Art. XLI.—*On the Proposal for a Soil Survey of New Zealand.*

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[*Read before the Canterbury Philosophical Institute, 6th December, 1916; received by Editors, 30th December, 1916, issued separately, 7th December, 1917*]

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I. General Methods of Soil Survey.

In considering the relative advantages of the various methods of soil survey that have been proposed it is reasonable to demand that a method shall take into account to the greatest degree possible all those features that most profoundly affect the agricultural potentialities of the soil. These are (1) local climate; (2) soil texture; (3) composition; (4) nature of subsoil. It is difficult to arrange these in order of relative importance, but it can be shown that, except in abnormal cases, *chemical composition is of least consequence; while soil texture and nature of subsoil deserve most consideration,* in that they determine the suitability of the soil as the abode of the plant in respect of moisture-supply, air-supply, and temperature. On local climate depends to a considerable extent the suitability or otherwise of a soil area to the growth of various kinds of agricultural plants.

The various methods of soil-classification hitherto proposed may now be considered. According to Tulaikoff,* all classifications of soils yet proposed may be divided into two groups: (*a*) *scientific classifications,* which are based on the natural characteristics of the soil, and (*b*) "*applied*" *classifications,* which are based on the suitability of soils for certain crops, or on the revenue that may be derived from them. In New Zealand the practical man uses such an "applied" method when he loosely classifies land as (1) dairying land, which comprises the heavier soil with a rainfall of, say, over 25 in., (2) sheep country, which comprises hill pastures inaccessible to the plough, as well as the "lighter" and drier soils at lower levels; (3) cropping land, intermediate between these.

According to the features on which the study of soils is based, the "scientific" classifications are divided into—(1) the *geologico-petrographical,*

* N. M. Tulaikoff, The Genetic Classification of Soils, *Journ. Ag. Sci.*. vol. 3, 1908, p. 81.

in which the soils are grouped according to the geologico-petrographical character of the rocks which make up the soil (the classification of Fallow, Mayer, and others); (2) the *chemical* or *chemico-petrographical,* according to the main chemical features of the soil (Krop); (3) the *physical,* according to the mechanical composition and the physical characteristics derived from it (Thaer, Schubler, the classification adopted by the Bureau of Soils of the United States); (4) the *combined* classification, by which soils are divided into groups, for example, according to their mechanical composition, and subdivided according to either their chemical composition or other features (Senft, Kosticheff, and others); (5) the *genetic,* by which soils are divided into groups depending on their origin and development (Professor Docuchaiev, Professor Hilgard, Professor Ramman (in part), and Professor Sibirtzev).

The last-named, the genetic classification of Sibirtzev, provides a means of differentiating in a broad way the soils of continental masses by means of features that ultimately depend wholly on climate. Thus, while the method provides a comprehensive classification in areas, such as Eurasia, with more or less definite climatic zones, it cannot be applied to smaller countries lying wholly within one climatic zone (such as England), nor is it suited to a soil survey the objects of which are such as are outlined in the second part of this paper. The method is well criticized by Hall and Russell,* and no apology is necessary for quoting at length their remarks on the subject, since what applies to Great Britain in this connection applies equally well in New Zealand: "The genetic classification of soils such as has been suggested by Sibirtzev divides soils into a series of great types which are really determined by climatic zones. In the steppe area, for example, where the black soils (Tchernozem) prevail, climatic conditions have led to the accumulation of large proportions of mild or neutral humus until it has become the dominant factor in determining the character of the soil; whether the original substratum be sand or clay the amount of organic matter causes the soil to work lightly and yet retain moisture. In such an area, and the area will in the nature of things be large, soil analyses will be of little value because all differences, chemical or physical, in the nature of the substratum will be overridden by the preponderance of the humus. Such an area, again, will show little relation between the soil and the geology of the country, the soil being practically a drift deposit which has overgrown all the underlying formations alike. In the United Kingdom we must regard ourselves as living almost entirely within one only of these large climatic zones, but one which does not superimpose a soil type on all the various strata to be found there, so that a great diversity of soils may occur within a very small area. We do see the climatic divisions in the peaty soils which develop in all parts of the country above a certain elevation, for though some differences may be traced in the vegetation carried by the moorlands, in the main the character of the soils is alike and has been determined by the elevation and the rainfall and not by the nature of the underlying formation. As a rule, however, in the United Kingdom the soil is derived from and shares the character of the rock or drift material below; even where there might have once been a common forest or steppe soil over a considerable area the processes of cultivation carried on for so long have obliterated the excess

* A. D. HALL and E. T. RUSSELL, Soil Surveys and Soil Analyses, *Journ. Ag. Sci.*, vol. 4, 1911, p. 182.

of organic matter and given the underlying differences full play. The character of our climatic zone is such as to accentuate variety of soils, the humidity is considerable and carries the degradation of the rock material so far that there is an enormous range in the sizes of the particles making up the soil, from coarse sand grains down to clay particles of the order of colloids; there has also been sufficient accumulation of humus to modify the texture of the mass and make it work as a unit and not as a loose aggregate of powdered rock. Chemically also our soils lie between the semi-arid soils, with their richness in unleached salts derived from the decayed rock, and the 'podzols' from which all soluble material has been washed away."

The first method, the geologico-petrographical classification, and the second method, the chemico-petrographical classification, may conveniently be considered together, since they have usually been employed in conjunction with one another in Great Britain, where the adoption of the combination by Hall and Russell in their *Agriculture and Soils of Kent, Surrey, and Sussex** has firmly established it. The authors "have assumed that each [geological] formation represented in the district will give rise to a soil type which can be characterized both by its mechanical analysis and by special features in the farming which prevails over its outcrop. The justification for these cardinal assumptions was obtained in the early stages of the work by following the dividing-line representing the outcrop of two formations, and finding (1) that the dividing-line held for the soils as well as for the underlying formations; (2) that the soils from any formation (with one or two exceptions) did show on analysis certain common features which marked them off from the other soils These conclusions have been strengthened as our work proceeded; all our experience in the field goes to show that each formation in the area under consideration gives rise to a distinct soil type, the characteristic composition of which can further be recognized by making up an average from the mechanical analyses of the samples taken from the formation. Even in such a case as that afforded by the Lower Wealden soils, which vary from something near a sand to a heavy clay, there still exists but one type of soil, possessing very marked and special characters, though subject to a considerable range of variation from light to heavy"

Since the publication of this work surveys of various counties have been completed or taken in hand in Great Britain Practically all of this work, especially that done in England, follows consistently the methods of Hall and Russell. Thus in that most recently published—namely, a paper by Rigg†—we read, "The writer has followed Hall and Russell in using the geological formation to mark the extent of a series of soils which have a somewhat similar mineral structure. These series of soils have, however, then been separated into soil formations having different agricultural properties, and the extent of each has been mapped."

As one of the objects of the present paper is to show that in general, and more particularly in New Zealand, the geological map is not the best basis of a soil survey (in other words, that the geologico-chemico-petrographical method is not the best method of soil-classification), a detailed consideration of some of the British work is necessary.

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* Published by the Board of Agriculture and Fisheries, 1911

† T. Rigg, The Soils and Crops of the Market-garden District of Biggleswade. *Journ. Ag. Sci.*, vol. 7, 1916, p. 385.

In the first place, if what has been said above be borne in mind—namely, (*a*) that the objects of a soil survey are not merely to provide a scientific classification of soils, but to provide such a classification as will enable us the more readily to appreciate the agricultural potentialities of each soil type; and (*b*) that the fertility of a soil depends not so much on its chemical composition as on its texture, its climate, and the environment generally that it provides for the plant—then it must at once be conceded that the geologico-petrographical classification is inefficient, since it is based fundamentally on the nature of the rock from which the soil is derived. For the character of the parent rock can affect only the chemical composition (and in some few exceptional cases mechanical composition) of the soil, but it cannot affect climate, water-supply, texture, &c., which are by far the most important fertility factors.

Proceeding from this general statement to the consideration of specific cases, we shall deal first with Rigg's paper mentioned above. Rigg examined the following geological formations, and the series of soils occurring on them were divided into soil formations which had different agricultural properties:—

(1.) Oxford clay, giving rise to two soil formations—
- (*a*.) Pure-clay soil';
- (*b*.) A clay loam, probably resulting from an alluvial wash on to the clay soil.

(2.) Greensand, giving rise to two soil formations—
- (*a*.) Dark sands;
- (*b*.) Brown sands.

(3.) Gault, giving rise to two soil formations—
- (*a*) Pure-clay soil;
- (*b*.) A sandy loam, locally known as "redland," occurring as a narrow strip between greensand and the pure Gault clay soil (*a*).

(4.) Boulder clay, giving rise to three soil formations—
- (*a*.) Pure boulder-clay soil,
- (*b*) Heavy loam produced by wash on boulder clay;
- (*c*.) Sandy loam produced by a thin capping of boulder clay on greensand.

(5.) Brick-earths, giving rise to only one soil formation.

(6.) Glacial, giving rise to one soil formation, which, however, is not quite so uniform as the brick-earth formation.

(7.) Valley gravels, giving rise to three soil formations—
- (*a*.) A brown-soil formation (referred to as "Old Brown");
- (*b*.) A heavy brown-soil formation;
- (*c*.) A more recent dark-soil formation (referred to as "New Dark").

Samples of soil from each formation were collected and submitted to chemical and mechanical analysis; and by this means it is claimed that not only were field observations verified, but analysis differentiated between the various soil formations and showed an extraordinary uniformity between the samples taken from any soil formation. The greensand soils are given as an illustration of this. This series of soils is said to be "differentiated from any other by the low percentage of potash and mineral salts and an almost entire absence of calcium carbonate. The coarse-sand fraction is particularly high, and this fact alone would be almost sufficient to distinguish it from any other series." When, however, we turn to the analytical results in the appendix we find (1) that a low percentage of potash is characteristic also of the "Old Brown" formation of the valley-gravel series, so also a low percentage of CaO and MgO; (2) that P_2O_5 is not phenomenally low—average for greensands, 0·21 per cent.; average for other formations, 0·20 per cent.

It is further stated that "The dark sand seems to be differentiated by a much lower content of potash and phosphoric acid." This statement, however, is not justified by the analyses of the four soils given, for the figures for potash are 0·24, 0·13, 0·18, and 0·23, two of these being quite up to the average of the brown sands; while the figures for phosphoric acid are 0·43, 0·11, 0·19, and 0·16, one of these being exceptionally high and at least one other not exceptionally low.

The percentage of $CaCO_3$ is admittedly phenomenally low (average 0·08 per cent.); but the Old Brown valley-gravel soils have only 0·11 per cent., the Oxford clay formation only 0·12 per cent., and a Gault formation only 0·15 per cent. Moreover, in the discussion of the "characteristic properties and agriculture" of the various soil formations there is no mention of the necessity for liming or of an excessive use of artificial manures On the contrary, it is stated that, though "the dark sand formation is characterized by very low percentages of phosphoric acid, potash, and calcium carbonate," it is nevertheless "reported by market-gardeners as being not quite so 'hungry' as the brown sand formation." Again, the table of distribution of crops shows that the main crop is early potatoes, which are "associated with brown and dark greensand and valley-gravel soil formations," while it is stated also that the success of the crops depends to a large extent on the rainfall.

The present writer therefore submits—(1) that a unique chemical composition does not characterize this soil formation; (2) that the chemical composition of the soils of the formation does not in any way affect their agricultural utilization or treatment; (3) that the only agricultural feature of the formation apparently connected with geological origin is the high percentage of coarse sand, but that (4) this is not an invariable feature of greensand-derived soils, for Hall and Russell find that "the soils [of the Upper Greensand in Kent, Surrey, and Sussex] are well balanced and contain all the fractions suitably developed . . . the soils always show a sufficiency of carbonate of lime" The Folkestone sand, however, is "coarse-grained and devoid of carbonate of lime."

Rigg's next illustration is the Oxford clay series. This is divided into two soil formations—(*a*) pure-clay soils, (*b*) clay loams. "The results of chemical analysis," he says, "are sufficient to distinguish the Oxford clay series from all the other clay formations dealt with in this paper, for the percentage of calcium carbonate and phosphoric acid is extremely low in all the samples taken from this series."

The analyses submitted, however, in no wise support the assertion, for the percentage of phosphoric acid for the clay loam formation averages 0·13 per cent., which compares with the average for the dark greensands (0·15 per cent.), the heavy valley gravels (0·17 per cent.), the boulder clays (0·17 per cent. and 0·15 per cent.), and the brick-earths (0·14 per cent.), while the $CaCO_3$ for the samples given is 0·47 per cent., 0·70 per cent., and 0·06 per cent As for the pure-clay soils in this series, it is scarcely fair to generalize, seeing that the analysis of only a single sample is given. Moreover, one of the three samples of clay loam analysed shows only 0·06 per cent. of $CaCO_3$, a feature which has been cited as characteristic of the greensand series. Lastly, we may refer to Foreman's paper,* which shows that the Oxford clays of Cambridgeshire are phenomenally rich in $CaCO_3$.

"Again," says Rigg, "mechanical analysis at once reveals the necessity for a subdivision into two soil formations, since there is a constant difference of 9 per cent. in the percentage of clay found in the two soil formations mapped from field observations." This is true, and it shows that this clay loam formation, though derived from the Oxford clay, is, as judged by the mechanical analyses given in the appendix, really quite like the clay loam formation of the boulder clay series and the glacial clay; while the pure Oxford clay is quite similar to the pure Gault clay.

The table showing the distribution of crops (abridged below) brings to light the same fact: the clay soils, *of whatever geological formation*, mainly carry legumes and cereals, while the clay loams, of whatever geological formations, are characterized by a greater variety of crops.

DISTRIBUTION OF PRINCIPAL CROPS, MARKET-GARDEN DISTRICT OF BIGGLESWADE.
(After T Rigg. Figures give percentage of total area occupied by crop.)

Crop	Pure-clay Soils			Clay Loams			
	Oxford	Gault	Boulder	Oxford	Boulder	Brick-earths	Glacial
Cereals ..	72·5	63 5	62·5	25·0	31·9	40·0	36·5
Legumes ..	14·3	14·4	10·3	6·3	4·7	1·3	4·2
Potatoes ..	2 2	2·4	5·5	14·2	16·3	20·7	21·0
Brussels sprouts ..	1·9	4·9	8·3	23·5	21·3	16·9	19·8

Rigg's account of the "characteristic properties and agriculture" of the soils emphasizes the same facts—that agriculturally clay soils, of whatever geological origin, are alike; and the same applies to loams.

Referring to the Gault clay, Rigg says that the "content of calcium carbonate distinguishes it from the Oxford clay formation." To prove this, however, he cites only one analysis of each. It may also be noted that two soils of the three analysed from the "redlands" formation (Gault clay series) have only 0·05 per cent. and 0·09 per cent. of $CaCO_3$. Moreover, Hall and Russell's analyses show that the Gault clay soils of their district are by no means rich in $CaCO_3$—one has as little as 0·01 per cent. —so that Rigg's generalization from the analysis seems totally unjustified. Finally, Rigg concedes that in other respects the Oxford clay "resembles the Gault clay very closely."

After a careful review of Rigg's paper the present writer concludes that in classifying for agricultural purposes the soils therein described—

(1.) Geological origin is relatively unimportant.

(2) Mechanical analysis and physical structure are all-important.

(3.) The clays of all three geological formations resemble one another in more numerous and in more important points than they differ from one another; and the same statement applies to the loams and to the lighter soils.

(4) A simple classification showing three series only—clays, clay loams, sandy loams—would be more useful from the agricultural standpoint. Subdivision of these series into "facies," determined by geological origin, might follow if desired for detailed description.

* F W. FOREMAN, Soils of Cambridgeshire, *Journ. Ag. Sci.*, vol, 2, 1907, p. 161.

We shall turn now to another example of soil classification by similar methods—" Soils of Cambridgeshire," by F. W. Foreman.* In an introductory note Professor T. H. Middleton says, *inter alia,* " We were anxious to ascertain whether there exists any close connection between local soils and the underlying rock formation " ; and he comes to the conclusion that " the majority of the mechanical analyses do show a relationship between all the soils on the one formation."

The soils are treated in the following order :—

Clay Soils—
- Boulder clay.
- Gault.
- Kimeridge clay.
- Ampthill clay.

Sandy Soils
- River gravel.
- Lower greensand.

In the following table the more important analytical results for the soils of the various clay formations are averaged and summarized for convenience of comparison :—

SUMMARY OF FOREMAN'S ANALYTICAL RESULTS.

—	Boulder Clay	Gault	Kimeridge and Ampthill Clays *	Oxford Clay
Coarse fractions† .	30·58	18·0	29·93	24·90
Silt ..	12·97	9·54	13·77	12·76
Fine fractions‡ .	38·77	50·03	40·60	42·17
Clay	25·77	33·12	26·84	29·25
Loss on ignition .	9·03	10·62	9 13	9·15
$CaCO_3$	2·16	5·23	0·184	4·07
P_2O_5 .	0·115	0·121	0·108	0·134
K_2O	0·922	1·194	1·091	1·09

* Foreman says, "Ampthill clay very closely resembles Kimeridge clay, and the soil derived from it was similar to those from the Kimeridge in every respect "

† Fine gravel, coarse sand, and fine sand

‡ Fine silt and clay

The only outstanding features revealed by this table are (1) the markedly high clay content of the Gault, which admittedly distinguishes it from the rest ; (2) the markedly low $CaCO_3$ content of the Kimeridge and Ampthill clays.

The boulder clay differs from the Kimeridge clay only in having a higher content of $CaCO_3$, though itself in need of lime, we are told The Gault differs from the Oxford clay only in having a rather greater percentage of the finer fractions. If, however, we take into consideration the analyses given by Rigg of soils from the same geological formation in the adjoining County of Bedfordshire, we find some of these discrepancies completely removed. Thus the average percentage of clay in the pure Gault is 29·3, in good agreement with 29·5 in the Oxford clay soils. We note also that Rigg cites as characteristic of the Oxford clay that " the percentage of calcium carbonate and phosphoric acid is extremely low in all samples taken from this series "—a conclusion in total disagreement with the results of Foreman shown in the table above.

Both Rigg and Foreman claim that their results show that each geological formation gives rise to soils possessing certain characteristic

* *Journ. Ag. Sci.*, vol. 2, 1907, p. 160.

properties. The characteristic properties cited by each for the same formation are, however, frequently the exact opposites of one another, although the soils examined were in adjoining counties. Thus Rigg shows that Oxford clay soils are poor in calcium carbonate, while Foreman proves that they are rich in that substance. Both quote the Gault clay as extremely rich in $CaCO_3$, while Hall and Russell say, "The most typical Gault soil is deficient in calcium carbonate: all the samples analysed show less than 0·05 per cent. of calcium carbonate, except No. 30."

These results certainly do not furnish convincing proof that a given geological formation gives rise to a soil differing consistently from the soil derived from another geological formation. In Cambridgeshire, for example, there are clay soils from five different geological formations, but these soils do not differ in really important characters, and such differences as do occur are frequently not carried consistently even into the adjoining county.

Foreman will now be followed in his account of the other properties of these soils described by him. For convenience of comparison these are brought together into a concise summary.

A. *Soils of the Boulder Clay.*

1. Colour: "Brownish."
2. Texture: "Extremely tenacious." Almost impossible to obtain a satisfactory tilth, except in very good seasons.
3. Crops: Barley, oats, wheat, clover, beans, or mangolds—fair to moderate. Undrained land carries very poor pasture; greatly benefited by basic slag.
4. Weeds: Abundant—(1) *Avena fatua,* (2) *Ranunculus repens,* (3) *Brassica sinapis,* (4) *Sonchus arvensis,* (5) *Carduus arvensis,* (6) *Carduus acaulis,* (7) *Rumex crispus,* (8) *Galium Aparine,* (9) *Agrostis stolonifera.* In small quantity—(11) *Stellaria media,* (12) *Senecio vulgaris.*

B. *Soils of the Gault.*

1. Colour. Light ("thus readily distinguished from those of boulder clay").
2. Texture: "Very stiff and sticky"; "difficult to till, a bare fallow is absolutely necessary at frequent intervals."
3. Crops: Wheat, clover, barley, oats—fair crops in favourable seasons.
4. Weeds: Abundant—(13) *Taraxacum dens-leonis,* (14) *Tussilago farfara,* and (2), (5), (7), (3), above. In small quantity—(15) *Euphorbia Peplus,* (16) *Geranium molle,* (17) *Veronica agrostis,* (18) *Potentilla reptans,* (11), (12), above.

C. *Soils of the Kimeridge and Ampthill Clays.*

"Ampthill clay very closely resembles Kimeridge clay, and the soil derived from it was similar to those from the Kimeridge in every respect."

1. Colour: Dark brown.
2. Texture: "Very stiff, sticky, and troublesome, necessitating a frequent bare summer fallow."
3. Crops: Wheat, oats, clover, beans—fair to moderate.
4. Weeds: Abundant—(1), (14), (3), (5), (6), (7), above. Fairly prevalent —(13), (11), (8), (16), (17), above.

D. *Soils of the Oxford Clay.*

1. Colour: Shade darker than Gault.
2. Texture: "The soils are not quite so sticky as those of a typical Gault, but in all other respects they are much the same"; "bare fallow is necessary."
3. Crops: Clover, beans, wheat, barley, oats—fair crops in good seasons; basic slag a profitable manure.
4. Weeds: Abundant—(14), (3), (2), (5), (7), (16), *Anthemis Cotula, Sherardia arvensis.*

Discussion: This summary makes it perfectly clear that all these clay soils resemble one another closely so far as their agricultural properties are concerned. Their textures are the same, their crops, and their weeds. Bearing in mind, therefore, the purposes of a soil survey it would be much more useful to group them all together in one series. Thus we arrive at the following conclusions:—

1. The generalization that each geological formation produces a unique soil type is not justified.

2. On the contrary, clays from all formations resemble one another as closely as possible in all essential agricultural characteristics—namely, in texture, in cropping-capacity, and in methods of farming; and the same remarks apply to loams.

3. The rigid application of the geologico-chemico-petrographical method of classification used in recent British work leads only to a needless multiplication of soil series and formations. (Rigg finds seven series in the Biggleswade district, subdivided into fourteen formations.)

4. In exceptional cases a geological formation may consistently give rise to a unique type of soil—for example, it appears that soils on the greensand always have an exceptionally high percentage of coarse sand.

Returning now to Tulaikoff's summary of scientific classifications (p. 476), there still remain—(3) the *physical*, according to the mechanical composition and the physical characteristics derived from it; and (4) the *combined classification*, by which soils are divided into groups—for example, according to mechanical composition—and subdivided according to either their chemical composition or other features. The fourth method embodies the principle of the third, and we may conveniently discuss them together.

It will be seen at once that mechanical composition, on which soil-fertility so much depends, is given due prominence; while that misleading feature, chemical composition, is properly suppressed. This is the method of classification adopted by the United States Bureau of Soils. With them the series is the central term. A series is a group of soils having a common origin, and agreeing in such physical characteristics as colour, and differing only in texture. The units of which the series is composed are called "types." Thus the Miami series includes the Miami gravelly loam, the Miami fine sand, the Miami silt loam, &c. Altogether there had been recognized, in 1909, 715 different types of soil, classified into eighty-six series, which again are grouped into thirteen great soil provinces. The broader grouping into soil provinces "depends upon certain similarities in the soil, due in part to the character of the original material and in part to dominant agencies operating in the formation of the soils," such as climate, heat metamorphism, oceans, rivers, volcanoes, topography.

Any one studying Milton Whitney's bulletin* on the soils of the United States with a view to getting clear ideas as to their criteria of differentiation will be disappointed in the rather rambling, not to say ambiguous, way in which the information is given. It is believed, however, that the following is an accurate summary of the more important of their criteria of differentiation within the various divisions :—

Soil province: Climate, and mode of formation (distinct from geological origin).

Soil series: Colour†; mode of origin; structure(?) as distinct from texture; nature of subsoil to depth of 3 ft. to 6 ft.

Soil type: Texture.

It will be observed that this scheme is less likely to create distinctions where there is little or no difference, being based on those properties which play the largest part in creating differences in the agricultural characters of soils.

The present writer proposes for this Dominion a method of soil-classification similar in principle to the above, but differing in the significance of the terms "series" and "type" (formation) in ways that will presently be explained. Arguments in its favour which are of general application have been brought forward already; and in the next section arguments that apply more particularly to our special New Zealand conditions will be submitted to the reader.

II. Method of Soil Survey for New Zealand.

It has been shown in the preceding section that the application of the geologico-petrographical method of classification in England has resulted in a multiplication of soil formations even within small areas, many of these formations being exactly similar so far as concerns their agricultural potentialities. As it has been proposed to apply this method to a soil survey of New Zealand, it is necessary to add one or two arguments that, in the writer's opinion, totally discount the applicability of this method to the soils of this Dominion.

In the first place, even assuming the success of the method in England, we must draw attention to the very different conditions here. England is a country roughly triangular in shape, of relatively low elevation, and covered to a considerable extent with soils formed *in situ*. New Zealand is a long and narrow country ranging through a thousand miles in latitude, dominated by a mountain axis of great altitude, and bordered on either flank by plains formed from the material carried down from these mountains by rivers and streams. These plains comprise a great portion of the agricultural land of the country. Many of them in both Islands are formed from the detritus of the main axis, which, throughout a great part of its length, is of tolerably uniform geological structure. The plains so formed should therefore, in a geologico-petrographical classification, be put into the same soil group.

But it has already been shown that the features chiefly responsible for the productivity of a soil are, in order of their relative importance,‡ (1) climate, internal and external; (2) texture; (3) composition; (4) nature

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* U.S. Dept. of Agric., Bureau of Soils, *Bull. No. 55.*

† Colour is considered an important indicator of soil-fertility conditions by the United States Soil Survey, though why this is so is not apparent.

‡ These factors cannot be arranged in a rigid order of importance, as they react on one another.

of subsoil. Now, not only are there found in widely separated districts—*e.g.*, the Wairarapa and Canterbury Plains—soils of similar geological origin but of diverse agricultural properties owing to differences in climate, but the same thing is found even in areas of narrow limits. Thus within a few miles of Lincoln there are three different types of soil: (1) The heavy clay loam on sandy-clay subsoil of Lincoln; (2) the silty loam on fine sandy subsoil of Tai Tapu; (3) the light gravelly soil on gravel beds of Burnham.

All these soils are, of course, derived from the same kind of material (petrologically), and two at least are of similar mode of formation; they experience in general the same climatic conditions; and they are of about the same chemical composition. But because of wide differences in their textures and in the nature of their subsoils the methods of farming them are entirely different.

The writer does not deny, however, that sometimes a geological formation does give rise to a peculiar soil type—as, *e.g.*, the Lower Greensand in England. In the North Island the rhyolites and pumice of the central volcanic plateau seems to be of such a type; while in Otago the mica schists probably produce a type of soil unique physically because of the presence in amount of flat plates of mica.

In a classification of the soils of New Zealand, therefore, it is urged that the great divisions must be decided on by climatic considerations—as, indeed, nature has already indicated in the distribution of her own vegetation—while soil texture must be looked to as the main guide in further subdivision. Geological formations that give rise to soils of peculiar type must, however, be recognized, and this may be done in either of two ways: (1) by throwing such areas outside the general scheme of classification, or (2) by subdividing according to geological structure the primary divisions (see "Soil districts," below) based on climatic differences.

At this stage it will be well to take into consideration some suggestions made by Mr. H. T. Ferrar at the meeting of the Canterbury Philosophical Institute at which the first part of this paper was read. He pointed out that, as the detailed work of soil-surveying is first directed towards a classification of the cultivated land, a preliminary division of the country on soil-utilization lines is useful. He suggested that there should first be marked out: (1) Unproductive areas—*e.g.*, the mountainous region of south-west Otago; (2) areas capable of being made productive—*e.g.*, North Island forests; (3) areas that cannot be other than pasture—*e.g.*, tussock mountain-slopes; (4) areas available for cultivation. To the last two classes of land attention would naturally first be paid; the third class is capable of being made to carry more stock when the most appropriate grasses have been experimentally determined; while the fourth class includes land the productiveness of which can be raised by the discovery of the most suitable systems of cropping and manuring.

Definition of Terms used in the Proposed Scheme of Classification.

Soil districts: The great divisions based on climatic factors we propose to call "soil districts." The United States Bureau of Soils uses the term "soil province" in this sense, but in our country this term would obviously lead to confusion with the political divisions of that name.

Subdistricts: If geological formations occur within a soil district that give rise to soils of peculiar type the district is to be subdivided accordingly.

Such subdivisions are to be called "subdistricts." It must be emphasized, however, that such subdistricts are not to be recognized unless their soils possess unique agricultural properties, and unless such properties are directly due to geological factors.

Soil formation: The unit in our proposed scheme is the soil formation. This term is universally employed, though not by any means always in the same sense. We propose the following definition: A "soil formation" is a geographically continuous area covered by a soil uniform throughout as regards mode of origin, climatic conditions, texture, profile, and composition, and therefore as regards all agricultural properties. By "profile" is meant the soil section down to a depth of, say, 4 ft.

If one held rigidly to this definition a soil formation of any considerable size would not be found: every farmer will declare that he has two or three kinds of soils on his farm. Nevertheless, areas of some magnitude, thirty to forty square miles and upwards, do exist in which the exceptional parts are relatively so small as to be negligible, and such areas can conveniently be studied as units.

Soil series: A "soil series" is defined as a group of separate formations alike in the aggregate of their agricultural properties. The formations need not necessarily be identical in every respect, but if they agree so far that their agricultural properties and potentialities are the same they are put into the same soil series. To give an illustration: The Lincoln formation differs in some respects from the Methven formation—their subsoils, for instance, are not alike; that at Lincoln is a sandy clay, while that at Methven is more porous. But the smaller capacity of the Methven soils to retain water is compensated by a rather greater rainfall, so that agricultural practice on each formation is very similar. These formations are therefore put (provisionally at least) in the same series.

Facies: It has been said that a formation will usually include small areas with exceptional characters. These are not likely to be delineated or described until the individual formations come to be studied in detail, and when this stage is reached the term "facies" may be appropriately applied to them. Thus the typical soil of the Lincoln formation is a clay loam on a deep sandy-clay subsoil; but near Lincoln College there is a strip of gravelly soil in a shallow sandy-clay subsoil, on gravel beds. This exceptional area is more or less clearly marked, and constitutes a "facies."

Nomenclature.

The soil districts may conveniently be described in geographical language, thus: The Canterbury Plains district, the North Otago district, the Wellington East district, and so on. The series-names obviously should not be place-names, as the idea of a series is simply a set of soil formations of like agricultural properties. It is suggested, therefore, that the most suitable form of name is one indicative of the more important characters common to the formations constituting the series—as the Loam-on-clay series; the Alluvial series; the Scrub-lands series; the Downs series. The formation, being a geographical entity, is best named after some local place name. This need not be the most important place politically, but should be that place where the soil is being studied by means of continuous field experiments or otherwise. Thus the experimental farms should give their names to the local forma ion—as, *e.g.*, the Weraroa formation, the Ruakura formation.

Recapitulation

The writer submits the following proposals regarding the proposed soil survey of the Dominion:—

(1.) A combined system of classification is best suited to New Zealand conditions.

(2.) The Dominion should first be divided into soil districts, the critical differences being climatic; and districts may be subdivided into sub-districts if important differences in agriculture due to geological structure so demand.

(3.) Within the soil districts the limits of individual soil formations must be determined by study in field and laboratory, the critical differences being (*a*) mode of origin, (*b*) texture, (*c*) situation with reference to water-supply, (*d*) profile, (*e*) composition.

(4.) Formations alike as regards chief agricultural properties and potentialities should be grouped into series, so that full use may be made of the results of field experiments.

Finally, we may represent our scheme of classification diagramatically as shown below:—

Soils of New Zealand

Unproductive. | Capable of being made productive. | Pasture only | Suitable for cultivation.

Soil districts.

Soil formations (grouped into soil series).

III Application of Principles

In this section an attempt is made to apply some of the principles advocated above by a consideration of the soils of the South Island.

Following is a provisional list of the soil districts It is open to revision or even to complete recasting, because it has been shown that the proper demarcation of district boundaries involves a knowledge of the meteorology, the geology, the botany, and the topography of the Dominion—in fact, it is the work of a committee rather than of an individual In practice a knowledge of the distribution of the native flora should be of first-class importance; when the ecologist has shown us the boundaries of the plant provinces it will probably be found that the same boundaries will serve for the soil districts.

Soil Districts of the South Island, New Zealand

1. South Marlborough District: Bounded on the north by the Wairau Valley (included), on the west by the average limit of the western rainfall, and on the south by the Waipara Valley (excluded). Mean annual rainfall, 25–40 in.

2. Canterbury Plains District: Bounded on the north by the Waipara Valley (included), on the west by the average limit of the western rainfall, and on the south by the Waitaki Valley (included) Mean annual rainfall, 18–26 in on the coastal margin, 25–40 in. inland

3. Banks Peninsula District: Banks Peninsula Mean annual rainfall, 30–50 in.

4. Central and North Otago District: Bounded on the north by the Waitaki Valley (excluded), on the west by the limit of western rainfall, and on the south by a line joining Queenstown and Palmerston. Mean annual rainfall, 15–30 in. (Note: A subdivision of this district will probably prove necessary.)

5. South Otago District: Bounded on the north by a line from Palmerston to Queenstown, thence to Manapouri, thence (including the Mossburn, Five Rivers, and Waimea Plains) along the Mataura Valley (excluded) to the sea.

6. Southland District: Bounded on the east by the Mataura Valley (included), on the north by the South Otago District, on the west by the Waiau Valley (included). Mean annual rainfall, 40–60 in.

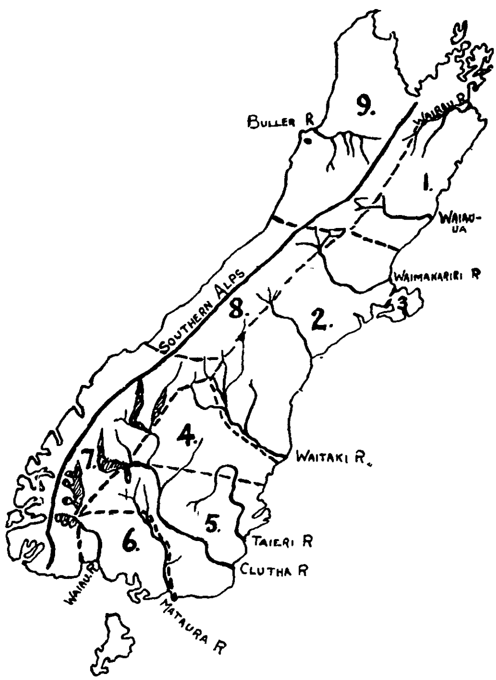

FIG. 1.—Soil districts of the South Island, New Zealand.

1 South Marlborough. 2. Canterbury Plains. 3. Banks Peninsula. 4. Central and North Otago. 5. South Otago. 6. Southland. 7. Sounds 8. Westland. 9. Nelson.

7. Sounds District: Bounded on the east by the Southland and South Otago Districts to Queenstown, thence by the limit of western rainfall to the Haast River. Mean annual rainfall, 100–200 in.

8. Westland District: Bounded on the south by the Haast River, on the east by the limit of western rainfall, and on the north by the Taramakau River. Mean annual rainfall, 100–150 in.

9. Nelson District: Bounded on the south by the Taramakau River, on the east by the limit of western rainfall as far north as the Wairau Valley, thence along the Wairau Valley (excluded). Mean annual rainfall, 30–100 in. (Note: A subdivision of this district will probably prove necessary.)

Fig. 1 shows the approximate boundaries of these districts.

We further suggest a standard method for the description of a soil formation. One advantage of the methods of soil survey proposed in this article is that the whole is built up from small units. It will be possible for the qualified teachers of agricultural science in the schools and colleges throughout the Dominion to describe the soil formation on which they are located; so that gradually, as information accumulates, the formations may be grouped into series, and practical conclusions of some importance may be expected.

Scheme for Description of Soil Formation.

1. Boundaries: Roads or railways will usually be found most suitable until the exact boundaries can be determined in detail. Rivers and hills will usually be unsuitable, as lying wholly within or wholly without the formation.

2. Physiography and topography: A general account of the more important physiographical features, such as rivers, hills, &c.

3. Mode of formation of soil, whether sedentary or transported; water-supply, surface and subsurface.

4. Meteorological statistics so far as available: Rainfall, average annual fall, and seasonal distribution; mean monthly temperature, maximum and minimum; amount of bright sunshine; quality and quantity of wind

5. Mechanical analyses of samples taken on an average of one per square mile: Soil should as a rule be taken 6 in. deep, subsoil (the next layer) 6 in. deep

6. Chemical analyses of composite samples representing uniform areas of ten or twelve square miles: The chief determinations should be of lime, magnesia, phosphoric acid, and potash soluble in strong hydrochloric acid Organic matter may be determined as loss on ignition The amount of calcium carbonate will often be a matter of importance A lookout should always be kept for any connection between the amounts of the minerals and the manurial requirements of the soils.

7. Profile · This can usually best be represented by a sketch, the various materials being conventionally represented as shown in fig. 2

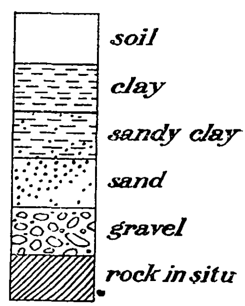

Fig. 2.—Conventional sketch of a soil profile.

8 Information from experienced farmers on the formation regarding crops, manures, and cultivation best suited to the soil.

9. Results of any reliable manurial or varietal experiments that have been made.

10. Lists of prominent weeds, especially those of untended land

It should be clearly understood that the primary object of the preliminary local work is not an attempt to discover the "philosopher's stone" of the local agriculturist. The first aim is descripton; then comes correlation—an attempt to connect the practical field observations with analytical and other results obtained in the laboratory; finally, when sufficient results have been collected and compared, will come inference—the laying-down of such rules of practice the proof of which has been found in the previous systematic study.