now almost completely surveyed in the field is that covered by the Geological Survey 4 miles to the inch maps Nos. 9 and 12, i.e. the area east of a line approximately from Nairn on the Moray Firth to Perth. An introductory paper covering the genesis, classification and utilization of peat with reference to conditions in this country is now on the point of publication by the Geological Survey as the first of a series of wartime pamphlets covering the peat survey, and similar in form to the corresponding limestone pamphlets.[13] Data obtained during the survey are now being summarized and will form, along with similar data prepared by the Geological Survey for the Midland Valley area, the subject-matter of pamphlet No. 2.

### Peat and Compost Investigations

*The Water-holding Characteristics of Peat.* Processed peats, collected mainly during the survey, have been and are being tested as regards their water-holding and retaining power. Considerable differences in this respect are found between different types.

*Growth Tests using Peat or Composts made up with Peat.* Most of the larger bulk samples collected during the earlier part of the survey season have been tested as regards their general horticultural value by routine growth tests with tomato seeds and seedlings. Previous generalizations as to the suitability of various types of peat for this purpose have been on the whole confirmed.

*Tests on a Commerical Growth-promoting Medium.* At the request of the Department of Agriculture for Scotland, a series of experiments have been laid down to obtain information regarding the claims made for a commercial, non-manurial, growth-improving material. These have included garden tests but have been confined mainly to tomatoes under glass both at the Institute and at a commercial nursery. Final assessments of the crops have not yet been made, so that no conclusion can yet be given. These experiments have taken up most of the space available for this kind of work.

*The Use of Coarse Carbonate of Lime for Maintaining the pH of Soil under Horticultural Conditions of Heavy Watering.* Experiments on the same lines as previously reported (Ann. Rep. 1941-42) have been continued on a reduced scale this year. Shell sand has been used as a source of coarse lime. The crops are not finally assessed but there are indications that shell sand is a more suitable form of coarse lime than coarsely ground limestone for exact control of *p*H.

*Composting Experiments.* These have not been possible except on a reduced scale. The experiments carried out have been on the lines of previous peat mixed composts. Market garden refuse of different types was used instead of the usual grass mowings and weeds.

*Biotite Schist as a Source of Potash in Horticultural Work.* The experiment described in last year's report led to the final conclusion that the

biotite schist used is of limited value in horticultural work. In the earlier stages of growth, tomato plants in soil given a double dressing of biotite schist were approximately equal in growth to those given the dressing of potash normal for the first stages of growth. At a later date those plants growing in soils in which the normal sulphate of potash dressing was replaced wholly or partly with biotite schist showed potash deficiency in the form of weaker growth, while the normally manured plants continued to grow and set their first trusses. Plants top-dressed with sulphate of potash showed some recovery, but until the end of the experiment growth was unsatisfactory where biotite schist was the main or only source of potash.

The residual potash content of the soils was determined with the following results :

| *Treatment* | *Residual Potash soluble in conc.* HCl *per cent.* |
|---|---|
| (*a*) Soil treated normally with sulphate of potash | 0·30 |
| (*b*) ½ potash replaced by schist | 0·43 |
| (*c*) ¾ potash replaced by schist | 0·37 |
| (*d*) Potash wholly replaced by schist | 0·28 |
| (*e*) Soil treated with twice the schist in (*d*) | 0·29 |

These results were obtained from duplicate boxes and give good duplicate determinations. From (*a*), (*d*) and (*e*) it appears that the use of biotite schist alone has not increased the soluble potash residue in the soil as compared with sulphate of potash, although (*b*) and (*c*) mixtures of schist and sulphate of potash seem to do so.

In order to determine whether peat liberates potash from schist, the following experiments were carried out. Schist sieved to pass a 50-mesh sieve was mixed with two different types of peat and, as a control, with pure sand, kept moist, and leached at intervals of about one week with 1 litre of water over a period of 6 months. The major changes taking place in the bases were determined at the end of this time. The following are the quantities of material used :

Volume of material in each pot, 5 litres :
600 g. schist mixed into each.
5 l. sphagnum peat weigh 680 g. (oven-dry wt.).
5 l. cottongrass peat weigh 1400 g. (oven-dry wt.).
5 l. fine sand weigh 4250 g. (oven-dry wt.).

The major base contents of the materials are given in Table I.

After leaching with 15 litres of water, the bases present in the leachate, and the exchangeable and HCl soluble bases in the residual materials were determined.

It does not appear that peat has had any considerable effect in bringing about decomposition of the biotite schist under the conditions of the experiment. When it is borne in mind that, as a rule, more than 50 per cent. of the bases present in the peat itself are exchangeable and so may be readily leached out, the interaction between peat and schist must be very slight. The few slight discrepancies in the data presented result from the difficulty in obtaining thorough mixing of the heavy schist with the light peat while sampling.

*Investigation into the Replacement of Farmyard Manure by Peat Fortified with Artificial Manures.* Experiments laid down last year have as far as possible been examined and sampled for this year's crops. The results

TABLE I.

BASE CONTENTS OF PEAT MIXTURES AS USED; STATED IN G. PER POT OF 5 L. VOLUME

| Pot No. | Material. | HCl soluble* base content per pot. | | |
|---|---|---|---|---|
| | | CaO. | $K_2O$. | MgO. |
| 1 and 2 | Sphagnum | 1·03 | 0·09 | 2·09 |
| | Schist | 3·18 | 14·02 | 19·91 |
| | Total | 4·21 | 14·11 | 22·00 |
| 3 and 4 | Cottongrass | 3·50 | 0·15 | 3·93 |
| | Schist | 3·18 | 14·02 | 19·91 |
| | Total | 6·68 | 14·17 | 23·84 |
| 5 and 6 | Sand | — | — | — |
| | Schist | 3·18 | 14·02 | 19·91 |
| | Total | 3·18 | 14·02 | 19·91 |

* I.e. the bases dissolved by evaporation with dil. HCl, and taking up and re-evaporating 3 times with conc. acid.

indicate that, as for last year, no difference can be detected between the manurial effect of peat with artificials, and dung, the differences between plots of the same treatment being of the same order as those between

TABLE II

BASES RECOVERED AFTER LEACHING. WEIGHTS IN G. PER POT

| Pot No. | (*a*) Leached. | | (*b*) Exchangeable. | (*c*) HCl Soluble. | Total (*a* + *b* + *c*). | Total (from Table I). |
|---|---|---|---|---|---|---|
| 1 and 2 | CaO | + | 1·60 | 3·0 | 4·6+ | 4·2 |
| | $K_2O$ | 0·12 | 0·18 | 14·2 | 14·5 | 14·1 |
| | MgO | 1·92 | 0·61 | 19·6 | 22·1 | 22·0 |
| 3 and 4 | CaO | + | 2·90 | 4·2 | 7·1+ | 6·7 |
| | $K_2O$ | 0·12 | 0·39 | 14·1 | 14·6 | 14·2 |
| | MgO | 1·74 | 2·80 | 19·5 | 24·0 | 23·8 |
| 5 and 6 | CaO | + | 0·45 | 3·2 | 3·6+ | 3·2 |
| | $K_2O$ | 0·17 | 0·37 | 13·6 | 14·1 | 14·0 |
| | MgO | 0·06 | 0·02 | 20·0 | 20·1 | 19·9 |
| 600 g. original schist for comparison | CaO | — | 0·84 | 2·3 | 3·1 | 3·2 |
| | $K_2O$ | — | 0·14 | 13·9 | 14·0 | 14·0 |
| | MgO | — | 0·14 | 19·8 | 19·9 | 19·9 |

\+ not determined.

differently treated plots. Fresh experiments have been laid down this year, including one on a heavy clay soil. These have not yet been harvested.

On the experimental allotment at the Institute the results from this year's crops are not complete. Last year the potato crops were almost

the same for all treatments, with the peat-treated plot somewhat better. This year the peat-treated plot is definitely the poorest with each of three different varieties of potatoes. On the whole the legumes and the cabbage group of brassicas have been best on the peat-treated plots, and root crops on dung.

### Laboratory Work

(*a*) Routine analyses are carried out on peats from the survey, on experimental soils. Some of the former have been quoted in the Peat Survey Pamphlet No. 1.[13]

(*b*) Investigation of the methods of examination of soil organic matter has been largely confined to the use of catalysts for the transformation of organic nitrogen to ammonia. The fractional estimation of nitrogen in this way has been studied by carrying out partial Kjeldahl digestions of peat, other forms of soil organic matter (including compost materials) and fractions of these. Various metallic sulphates which might be expected to have a catalytic effect have been compared under varied lengths of time of digestion, amount of catalyst and concentration of sulphuric acid. The catalytic effect of copper sulphate depends on the amount present. When the time of digestion and concentration of acid are kept constant, the addition of small amounts of copper sulphate is without effect up to a certain concentration. Then it suddenly becomes marked and further additions have no appreciable effect. The limiting amount of copper sulphate for maximum conversion is found to be greater the shorter the time of digestion, and the greater the dilution of the reaction mixture. No parallel effects have been detected with a considerable number of other metallic sulphates. With silver sulphate, on the other hand, a negative effect was observed (i.e. an absolute reduction in the conversion of organic nitrogen to ammonia). This effect was independent of the time of digestion but was, like the catalytic action of copper, reduced by dilution of the reaction mixture.

With some of the simpler pure organic compounds, no catalytic effect of copper could be detected.

The application of the standard methods of determining polyuronic substances to peat and other soil organic matter has been studied, and the value of the methods for such is found to be extremely doubtful.

(*c*) Special samples selected during the peat-land survey for specific reasons are subjected to specific analyses.

(*d*) Following the establishment of a satisfactory technique for determining the ionic exchange properties of peat, a considerable number of routine determinations of these and of the exchangeable nutrient reactions of peat types and fractions of soil organic matter are under investigation.

During the year two papers dealing with the fractionation of organic matter in soils and during composting have been published.[4, 5]

## SOIL SURVEY

The need for the rapid production of soil maps on a less detailed scale than that of the primary 6-inch survey has often been felt and a beginning has now been made with a reconnaissance survey of Aberdeenshire on the scale of 2·5 inches to 1 mile. Only the boundaries of the major associations are traced, but note is made of the most important associates in each case. As a result of this reconnaissance, work on the primary 6-inch survey has had to be curtailed.

Laboratory chemical work on soil profiles collected during the survey has brought out some marked differences between the different members of an association resulting from their drainage properties. Such differences are especially marked in the phosphate and humus contents, but are also observed in the exchangeable base distribution. Results bearing on these points will be found in an account of the soils of the Insch area in Central Aberdeenshire which will shortly be published.[14]

The results of the X-ray studies on soil clays (*vide infra*) confirm that in many cases little use can be made of the silica : sesquioxide ratios for the whole $2\mu$ clay fraction, since the values are often well outside the limits for known clay minerals. In such cases the presence of free sesquioxides must be suspected, and certain chemical evidence for this exists. It appears that the results of X-ray analysis of the soil clays together with the determination of "free" sesquioxides would be a more satisfactory means of characterizing soil types than the silica : sesquioxide ratios by themselves.

In conjunction with planning authorities a 6-inch survey of parts of Fifeshire has been made, and joint work with the Forestry Commission and others has been continued.

A short account of Soil Survey work has been published.[6]

### Aberdeenshire

#### (*a*) 6-*inch primary survey*

The soil survey on the 6 in. to 1 m. scale was continued in an area about Bartholchapel, in the parishes of Tarves and Methlick. The area covered was 6 square miles. Another area about Turriff in the parishes of Turriff and Monquhitter was also surveyed. The area covered was 18 square miles, so that a total of 24 square miles has been surveyed on the detailed scale.

The Bartholchapel area has a smooth, gently rolling topography. It is underlain by the Fyvie schist series of andalusite and knotted schists, grits and argillaceous schists. Glacial drift covers all this area.

The soils belonging to the Bartholchapel association are generally heavy loams on a fine sandy drift and are well drained. Stony heavy loams on a stony sandy drift also occur.

The Turriff area is very diversified topographically. Prominent features of this area are the overdeepened valleys of the Deveron and its tributaries, the Idoch Water and the Burn of Balquholly. The waters of the Deveron which now run north would seem, during the retreat of the last ice-sheet,

to have turned south at Turriff and joined the Ythan. Hence the broad deep valley between Turriff and Fyvie now occupied by much smaller streams running through large alluvial flats. Gravel terraces are found at higher levels up to 200 ft. The general topography of the area is broadly rolling, with the hilly ground rising to over 500 ft. in the neighbourhood of Turriff, both north and south of the Idoch Water.

The following rock groups occur :

Macduff Schist Series.
Old Red Sandstone.
? Pliocene Gravel.

The Macduff schists consist of argillaceous schists and grits and are found both in the western and eastern districts of the area. The Old Red Sandstone formation found here is formed mainly of conglomerates, but in the eastern part of the area, around Delgaty and Cuminestown, dull red sandstones occur. At Delgaty, north-east of Turriff, there is a small development of ? Pliocene gravels intimately mixed with glacial drift. A more extensive occurrence of these gravels is found at Windyhills, east of Fyvie (Ann. Rep. 1941-42).

All the area has been glaciated and, apart from the higher ground, a covering of drift is found over the solid rocks. In those parts of the area where the Macduff schists are developed the drift is largely derived from these rocks. It is fawny in colour and has a stony, fine sandy loam texture.

In the Old Red Sandstone area the drift is similarly strongly influenced by the local rocks. It is generally reddish brown, pebbly and of a clay loam texture. Iron mottling is a feature of this drift. About Delgaty and in the Howe of Teuchar near Cuminestown the drift is sandier in texture, being derived from the local red sandstone. North-west of Delgaty the drift is strongly influenced by the rounded quartzite pebbles and flints of the ? Pliocene gravels.

Intermittent morainic mounds, formed of gravels, are found to the east of Turriff extending from Woodside Farm towards Ardin Farm on the Idoch Water.

In the broad valley south-east of Turriff and in the valley of the Idoch Water there are extensive alluvial deposits. The first terrace alluvium is coarse sandy in texture at Turriff, whereas towards Fyvie it is very fine sandy to silty. The alluvium of the Turriff Water is coarse sandy in texture with high terraces of gravel. At about the 200 ft. contour around the farms of Colp there is a broad terrace consisting predominantly of coarse sand. On the south side of the Idoch Water and stretching along the Burn of Balquholly at Hatton this terrace is also found, but it is more gravelly in texture and is similar to the gravels occurring further south near Fyvie.

Peat deposits occur extensively over the Waggle Hill and at Sprottynook, south of Cuminestown. The Waggle Hill deposit is largely cut-over, but at Sprottynook peat banks of 12 ft. are to be found. The higher ground on both sides of the Howe of Teuchar has been largely reclaimed from peat.

*Soil Associations.* Soil associations similar to those described in the 1941-42 Annual Report have been found.

| *Association* | *Parent Material* | *P.M. Group* |
|---|---|---|
| Rothie | Till | Argillaceous schist |
| Haddo | ,, | Old Red Sandstone conglomerate |
| Cuminestown | ,, | Old Red Sandstone |
| Fyvie | Sand and gravel | Pebbly sands |
| Delgaty | Morainic sand and gravel | Pebbly sands |

*Rothie Association.* This association, previously found at Auchterless, extends northwards, and similar soils are also found in the Waggle Hill district south of Cuminestown. Descriptions of this association can be found in the 1940-41 Report.

*Haddo Association.* This association has been found to extend northwards to Turriff and is described in the 1941-42 Report. The freely drained associate occurs extensively on the western side of the valley through which runs the Burn of Balquholly to the south-west of Turriff. Extensive areas of the wet associate occur at Hatton and over the Hill of Greenness. On the northern slopes of this hill there are areas of land formerly cultivated but now abandoned and under a juncaceous vegetation, due to the excessive wetness. Part of this area has been recently planted. The hill top of Greenness is moorland and the soil is a peaty gley.

*Cuminestown Association.* This has been examined in the district south of Cuminestown on the eastern edge of the Old Red Sandstone belt of rocks and also in the neighbourhood of Delgaty, east of Turriff. The drift here is formed mainly from the local reddish-brown sandstone and is sandy in texture. The freely drained soils are reddish-brown in colour and fine sandy heavy loams in texture. In the wet types the surface soil is a dark brown fine sandy loam overlying a grey bleached fine sandy loam on a reddish-brown sandy drift.

*Fyvie Association.* The soils of this association are found on a broad flat terrace to the south-east of Turriff and consist of relatively uniform coarse sandy loams overlying coarse sand. In general they are freely drained. In the neighbourhood of Hatton Castle this terrace feature is not so pronounced and the soils are stony sandy loams on sands and gravels and are coarser in texture.

*Delgaty Association.* This association occurs to the east of Turriff and is of small extent. The soils are stony light loams on coarse and fine gravel, and the topography is morainic. This association is only separated provisionally and it differs from the Fyvie association mainly in its topographic relations.

(*b*) *Reconnaissance Survey*

A reconnaissance survey on the scale of 2·5 in. to 1 m. of the northern part of Aberdeenshire, covering about 250 square miles, has been carried out. The area stretches north of a line joining Fyvie and Port Errol to the Moray Firth. The purpose of this survey was to distinguish the main soil associations and their parent materials in this area. The soils were inspected

in traverses at about half-mile intervals. The chief associations found are shown in the table below :

| *Association* | *Parent Material* | *Associates* * | *Topography* |
|---|---|---|---|
| 1. Pennan | Thin drift over Old Red Sandstone conglomerate | O, P & HP | Hilly and dissected |
| 2. N. Mormond-Fetterangus | Mixed acid drift | P, PH & HP | Smooth slopes |
| 3. Mormond | Thin quartzite drift and quartzite | PH, HP & H | Hilly |
| 4. Strichen | Quartz schist drift | P, PH & H | Rolling |
| 5. New Pitsligo | Thin granitic drift on weathered granite | PH, HP & H | Flat basin |
| 6. Bonnykelly | Drift from varied schistose rocks | P | Smoothly rolling |
| 7. Maud | Mixed diorite drift | P & PH | Rolling to flat |
| 8. Skelmuir | Flint and pebbly quartzite drift | PH & HP | Hilly to broadly rolling |
| 9. Cruden | Reddish-brown boulder clay and heavy clay | P, PH & HP | Smoothly rolling |
| 10. Memsie | Fluvioglacial sands and gravels | O, P & H | Broad flats and ridges |
| 11. Fraserburgh | Alluvium of mixed beach and blown sand | O, P & PH | Smooth gentle slopes |
| 12. Strathbeg | Varied water-worked deposits | O, P, PH, HP & H | Flat |
| 13. Ugie | Alluvial sands and gravel | P | Terraced |

* The symbols are : O = oromorphic associate
P = phytomorphic associate
PH = phytohydromorphic associate
HP = hydrophytomorphic associate
H = hydromorphic associate.

Numerals preceding the symbols refer to depth of A horizon : (1) < 7 in. ; (1-2) 7-12 in. ; (2) > 12 in. (cf. also Ann. Rep., 1939-40, p. 17).

1. *Pennan Association.* The arable soils of this association are mainly cobbly light loams overlying a very cobbly thin drift. On the uncultivated areas calluna moor occurs with podzolization and strong iron pan development.

2. *North Mormond and Fetterangus Association.* Along the north and east sides of Mormond Hill there are areas of mixed glacial drift, with schist, granite and Old Red Sandstone pebbles present. The dominant soil developed on the north side is a phytohydromorphic medium loam on a drab grey fine sandy drift which passes into a grey-brown clay loam drift. On the east side the soils are phytohydromorphic to hydromorphic.

3. *Mormond Association.* The higher slopes and top of Mormond Hill (769 ft.) are covered by a calluna moor with podzolized and gleyed soils on thin quartzite drift or residual quartzite.

4. *Strichen Association.* The main soil is a phytomorphic medium loam on a fawny fine sandy and stony quartz schist drift.

5. *New Pitsligo Association.* The phytohydromorphic to hydromorphic associates predominate in this district. There are widespread areas of deep peat and much of the cultivated land has been recovered from peat. A typical arable soil is a humose gritty loam on a grey gritty heavy loam on a mottled stony coarse sandy granitic drift. In the eastern part of this area large granitic boulders are common in the fields.

6. *Bonnykelly Association.* The soils of this association are developed on a mixed glacial drift, formed from schistose rocks (knotted and argillaceous schist and quartz mica schist). The phytomorphic associate is a fine sandy heavy loam on a khaki fine sandy drift.

7. *Maud Association.* The area covered by this association has a rather indefinite boundary. The soils are developed on a mixed glacial drift and only locally is the drift predominantly dioritic in composition. Schistose rocks as well as diorite are found commonly in the drift to the west. The well-drained soils are medium loams on a drab khaki fine sandy drift. The wetter soils are heavy loams on a mottled sandy clay drift.

8. *Skelmuir Association.* Two distinctive sub-associations are found: one, a stony, peaty loam on a grey, thin stony sandy drift with flints and quartzite pebbles, developed on the higher ground about and to the east of the Carse of Balloch. The soils of this sub-association vary from phytohydromorphic to hydromorphic. The other sub-association occurs south of Longside and north of the Carse of Balloch. It consists of a heavy loam to clay loam on a brownish sandy loam to clay loam drift, with quartzite pebbles and flints, and includes phytomorphic to phytohydromorphic associates.

9. *Cruden Association.* This association occurs in a well-defined area, extending in a belt from two to four miles wide up the eastern coast. The glacial drift underlying this association has been strongly influenced by the rocks of the Old Red Sandstone formation in Strathmore to the south. Where well developed, it is a reddish-brown to red heavy clay, with some stones. There are local areas of a practically stone-free heavy clay drift, and a black clay drift occurs near Lamb's Farm (1 mile south-west of Crimonmogate House). Around the margin of the area the soils tend to be heavy loams to clay loams developed on a grey-brown clay drift. In the central part of the area the freer-drained soils are reddish-brown clay loams on heavy clay and are generally phytomorphic to phytohydromorphic. Under wetter conditions the soils are greyer, overlying a grey iron-mottled clay, and under hydromorphic conditions peaty clay loams on a blue heavy clay are found. Under favourable topographic conditions drainage is difficult, but the intractability of the soil can now be readily overcome by power-driven implements. Wheat is grown extensively on this association.

10. *Memsie Association.* This association is predominantly developed on fluvioglacial and morainic sands and gravels. There are along ridges with flats between, so that light textured soils of free to excessively free drainage are found on the higher ground, and wet to excessively wet conditions on the lower areas. Texturally the soils range from stony light loams on bouldery gravels through coarse sandy loams on coarse sand to fine loamy sands. In the wet areas sandy peat loams on sand and peat are found.

11. *Fraserburgh Association.* The soils of this association are generally deep (2P) heavy sandy loams to heavy fine sandy loams developed on sands which are sometimes shelly. The drainage is good to only slightly impeded. Shell sand deposits worked for lime occur at Phingask, west of Fraserburgh. Small areas of blown sand occur.

12. *Strathbeg Association.* Although only of small extent a complex of soils, with a wide textural variation, is found on a fairly uniform topographic feature formed by a raised beach. Loams to heavy loams, developed on

a water-worked drift, heavy loam to clay loam on clay, sandy loam to loamy sand on sands, and peaty sand on peat occur. Provisionally these are all included in this association pending further investigation. Drainage on the whole is seriously impeded through a lack of adequate outfall.

13. *Ugie Association.* A high level alluvial terrace along the Ugie has given rise to well-drained medium loams to heavy sandy loams on sands and gravel.

FIFESHIRE

Two areas in Fifeshire were surveyed at the request of the Planning Department of Fife County Council. One area in Western Fife, with Lochgelly as a centre, has been very badly affected by subsidence due to underground coal workings, so that both the natural and artificial drainage of the area is seriously impeded. There are relatively small areas of freely drained soil, and the most extensive soils of the district are heavy loams to clay loams developed on a stiff boulder clay, which is mainly derived from local carboniferous rocks. The soils are strongly gleyed and waterlogging is frequent. Peaty gley types are common, especially on the uncultivated boulder clay land. An extensive area of deep peat is also found. The surface subsidences in this area not only hinder cultivation when they occur as isolated areas in a field, but have also caused large areas to go out of cultivation when flooding is caused alongside streams. Dairying is extensively carried on in this district and also mixed farming. There is a great need for tree plantations, for even shelter belts are conspicuously absent.

The other area, west of Thornton, in Central Fife, is, so far, little affected by industrial development, but is likely to be in the near future. Here the soils are developed on a sandier boulder clay and are generally lighter in texture and more freely drained. The area is relatively low-lying with only a slight fall in the two streams which drain it. There is every indication that, if coal mining proceeds as it has done in West Fife and subsidences occur, severe flooding and damage to agricultural land will result. This area is at present highly developed agriculturally.

STIRLINGSHIRE

In the eastern and southern parts of the county there are considerable areas of heavy textured gley soils similar to those found in Fife, and likewise formed on till derived from carboniferous rocks. These soils naturally are peaty gleys with a thin grassy peat covering where grazed. Freely drained areas are rare, being confined to areas of sands and gravels, or where the Millstone Grit affects the till sufficiently to lighten its texture. The drift from the Campsie basalts gives very distinctive soils which, however, are usually of heavy texture and tend to be of a gley type like those on the carboniferous drift.

An area was surveyed near Killearn on a valley slope facing north on which three main soil associations occur. On the first of these occupying the higher land, the soils are derived from an arenaceous Old Red Sandstone drift, with phytomorphic associates having red-brown fine loam to fine sandy loam A horizons of moderate depth on a relatively stone-free red very fine sandy loam drift. The phytohydromorphic associate has a dark brown fine sandy loam surface on yellow and red mottled sandy subsoils.

The second association lower down the slope has predominantly phytohydromorphic soils with brown to grey-brown heavy sandy loam A horizons

on yellow fluvioglacial sand mottled with grey and red colours. Phytomorphic associates in this association occupied hogsback ridges with subsoils of rounded stone and gravel.

The third association comprised phytohydromorphic associates with red-brown clay loam and clay A horizons on varved heavy clay with grey silty and red-brown clay bands alternating.

The first association appears to be related to the arenaceous Old Red Sandstone associates found east of Turriff and about Cuminestown in Aberdeenshire. The other two associations have not yet been correlated with associations previously established, although they may be related to the Allan and Kincraig associations of Easter Ross (Ann. Rep. 1941-42).

### Soil Mineralogy

The results of an investigation on the glacial drifts and the related soils of Kincardineshire (Ann. Rep. 1940-41) have been published.[7]

The mineralogical investigation of the soils and their parent materials from the surveyed areas of Northern Aberdeenshire has been continued. The parent materials of the cultivated soils of this district are mainly glacial drifts, which are underlain by metamorphic rocks, with some granitic intrusions, and a belt of conglomerate and sandstone rocks belonging to the Old Red Sandstone formation. The mineral composition of the fine sand fractions of the drifts was determined on samples collected during the survey, and marked variations in composition have been found. The western part of this area is covered by a glacial drift, which overlies a belt of argillaceous schists, and the soil profile over this area is fairly uniform. The fine sand fraction of this drift has a fair proportion (about 10 per cent.) of ferromagnesian silicate minerals and iron oxides and a small proportion (about 5 per cent.) of felspars, mainly plagioclase with a little orthoclase. Small slate fragments also occur in this fraction. The drift in this area is locally affected by bands of grits in the slates, and examination of such drifts shows an increased quartz content and also a higher proportion of felspars.

A few samples were examined from the drift overlying rocks of the Old Red Sandstone formation. These showed a smaller proportion (about 5 per cent.) of ferromagnesian silicate minerals and a higher proportion (about 8 per cent.) of the felspar group than did the drift over the slate area. The chloritic and sericitic material common in this latter drift is not such a feature and the drift is more siliceous. The argillaceous rocks to the west have strongly influenced the drift over the western part of this Old Red Sandstone area, and slate fragments are found in the fine sand fraction of the drift.

The drift over the granitic and gneissic rocks in the south-eastern part of the area was also examined. The fine sand fractions were found to contain a high proportion (about 17 per cent.) of ferromagnesian silicate minerals. Orthoclase felspar, and both biotite and muscovite were common.

From these results it is possible to characterize the drifts, even when of mixed rock origin, and to delimit the areas of uniform composition.

The fine sand fractions of soils from typical profiles on these drifts were similarly examined. Variations in composition according to the underlying drift were found, and changes caused by decomposition of the minerals through weathering also noted.

## SPECTROGRAPHIC INVESTIGATIONS

### The Cathode Layer Arc Method

The determination of trace constituents in soils and plant materials by spectrographic methods has been continued and extended. The chief method employed has been the direct current cathode layer carbon arc which provides, for many elements of agricultural significance, a means of determining contents of the order of 5-5000 parts per million. During the year some attention has been paid to the spectrographic technique employed, in order to improve the accuracy of the determinations, especially at the lower concentration limit. With this in view, an investigation into the effects of background interference has been carried out and a method for the elimination of this effect has been worked out. This method [15] involves the correction for background intensity in the spectrogram at a constant photographic blackening value. It has been applied to the internal standard method of analysis previously used, and has for instance extended the lower limit of accurate determination of cobalt from about 30 to below 10 p.p.m. In the evaluation of the results of analyses by this method, the calculation is simplified by the use of Gaussian or subtractive logarithms, and as an appendix to this Report (p. 30) will be found a suitable 3-figure table of these logarithms which enable the direct determination of log A, knowing log (A + B) and log B, to be made. All published tables of similar logarithms that have been seen are calculated to six figures and are much too cumbersome for quick reference for the purpose noted above.

At the same time, an investigation has been made into the effects of the composition of the basal material on the determination of trace constituents contained therein, using an internal standard method. Besides being of importance in determining how far a standard curve obtained for one type of base may be applied to a material of quite different composition, this investigation has suggested improvements in the concentration method [8] for cobalt, nickel, molybdenum and other elements in soil extracts and plant material by 8-hydroxyquinoline. Thus it appears that alumina or sodium chloride is preferable to silica for the dilution of the ignited 8-hydroxyquinoline precipitate to constant weight. The background intensity is then considerably less, and improvement in the accuracy of the molybdenum determination is obtained, as it has been found that if silica is present, the intensity of the molybdenum lines is dependent on the silica content. Similar relationships, e.g. that shown by chromium and vanadium to the calcium content, demonstrate the complexity of the problems involved in spectrographic analysis, and this investigation, which is still in progress, is an attempt to clarify the position in a systematic manner. It is hoped that preliminary results will be ready for publication in the near future. It is interesting to note that, for the determination of cobalt (3453A), using iron (3449A) as internal standard, the relative intensities appear to be independent of the composition of the base, provided correction is made for the effect of background. Such different bases as NaCl, $Al_2O_3$, $SiO_2$, $CaCO_3$, $Na_2CO_3$, $Na_4P_2O_7$ and $Ca_3(PO_4)_2$ have been examined.

### Determination of Trace Constituents in Soils and Plants

The applications of the cathode layer arc method have been mainly in the continued study of the relationship of soil content of trace constituents to uptake by the plant. Work is in progress on the uptake of different pasture species, in pots and in the field, from soils which have received incremental dressings of cobalt in connexion with investigations into the effect of cobalt on the incidence of pining in sheep. The uptake of various elements by other plant species—crops such as oats, turnips, flax and also some of the commoner weeds—is being studied on various soils. The availability of the trace constituents in the soil is obviously a factor of importance and not only the total content in the soil, but also the amount extracted by various solvents and its relation to the uptake by the plant, is being investigated.

The diagnosis of soil deficiencies and excesses is nevertheless facilitated by a knowledge of the probable distribution of the trace constituents in soils derived from different parent materials, and investigation of the contents of trace constituents in various soils and their parent materials is progressing. The geochemical relationships, in the case of igneous rocks, have been discussed in a paper concerning the contents in various Greenland rocks,[9] and this line of work has been extended to Scottish rocks of both sedimentary and igneous origin and to the individual minerals they contain.

In the taking of samples for the determination of trace constituents there are two points which must be noted. Firstly, it is essential that the sample is representative of the material which it is desired to analyse. Thus, a pasture sample must consist of the different species in their proper proportions and, if it is grazed pasture which is being analysed for determinations of animal diet, precautions must be taken to ensure that what is sampled is what the animal eats and not what it rejects. It is indeed necessary to fence off portions of the field in order to obtain a sample. Secondly, the sample must be uncontaminated. Considerable difficulty has been found in obtaining such samples from grass pastures, and for this reason, too, it may be desirable to fence off a portion. In any case the herbage should be cut and not pulled, as soil particles inevitably adhere to the lower portions and roots of the plant. Evidence of soil contamination is found in the iron content: it must be suspected if the $Fe_2O_3$ content of the dry matter exceeds 100-150 p.p.m. Generally during the growing season the content is below the former figure. Samples of plants of low habit should not be taken immediately following heavy rain, nor after a lengthy dry, dusty period. Other types of plants are less difficult to sample, but it must be emphasized that composite samples of leaves and roots which have been sent to us have invariably been found to be soil contaminated. The importance of soil contamination varies with the element to be determined. For cobalt, where the soil content may be more than one thousand times that of the plant, it is obviously great. Another source of contamination which has been encountered has been the use of metal containers: a sample of sheep ticks examined showed an abnormal tin content which was traced to this origin.

### The Lundegardh Flame Emission Method

Some 7,000 samples of soil extracts or solutions of plant materials have been examined during the year: approximately the same number as in

1941-42. On an average three elements have been determined in each sample ; for acetic acid soil extracts only potassium being determined, and for exchangeable cations in peats and soil profiles, calcium, magnesium, strontium, potassium, sodium and manganese.

This method is being used generally for the routine determination of the alkali and alkaline earth metals and manganese in solution and also, where concentrations are adequate, for the determination of copper, nickel and other elements which are sensitive in the flame. The results obtained are discussed in the sections dealing with the specific problems involved.

Some preliminary trials have indicated the possibility of determining contents of potassium and other elements in plant materials by acid digestion of the oven-dry material. Comparison of concentrated hydrochloric acid extraction of the ashed material with the extract from 1 g. of dry matter shaken overnight with 50 ml. N hydrochloric acid by the Lundegardh method has given agreement for sodium and potassium, whilst rather higher results are obtained for manganese, indicating that after ashing, a portion of the manganese in the ash may not be taken up by concentrated hydrochloric acid. Extraction of calcium, magnesium and phosphate (chemical data) appears, however, to be incomplete in the dilute acid. Results obtained for potassium and phosphate are appended.

Potassium and Phosphate Contents of Pasture Ash and Amounts Removed by Extraction of Oven-Dry Material

| Sample No. | Per cent. $K_2O$. | | | Per cent. $P_2O_5$. | |
|---|---|---|---|---|---|
| | After ashing. | | Direct extraction Spectro. | After ashing Chem. | Direct extraction Chem. |
| | Chem. | Spectro. | | | |
| 27851 | 1·76 | 1·85 | 1·73 | 0·42 | 0·32 |
| 27852 | 1·40 | 1·41 | 1·67 | 0·61 | 0·46 |
| 27858 | 2·34 | 2·41 | 2·33 | 0·71 | 0·48 |
| 27860 | 1·77 | 2·03 | 2·01 | 0·55 | 0·36 |
| 27862 | 2·36 | 2·41 | 2·51 | 0·65 | 0·46 |
| 27864 | 1·90 | 1·70 | 1·74 | 0·56 | 0·38 |
| 27870 | 1·82 | 1·76 | 1·70 | 0·53 | 0·27 |
| 27940 | 2·19 | 1·88 | 2·20 | 0·53 | 0·32 |

Although, in view of the incomplete extraction of phosphate, no further work has been done using direct extraction, the method may be of interest for certain purposes, as it is very speedy and convenient when, say, potassium alone has to be determined.

## Absorptiometric Methods of Analysis

The use of the Hilger Spekker Absorptiometer for the determination of trace constituents is being extended. A method for the determination of copper in plant materials based on that of Green and Eden (*Biochem. J.*, **34,** 1202 (1940)) has been tried out and so far the results appear promising. Such methods are being applied where difficulties arise in the determination of the element concerned by spectrographic methods, in the case of copper it being found impossible at present to obtain satisfactory copper-free electrodes.

## Other Investigations

Amongst the other problems which have arisen during the year may be noted determinations of the vanadium and molybdenum contents of burnt oil shales; those examined, however, proved to have much lower contents than have been found in shales from other countries and from which these metals are being extracted. The spectrographic method has also proved its usefulness in the examination of precipitates and preparations for purity, and for the quick identification of impurities.

Work on concentration methods prior to spectrographic analysis is being continued, and the applicability of different organic reagents for the concentration of various metallic trace constituents examined.

## SPECIAL INVESTIGATIONS

### Joint Work with the Animal Diseases Research Association

(*a*) *Cobalt Manuring and Pining in Stock.* The investigation has been continued on the general lines indicated in last year's report. Aspects of the problem to which special attention has been given during the year include :

(1) Analyses of soils and pastures from areas previously treated with manurial dressings of cobalt salts, with a view to obtaining information on the duration of the effects of dressings of cobalt on different soils.

(2) The relative uptake of cobalt and other trace elements by individual pasture species, with a view to obtaining information on the grass and clover seeds mixtures likely to be most suitable for cobalt-deficient soils.

(*b*) *Other Stock Disease Problems.* Other joint investigations on which work has been undertaken during the year include studies on Solway Pine, Lactation or Grass Tetany, Abortion in Ewes and Swayback in Lambs. In each case an examination is being made, with particular reference to trace element contents, of samples of soil and produce from the affected areas in order to find out if there is a relationship between soil properties and incidence of the disease.

### Differences of Feeding Value 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 joint investigation of the differences of feeding value for cattle of the produce from different farms where there is no obvious soil or other factor to account for such differences. A number of samples of soil and produce (pasture, oats, turnips and swedes) have been taken from farms in Aberdeenshire where differences in feeding quality have been reported. The analytical work which is in progress involves comprehensive examination of the soils and determinations of the mineral, especially trace element, contents of the produce.

### Survey of Scottish Limestone Resources

This has now been completed, and altogether some 270 samples of limestone have been analysed either partially or completely. Most of the pamphlets describing the occurrences have now been issued ; [10, 11] that on Area VIII, Orkney and Shetland, [17] is in the press, and the report on Area I, Southern Scotland,[18] is in active preparation.

### X-Ray Work

The clay fractions of a number of soils of the Insch association have been investigated. For this purpose the 2$\mu$ clays were further fractionated by centrifugation, using either the supercentrifuge method described by Bray, Grim and Kerr (*Bull. Geol. Soc. Amer.*, **46**, 1909-26, 1935), or else the modified two-layer method mentioned below. X-ray photographs were

taken of the two extreme fractions, and in some cases also of an intermediate fraction. From the photographs a rough estimate of the percentage composition could be made by visual comparison of the diagrams with a set of photographs of standard minerals, which had received various exposures up to the maximum. The most important constituent of most of the clays investigated was of the montmorillonite type (basal spacing about 14 A), but hydrous mica, quartz and kaolinite-type minerals (basal spacing about 7 A) also occur in appreciable amount. In some cases the sum of the percentages obtained in the way described was very much less than 100, suggesting the presence of undetected (perhaps amorphous) components. The lowness of the silica-sesquioxide ratios for most of the clays (generally between 1 and 2) suggests that these undetected components might be free sesquioxides; on the other hand, no iron or aluminium hydroxides could be identified with certainty from the X-ray diagrams. The possibility of electrophoretic separation of electropositive and electronegative colloids is now being investigated with a view to getting more information on this problem.

For the rapid centrifugal fractionation of small quantities of clay for X-ray analysis, a new technique based on Marshall's two-layer method is being used, enabling as many as 10 fractions to be obtained in about 3 hours, using about 200 mg. of material. The possibility of making the method quantitative is being investigated: it is not known exactly how clean a separation is obtained by this means, but it has been verified that X-ray examination of fractions thus separated gives the same results as that of fractions separated with the supercentrifuge.

X-ray photographs have been taken of clay minerals which have been treated with phosphate solutions at *p*H 4 and 7, principally in order to test a suggestion made by Stout (*Amer. Soil Sci. Soc., Proc.*, **4**, 177, 1939) that phosphated kaolinite shows a new structure with a basal spacing of 8 A. No such change was found either with kaolinite or halloysite, though a slight breakdown of the halloysite lattice took place at *p*H 4. The minerals used for these experiments were, however, not ground before treating with phosphate.

A 9 cm. powder camera for photographs of clay minerals has been designed, and two of these are being constructed to replace the one 9 cm. camera which is at present in use.

### Studies on Soil Drainage Water

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

Rape was again grown as the crop for 1942, lysimeters 2 and 3 each being given, per acre, sulphate of ammonia ¾ cwt., superphosphate 2½ cwt., and muriate of potash ½ cwt. The crop was cut in December 1942, giving the following weights, per acre:

| Lysimeter | 1. | 2. | 3. |
|---|---|---|---|
| As cut . . . . | 71 cwt. 48 lb. | 107 cwt. 16 lb. | 107 cwt. 16 lb. |
| Dry matter . . . | 14 cwt. 6 lb. | 20 cwt. 70 lb. | 21 cwt. 42 lb. |
| Per cent. dry matter . | 19·68 | 19·25 | 19·96 |

After the crop was removed the lysimeters were dug over, the roots of the rape being turned under. Ground lime at the rate of 22½ cwt. CaO

per acre was applied to lysimeter 3 and raked in. In May the soil was dug over again, and nos. 2 and 3 each given, per acre, 12 tons dung, 1½ cwt. sulphate of ammonia, 5 cwt. superphosphate and 1½ cwt. muriate of potash. Turnips were sown in three drills on each lysimeter.

*Rainfall and Drainage.* Rainfall, including snow, during the year 1st October, 1942, to 30th September, 1943, totalled 31·18 inches, of which from 34 to 45 per cent. appeared as drainage.

*Colloidal Suspended Material.* Very slight amounts of material in suspension appeared in the drainage waters.

## PUBLICATIONS

*Issued during the year—*

1. " Phosphatic Manuring in Wartime." By W. G. Ogg and A. B. Stewart. (*Scot. J. Agric.*, **24,** 118-120, 1943.)
2. " Some Practical Applications of Soil Research." By A. B. Stewart. (*Trans. High. and Agric. Soc. of Scot.*, **55,** 1-15, 1943.)
3. " Phosphate Fixation in Soils." By E. G. Williams. (*Scot. J. Agric.*, **24,** 156-62, 1943.)
4. " The Fractionation of the Organic Matter, including Nitrogen, of Certain Soils and its Relation to their Quality." By M. R. F. Ashworth. (*J. Agric. Sci.*, **32,** 349-59, 1942.)
5. " Changes occurring in the Organic Matter during the Decomposition of Compost Heaps." By M. R. F. Ashworth. (*J. Agric. Sci.*, **32,** 360-72, 1942.)
6. " Soil Surveys." By A. Muir. (*Aberdeen University Review*, **30,** 35-41, 1943.)
7. " Soil Studies in Relation to Geology in an Area in North-east Scotland. Part II : The Soils and their Development." By R. Hart. (*J. Agric. Sci.*, **32,** 373-88, 1942).
8. " Concentration methods in spectrographic analysis. I. Recovery of cobalt, nickel, molybdenum, copper and zinc from plant materials and soil extracts by 8-hydroxyquinoline." By R. O. Scott and R. L. Mitchell. (*J. Soc. Chem. Ind.*, **62,** 4-8, 1943.)
9. " Preliminary Observations on the Distribution of Trace Elements in the Rocks of the Skaergaard Intrusion, Greenland." By L. R. Wager (Reading University) and R. L. Mitchell. (*Mineralogical Mag.*, **26,** 283-96, 1943.)
10. " Limestones of Scotland. Area II. West-Central Scotland." By J. B. Simpson, M. Macgregor and T. Robertson (Geological Survey) ; and A. Muir and H. G. M. Hardie. (Geological Survey of Great Britain, Wartime Pamphlet No. 13.)
11. " Limestones of Scotland. Area VII. Northern and North-western Scotland." By T. Robertson, J. Knox and J. G. C. Anderson (Geological Survey) ; A. Muir and H. G. M. Hardie. (Geological Survey of Great Britain, Wartime Pamphlet No. 13.)

*In preparation—*

12. " 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. (To appear in *J. Agric. Sci.*)
13. " Peat Deposits of Scotland, Part I." By G. K. Fraser. (Geological Survey of Great Britain, Wartime Pamphlet No. 36.)
14. " Studies on Soils developed on Basic Igneous Rocks in Central Aberdeenshire." By R. Glentworth. (To appear in *Trans. Roy. Soc. Edin.*)
15. " Background Interference in Spectrographic Analysis and its Correction at a Constant Blackening Value." By R. O. Scott. (To appear in *J. Soc. Chem. Ind.*)
16. " The Distribution of Trace Elements in Soils and Grasses." By R. L. Mitchell. (To appear in *Proc. Nutrition Soc.*)
17. " Limestones of Scotland. Area VIII. Orkney and Shetland." By D. Haldane (Geological Survey) and H. G. M. Hardie. (Geological Survey of Great Britain, Wartime Pamphlet No. 13.)
18. " Limestones of Scotland. Area I. Southern Scotland." (Geological Survey of Great Britain, Wartime Pamphlet No. 13.)

# APPENDIX

## A. Table of Gaussian or Subtractive Logarithms

for the determination of log A knowing log (A + B) and log B

Log (A + B) − log B = $\delta$ and log (A + B) − $\gamma$ = log A. Values of $\gamma$ can be obtained in the table from the corresponding entering values of $\delta$.

Applied to the correction for background in spectrographic analysis * the table may be used as follows :

(1) *Blackening Mark Method.* If log ($I_{T.E.} + I_{Bg}$) is the log intensity of the trace element line plus background, and log $I_{Bg}$ the log intensity of the background, then $\delta$ is the difference of these values and log $I_{T.E.}$ is found by subtraction of the corresponding value of $\gamma$ from log ($I_{T.E.} + I_{Bg}$).

(2) *Constant Blackening Background Correction Method.* Log (A + B) and log B are taken as log ($1/w_{(T.E.+Bg)}$) and log ($1/w_{Bg}$) respectively, where these latter values are the logarithms of the reciprocals of the sector apertures which produce equal blackenings of the line plus background and the background. Then

$$\log (1/w_{(T.E.+Bg)}) - \log (1/w_{Bg}) = \delta$$

and

$$\log (1/w_{(T.E.+Bg)}) - \gamma = \log (1/w_{T.E.}).$$

Log intensity of the trace element line then corresponds to the value of log ($1/w_{T.E.}$) found.

In either method the log intensity of the internal standard line is calculated in a similar manner, and, from the values of log $I_{T.E.}$ and log $I_{I.S.}$ obtained, log ($I_{T.E.}/I_{I.S.}$) is found by subtraction.

## B. Table of log ($i_0/i$) for $i_0 = 50$

for the calculation † of the blackening S = log ($i_0/i$) of a photographic plate where

$i_0$ = galvanometer deflection through unexposed emulsion = 50·0,
$i$ = galvanometer deflection through exposed emulsion.

* See Scott, R. O. " Background Interference in Spectrographic Analysis and its Correction at a Constant Blackening Value." *J. Soc. Chem. Ind.*, **63**, (1944), in press.

† See Davidson, A. M. M., and Mitchell, R. L. " Spectrographic Determination of Trace Elements in Soils II." *J. Soc. Chem. Ind.*, **59**, 213, (1940).

## A. Table of Gaussian or Subtractive Logarithms

| s | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0·00 | 6·000 | 2·638 | 2·338 | 2·162 | 2·038 | 1·941 | 1·863 | 1·796 | 1·739 | 1·688 |
| 0·01 | 1·643 | 1·602 | 1·565 | 1·530 | 1·499 | 1·469 | 1·442 | 1·416 | 1·391 | 1·368 |
| 0·02 | 1·347 | 1·326 | 1·306 | 1·288 | 1·270 | 1·252 | 1·236 | 1·220 | 1·205 | 1·190 |
| 0·03 | 1·176 | 1·162 | 1·149 | 1·136 | 1·123 | 1·111 | 1·099 | 1·088 | 1·077 | 1·066 |
| 0·04 | 1·055 | 1·045 | 1·035 | 1·026 | 1·016 | 1·007 | 0·998 | 0·989 | 0·980 | 0·972 |
| 0·05 | 0·964 | 0·955 | 0·948 | 0·940 | 0·932 | 0·925 | 0·917 | 0·910 | 0·903 | 0·896 |
| 0·06 | 0·889 | 0·883 | 0·876 | 0·870 | 0·863 | 0·857 | 0·851 | 0·845 | 0·839 | 0·833 |
| 0·07 | 0 827 | 0·821 | 0·816 | 0·810 | 0·805 | 0·800 | 0·794 | 0·789 | 0·784 | 0·779 |
| 0·08 | 0·774 | 0·769 | 0·764 | 0·760 | 0·755 | 0·750 | 0·746 | 0·741 | 0·737 | 0·732 |
| 0·09 | 0·728 | 0·723 | 0·719 | 0·715 | 0·711 | 0·707 | 0·703 | 0·699 | 0·695 | 0·691 |
| 0·10 | 0·687 | 0·683 | 0·679 | 0·675 | 0·672 | 0·668 | 0·664 | 0·661 | 0·657 | 0·654 |
| 0·11 | 0·650 | 0·647 | 0·643 | 0·640 | 0·637 | 0·633 | 0·630 | 0·627 | 0·624 | 0·620 |
| 0·12 | 0·617 | 0·614 | 0·611 | 0·608 | 0·605 | 0·602 | 0·599 | 0·596 | 0·593 | 0·590 |
| 0·13 | 0·587 | 0·584 | 0·582 | 0·579 | 0·576 | 0·573 | 0·570 | 0·568 | 0·565 | 0·562 |
| 0·14 | 0·560 | 0·557 | 0·555 | 0·552 | 0·549 | 0·547 | 0·544 | 0·542 | 0·539 | 0·537 |
| 0·15 | 0·535 | 0·532 | 0·530 | 0·527 | 0·525 | 0·523 | 0·520 | 0·518 | 0·516 | 0·513 |
| 0·16 | 0·511 | 0·509 | 0·507 | 0·505 | 0·502 | 0·500 | 0·498 | 0·496 | 0·494 | 0·492 |
| 0·17 | 0·490 | 0·487 | 0·485 | 0·483 | 0·481 | 0·479 | 0·477 | 0·475 | 0·473 | 0·471 |
| 0·18 | 0·469 | 0·467 | 0·466 | 0·464 | 0·462 | 0·460 | 0·458 | 0·456 | 0·454 | 0·452 |
| 0·19 | 0·450 | 0·449 | 0·447 | 0·445 | 0·444 | 0·442 | 0·440 | 0·438 | 0·436 | 0·435 |
| 0·20 | 0·433 | 0·431 | 0·430 | 0·428 | 0·426 | 0·424 | 0·423 | 0·421 | 0·420 | 0·418 |
| 0·21 | 0·416 | 0·415 | 0·413 | 0·412 | 0·410 | 0·408 | 0·407 | 0·405 | 0·404 | 0·402 |
| 0·22 | 0·400 | 0·399 | 0·398 | 0·396 | 0·395 | 0·393 | 0·392 | 0·390 | 0·389 | 0·387 |
| 0·23 | 0·386 | 0·384 | 0·383 | 0·382 | 0·380 | 0·379 | 0·378 | 0·376 | 0·375 | 0·373 |
| 0·24 | 0·372 | 0·371 | 0·369 | 0·368 | 0·367 | 0·365 | 0·364 | 0·363 | 0·361 | 0·360 |
| 0·25 | 0·358 | 0·357 | 0·356 | 0·355 | 0·354 | 0·353 | 0·351 | 0·350 | 0·349 | 0·348 |
| 0·26 | 0·346 | 0·345 | 0·344 | 0·343 | 0·341 | 0·340 | 0·339 | 0·338 | 0·337 | 0·336 |
| 0·27 | 0·335 | 0·333 | 0·332 | 0·331 | 0·330 | 0·329 | 0·328 | 0·326 | 0·325 | 0·324 |
| 0·28 | 0·323 | 0·322 | 0·321 | 0·320 | 0·319 | 0·318 | 0·316 | 0·315 | 0·314 | 0·313 |
| 0·29 | 0·312 | 0·311 | 0·310 | 0·310 | 0·309 | 0·308 | 0·307 | 0·305 | 0·304 | 0·303 |
| 0·30 | 0·302 | 0·301 | 0·300 | 0·299 | 0·298 | 0·297 | 0·296 | 0·295 | 0·294 | 0·293 |
| 0·31 | 0·292 | 0·291 | 0·290 | 0 289 | 0·288 | 0·287 | 0·286 | 0·286 | 0·285 | 0·284 |
| 0·32 | 0·283 | 0·282 | 0·281 | 0·280 | 0·279 | 0·278 | 0·277 | 0·277 | 0·276 | 0·275 |
| 0·33 | 0·274 | 0·273 | 0·272 | 0·271 | 0·270 | 0·269 | 0·269 | 0·268 | 0·267 | 0·266 |
| 0·34 | 0·265 | 0·264 | 0·264 | 0·263 | 0·262 | 0·261 | 0·260 | 0·259 | 0·259 | 0·258 |
| 0·35 | 0·257 | 0·256 | 0·255 | 0·255 | 0·254 | 0·253 | 0·252 | 0·251 | 0·251 | 0·250 |
| 0·36 | 0·249 | 0·248 | 0·248 | 0·247 | 0·246 | 0·245 | 0·244 | 0·244 | 0·243 | 0·242 |
| 0·37 | 0·242 | 0·241 | 0·241 | 0·240 | 0·239 | 0·239 | 0·238 | 0·237 | 0·236 | 0·235 |
| 0·38 | 0·234 | 0·233 | 0·233 | 0·232 | 0·231 | 0·231 | 0·230 | 0·229 | 0·229 | 0·228 |
| 0·39 | 0·227 | 0·226 | 0·226 | 0·225 | 0·224 | 0·224 | 0·223 | 0·222 | 0·222 | 0·221 |
| 0·40 | 0·220 | 0·220 | 0·219 | 0·218 | 0·218 | 0·217 | 0·216 | 0·216 | 0·215 | 0·214 |
| 0·41 | 0·214 | 0·213 | 0·212 | 0·212 | 0·211 | 0·211 | 0·210 | 0·209 | 0·209 | 0·208 |
| 0·42 | 0·207 | 0·207 | 0·206 | 0·206 | 0·205 | 0·204 | 0·204 | 0·203 | 0·203 | 0·202 |
| 0·43 | 0·201 | 0·201 | 0·200 | 0·200 | 0·199 | 0·199 | 0 198 | 0·197 | 0·197 | 0·196 |
| 0·44 | 0·196 | 0·195 | 0·194 | 0·194 | 1·193 | 0·193 | 0·192 | 0·192 | 0·191 | 0·191 |
| 0·45 | 0·190 | 0·190 | 0·189 | 0·188 | 0·188 | 0·187 | 0·187 | 0·186 | 0·186 | 0·185 |
| 0·46 | 0·185 | 0·184 | 0·184 | 0·183 | 0·183 | 0·182 | 0·182 | 0·181 | 0·181 | 0·180 |
| 0·47 | 0·179 | 0·179 | 0·178 | 0·178 | 0·177 | 0·177 | 0·176 | 0·176 | 0·175 | 0·175 |
| 0·48 | 0·174 | 0·174 | 0·173 | 0·173 | 0·172 | 0·172 | 0·172 | 0·171 | 0·171 | 0·170 |
| 0·49 | 0·170 | 0·169 | 0·169 | 0·168 | 0·168 | 0·167 | 0·167 | 0·166 | 0·166 | 0·165 |
| 0·50 | 0·165 | 0·165 | 0·164 | 0·164 | 0·163 | 0·163 | 0·162 | 0·162 | 0·161 | 0·161 |
| 0·51 | 0·161 | 0·160 | 0·160 | 0·159 | 0·159 | 0·158 | 0·158 | 0·157 | 0·157 | 0·157 |
| 0·52 | 0·156 | 0·156 | 0·155 | 0·155 | 0·154 | 0·154 | 0·154 | 0·153 | 0·153 | 0·152 |
| 0·53 | 0·152 | 0·151 | 0·151 | 0·151 | 0·150 | 0·150 | 0·149 | 0·149 | 0·149 | 0·148 |
| 0·54 | 0·148 | 0·147 | 0·147 | 0·147 | 0·146 | 0·146 | 0·145 | 0·145 | 0·145 | 0·144 |
| 0·55 | 0·144 | 0·143 | 0·143 | 0·143 | 0·142 | 0·142 | 0·141 | 0·141 | 0·141 | 0·140 |

| δ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0·56 | 0·140 | 0·140 | 0·139 | 0·139 | 0·138 | 0·138 | 0·138 | 0·137 | 0·137 | 0·137 |
| 0·57 | 0·136 | 0·136 | 0·135 | 0·135 | 0·135 | 0·134 | 0·134 | 0·134 | 0·133 | 0·133 |
| 0·58 | 0·133 | 0·132 | 0·132 | 0·131 | 0·131 | 0·131 | 0·130 | 0·130 | 0·130 | 0·129 |
| 0·59 | 0·129 | 0·129 | 0·128 | 0·128 | 0·128 | 0·127 | 0·127 | 0·127 | 0·126 | 0·126 |
| 0·60 | 0·126 | 0·125 | 0·125 | 0·125 | 0·124 | 0·124 | 0·124 | 0·123 | 0·123 | 0·123 |
| 0·61 | 0·122 | 0·122 | 0·122 | 0·121 | 0·121 | 0·121 | 0·120 | 0·120 | 0·120 | 0·119 |
| 0·62 | 0·119 | 0·119 | 0·118 | 0·118 | 0·118 | 0·118 | 0·117 | 0·117 | 0·117 | 0·116 |
| 0·63 | 0·116 | 0·116 | 0·115 | 0·115 | 0·115 | 0·114 | 0·114 | 0·114 | 0·114 | 0·113 |
| 0·64 | 0·113 | 0·113 | 0·112 | 0·112 | 0·112 | 0·112 | 0·111 | 0·111 | 0·111 | 0·110 |
| 0·65 | 0·110 | 0·110 | 0·109 | 0·109 | 0·109 | 0·109 | 0·108 | 0·108 | 0·108 | 0·108 |
| 0·66 | 0·107 | 0·107 | 0·107 | 0·106 | 0·106 | 0·106 | 0·106 | 0·105 | 0·105 | 0·105 |
| 0·67 | 0·104 | 0·104 | 0·104 | 0·104 | 0·103 | 0·103 | 0·103 | 0·103 | 0·102 | 0·102 |
| 0·68 | 0·102 | 0·102 | 0·101 | 0·101 | 0·101 | 0·100 | 0·100 | 0·100 | 0·100 | 0·099 |
| 0·69 | 0·099 | 0·099 | 0·099 | 0·098 | 0·098 | 0·098 | 0·098 | 0·097 | 0·097 | 0·097 |
| 0·70 | 0·097 | 0·096 | 0·096 | 0·096 | 0·096 | 0·095 | 0·095 | 0·095 | 0·095 | 0·094 |
| 0·71 | 0·094 | 0·094 | 0·094 | 0·093 | 0·093 | 0·093 | 0·093 | 0·093 | 0·092 | 0·092 |
| 0·72 | 0·092 | 0·092 | 0·091 | 0·091 | 0·091 | 0 091 | 0 090 | 0·090 | 0·090 | 0·090 |
| 0·73 | 0·089 | 0·089 | 0·089 | 0·089 | 0·089 | 0·088 | 0·088 | 0·088 | 0·088 | 0·087 |
| 0·74 | 0·087 | 0·087 | 0·087 | 0·087 | 0·086 | 0·086 | 0·086 | 0·086 | 0·085 | 0·085 |
| 0·75 | 0·085 | 0·085 | 0·085 | 0·084 | 0·084 | 0·084 | 0·084 | 0·084 | 0·083 | 0·083 |
| 0·76 | 0·083 | 0·083 | 0·082 | 0·082 | 0·082 | 0·082 | 0·082 | 0·081 | 0·081 | 0·081 |
| 0·77 | 0·081 | 0·081 | 0·080 | 0·080 | 0·080 | 0·080 | 0·080 | 0·079 | 0·079 | 0·079 |
| 0·78 | 0·079 | 0·079 | 0·078 | 0·078 | 0·078 | 0·078 | 0·078 | 0·077 | 0·077 | 0·077 |
| 0·79 | 0·077 | 0·077 | 0·076 | 0·076 | 0·076 | 0·076 | 0·076 | 0·076 | 0·075 | 0·075 |
| 0·80 | 0·075 | 0·075 | 0·075 | 0·074 | 0·074 | 0·074 | 0·074 | 0·074 | 0·073 | 0·073 |
| 0·81 | 0·073 | 0·073 | 0·073 | 0·073 | 0·072 | 0·072 | 0·072 | 0·072 | 0·072 | 0·071 |
| 0·82 | 0·071 | 0·071 | 0·071 | 0·071 | 0·071 | 0·070 | 0·070 | 0·070 | 0·070 | 0·070 |
| 0·83 | 0·070 | 0·069 | 0·069 | 0·069 | 0·069 | 0·069 | 0·068 | 0·068 | 0·068 | 0·068 |
| 0·84 | 0·068 | 0·068 | 0·067 | 0·067 | 0·067 | 0·067 | 0·067 | 0·067 | 0·066 | 0·066 |
| 0·85 | 0·066 | 0·066 | 0·066 | 0·066 | 0·065 | 0·065 | 0·065 | 0·065 | 0·065 | 0·065 |
| 0·86 | 0·065 | 0·064 | 0·064 | 0·064 | 0·064 | 0·064 | 0·064 | 0·063 | 0·063 | 0·063 |
| 0·87 | 0·063 | 0·063 | 0·063 | 0·062 | 0·062 | 0·062 | 0·062 | 0·062 | 0·062 | 0·062 |
| 0·88 | 0·061 | 0·061 | 0·061 | 0·061 | 0·061 | 0·061 | 0·060 | 0·060 | 0·060 | 0·060 |
| 0·89 | 0·060 | 0·060 | 0·060 | 0·059 | 0·059 | 0·059 | 0·059 | 0·059 | 0·059 | 0·059 |
| 0·90 | 0·058 | 0·058 | 0·058 | 0·058 | 0·058 | 0·058 | 0·058 | 0·057 | 0·057 | 0·057 |
| 0·91 | 0·057 | 0·057 | 0·057 | 0·057 | 0·056 | 0·056 | 0·056 | 0·056 | 0·056 | 0·056 |
| 0·92 | 0·056 | 0·055 | 0·055 | 0·055 | 0·055 | 0·055 | 0·055 | 0·055 | 0·055 | 0·054 |
| 0·93 | 0·054 | 0·054 | 0·054 | 0·054 | 0·054 | 0·054 | 0·053 | 0·053 | 0·053 | 0·053 |
| 0·94 | 0·053 | 0·053 | 0·053 | 0·053 | 0·052 | 0·052 | 0·052 | 0·052 | 0·052 | 0·052 |
| 0·95 | 0·052 | 0·052 | 0·051 | 0·051 | 0·051 | 0·051 | 0·051 | 0·051 | 0·051 | 0·051 |
| 0·96 | 0·050 | 0 050 | 0·050 | 0·050 | 0·050 | 0·050 | 0·050 | 0·050 | 0·049 | 0·049 |
| 0·97 | 0·049 | 0·049 | 0·049 | 0·049 | 0·049 | 0·049 | 0·049 | 0·048 | 0·048 | 0·048 |
| 0·98 | 0·048 | 0·048 | 0·048 | 0·048 | 0·048 | 0·047 | 0·047 | 0·047 | 0·047 | 0·047 |
| 0·99 | 0·047 | 0·047 | 0·047 | 0·047 | 0·046 | 0·046 | 0·046 | 0·046 | 0·046 | 0·046 |
| 1·00 | 0·046 | 0·046 | 0·046 | 0·045 | 0·045 | 0·045 | 0·045 | 0·045 | 0·045 | 0·045 |
| 1·0 | 0·046 | 0·045 | 0·044 | 0·043 | 0·042 | 0·041 | 0·040 | 0·039 | 0·038 | 0·037 |
| 1·1 | 0·036 | 0·035 | 0·034 | 0·033 | 0·033 | 0·032 | 0·031 | 0·030 | 0·029 | 0·029 |
| 1·2 | 0·028 | 0·028 | 0·027 | 0·026 | 0·026 | 0·025 | 0·024 | 0·024 | 0·023 | 0·023 |
| 1·3 | 0·022 | 0·022 | 0·021 | 0·021 | 0·020 | 0·020 | 0·019 | 0·019 | 0·018 | 0·018 |
| 1·4 | 0·018 | 0·017 | 0·017 | 0·016 | 0·016 | 0·016 | 0·015 | 0·015 | 0·015 | 0·014 |
| 1·5 | 0·014 | 0·014 | 0·013 | 0·013 | 0·013 | 0·012 | 0·012 | 0·012 | 0·012 | 0·011 |
| 1·6 | 0·011 | 0·011 | 0·011 | 0·010 | 0·010 | 0·010 | 0·010 | 0·009 | 0·009 | 0·009 |
| 1·7 | 0·009 | 0·009 | 0·008 | 0·008 | 0·008 | 0·008 | 0·008 | 0·007 | 0·007 | 0·007 |
| 1·8 | 0·007 | 0·007 | 0·007 | 0·006 | 0·006 | 0·006 | 0·006 | 0·006 | 0·006 | 0·006 |
| 1·9 | 0·005 | 0 005 | 0·005 | 0·005 | 0·005 | 0·005 | 0·005 | 0·005 | 0·005 | 0·004 |
| 2·0 | 0 004 | 0·004 | 0·004 | 0·004 | 0·004 | 0·004 | 0·004 | 0·004 | 0·004 | 0·004 |
| 2·1 | 0·003 | 0·003 | 0·003 | 0·003 | 0·003 | 0·003 | 0·003 | 0·003 | 0·003 | 0·003 |
| 2·2 | 0·003 | 0·003 | 0·003 | 0·003 | 0·003 | 0·002 | 0·002 | 0·002 | 0·002 | 0·002 |
| 2·3 | 0·002 | 0·002 | 0·002 | 0·002 | 0·002 | 0·002 | 0·002 | 0·002 | 0·002 | 0·002 |
| 2·4 | 0·002 | 0·002 | 0·002 | 0·002 | 0·002 | 0·002 | 0·002 | 0·001 | 0·001 | 0·001 |
| 2·5 | 0·001 | 0·001 | 0·001 | 0·001 | 0·001 | 0·001 | 0·001 | 0·001 | 0·001 | 0·001 |

## B. Table of $\log (i_0/i)$ for $i_0 = 50$

| $i$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0. | $\infty$ | 2·699 | 2·398 | 2·222 | 2·097 | 2·000 | 1·921 | 1·854 | 1·796 | 1·745 |
| 1. | 1·699 | 1·659 | 1·620 | 1·585 | 1·553 | 1·523 | 1·495 | 1·469 | 1·444 | 1·420 |
| 2. | 1·398 | 1·377 | 1·357 | 1·337 | 1·319 | 1·301 | 1·284 | 1·268 | 1·251 | 1·236 |
| 3. | 1·222 | 1·208 | 1·194 | 1·181 | 1·168 | 1·155 | 1·143 | 1·131 | 1·119 | 1·108 |
| 4. | 1·097 | 1·086 | 1·076 | 1·066 | 1·056 | 1·046 | 1·036 | 1·027 | 1·018 | 1·009 |
| 5. | 1·000 | 0·991 | 0·982 | 0·975 | 0·967 | 0·959 | 0·951 | 0·943 | 0·936 | 0·928 |
| 6. | 0·921 | 0·914 | 0·907 | 0·900 | 0·890 | 0·886 | 0·880 | 0·873 | 0·867 | 0·860 |
| 7. | 0·854 | 0·848 | 0·842 | 0·836 | 0·830 | 0·824 | 0·818 | 0·813 | 0·807 | 0·801 |
| 8. | 0·796 | 0·791 | 0·785 | 0·780 | 0·775 | 0·770 | 0·765 | 0·760 | 0·755 | 0·750 |
| 9. | 0·745 | 0·740 | 0·735 | 0·731 | 0·726 | 0·721 | 0·717 | 0·713 | 0·708 | 0·703 |
| 10. | 0·699 | 0·695 | 0·690 | 0·686 | 0·682 | 0·678 | 0·674 | 0·670 | 0·666 | 0·662 |
| 11. | 0·659 | 0·654 | 0·650 | 0·646 | 0·642 | 0·638 | 0·635 | 0·631 | 0·627 | 0·624 |
| 12. | 0·620 | 0·616 | 0·613 | 0·609 | 0·606 | 0·602 | 0·599 | 0·595 | 0·592 | 0·588 |
| 13. | 0·585 | 0·582 | 0·579 | 0·575 | 0·572 | 0·569 | 0·566 | 0·562 | 0·559 | 0·556 |
| 14. | 0·553 | 0·550 | 0·547 | 0·544 | 0·541 | 0·538 | 0·535 | 0·532 | 0·529 | 0·526 |
| 15. | 0·523 | 0·520 | 0·517 | 0·514 | 0·512 | 0·509 | 0·506 | 0·503 | 0·500 | 0·498 |
| 16. | 0·495 | 0·492 | 0·490 | 0·487 | 0·484 | 0·482 | 0·479 | 0·476 | 0·474 | 0·471 |
| 17. | 0·469 | 0·466 | 0·463 | 0·461 | 0·459 | 0·456 | 0·454 | 0·451 | 0·449 | 0·447 |
| 18. | 0·444 | 0·441 | 0·439 | 0·437 | 0·434 | 0·432 | 0·430 | 0·428 | 0·424 | 0·423 |
| 19. | 0·420 | 0·418 | 0·416 | 0·413 | 0·411 | 0·409 | 0·407 | 0·405 | 0·403 | 0·400 |
| 20. | 0·398 | 0·396 | 0·394 | 0·392 | 0·389 | 0·387 | 0·385 | 0·383 | 0·381 | 0·379 |
| 21. | 0·377 | 0·375 | 0·373 | 0·371 | 0·369 | 0·367 | 0·365 | 0·363 | 0·361 | 0·359 |
| 22. | 0·357 | 0·355 | 0·353 | 0·351 | 0·349 | 0·347 | 0·345 | 0·343 | 0·341 | 0·339 |
| 23. | 0·337 | 0·335 | 0·334 | 0·332 | 0·330 | 0·328 | 0·326 | 0·324 | 0·322 | 0·321 |
| 24. | 0·319 | 0·317 | 0·315 | 0·313 | 0·312 | 0·310 | 0·308 | 0·306 | 0·305 | 0·303 |
| 25. | 0·301 | 0·299 | 0·298 | 0·296 | 0·294 | 0·293 | 0·291 | 0·289 | 0·287 | 0·286 |
| 26. | 0·284 | 0·282 | 0·281 | 0·279 | 0·277 | 0·276 | 0·274 | 0·273 | 0·271 | 0·269 |
| 27. | 0·268 | 0·266 | 0·264 | 0·263 | 0·261 | 0·260 | 0·258 | 0·257 | 0·255 | 0·253 |
| 28. | 0·251 | 0·250 | 0·249 | 0·247 | 0·246 | 0·244 | 0·243 | 0·241 | 0·240 | 0·238 |
| 29. | 0·236 | 0·235 | 0·234 | 0·232 | 0·231 | 0·229 | 0·228 | 0·226 | 0·225 | 0·223 |
| 30. | 0·222 | 0·220 | 0·219 | 0·218 | 0·216 | 0·215 | 0·213 | 0·212 | 0·210 | 0·209 |
| 31. | 0·208 | 0·206 | 0·205 | 0·204 | 0·202 | 0·201 | 0·199 | 0·198 | 0·197 | 0·196 |
| 32. | 0·194 | 0·193 | 0·191 | 0·190 | 0·189 | 0·187 | 0·186 | 0·185 | 0·183 | 0·182 |
| 33. | 0·181 | 0·179 | 0·178 | 0·177 | 0·175 | 0·174 | 0·173 | 0·171 | 0·170 | 0·169 |
| 34. | 0·168 | 0·166 | 0·165 | 0·164 | 0·162 | 0·161 | 0·160 | 0·159 | 0·157 | 0·156 |
| 35. | 0·155 | 0·154 | 0·153 | 0·151 | 0·150 | 0·149 | 0·148 | 0·146 | 0·145 | 0·144 |
| 36. | 0·143 | 0·142 | 0·140 | 0·139 | 0·138 | 0·137 | 0·136 | 0·134 | 0·133 | 0·132 |
| 37. | 0·131 | 0·130 | 0·129 | 0·127 | 0·126 | 0·125 | 0·124 | 0·123 | 0·122 | 0·120 |
| 38. | 0·119 | 0·118 | 0·117 | 0·115 | 0·114 | 0·113 | 0·112 | 0·111 | 0·110 | 0·109 |
| 39. | 0·108 | 0·107 | 0·106 | 0·105 | 0·103 | 0·102 | 0·101 | 0·100 | 0·099 | 0·098 |
| 40. | 0·097 | 0·096 | 0·095 | 0·094 | 0·093 | 0·091 | 0·090 | 0·089 | 0·088 | 0·087 |
| 41. | 0·086 | 0·085 | 0·084 | 0·083 | 0·082 | 0·081 | 0·080 | 0·079 | 0·078 | 0·077 |
| 42. | 0·076 | 0·075 | 0·074 | 0·073 | 0·072 | 0·071 | 0·070 | 0·069 | 0·068 | 0·067 |
| 43. | 0·066 | 0·064 | 0·063 | 0·062 | 0·061 | 0·060 | 0·059 | 0·058 | 0·057 | 0·057 |
| 44. | 0·056 | 0·055 | 0·054 | 0·053 | 0·052 | 0·051 | 0·050 | 0·049 | 0·048 | 0·047 |
| 45. | 0·046 | 0·045 | 0·044 | 0·043 | 0·042 | 0·041 | 0·040 | 0·039 | 0·038 | 0·037 |
| 46. | 0·036 | 0·035 | 0·034 | 0·033 | 0·032 | 0·031 | 0·031 | 0·030 | 0·029 | 0·028 |
| 47. | 0·027 | 0·026 | 0·025 | 0·024 | 0·023 | 0·022 | 0·021 | 0·020 | 0·020 | 0·019 |
| 48. | 0·018 | 0·017 | 0·016 | 0·015 | 0·014 | 0·013 | 0·012 | 0·011 | 0·011 | 0·010 |
| 49. | 0·009 | 0·008 | 0·007 | 0·006 | 0·005 | 0·004 | 0·003 | 0·003 | 0·002 | 0·001 |

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