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A GUIDE TO THE BUD-GRAFTING OF RUBBER IN PAPUA AND NEW GUINEA

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THE production of high yielding strains of plants or animals is usually brought about by selection with or without preliminary cross-breeding. The importance of natural rubber from the rubber tree *Hevea brasiliensis* is very great in spite of its relatively late appearance in the world as a major economic crop, and a great deal of investigation and experimental work have been carried out with this crop. The results have been most encouraging. It is an established fact that trees from clonal seed or bud-grafts can yield several times as much rubber as unselected seedlings.

Early investigators proved that relatively few rubber trees were responsible for the bulk of production in seedling stands. The property of high yield is most easily fixed by asexual or vegetative propagation which permits the production of an unlimited number of individuals with exactly the same characteristics as the parent plant. Vegetative propagation can be carried out by means of cuttings, layers, runners, buddings, and other means. With rubber, budding has proved to be the most satisfactory method of propagation. Had the earliest clonal selections been entirely satisfactory, no further investigation would have been necessary and the planter would need only to propagate vegetatively from such selections indefinitely. Such a situation has occurred with many varieties of fruit trees which are still as much in demand as the first buddings made centuries ago. However, geneticists assumed that by permitting crosses to occur freely between high yielding trees or by hand pollination of high yielding clones (a clone is the vegetative progeny of one parent plant), still better material might be obtained. This has proved to be the case with rubber, and some new clones produced by selective hand pollination have given early yields in small scale trials up to about 2,000 lb. of dry rubber per acre. The average annual yield of mature rubber in the Territory is just under 400 lb. per acre. All trees have originated from unselected seed or at least from seed from uncertain sources.

This article has been compiled as a guide to the bud-grafting of rubber. There can be no doubt that the planting of budded stumps entails a certain amount of extra work and care when compared with the use of either unselected or clonal seed. These facts must be faced and balanced against the ultimate benefit to be derived from bud-grafting before a planter can estimate whether it is worth his while to overcome the obstacles to planting say 100 or more acres of bud-grafts per year. Planting on a much larger scale than this has been carried out in all major rubber producing countries since the war, and more recently in West Africa. Bud-grafting has been adopted not only by some of the biggest estates, but also by small holders. The theory that bud-grafting is not practical in this Territory cannot be supported as it

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would infer not only ineptitude on the part of the indigenous population to learn the necessary techniques, but also of the management to handle the problems associated with the use of bud-grafts.

This article is a summary of experience gained at Bisianumu over a period of three years and should be of assistance to planters, although no guide can make up for experience. Little that is written here deals with original techniques and much is owed to the experience of workers overseas.

The Principles of Bud-Grafting.

A small patch of bark with a dormant bud in the centre is removed from a tree with high yield and other desirable characteristics. At the same time a vigorous seedling between one and two years of age is prepared by peeling off a patch of bark similar in size to the bud patch. The bud patch is then inserted on the seedling stock in such a way as to secure a permanent living union. Quick and careful manipulation is essential to minimize damage to the active cells on the exposed part of the bud patch and stock. If much damage is done to these cells, the operation will be a failure and the bud patch will die, but when successful, the unharmed cells divide and form a perfect union. After the bud has taken it is necessary to ensure that no other bud from the stock is allowed to develop. In this way the new tree has all the characteristics of, and is genetically identical with, the one from which the bud patch was chosen. A detailed description of the preparations for budding, each step of the budding process and the necessary after care will now follow.

1. *Preparation of Seed Beds.*—

Budding may take place either in nurseries or in the field. Budding in the nursery will be dealt with first, although much of what is said will apply equally to budding at stake in the field.

The first step for nursery budding is the preparation of seed beds at least twelve months before budding is to commence. A level site is desirable and a small alluvial flat which is handy to water but not liable to flooding or waterlogging is most suitable. Seed beds are dug to the usual depth of 2½ feet to 3 feet. Shade should be provided at a height of about 3 feet and the usual type of shade is a rough wooden framework covered with kunai grass. Seeds should be planted about 12 inches apart in rows 2 feet apart. It is advisable to plant two or three seeds at each point and rogue later to the most vigorous seedling. Rogueing is best carried out just after the removal of the shade. When the shade is removed it is very desirable that the kunai grass be spread as a mulch between the seedlings, a practice which is indubitably beneficial to their growth. A rather wide spacing when compared with spacing in ordinary seed beds is necessary to allow the operator to work efficiently when bud-grafting is performed, and it also makes for more vigorous and healthy stock from which the bark will peel more readily.

The width and length of beds is a matter of convenience, although it is probably desirable to have not more than four rows in one bed for ease of working. The total area of beds, of course, depends on the area of bud-grafts which it is intended to plant in the field. The nursery should contain at least twice as many seedlings as it is intended to plant out as bud-grafts into the field, and when the bud-grafters are relatively inexperienced it is probably wise to grow three seedlings for every bud-graft which will eventually be required. It is not necessary to use any special or clonal seed for nursery stock as investigations have indicated the complete suitability of unselected seedlings for this purpose. At about twelve months to fifteen months vigorous stock suitable for budding should be ready provided the beds have been well prepared and the usual rubber nursery practices such as adequate watering and weeding are not neglected. Good stock ready for bud-grafting should be somewhat over 1 inch in diameter at ground-level with a straight unbranched stem, a straight unbranched taproot, about 7 feet or more in height, and in a state of active growth so that the bark will peel easily when it is lifted with the knife.

2. *Tools and Materials.*—

It is advisable to order tools when seed beds are prepared as most are not available locally, and there is thus some lag before delivery. It is, of course, wise to order more than actual requirements so that losses and breakages will not interfere with progress. For bud-grafting rubber, all that is required is a budding knife and a set of templates.

Fig. 1.—A nursery of seedling stocks ready for budding. [Photo G. Warr.]

One of the templates recommended cuts a standard sized piece of bark from the scion with the bud in the centre, and the other makes a double incision in the bark of the stock which matches exactly the size of the bud piece removed from the scion. Both budding knifes and templates may be obtained from Hunter & Co., P.O. Box 214, Colombo, Ceylon. Budding knife 1131 costs approximately £1, and the pair of templates approximately 10s. per set. Other tools which may be required are sharp kitchen or pocket knives, pruning saws, labels, tree sealing compounds and a pair of secateurs. Bagging twine is a satisfactory tying material and is available in hanks at about 4s. each. At least six dozen hanks should be ordered if serious budding on any scale is intended.

Calico strips specially prepared by dipping in a mixture of molten paraffin wax, resin and tallow were previously used almost universally as a tying medium. This tying medium is not only tedious to prepare and expensive, but has been found to be less successful than the cheap and simple method using coconut fronds which will be described later. Coconut fronds are available almost everywhere in the Territory where rubber is grown, and a fresh frond will be required every day or two when budding on any scale is attempted although a frond remains fresh enough for use for about one week after cutting. 1 inch masking tape used in conjunction with coconut fronds has boosted the percentage of takes somewhat, but the expense is probably justified only when using expensive imported budwood.

3. *Budwood.*—

Budwood should be obtained when the seedling stocks are ready. The sources of suitable budwood are restricted and the type should be carefully chosen. The taking of budwood from a local tree which seems to be high yielding is unsound. The slight possibility of selecting a superior clone cannot be denied, but it is most unlikely that a chance selection would be the equal of the commercial clones evolved by major rubber producing countries over a considerable number of years. The major rubber producing countries have rubber research institutes with highly trained staff with long experience, and there are also very large private firms in Malaya and elsewhere which are engaged in the production of superior clones. There are at present more than a dozen clones which are recommended for planting out on a moderate or large scale. The distribution of some clones is likely to be restricted, a kind of patent being held on these clones by their producers. There are, however, a few free clones available which are worth establishing on plantations as well as certain restricted clones. A few good clones were introduced into the Territory before the Department began work at Bisianumu, but in some cases the subsequent history of these clones is uncertain and their identity doubtful. Accordingly the Department has in recent years reintroduced all the older clones and a wide range of new material. Budwood may be purchased from overseas, but the Department of Agriculture, Stock and Fisheries is now in a position to supply limited quantities of budwood from Bisianumu. Twenty yards of budwood should make a good nucleus for working up a multiplication area from which budwood can be cut in due course for large scale budding. With some of the most expensive new clones just one or two yards is sufficient to establish the clone and multiply it in the plantation nurseries.

Good budwood should be not less than 1 inch and not more than 2 inches in diameter. It should have at least fifteen well spaced buds per yard and should be of a rusty brown colour. The bark should strip easily. It is essential that the budwood be sufficiently mature to have developed a brown or greyish colour if it is not to be used immediately. If cut from the multiplication nursery on a plantation for immediate local use, it can be cut two days in advance without fear of deterioration. Green budwood can be satisfactory if it is cut and worked the same day. If budwood is to be despatched for any distance the ends should be dipped in paraffin wax to prevent deterioration or decay. Budwood which is to be sent away is best packed in some insulating material like sawdust, coconut fibre, or hessian, the packing material being slightly moistened. Budwood received from overseas is usually dusted heavily with sulphur to prevent transmission of fungal diseases and it is wise to wipe imported budwood sticks with a moist cloth before use. Care should be taken to wipe in the direction of growth, that is from the thick to the thin end, so as not to injure the buds. Budwood is always sold in sticks one yard long which should be straight and it is the usual practice to enclose an extra yard or two if the budwood does not come up to the specifications mentioned above.

4. *Multiplication Beds.*—

The best budwood is obtained from multiplication beds or budwood nurseries. It is remarkable how small a quantity of good budwood can be obtained from mature trees and the establishment of a budwood nursery is essential if large scale budding is contemplated. The establishment of multiplication nurseries is also a good way for a beginner to get experience in handling budwood. Another advantage of the establishment of multiplication nurseries is that it is possible to increase the supply of expensive budwood greatly in these nurseries before commencing budding on a large scale for the establishment of a clone in the field.

The site for a permanent budwood nursery should be chosen in the same way as the site for the temporary nursery beds. For permanent budwood nurseries a spacing of 4 feet by 4 feet is recommended with only two rows per bed. Successful buddings can be transplanted from temporary nurseries or alternatively stocks can be budded at stake. Another simple way of establishing the permanent nursery is to leave the right number of buddings in a temporary nursery after the rest have been removed and planted into the field. If more than one clone is being established in a multiplication plot it is desirable to miss a row of trees or make a very distinct mark in some way to prevent possible confusion. Labelling can be carried out but should not be relied upon entirely as tags come off and labels become indecipherable over a period of time. The only certain way to exercise satisfactory control with regard to the nomenclature of clones, date of budding, etc., is to make a careful diagram of the area and keep the records up to date. This is equally important with nurseries, multiplication plots and field plantings.

Good budwood should be available from permanent nurseries about fifteen months after budding, when one or two yards per tree can be expected. If left for eighteen months the quantity should be increased to 2 to 4 yards per tree. The budwood nursery should be regularly inspected and side shoots cut out in order to produce straight sticks of high quality budwood. When cutting budwood from a multiplication tree, the stick should be cut off about 1 foot above the union or what is known

Fig. 2.—A permanent budwood nursery. [Photo G. Warr.]

Fig. 3.—Cutting a stick of budwood from the permanent budwood nursery. [Photo G. Warr.]

Fig. 4.—Two new shoots have come away after cutting a stick of budwood from the nursery. [Photo G. Warr.]

as the " elephants foot ". This permits dormant buds to develop on the scion and two or three leaders can be permitted to take the place of the original one. Further care of the tree consists of cutting back from time to time and not allowing more than three shoots of no more than $2\frac{1}{2}$ inches diameter to develop. As from this nursery all budded trees will originate, extra attention should be given to weeding and pest and disease control, and an occasional application of fertiliser is recommended. It should be remembered that the drain of the nursery on nutrients is high because the trees are constantly being cut back.

5. *When to Bud-Graft.*—

A skilled operator will obtain reasonable success at any time. However, success is naturally greater under good weather conditions. Budding cannot be done successfully in the rain or when the stem of the stock is wet or water is dripping from the leaves. The best time to bud is on an overcast day when the tree is in full sap, the wintering period being best avoided. If a few dry days follow the budding operation and good showers then set in, it is certain that if successes are not as high as expected the weather has not been to blame. In the Sogeri district it has been found that September to February are the best months. The advantage of budding during this period is that the weather will usually be suitable for transplanting the successful buddings. Similar times will apply to most of the rubber areas of the Territory, although local variations may occur. Budding should commence early in the morning, as soon as most of the dew has disappeared. In the nurseries, budding can be continued throughout the day, but field budding should be discontinued in the middle of the day when there is hot sunshine. Naturally when using imported budwood or budwood which has already been cut for several days, work should proceed immediately even if conditions are not entirely suitable.

6. *Final Preparations for Budding.*—

Before starting to bud the operator should be equipped with a suitable small box in which his equipment is carried. He will need a budding knife, templates, as many coconut frond slips as he is likely to use during the day, and two hanks of bagging twine. The coconut fronds should be cut into slips about 4 inches long, and a good frond will produce 400 to 500 slips. A budder should also take as much budwood as he is likely to need, and leave it in a convenient shady spot or cover it with branches. Budwood should be carried carefully as it is easily bruised.

7. *Making the Incision in the Stock.*—

The incision should be made as low on the panel as possible, but not so low that it will be affected by rain and mud splashing from the ground. The best height is usually about 2 to 4 inches from ground-level. In order to mark stock uniformly the appropriate template should be used, especially by beginners. After some experience has been gained, it will be found that the use of the template can be dispensed with, thus speeding up operations slightly. In this case two parallel incisions are made with the budding knife $2\frac{1}{2}$ inches long and about $\frac{3}{4}$ inches to $\frac{7}{8}$ inches apart. A horizontal incision along the top joins the cuts. This process is repeated on as many stocks as can be worked up in about twenty minutes. A beginner is advised to mark no more that four or five stocks in advance. The advantage of

Fig. 5.—The stock prepared for insertion of the bud. [Photo G. Warr.]

marking stocks some distance in advance is that the latex has time to exude and coagulate and is less likely to contaminate the tissues underlying the bark. A speedy operator is not hampered by the flow of latex and can carry out the operation so quickly that the latex has no time to flow or coagulate. After the horizontal cut is made, and the bud patch has been cut, the bone end of the budding knife is inserted and just sufficient leverage is given to free the flap from the stock without breaking it off at the bottom.

8. *Choice of the Bud Patch.*—

When taking buds from a stick of budwood it is desirable to acquire the habit of working from the upper or thinner end downwards. In this way the younger and softer budwood which will deteriorate more quickly is used first and it is in any case better to work systematically from one end rather that taking buds at random as fewer buds are then lost. The loss of some buds is unavoidable as they are sometimes very closely spaced and an attempt to save all the buds by cutting them out with very small pieces of bark will prove unprofitable. A further advantage of starting from the top end and working down with Native operators is that it helps them to know which is the right way up to insert the bud.

A good bud should be dormant and should therefore not protrude too much when the bud stick is inspected. With expensive or scarce budwood all buds will be used, but if the budwood is plentiful the buds right at the end of the stock, which may be somewhat dried out, can be left. On many sticks of budwood a compact ring of fine horizontal leaf scars will be observed. These are produced when the shoot goes through a resting period or a period of slow growth between flushes. Bud patches taken from this region are quite satisfactory and it often happens that they produce two or three shoots. Sometimes when taking buds it is observed that what appears to be a bud is shown on closer inspection to be only the scar left by a bud which has shot and then dried back; this is quite useless. When the bud patch is removed the inner side should be inspected for bruises which show up much better than on the bark. If bruised, the bud should be discarded. If the bud is broken off internally, one will find a small pit or hole on the underside of the patch and a point left on the budwood stock. Such a bud is useless. Budwood which has been cut for a lengthy period without being used shows thin dark lines usually commencing from both ends. These are easily observed when the bud patch is lifted out. Little if any success can be anticipated when budwood has reached this stage.

9. *Lifting and Inserting the Bud Patch.*—

To cut and lift the bud patch the second template of the set is used. It is a rectangular frame with sharp cutting edges and a handle to apply leverage. The tool is applied to the budwood with the bud in the centre of the rectangular frame, the long axis of the frame running along the budwood. Slight pressure is exerted to cut through the bark, and a gentle twisting movement lifts the bud patch. The bud

Fig. 6.—Removal of the bud from the scion with the budding template.
[Photo G. Warr.]

patch is then removed from the template without touching the exposed tissue. The flap on the stock is gently pulled away and the bud inserted without touching the exposed tissue of the stock. Scraping or

Fig. 7.—Inserting the bud patch.
[Photo G. Warr.]

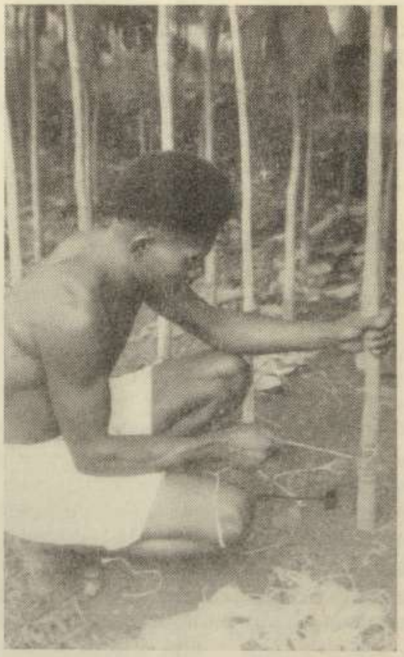

Fig. 8.—Tying. Note slip of coconut frond covering the bud-graft.
[Photo G. Warr.]

touching of the exposed surfaces of either stock or bud will result in certain loss. The same is true if any foreign matter is allowed to contact these surfaces. The flap is then pressed back on to the stock so that it exerts pressure to bring the cambium layer of the bud patch into close contact with the cambium layer of the seedling stock. Again it must be emphasized that the bud must not be allowed to move after it is pressed firmly against the stock. Any movement after this operation will damage the delicate tissues and cause certain loss.

10. *Binding and Shading.*—

Whilst the flap is held pressed against the stock, three short lengths of 1 inch masking tape can be stuck over the wound. It is advisable to start just over the horizontal cut so that everything is fixed firmly in position and then attach the other two strips slightly overlapping each other and coming half-way around the girth of the stock. The use of masking tape is not essential but at Bisianumu it has always boosted takes by a few per cent. If stock and budwood are in abundant supply, tape will be dispensed with as extra speed and lower cost

Fig. 9.—Shading the finished bud-graft with leaves.
[Photo G. Warr.]

will compensate for a small reduction in takes. The next step or the first step if masking tape is not used, is to press a coconut frond strip over the wound, the central vein of the frond facing outwards and running vertically up and down the stock. A length of twine is then wound around it as tightly as possible. The best method is to start from the top holding one end of the twine behind the stock, make a loop round the stock to fix the end firmly, run a few coils down to the lower end of the coconut slip, then run a few loops back to the top and tie firmly to ensure that water dripping down the stem cannot enter. Two or three rubber leaves tied on with string so attached as to shade the bud patch complete the operation.

11. *Opening up and Inspection.*—

After budding is completed plants are left undisturbed for seventeen to twenty-one days. If the weather during this period is dry it is best to wait the full twenty-one days, but if more than 2 inches of rain have fallen since budding was carried out, it is better to open up a few days earlier. The binding material is removed and the bone end of the budding knife inserted between the flap and the bud patch and the flap prised away and broken off so as to expose the complete bud patch. At this stage all writers on the subject recommend that the bud patch be scratched to find out whether it is still green. Although it is certainly true that patches which are already dead can be written off, not all bud patches which are still green can be counted as successful takes. Under favourable climatic conditions many of the bud patches will appear to be in good condition to any but the experienced observer, only to die off later. There thus seems to be no real advantage in this initial scratching and inspection and there are some disadvantages. It is recommended that the bud-grafters be trained when opening up to use the spatula of the budding knife with great care, inserting it gently and to the minimum extent which is necessary to open up properly, in order to prevent any damage to the bud patch. They can then go round ten days later to make the final inspection, which is necessary in any case whether the first inspection is made or not. Ten days is the minimum period which must elapse before the final inspection and a few extra days make no difference. It is most advisable that the final inspection be carried out by the person in charge of operations and not by the men bud-grafting, especially if it is intended to give bonuses for successful takes. Thousands of grafts can be inspected within a few hours if budding has been carried out in a nursery, and it is obviously worthwhile to undertake the small amount of work involved in order to minimize the risk of planting failures into the field or alternatively overlooking takes. The inspection is carried out by making two slight scratches with the point of the budding knife, one above and one below the bud. If they are clearly green all is well. If the bud has not taken, it may be very obvious when for instance the bud has fallen off, but sometimes the brownish discoloration of the bud patch when scratched is the only indication of failure. Even at this stage there may be doubtful cases. The scratch at the top may be perfectly green whilst the bottom is decayed or vice versa. Fortunately the portion of the bud patch surrounding the bud is always slightly thicker that the rest of the patch and is thus held in firmer contact with the stock and is therefore more liable to take. In cases where there is only partial discoloration of the patch it should be scratched carefully near the bud which will frequently be found to be alive.

12. *Re-budding.*—

After about two months, during which time successfully budded stumps should be removed and transplanted, failures and those seedlings which were not quite ready during the first round of budding can be done again. In the case of failures the incision should now be made on the opposite side either just above or just below the old wound. It is not worthwhile re-budding again any stock which has had two failures, as the trees have then reached the stage where they are likely to lose vigour or become infected with rotting organisms because of the damage. Such trees should be thrown away.

Stock, of course, becomes progressively larger when re-budding and a few remarks about larger stock are thus worthwhile. Larger stock very often gives just as many successful takes as stock of the optimum size. It may even get away more quickly when properly transplanted as it has more reserves to draw upon, but the real drawback with large stock is the additional work involved in pulling and planting out.

13. *The After Care of Bud-grafts.*—

Sooner or later the stock must be cut back to a stump. When budding is done in the field or stumped buddings are to be produced in the nursery, it is practicable to have one man doing the stumping at the same time as the final inspection is carried out. Cutting back should not be delayed more than two months after budding as the continuous physiological changes in the stock over a longer period gradually impair the effectiveness of the bud. The cut should be started 4 inches to 6 inches above the graft and sloping downwards to the side of the stock away from the graft so that rain or latex do not run on to the bud graft. A pruning saw is recommended for this purpose and a dressing to prevent the entrance of wood rotting fungi may be applied. After cutting back, the bud should begin to shoot, although some buds remain dormant for a lengthy period. A monthly patrol to cut off unwanted shoots developing from dormant buds on the stock is essential. This work can be left to budding operators who should by this time understand the object of the operation. The stems developing from buds usually show a slightly greater tendency than seedling stock to develop branches. The side branches should be cut off in the green stage. As mentioned previously, some bud patches contain more than one bud and when several shoots emerge, the most vigorous should be chosen and the remainder carefully removed while still young.

After a year of two, the snags, that is the dry dead stumps above the union, will fall or break off. Sometimes it takes longer and for the sake of appearance the operator may, if he desires, cut off remaining snags with a pruning saw immediately above the union, the cut being made on the same slope as when cutting back to stump the previous year.

14. *Transplanting.*—

Transplanting of budded material can be done either as budded stumps or stumped buddings. The obvious confusion which can occur on account of this nomenclature is unfortunate, but the terms are thoroughly established in the literature. A budded stump is a budded stock on which the bud-graft is still dormant and which is planted out within a relatively short time after inspection. A stumped budding is a budded stock which has been cut back in the nursery and there has undergone the necessary after care and is ready for transplanting about a year later. The advantages of planting stumped buddings are that they do not require much after care and can generally be treated like any rather advanced transplanted seedling. The disadvantage is the added difficulty and expense of handling stumped buddings when compared with budded stumps as the former have developed a strong root system, they are harder to pull, and planting holes must be larger. Before planting out, stumped buddings are treated in the same way as seedlings, that is all but a few inches of the green part of the plant is entirely removed. It is a good practice to keep a few buddings in the nursery to plant up any misses in a field planted with budded stumps. The supplies are then of the same age as the initial plantings and do not suffer the same set-back as would new budded stumps.

Budded stumps can be planted out in two ways, but only the second method which will be described in really recommended. The first method is to cut the stock back above the bud, in the way described in the paragraph on after care of bud-grafts, immediately after inspection and plant out within ten days. With careful transplanting this method undoubtedly works and when budded stumps are to be sent to plantations some distance away, they should be despatched in this manner because of the saving in freight. The second method which is generally recommended is to prepare the budded stumps when weather conditions are favourable in the same way as seedling stumps; that is cut them back close to the woody part of the stock at a height which will usually vary between 4 feet and 7 feet above the ground and endeavour to plant them out within ten days. When the stock begins to sprout it is apparent that transplanting has been successful. The stock may then be cut back to stump in the field and after care is the same as previously described. This second method of planting out has advantages when compared with the first, namely :—

(*a*) Should unfavourable weather conditions or other circumstances prevent immediate planting, no great harm is done as stock can be trimmed back again after commencing to shoot. If the first method is adopted the stump must either be planted immediately or left for another year to develop into a stumped budding.

(*b*) Handling when planting out is easier.

(*c*) Losses on transplanting can be detected at a glance which is not the case with short stumps.

When a surplus of budded stumps exists after the intended acreage is planted, they should be cut to stump in the nursery and left to grow into stumped buddings, when they will come in handy for replanting misses.

When transplanting from the nursery into the field, no notice should be taken of the height of the bud-graft or the union. It is of no importance at all that height should be entirely uniform, and trees must be planted at the same level as they stood in the nursery with the whorl of lateral roots just below ground-level.

When pulling stumped buddings, the tap roots will often be rather large. Any severe pruning is harmful and it is a sound rule never to prune more severely than a single cut with a sharp penknife will permit. Generally speaking no great trouble will occur with transplanting buddings as long as the best practices for planting seedling stumps are followed, but additional care is worthwhile because of the value of the material.

Budding in the Field Versus Nursery Budding.

Most of the previous notes refer specifically to budding in the nursery with a view to transplanting the budded stumps into the field. Budding in the field is not very difficult, but a few points should be observed. About four seeds are planted at stake at each point. When the best developed seedling reaches an optimum stage for budding, this one and the next best seedling should be left and the others removed. Choose dull days for budding and if the weather is consistently fine, bud only in the early morning and in the late afternoon, and place the buds on the side of the stock facing south. After opening up, the shade should be placed in position again to prevent sudden drying out of the bud patch, exposure to dry air and sun being more severe than in a nursery. Shades can be removed at the final inspection and cutting to stump can be done at the same time. The after care is the same as in the nursery. When the bud has come away successfully the second seedling at each point can be discarded. In the second round of budding to make up for failures, the second seedling is budded. Should failure occur again, the first seedling can be budded a second time, and so on. Thus if only 25 per cent. takes are obtained, a full stand of clonal trees can still be achieved. The pros and cons of budding in the field or the nursery depend partly on local conditions. Provided the budders are reasonably efficient and an area of 20 acres or more is to be planted with only one or a very few clones, budding in the field is to be preferred. The chief advantage of budding in the field is the fact that transplanting is avoided. Not only are transplanting losses more serious with budded material than seedling stumps because of their high value, but transplanting, however carefully done, inevitably checks the growth of the tree. As every tree is checked to a different degree, the times of the bursting of the buds is often a good indication as to the care with which the stumps were transplanted. Over a few years, of course, the differences in development are smoothed out. From the viewpoint of economy, budding in the field avoids both nursery and transplanting costs. Drawbacks of budding in the field is the greater difficulty in supervising operators and the lower number of buddings performed in a given time. Budding in the nursery is easier although not necessarily more successful. If a variety of clones is handled the chances of confusion are less in the nursery than in the field.

Spacing.

With bud-grafted trees the initial field spacing should be such as to give a stand of 180 to 200 trees per acre. If avenue planting is adopted the distance between trees should not be less than 8 feet. Spacings such as 20 feet by 11 feet or 20 feet by 12 feet are generally useful on flat or slightly undulating country, while 30 feet by 8 feet on the contour is recommended for hilly country. Extreme avenue planting, such as 50 feet by 5 feet or 60 feet by 4 feet, is not recommended and 30 feet is about the maximum distance between rows if yield is not to be sacrificed. As the trees grow they are progressively thinned over six or seven years to a final stand of about 120 to 130 per acre. As all trees of a clone have equal genetical yield potential, thinning may be carried out satisfactorily on the basis of girth and vigour. Since up to about one-third of the initial stand will finally be thinned, it is not essential after transplanting to fill in every miss, provided two or more misses do not occur together.

Costs of Budding.

Nursery budding requires three times as many seed beds as does the use of clonal seed and the additional costs can best be worked out by the individual planter. Budwood is also an expensive item and varies according to the clone. Conditions of sale and the prices of most of the valuable clones are fixed by the companies which introduced them and cannot be varied by the Department. Other expenses are estimated at about ½d. per bud-graft for materials and tools and 2½d. for labour costs. Variations occur, depending mainly on the efficiency of the bud-grafter and the scale of the operations.

Variations in Bud-Grafting Techniques.

Over the years many minor variations in the bud-grafting of rubber have been suggested. Amongst such variations are different methods of making the incision, for instance a cut shaped like a Gothic church window, opening up from below, using kitchen knives instead of budding knives, removing the bud from the bud stick with a sliver of wood attached, the wood being peeled off before incision, tying with specially prepared bandages and other materials, shading with pieces of bamboo stuck in the ground, and so on. Most of these procedures are more or less interchangeable. Many of them have been tried at Bisianumu but the method described in detail has been found satisfactory in continuous practice. It is the method which the Department will demonstrate to interested persons and in which Papuans are trained at Bisianumu.

The Training of Papuans as Bud-Grafters.

Although only Papuans in the restricted sense of the word have so far been instructed, there is no reason to believe that selected New Guinea Natives would not also be suitable for instruction. The reason for the choice of Papuans is self-evident. The rubber industry is concentrated in Papua and as training is not a matter of a few days only, it is natural to select men who are likely to stay on the plantation or station for a lengthy period. Family men living on the property are likely to be most suitable. Any basic education or aptitude for a trade or skill is a good guide for selecting suitable trainees. A very good tapper is likely also to possess the manual dexterity required for a bud-grafter. Trainees must also be clean, with an aptitude for neat and quick work. These qualities can be taught to some degree and the operators trained by the Department of Agriculture, Stock and Fisheries were merely casual workers who came to the Station seeking work. A plantation is likely to have men on the pay-roll with suitable aptitudes for selection.

It takes at least one month to get an indication of how a trainee is shaping. If after one month the trainee is getting less than 10 per cent. of takes, he should be considered unsuitable for training. If after a further two months he is achieving one success in three attempts he is usually worth employing as a bud-grafter and should improve further. At this stage at Bisianumu suitable trainees are graded as nurserymen and recorded as skilled employees. Procedures on private plantations, of course, are at the discretion of the employers and bonuses for percentage of successes might be considered. An 85 per cent. take or about 100 successes per day is considered very good at Bisianumu, and a man who can achieve this level is a skilled workman.

If more than one man is trained, the specialization of labour should not be allowed. To permit one man to make the incision and another to do the binding is not a satisfactory procedure. The extra handling and delay because of different rates of work do not improve the chances of success. In addition, every part of the manipulation is equally important and unless one man carries out the whole process it is impossible to trace who is working unsatisfactorily if successes are low. However, if two skilled men are engaged in budding, an unskilled labourer or a potential trainee can profitably be used to cut up coconut strips and string to the required length, to clean the stock before budding, and to affix the shade leaves after budding. The first step with trainees is to cut some ordinary seedling material for budwood and let each man work on a few seedling stocks on which he may make as many buddings as he likes. Trained men must watch and correct every step. Any European training Papuans should, of course, be himself well acquainted with the technique before embarking on instruction. Stock even for training should be well grown and in good condition. Old or deformed seedling stock left in an old nursery should not be used for training. It is often bark bound and peels badly, and because of the difficulties encountered in its use the trainees become discouraged. The following points are important in influencing success or failure in bud-grafting :—

(*a*) The manual dexterity of the operator. Speed is essential. To fuss is usually fatal.

(*b*) Cleanliness (hands, tools and materials) and tidiness, which includes keeping tools sharp at all times and materials handy and ready for use.

(*c*) Secure tying to prevent the entrance of water.

(*d*) Power of observation so that useless patches are not used, nor are bud patches inserted upside down.

(*e*) Well grown stock and good budwood are an advantage.

(*f*) Unfavourable weather conditions will lower success.

(*g*) During the wintering period of the rubber tree successes are less.

(*h*) Some clones are more difficult to bud than others.

(*i*) Opening up at the wrong time will destroy many otherwise sound buddings.

Bud-Grafting Versus Clonal Seed.

Although there are other points to consider, the most important question in comparing bud-grafted material with clonal seed is the comparative yield of the two. If budwood of the newest clones is used there can be no doubt that the potential yield is considerably higher than will be obtained from good clonal seedlings. When bud-grafts are used the planter may also produce his own clonal seed if he so desires provided due consideration is given to the selection of clones so that all are good parents and in the right combination. A third point with bud-grafted clonal stands is that when clones are selected the secondary characteristics as well as yield are always taken into consideration. Special adaptability to poor soils, good bark renewal, good latex properties, resistance to wind damage, and other characteristics are always considered. A block of clonal seedlings will not possess good secondary characteristics as uniformly as a block of budded trees.

Summary and Conclusions.

The following table summarizes the procedures involved in bud-grafting :—

Task	*Optimum Time*	*Period of Usefulness*
Budding nursery beds	12-15 months after sowing	1-2½ years after sowing.
Budding seedlings at stake	12-15 months after sowing	1-2½ years after sowing.
Opening up buddings	17-21 days after budding	Not more than one day either way.
Inspection of buddings	10 days after opening up	Up to 1 month after opening.
Cutting to stump	Up to 2 months after inspection	No longer than 6 months after inspection.
Planting out budded stumps after cutting to stump	Up to 10 days after cutting to stump	Up to 10 days after cutting to stump.
Planting out budded stumps without cutting to stump	Up to 2 months after inspection	Up to 6 months after inspection.
Planting out stumped buddings	12-18 months after cutting to stump	Anytime after 12 months until too unwieldy to transplant.

In conclusion, anyone connected with the rubber industry is invited to visit Bisianumu to inspect the work going on there and to seek information on doubtful points. It is intended at a later date that demonstrations of budding technique will be given at central points in the main rubber growing areas if there is sufficient demand for this service.

The Department of Agriculture, Stock and Fisheries can undertake the training of a limited number of Native bud-grafters at Bisianumu and any planter wishing to avail himself of this service should contact the Chief, Division of Plant Industry, Department of Agriculture, Stock and Fisheries, Port Moresby. Any planter with practical experience in bud-grafting which adds to or diverges from the information on techniques in this article is requested to forward the information to the Director, Department of Agriculture, Stock and Fisheries, Port Moresby.

Acknowledgments.

I acknowledge with gratitude the help of the planters of the Sogeri District whom I have always found courteous and co-operative. I would especially like to mention Mr. J. Grimmer of Itikinumu Estate, British-New Guinea Development Company, whom I have found invaluable as a constant source of information. Mr. C. J. Sefton of Koitakinumu Estate I have to thank especially for demonstrating a method of bud-grafting he observed during a visit to Malaya. This technique has been incorporated in the standard method described here. Mr. G. Warr of Port Moresby was good enough to make a special visit to Bisianumu to take the photographs which illustrate this article. My thanks are also expressed to the Officers of the Department of Agriculture, Stock and Fisheries who have given advice and assistance in the work at Bisianumu.

INVESTIGATION OF SOILS OF THE WARANGOI VALLEY.

G. K. Graham *
S. C. Baseden †

Introduction.

AN account is given of a soil survey of Crown land on the Gazelle Peninsula, New Britain. The principal soil series, derived from recent andesitic volcanic ash is described together with analytical data. Possible forms of utilization of the area are discussed.

This soil survey was carried out on recently acquired Crown land in the Warangoi Valley to provide basic information for the proposed planned development of the area.

The overall uniformity of the soils of the area has permitted a simplified representation on the map, where variations in topography are closely identified with the mapping units.

The principal soil of the area is an immature sandy loam developed from recent andesitic volcanic ash and overlying a buried profile developed from andesitic tuffs.

The analysis of several profiles representative of the Warangoi series indicates that these soils have a high nutrient status. The levels of available phosphorus, potassium, calcium, magnesium, total nitrogen and organic matter are substantially greater than those found in most soils, including other volcanic ash soils. The high nutrient status is clearly dependent to a large extent upon the high organic matter content which has developed under the forest conditions on a base rich parent material.

The analysis of a large number of soils from other parts of the Gazelle Peninsula reveals similar characteristics, so that results of the investigations of the Warangoi series may be considered applicable to some extent to a much larger area.

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Part I.—By G. K. GRAHAM.

Characteristics of the Area.

The survey area is that portion of land lying between the Warangoi and Nengmutka Rivers, commencing at their junction and running upstream for approximately 10 miles, i.e., to within 3 miles of Riet Village and on to the Warangoi to its junction upstream with the Mamorga River. There is an additional, smaller area lying on the south-east bank of the Warangoi opposite the survey area, but by virtue of its topography and inaccessibility a full investigation of this area was not made.

The survey area is approximately 15,600 acres in extent and is accessible by road from Rabaul (26 miles) and Kokopo (14 miles). The northern half of the area is the subject of a timber lease and commercial logging is being carried out. As a result there is a substantial though temporary bridge across the Nengmutka River and a gradually expanding system of all-weather roads (see map for locations). A small bush track suitable for light 4 x 4 vehicles extends up the eastern side of the area to within 1 mile of the southern boundary.

Physiography.

The survey area appears as a small plateau or elongated terrace isolated on three sides by the Warangoi and Nengmutka Rivers and rising slowly, north to south, to the foothills of the Bainings Mountains.

The rivers run about 150 to 400 feet below the general level of the country while the lower reaches of the Ilugi Creek are entrenched 150 feet. This creek tends to bisect the area from south to north. The presence of a central drainage pattern has resulted in two more or less weakly developed though clearly defined divides running parallel to the rivers.

Geologically, the area consists of a thin superficial layer of pumice volcanic ash, andesitic in character, varying in depth from 8 feet in the north to 18 inches and less in the southernmost part of the block.

This surface layer covers a deeply weathered (10 feet to 20 feet) clay loam to light clay buried soil developed *in situ* from andesitic tuffs. These tuffs in turn overlie an unconsolidated conglomerate sediment.

Two types of physiography occur depending on whether the creeks have eroded through the tuff. This has occurred on the northern two-thirds of the area with the result that the underlying conglomerate sediments have, on exposure, been rapidly eroded and have undermined the tuff with the production of deep, steep-sided ravines often with small waterfalls up to 100 feet high where the small tributary creeks running on top of the tuff enter the major stream valleys. This section is typified by considerable dissection, steep gullies separated by relatively level ground varying in width from a few chains to half a mile (see figure 1).

This type of physiography also extends along both rivers to the southern boundary (see figure 2) though here there is little or no level ground in between.

The second physiographic form occurs in the south of the area where the streams have not broken through the tuff. Here is an undulating and rolling, sometimes moderately steep topography. The local variation in height, however, is within 50 feet with but few exceptions (see figure 3). The depth of pumice in this section is much shallower, i.e., 2 feet 6 inches to 3 feet on the top of the ridges and in places 12 inches to 18 inches on the slopes with occasional exposures of a buried profile. However, this correlation is not considered to be significant as the physiographic pattern was determined prior to the recent deposition of pumice which has merely mantled the already existing topographic form.

Climate.

The survey area lies in latitude 4 degrees 28 minutes south and longitude 152 degrees 14 minutes east, and is subject to the typical seasonal variation in weather of New Guinea, i.e., north-west monsoon "wet" season and south-east Trade "dry" season. Limited figures only, over a five year period 1952-1956, are available for the area. These were taken at the junction of the Warangoi and Nengmutka Rivers.

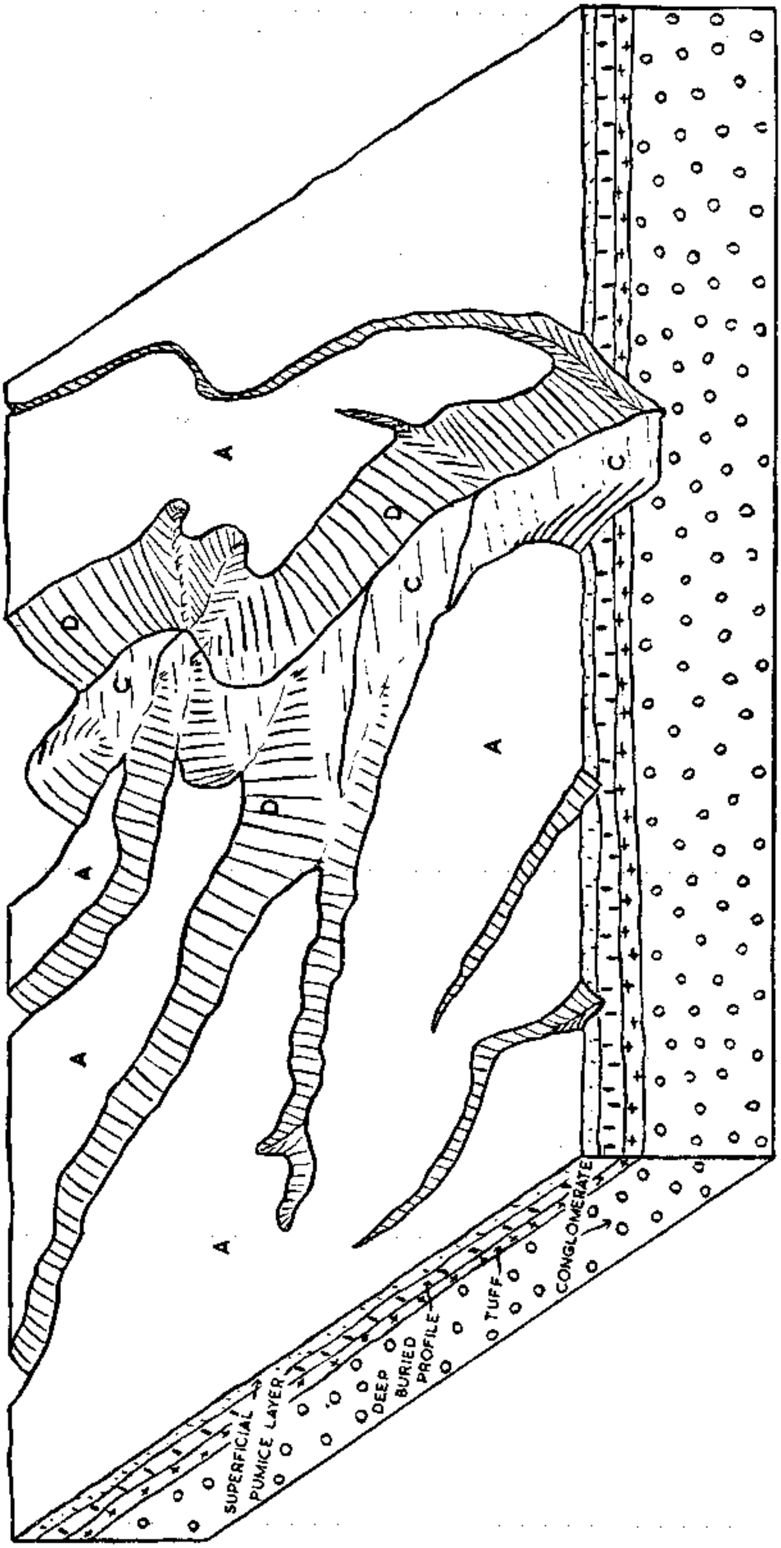

Fig. 1—Diagrammatic representation of the deeply dissected topography of the northern section, along the Ilugi Creek.

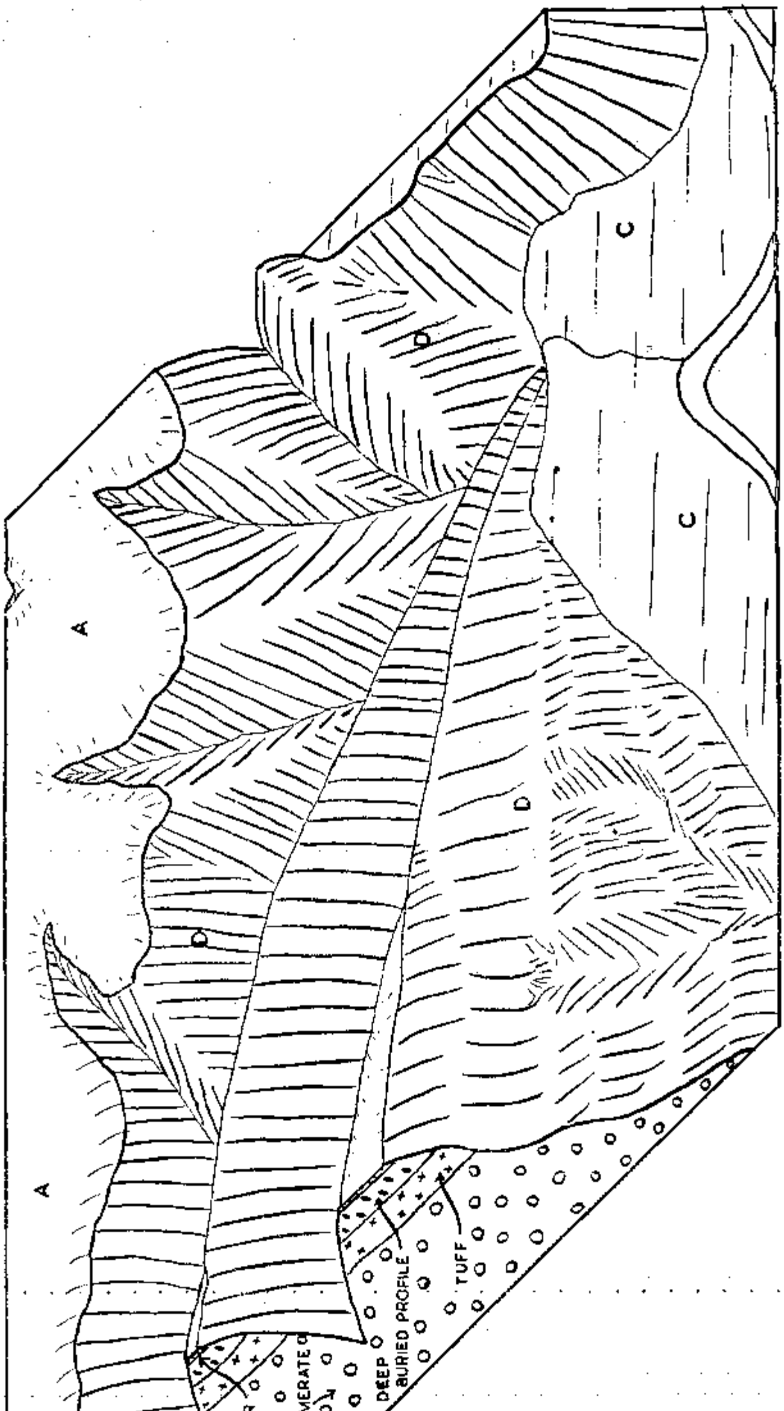

Fig. 2—Diagrammatic representation of the topography adjacent to the principal rivers.

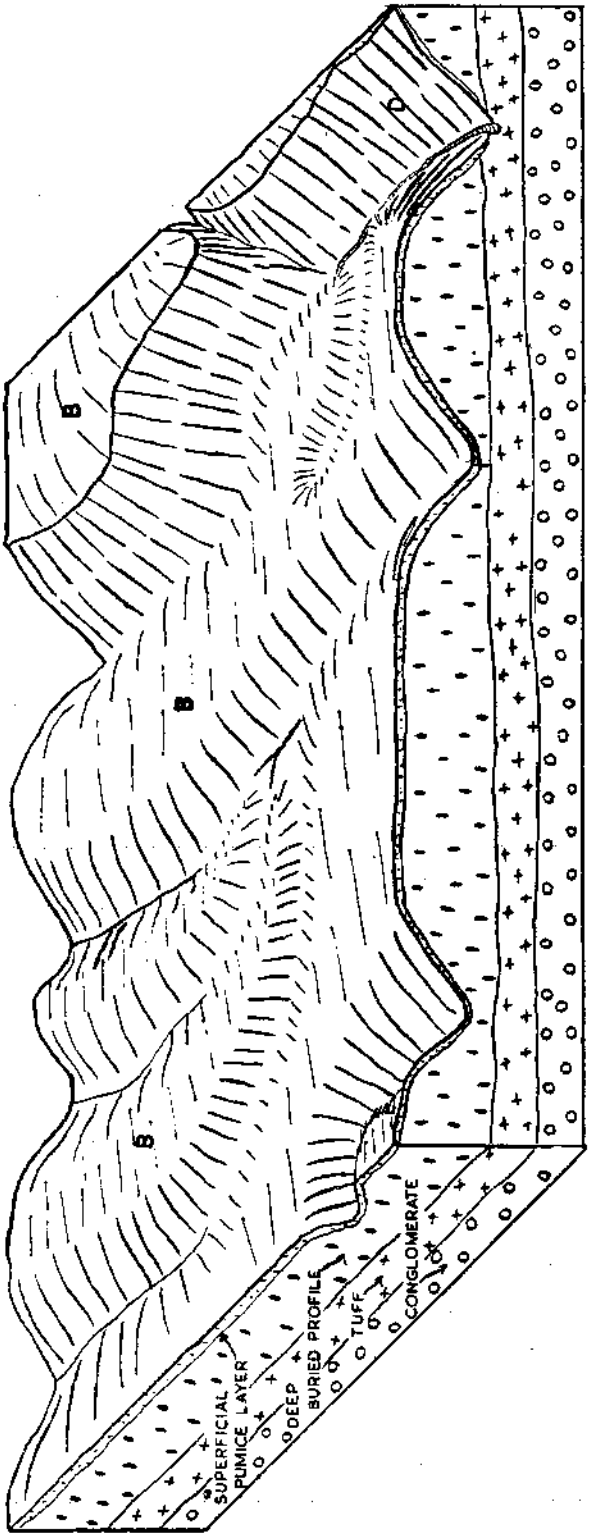

Fig. 3—Diagrammatic representation of the rolling topography of the southern section.

Average Rainfall Figures—Warangoi-Nengmutka River Junction

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Average monthly fall												
1162	807	1282	1330	447	572	535	433	455	541	1006	1103	9694
Average number wet days per month												
18	16	19	13	8	10	12	10	9	9	15	20	159
——N. W. Monsoons——				———— S. E. Trades ————								

Comparable figures from nearby recording stations are not available, but reference to the consolidated pre-war figures show that this rainfall is intermediate between the rainfall of the Rabaul-Kokopo area and the Keravat figures. On the average the distribution appears excellent with no dry months, however, in individual years there is usually a period of two to three months when rainfall comes within the accepted range for dry months (less than 60 mm. = 2.36 inches).

The presence of a heavier texture buried profile with its higher water retentive characteristics probably mitigates the worst effects of dry periods in the shallower soils.

Water Supply.

Reliable water supply is obtainable only from the two rivers and Ilugi Creek, plus a small spring fed creek on the Warangoi flats. Most streams during the wet season (December to May) contain a continuous flow of water and a number will carry through a moderate dry season, but in a dry season such as that of 1955 only the four sources mentioned above had any water. Many streams even under ideal rainfall conditions rarely carry sufficient water to meet the requirements of a plantation. Then, in some areas, total reliance on tanks will be necessary.

Vegetation.

The bulk of the area is forested with primary rain forest, or in places along the river flats where soils are shallow overlying gravel beds, with Kamarere (*Eucalyptus deglupta*). However, an area of 600 acres to 700 acres of secondary growth occurs in the vicinity of Sunum Village. The rain forest is on the pumice soils and on the occasional occurrences of deep alluvium on the river flats. The rain forest is not very old.

Population.

At the moment there is in the survey area the small village of Sunum with a population of approximately 64. These people were not the vendors and are, in fact, squatters. They rightly belong to Daudal Village to the south of the survey area and east of the Warangoi.

Soils.

With the exception of the alluvials, all the soils of the area are derived from pumice parent material. However, there is some variation, primarily in the depth of parent material and consequently the depth to the top of the buried profiles. As stated above the depth of the pumice decreases from north to south. At no place, however, does the pumice exceed 8 feet in depth while at the southern end and on the periphery of the more level stretches in the northern section 2 feet to 2 feet 6 inches seems to be the average depth. However, in the southern area on the slopes the depth of pumice ranges down to 12 inches to 18 inches (slopes of 25 degrees approximately) with occasional occurrences where the buried profile has been re-exposed on some of the steep slopes of the order of 30 degrees to 40 degrees.

On the laboratory analysis the available major plant minerals are more than adequate but very dependent on the organic matter content. The importance of the organic matter content cannot be overstated and also the need to conserve it in the interests of long term fertility of the soil as it represents 65 per cent. of the exchange complex of the soil. Secondly the very high organic matter content in the top soil has resulted in a soil with a high permeability for water and high stability under eroding conditions. This is shown when compared with the action of water on exposed layers below the immediate top soil on even the gentlest slopes. Under these conditions gullying commences immediately. Erosion on protected soils in this area is mainly tunnel erosion and it would seem that the presence of a buried profile of lesser porosity and heavier texture probably contributes to, if it is not a prerequisite for, this type of erosion. Under the particular set of circumstances it is due to more rapid intake of water into the pumice soil than can be infiltrated into the buried soil. As a result of this, lateral movement of the water occurs and in places tunnelling commences. As the buried profile is heavier than the topsoil it would seem possible that a perched water table could exist during the wet season. The upper layer of the buried profile has been observed to be saturated during the wet season. However, the soil colours indicate rather free drainage even if slightly less so than the pumice soil and this is supported by the analytical work. Studies of recently fallen forest trees show that fibrous feeding roots as well as tap roots readily penetrate the buried profile when this occurs near the surface. On the other hand it is possible that the greater water holding capacity may be an advantage in the dry season. It is considered that the buried profile will not have a detrimental effect on tree crops though it is a possibility that should poor tap root development occur in cacao where the pumice soil is shallow, it may be attributable to the water holding capacity of the buried profile.

Warangoi Series.

The Warangoi series includes light coloured immature soils developing from recent pumice ash. The ash is andesitic in character and is underlain by a buried profile. The series occupies gently undulating to steep slopes. The Warangoi series is separated from other related pumice soils primarily on the presence of the buried profile near the surface, i.e., 18 inches to 8 feet.

Soil profile (Warangoi sandy loam—virgin) see Section 6, Nos. 12, 34-43).

0-2½ inches—Dark brown (10YR 3/3 dry, 2.5Y 2/6 wet) sandy loam. A fine crumb structure plus small concretions which can be broken down with considerable pressure to a fine silt-clay and organic matter. Organic matter content is high, pH 7.3.

2½-7 inches—Dark grey brown (10YR 5/3 dry, 10YR 3/3 moist) loamy sand, weak crumb structure, friable, permeable, pH 7.2.

7-11 inches—Yellow brown (5Y 7/3 dry, 10YR 4/4 moist) sand, almost structureless, pH 7.1.

11-20 inches—Yellow grey (5Y 7/2 dry, 2.5Y 5/2 moist) sand, pH 6.9.

20-25 inches—Grey (5Y 8/2 dry, 2.5Y 5/2 moist) sand, pH 6.85.

25-30 inches—Dark brown (10YR 5/3 dry, 10YR 2/2 moist) sandy loam, pH 6.45.

30-48 inches—Dark reddish brown (10YR 5/4 dry, 5YR 3/3 moist) fine sandy clay, structureless at the time of inspection (wet), pH 6.3.

48-69 inches—Dark reddish brown (10YR 5/4 dry, 5YR 3/4 moist) fine sandy clay. pH 6.3.

69-101 inches—Brown (10YR 6/3 dry, 7.5YR 5/4 moist) light clay, pH 6.2.

101 inches +—Yellow brown (10YR 6/3 dry, 7.5YR 3/2 moist) light clay, pH 6.15.

Range of characteristics.—This series is essentially one consisting of a single predominant soil type. Solum development has reached a depth of 18 inches to 20 inches throughout the area and provided that the pumice layer has been 18 inches or more deep the normal profile development has taken place. Furthermore as the soils are quite juvenile no great profile differentiation has taken place while the high organic matter content of the top soil (the area being almost entirely and uniformly forested) masks any local variation in texture of the top soil. There is major variation in the thickness of the C horizon which ranges from 78 inches down to 1 inch to 2 inches and in isolated cases on very steep slopes may be entirely absent. It follows that the buried profile of D horizon may be at depths from 8 feet up to 18 inches, while on slopes in the order of 30 degrees to 40 degrees, truncation has taken place in isolated and small areas with the exposure of the D horizon. In addition in the deeper phases there is a tendency for pH to rise at depths of 4 feet to 5 feet to neutrality again.

Relief.—Gently undulating to steep landscape with relatively short slopes, i.e., 3 chains to 5 chains. Dominant slopes range from 3 per cent to 30 per cent.

Drainage.—Good. Run off slow to medium due to permeability of the soil. Internal drainage medium to rapid.

Vegetation.—Tropical rain forest with some secondary forest in a limited area.

Use.—Limited use only is being made of this soil for Native gardens. Taro, bananas and sugar-cane are the main crops. Subsidiary crops are sweet potatoes, yams and aibika (*Hibiscus* sp.). The forest on this soil is being exploited commercially for timber.

Potentially this series is suited to plantation types of agriculture, e.g., cacao, coconuts, rubber, coffee, also Native food crops though soil erosion would be a factor in the intensive use for this purpose.

Erosion.—Very susceptible to gully erosion if the top soil is removed or the organic matter content depleted. Tunnel erosion giving rise to gullies is the normal type of geological erosion occurring in this series. It is considered that the planting of bamboos at gully heads is the most satisfactory form of control. On 25 degrees slopes and above, surface movement of soil starts to take place with the development of step like formation with soil held behind lateral roots which have been fully exposed on their lower sides.

Distribution.—The Warangoi Valley, New Britain.

Remarks.—The mechanical analysis of the top soils of this series bears no relation to the field determination of texture due to either—

(*a*) the masking effect of the high organic matter content of the soil;

(*b*) the high base status of the soils with the resulting state of flocculation of the clay content.

Mapping Units—Warangoi Series—sandy loam.

1. *Deep Phases.*—

These soils are those where the total depth of the pumice layer exceeds 3 feet. As stated above, these occur on the northern section of the survey area and cover an area of approximately 6,620 acres. On a level, or gently sloping position, the total depth to the buried profile is from 5 feet to 8 feet, though shallower depths in the order of 3 feet 6 inches to 4 feet can occur on slopes of 25 per cent. to 30 per cent.; apart from the possible influence of depth there is no significant variation between this mapping unit and that following other than the fact that the streams in this area are entrenched to a greater degree. This latter aspect was considered in the general description of the area.

2. *Shallow Phases.*—

This unit consists of that section of the pumice soils having a total depth of less than 3 feet. The selection of 3 feet as the line of demarcation was based on two factors. Firstly, in the field there occurred a relatively rapid change in the depth of the pumice, i.e., from soils in the order of 5 feet plus to soils in the order of 2 feet 6 inches. This change occurred over about half a mile and also coincided with a change in the physiography of the area: this was considered in the general description of the area. Secondly, where the depth of the pumice layer is significantly in excess of 3 feet the roots of tree crops, cacao in particular, are not likely to come into direct contact with the buried profile while depths significantly less than 3 feet could well result in all roots coming into contact with the buried profile. The area occupied by this group is approximately 3,950 acres. In this mapping unit, slopes up to 15 degrees have soil depths around 2 feet 6 inches; up to 25 degrees 18 inches to 2 feet; 25 degrees to 30 degrees 12 inches to 18 inches and over 30 degrees some exposures of the buried profile can be expected. However, few slopes exceed 20 degrees to 25 degrees, most being under 20 degrees.

Miscellaneous soil types—Alluvial soils.

These soils occupy approximately 1,600 acres primarily along the Nengmutka and Warangoi Rivers though a small area occurs along the lower reaches of the Ilugi Creek.

Variation is primarily one of depth. Soils range from 12 inches to 18 inches to over 6 feet in depth. The shallow soils, which predominate, particularly along the Warangoi, overlie deep beds of water-worn rubble and are characterized by relatively pure stands of Kamarere (*E. deglupta*). The deeper soils permit the invasion of rain forest which tends to predominate though scattered Kamarere still occurs on it. However, natural regeneration of Kamarere has been stifled by the rain forest.

The shallow soils are naturally over drained and generally unattractive for plantation development while the deep soils, which are satisfactory, are limited in area and usually intermixed with the shallow alluvia.

Where exclusive areas of these soils occur, their best use at present appears to be in their continued use for forestry purposes.

A typical deep profile is :—

0-2 inches—Brown yellow silty loam, fine crumb, friable and permeable. Moderate humus, many roots.

2-10 inches—Brown silty loam, friable, permeable, many roots.

10-16 inches—Yellow brown loamy sand, weak crumb, loose texture, many roots.

16-24 inches—Brown yellow mottled silt, structureless, mottled rusty brown, many roots.

24-36 inches—Brown yellow silty loam, friable, crumb, many roots.

36-42 inches—Yellow brown, light clay loam, friable, permeable, many roots.

42-72 inches—Brown yellow river sand, some roots.

Colluvial soils.

These occur predominantly along the Warangoi and Nengmutka Rivers and also along Ilugi Creek. Their total mapped area is 3,150 acres. However, isolated additional occurrences have been included in the other mapping units, i.e., where these occur as narrow strips along steep banked streams and gullies.

The most extensive areas consist of steep slopes in excess of 25 degrees running down to the main streams. Here localized land slips and exposures due to fallen trees have resulted in the recent ash soils becoming mixed with the unconsolidated conglomerate sediments. As stated earlier in this report, these sediments underlie the survey area and are exposed along the sides of the more deeply entrenched streams.

Under mature rain forest an uneasy stability has been established but this could easily be upset by any extensive removal of the present cover.

Utilization.

The area can be divided into three components when considering its utilization—

(*a*) 10,250 acres of agricultural topography, the soil being the Warangoi series;

(*b*) 1,600 acres of alluvial river flats;

(*c*) 3,750 acres of steep slopes and predominantly colluvial soils, though some pockets of agricultural topography have been included.

It may be possible to utilize these pockets for agricultural purposes at a later date when the pattern of the land use has been established.

The colluvial area may be used in part for forestry purposes in conjunction with the alluvial flat area but primarily the forest should be maintained for its protective value.

The alluvial area consisting in the main of shallow soils overlying river wash, have little agricultural potential but are well suited to the natural regeneration of Kamarere (*E. deglupta*).

The point of immediate interest is the development and utilization of the compact block of 10,250 acres. The soils and climate permit the growing of a wide range of crops though in practice this would be narrowed to the plantation crops, cacao, coconuts, with coffee and rubber as mere possibilities, and Native food crops, mainly taro, sweet potatoes, bananas, yams, sugar-cane and minor vegetables, e.g., cucumber, melons, tomatoes and beans.

The factors affecting the choice of crops on this area are :—

(*a*) Topography. Approximately 30 per cent. of the area is steeply dissected and in the interests of soil conservation should be left under forest. On the southern sector the rolling country would be susceptible to erosion under intensive annual cropping.

(*b*) The necessity of maintaining the organic matter level. The organic matter constitutes the bulk of the exchange complex of this soil and in addition maintains the soil in a physical condition to resist erosion owing to the rapid penetration of water into the soil. Under tree crops the organic matter would tend to maintain itself. The indications are that the introduction of a green manure crop into Native subsistence gardening would be adequate.

(c) A third factor, probably of little significance, is the effect of the buried profile, particularly when this occurs at shallow depths. There is no indication at present that any effect can be expected. While the soil is less fertile than the pumice, it is still adequate in all respects other than phosphorus. On the other hand, the effects of the abrupt textural change and the possibility of perched water-tables are two unknown factors.

In regard to the type of development in the area there are two principal forms:—

(a) European style plantation development;

(b) Native settlement.

Neither is mutually exclusive and a combination of both forms will probably eventuate. It would be desirable to group Native producers, assuming they would operate peasant sized holdings, in order that advantage could be taken of central processing facilities.

Part II.—By S. C. BASEDEN.

Chemical characteristics of the Warangoi soils.

The typical soil profile of the Warangoi series is a shallow (10 inch to 20 inch) layer of sandy loam, developed on a volcanic ash layer of depth varying from 2 feet to 8 feet.

The soil colour merges from dark brown at the surface, through a yellowish-brown zone, to the light grey zone of the unweathered ash. The Munsell colours for the profile of a shallow ash layer (25 inches) overlying a weathered andesitic tuff layer (25 inches to 100 inches +), and of a deep ash layer (54 inches), are given in Table 1 together with mechanical analysis and organic matter content (%C x 1.73). At the base of the ash layer occurs a thin layer of pumice pieces of about 1 inch diameter which suggests that there was an early fall out of large particles when the ash was deposited. This is also indicated by the regular increase with depth of the sand fraction as shown in Table 1 and Figure 4.

Samples examined.

Profiles 1234-1243, 1244-1250, 1251-1256; 1257-1264, 1265-1271, 1280-1286, are representative of the main soil type.

Profile 1294-1299 is from a slope where the ash layer had been removed by erosion, exposing the weathered tuff. Profile 1273-1278 is an alluvial soil from the Nengmutka River.

The last two profiles are from sites of minor agricultural importance.

Influence of the depth of the ash layer on the profile development.

Deep ash layer.—

Ash layers 5 feet to 8 feet deep are characterized by a deep and gradual development of organic matter and clay—the result of the free drainage conditions which exist. An example is shown in Figure 4, profile 1251.

Shallow ash layer.—

Ash layers 2 feet to 3 feet deep are subjected to some lateral water movement where slope occurs, since underlying the ash layer is a weathered tuff which is much less permeable (50 per cent. to 70 per cent. clay). The tendency for subsurface lateral flow is probably an important factor in effecting the rather shallow development of clay and organic matter in the shallow ash layers (see also Figure 4, profile 1234).

A comparison of the development of organic matter in a series of four profiles in ash layers of varying depths is illustrated in Figure 5.

Factors dependent upon the organic matter and clay content, e.g., exchange capacity and exchangeable bases follow a similar pattern of distribution in the profile (see Figure 6).

Organic Matter.

As is typical of forest soils, the bulk of the organic matter is close to the surface, the content in the first few inches being about

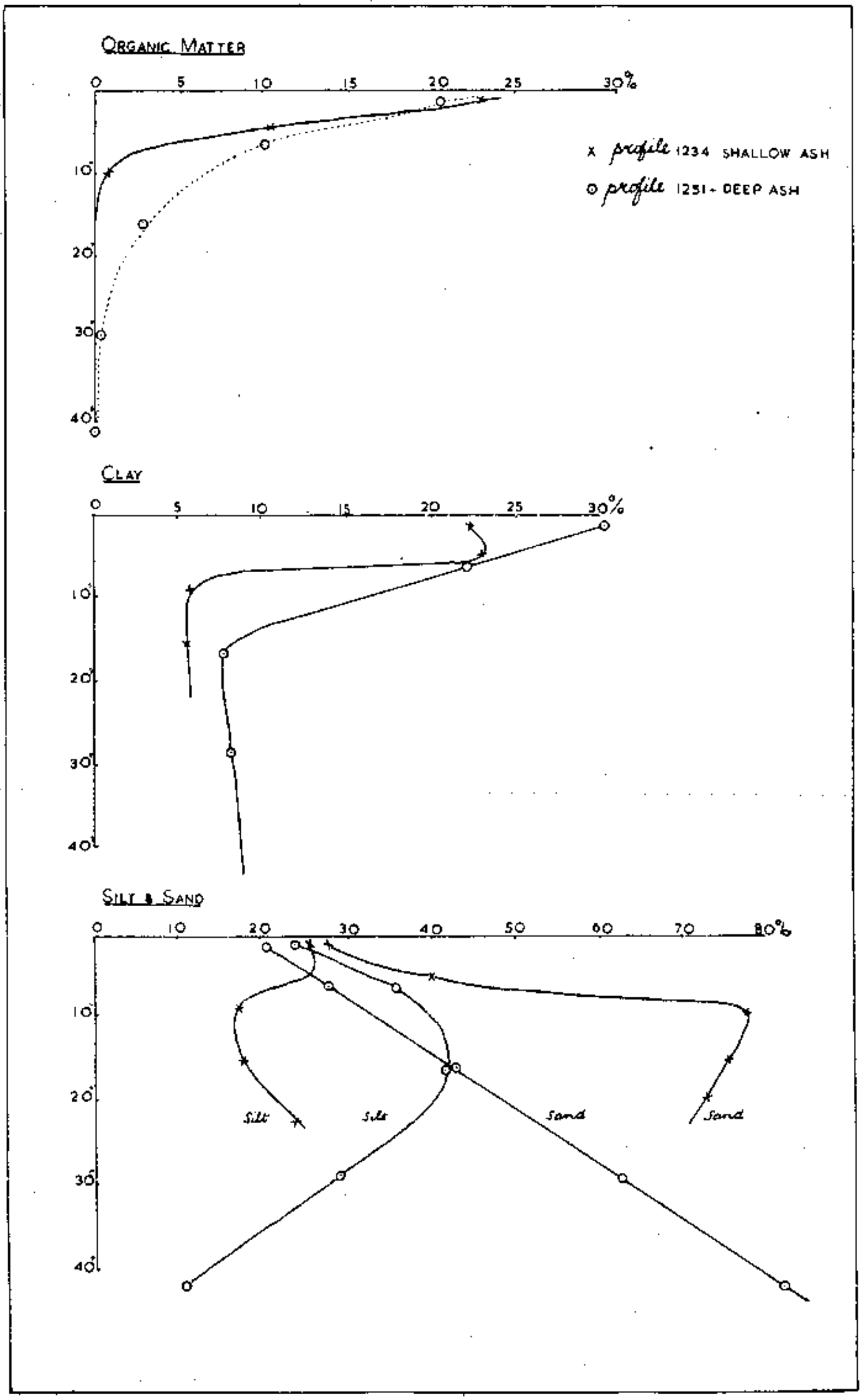
ORGANIC MATTER
0 5 10 15 20 25 30%
10"
20"
30"
40"
x profile 1234 SHALLOW ASH
o profile 1251 - DEEP ASH
CLAY
0 5 10 15 20 25 30%
10"
20"
30"
40"
SILT & SAND
0 10 20 30 40 50 60 70 80%
10"
20"
30"
40"
Silt
Silt
Sand
Sand

Fig. 4

23 per cent. and rapidly decreasing to nil at 15 inches and 40 inches in shallow and deep ash layers respectively.

The C/N ratios indicate that the organic matter is well humified. The averages of five profiles are :—

Depth.	C/N
0-2″	11.1
2-8″	9.7
8-14″	8.5

The distribution of the individual values is given in Figure 5.

Nitrogen.

The total nitrogen in these soils is high, and associated with C/N ratios in the range 8-12. Mineralization processes can be expected to release adequate available nitrogen for the initial crops. The conservation of the high nitrogen reserves of these soils is of first importance. Under conditions of management which permit the depletion of organic matter, nitrogen is likely to be the first major nutrient to become limiting to plant growth.

Calcium Carbonate.

Although there are no detectable amounts of free calcium carbonate in the parent ash material, substantial amounts were found in the organic horizon. This was noticed when investigating the source of calcium removed by normal ammonium acetate which was in excess of that required to saturate the exchange complex.

The presence of a high concentration of carbon dioxide in the surface soil atmosphere, abundance of calcium ions from the humified litter and the weathering of the volcanic ash and a pH environment of greater than 7 are the conditions prevailing which have assisted in the formation of calcium carbonate. A high correlation exists between the calcium carbonate and organic matter contents, as shown in Figure 7.

The calcium carbonate values account for only a part of the NH_4Ac soluble, non-exchangeable calcium.

Exchangeable cations and exchange capacity.

The exchange complex throughout the profiles is saturated with bases. In the topsoil where organic matter accounts for the larger part of the exchange capacity, calcium ions dominate the exchange complex. Below the organic horizon where the exchange capacity is due only to minerals in the clay and silt fractions, potassium ions occupy a high percentage of the exchange positions.

The ratio of divalent to monovalent cations is more than five times greater at the surface than in the subsoil.

The topsoils have a high exchange capacity, due to the presence of over 20 per cent. organic matter with an exchange capacity of approximately 200 m.e.% and the presence of over 20 per cent. clay with an exchange capacity of about 70 m.e.%

It is evident from the exchange data that it is very unlikely that calcium, magnesium or potassium will become factors limiting to plant growth. Details of the exchange characteristics of a deep and shallow ash profile are given in Table 2 and represented graphically in Figure 6.

Ignition loss proved to be unsatisfactory as a method for approximate determination of organic matter. This has been found to be partly due to the high moisture retention capacity of the clay at 103° C., and partly to a moisture loss by the parent material. Pumice lumps and sands from the bottom of the ash profile consistently lose 2 per cent. to 3 per cent. on ignition. In the organic horizons, ignition losses are a regular 5 per cent. to 6 per cent. higher than organic matter calculated from carbon by the combustion method.

Carbon determined by the Walkley-Black wet combustion method, provides a reasonably accurate and quick method of assessment of organic matter. A consistent recovery of about 75 per cent. of the carbon determined by the dry combustion method was obtained for samples throughout the profiles (see Figure 7).

Phosphorus.

Phosphorus determinations were carried out on profiles 1234-1243, which includes a buried profile (see Table 4 for a summary of analysis for phosphorus).

The total phosphorus figures indicate a high surface accumulation, there being four times as much in the 0 inches-2½ inches layer, and three times as much in the 2½

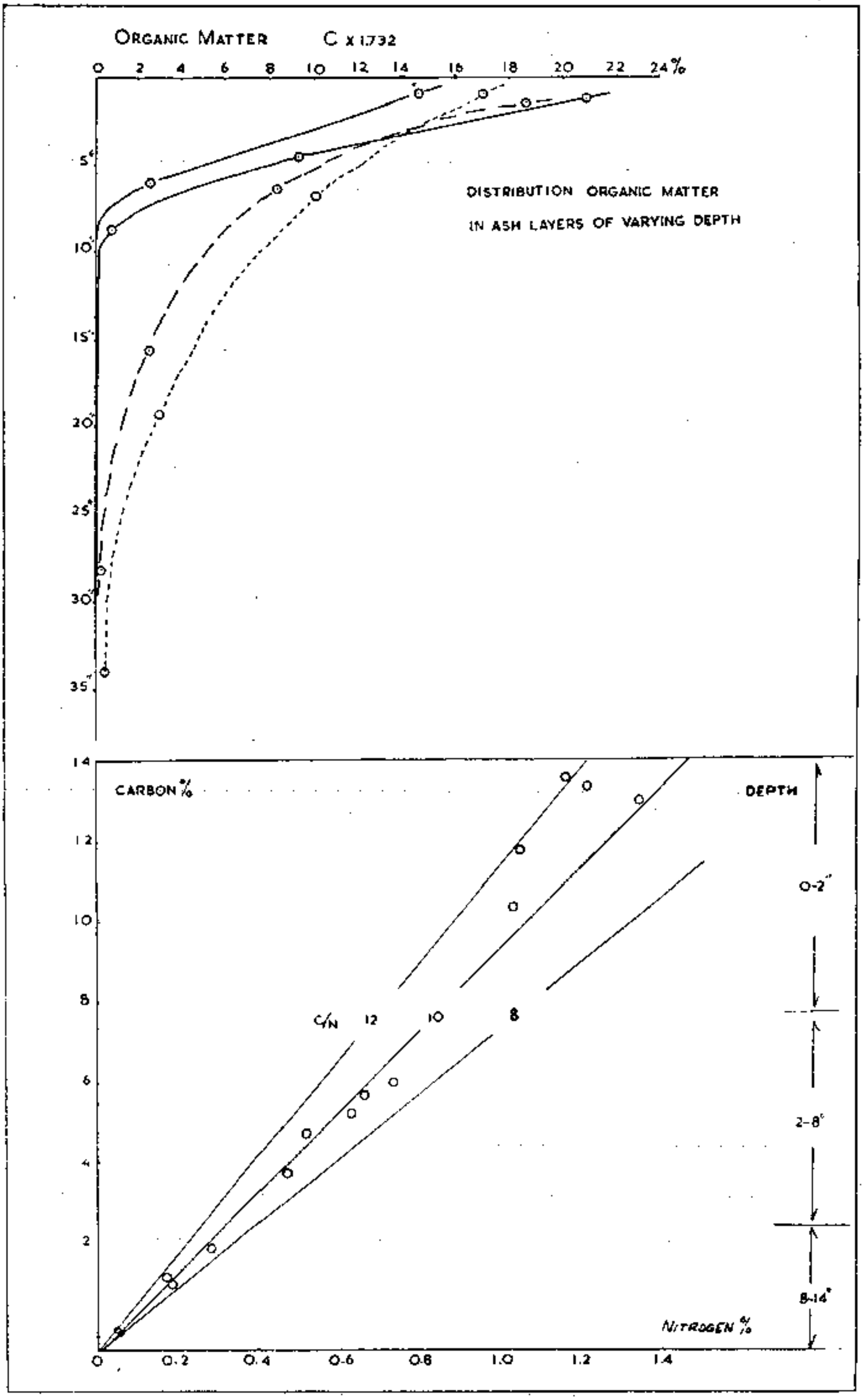
ORGANIC MATTER C x 1.732
0 2 4 6 8 10 12 14 16 18 20 22 24%
5"
10"
15"
20"
25"
30"
35"
DISTRIBUTION ORGANIC MATTER
IN ASH LAYERS OF VARYING DEPTH
CARBON %
14
12
10
8
6
4
2
C/N 12 10 8
DEPTH
0-2"
2-8"
8-14"
NITROGEN %
0 0.2 0.4 0.6 0.8 1.0 1.2 1.4

Fig. 5

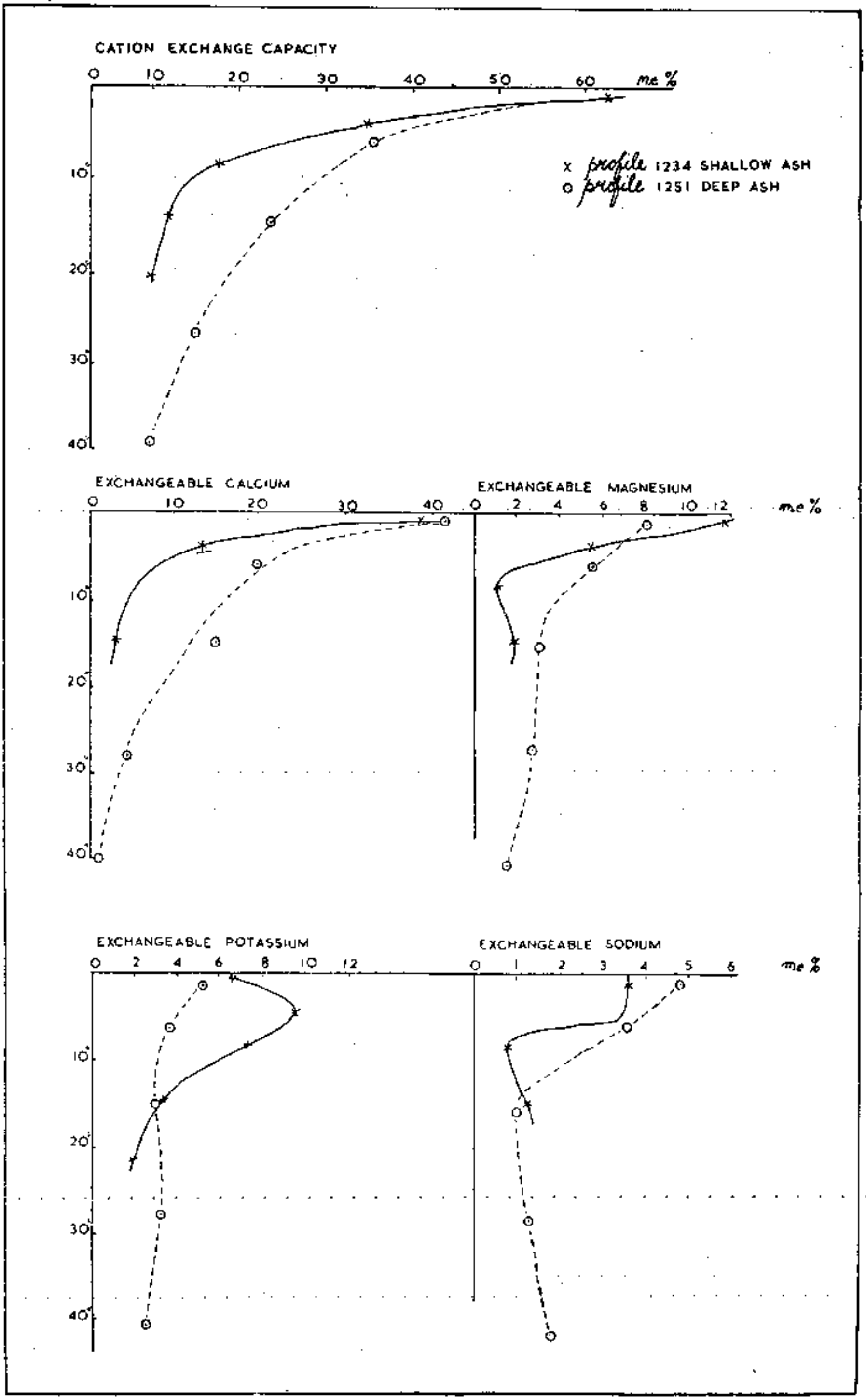
CATION EXCHANGE CAPACITY
me %
x profile 1234 SHALLOW ASH
o profile 1251 DEEP ASH
EXCHANGEABLE CALCIUM
EXCHANGEABLE MAGNESIUM
EXCHANGEABLE POTASSIUM
EXCHANGEABLE SODIUM

Fig. 6

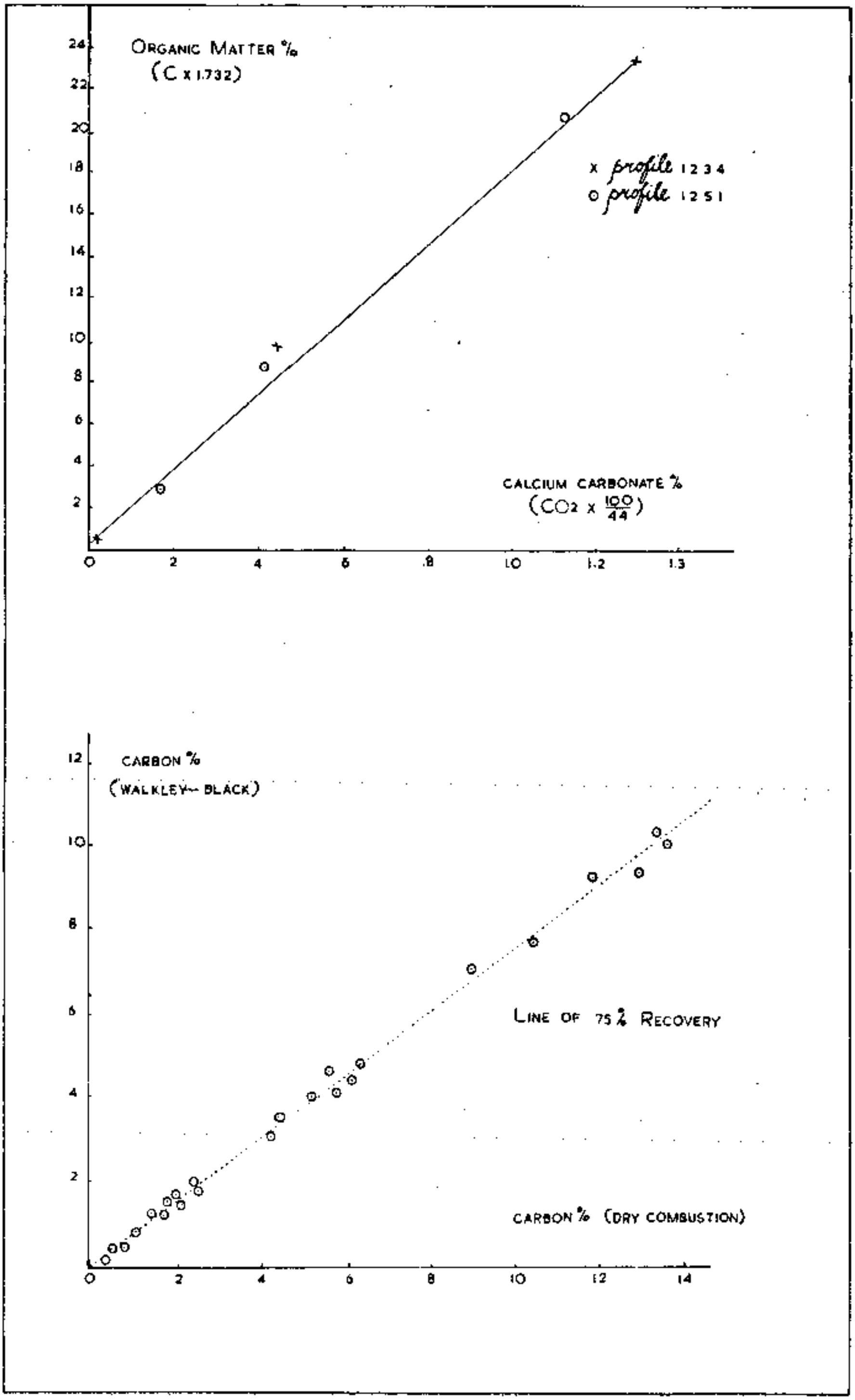
Organic Matter %
(C x 1.732)
x profile 1234
o profile 1251
Calcium Carbonate %
(CO2 x 100/44)
Carbon %
(Walkley—Black)
Line of 75% Recovery
Carbon % (Dry Combustion)

Fig. 7

inches to 7 inches layer as in the 7 inches to 25 inches unweathered ash layer. Pumice lumps in the 20 inches to 25 inches layer contained 500 p.p.m. P. The buried profile is relatively poor in total phosphrous.

Soluble phosphorus.—Dilute acid, alkaline and neutral extractants were used to obtain an idea of the solubility of the phosphorus.

The alkaline extractant, 0.5M $NaHCO_3$ pH 8.5, removed more phosphorus from the organic phase of the profile.

Water removed almost as much as the above extractant.

The dilute acid extractant, 0.01N H_2SO_4, removed substantial amounts of phosphorus throughout the ash profile, but very little from the buried profile.

About 1/3 of the total phosphorus in the unweathered ash was extractable with .01N H_2SO_4, indicating its high solubility under acid conditions.

An extractant of 0.2N H_2SO_4 removed practically all the phosphorus from the unweathered ash.

Organic Phosphorus.—An assessment of the organic phosphorus content was made by determining the phosphorus extractable with 0.2N H_2SO_4 before and after ignition of the sample, and taking the difference as being a measure of the organic phosphorus. As the figures in Table 4 show, there is a strikingly high accumulation of organic phosphorus at the surface.

The C : N : P (org) ratios are :—

1234	0-2½"	62 : 6 : 1
1235	2½-7"	61 : 6 : 1
1236	7-11"	53 : 6 : 1

Available Phosphorus.—The fairly low total phosphorus of the parent ash and the insolubility of phosphorus minerals under the prevailing pH conditions, suggest that a minor portion of the available phosphorus will come from this source.

The large accumulation of organic phosphorus associated with the low C : N : P (org.) ratios, most likely will be the major source of available phosphorus, supplied through a process of mineralization, similar to and possibly associated with nitrogen mineralization.

Phosphate Mineral.—Separation of the mineral fraction of specific gravity greater than 2.9 with bromoform, from the coarse and fine sand fractions of sample 1237, resulted in a fourfold concetration of the phosphorus in the heavy fraction.

A reaction between the phosphate mineral and ammonium molybdate acidified with nitric acid, carried out under the microscope, showed the development of colonies of phosphomolybdate crystals around inclusions in some of the heavy minerals. It seems evident that the phosphate mineral occurs as an apatite inclusion, which obtains some degree of resistance to weathering due to the resistant nature of the occluding minerals.

The Clay Fraction.

The judgment of texture in the field fails to indicate that nearly 30 per cent. of the soil of the first few inches of the profile is in the clay fraction. This is due to the considerable resistance to dispersion shown by the clay and the finer silt fractions. Only slight dispersion can be achieved with dispersing agents and prolonged mechanical stirring. Complete dispersion is possible only after final destruction of the organic matter. It seems likely that a strong organo-clay bond is largely responsible for the marked stability of the clay fraction in the organic horizon. A contributing factor is undoubtedly the calcium saturated nature of the exchange complex near the surface. Dispersibility increases significantly down the profile, as the organic matter content and the Ca^{++}/K^{+} ratio decrease. This is shown below for a profile on a deep volcanic ash layer.

Lab. No.	Depth (inches)	Less than 2μ fraction	Carbon %	Ca^{++}/K^{+}
1251	0-3	30.3	9.06	7.9
1252	3-10	23.2	3.90	5.3
1253	10-22	8.7	1.35	4.7
1254	22-36	8.2	0.17	1.3
1255	36-48	8.9	0.03	0.3
1256	48-54	5.3	0.04	0.4

(Carbon determination by Walkley-Black method. Values are approximately 75 per cent. of the values by ignition method.)

The instability of the sub-humic horizon is apparent in the field where lateral water movement over the buried tuff causes tunnel erosion. The undermining of the crust leads finally to the collapse of the organic horizon and gully formation.

Analysis of the Clay Fraction.

Clay fractions of less than 1.5*u* were separated from soil sample 1260, which was pretreated with hydrogen peroxide, and from the bulked soil sample 1248, 1249, 1250, which was not pretreated. The clay fraction was dispersed with ammonia at pH 10, made just acid with acetic acid, flocculated with calcium chloride, and washed with alcohol. Deferration was omitted, and the clay fraction kept at 50 per cent. humidity.

Analysis of the two clay fractions is given below. All analyses are calculated to an oven dry basis (103° C.).

Lab. No.	1248-50	1260
SiO_2	49.1	47.2
$Fe_2O_3 + TiO_2$	10.0	10.6
Al_2O_3	26.6	28.7
H_2O (100-1000° C.)	13.5	12.2
Molecular ratio SiO_2 Al_2O_3	3.1	2.8
Exchange Capacity m.e.%	75.0	64.0

Titration Curve.—The calcium clay fractions were converted to the hydrogen form by washing with 100 ml. of 0.004N HCl and 2000 ml. of 0.001N HCl and then with alcohol.

Figure 8 shows the titration curve for a 1 per cent. aqueous suspension of the hydrogen clay fraction of sample 1248-1250.

Dehydration Curve.—A dehydration curve of the calcium clay fraction of sample 1248-1250 is shown in Figure 8, together with curves for an allophane, kaolinite and a montmorillonite (10). The clay fraction of sample 1260 gave an almost identical curve.

Points on the curve were determined by heating of samples in a furnace for one hour at constant temperatures, cooling and weighing. Although the equipment and method were not particularly satisfactory for this type of investigation, repeated determinations failed to reveal any marked flexure in the dehydration curve.

Discussion.

Earlier work was carried out on the recent volcanic deposits and volcanic soils of New Britain by Hosking (1) who later (2) investigated the clay minerals present in the clay, silt and sand fractions of a light yellow grey subsoil of volcanic ash near Rabaul. Differential thermal and X-ray analyses showed that halloysite was the only clay mineral present, and the diffuse nature of the X-ray pattern indicated the presence in the soil of a large amount of amorphous clay.

The exchange capacities of the colloid, coarse clay and silt fractions (using 1N NH_4Ac at pH 9.0) found by Hosking (3) were 89, 58 and 33 m.e. per cent. respectively. Exchange capacities of the less than 1.5*u* clay fractions from two subsoils of the Warangoi series, 75 and 64 m.e.% (using 1N NH_4Ac at pH 7.0) are of the same magnitude as the above. It is possible that halloysite and an amorphous clay will be found also in the Warangoi soils, and that the latter clay may prove to be allophane.

The presence of allophane could account for the pattern of the dehydration curve which resembles those described by Ross and Kerr (4), Nutting (5) and Aomine and Yoshinaga (6). It could also account for the absence of flexure in the titration curve which is similar to that described by Birrell and Gradwell (7).

The unusual ability of the Warangoi and other ash soils of New Britain to accumulate organic matter and organic phosphorus under conditions of high temperature and rainfall, with a texture and base status favouring rapid oxidation of the organic matter, may be due to an allophanic nature of the fine mineral fractions (8).

General Conclusions.

The data accumulated from the investigation of the Warangoi soils indicate clearly their high nutrient status, and crops in this area can be expected to perform at least as well as they do on volcanic ash soils of other parts of New Britain.

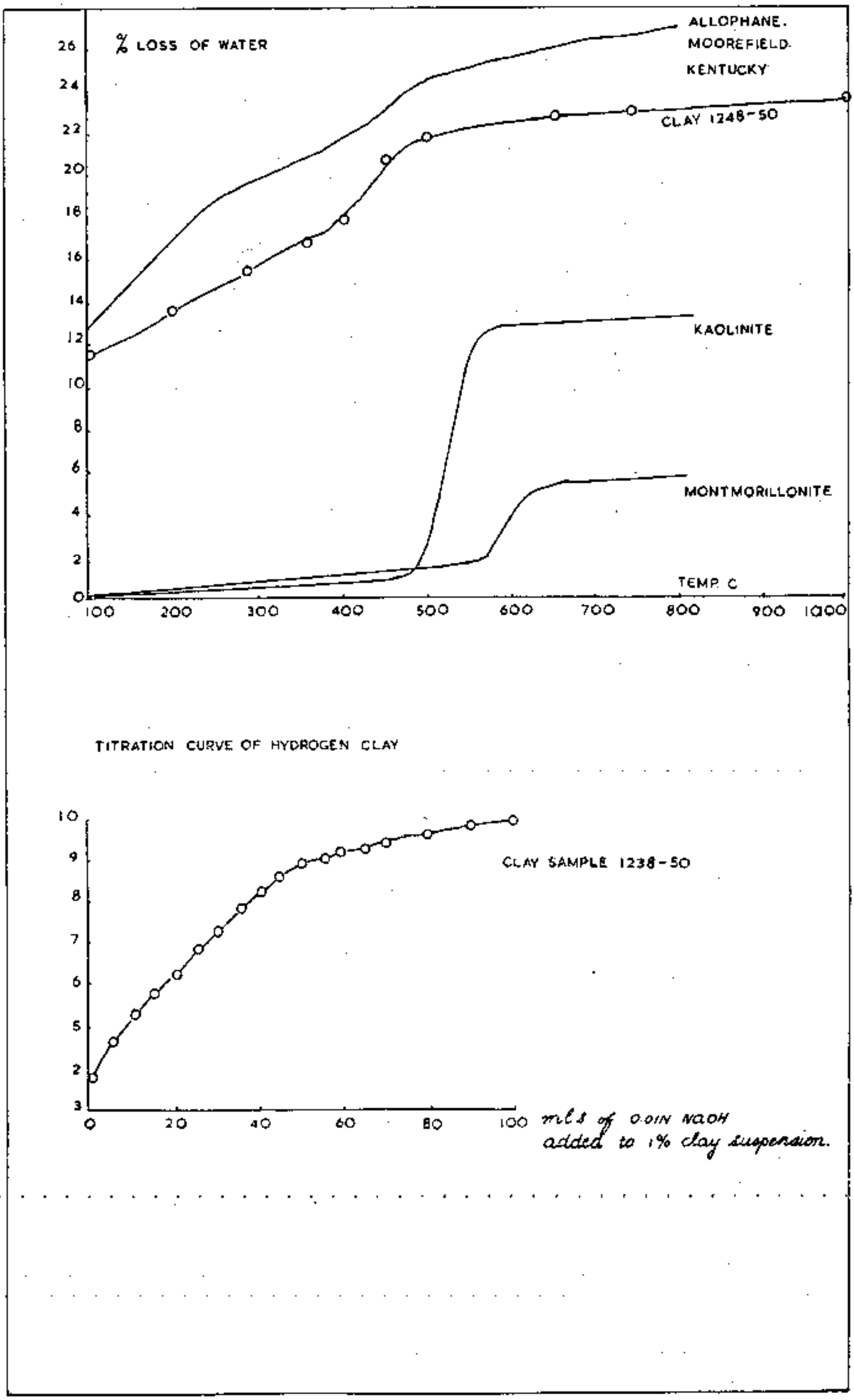
% LOSS OF WATER
ALLOPHANE. MOOREFIELD. KENTUCKY
CLAY 1248-50
KAOLINITE
MONTMORILLONITE
TEMP. C
26
24
22
20
18
16
14
12
10
8
6
4
2
0
100
200
300
400
500
600
700
800
900
1000
TITRATION CURVE OF HYDROGEN CLAY
CLAY SAMPLE 1238-50
10
9
8
7
6
5
2
3
0
20
40
60
80
100
mls of 0.01N NaOH added to 1% clay suspension.

Fig. 8

The present mechanical stability and fertility of these and other New Britain ash soils appears to depend to a large extent upon the organic phase, and management practices should aim at organic matter conservation.

Analytical Methods.

Mechanical Analysis.—The fractions were separated according to the International System described by Piper (9).

pH and Specific Conductivity.—Determinations made on a 1 : 5 soil/(CO_2 free) water suspension, after shaking for 1 hour. Measurements made with a Phillips conductivity bridge and glass electrode.

Echangeable Bases.—A technique which has been shown to give satisfactory results over the past few years in these laboratories was employed. Briefly the soil is treated as an exchange column; 5 gm. of soil is supported on a glass wool plug in a 20×1 cm. glass tube and 100 ml. of 1N NH_4Ac is poured into a funnel connected to the tube and allowed to percolate through the column overnight. The exchangeable bases contained in the effluent are determined flame photometrically with a Beckman DU.

Exchange Capacity.—The soil column above is eluted with 60 per cent. alcohol, approximately 75 ml., until excess NH_4Ac is removed, transferred to a Kjeldahl flask and distilled with MgO, the exchanged ammonia released being collected in a standard acid solution.

Carbon.—The Walkley-Black and dry combustion methods described by Piper (9) were used.

Total Nitrogen.—Kjeldahl method.

Total Phosphorus.—Samples were ignited with $Mg(NO_3)_2$, precipitated as the phosphomolybdate which was titrated with a standard acid solution.

Extractable Phosphorus.—Phosphorus in the extraction solutions was determined colorimetrically.

Clay Fraction Analysis.—Silica and sesquioxides were determined according to the method described by Piper (9).

Clay Exchange Capacity.—Samples were leached with IN Ammonium Acetate followed by elution with 60 per cent. alcohol until excess NH_4Ac was removed. The clay column was then transferred to a Kjeldahl flask and distilled with MgO as usual.

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(3) Hosking, J. S. (1948). The Cation Exchange Capacity of Soils and Soil Colloids. J. Coun. Sci. Industr. Res. Aust., Vol. 21, No. 1.

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(7) Birrell, K. S. and Gradwell, M. (1956). Ion Exchange Phenomena in Some Soils containing Amorphorus Mineral Constituents. Aust. J. agri. Res. Vol. 7, No. 1., 130-143.

(8) Jackman, R. H. (1955). Organic Phosphorus in New Zealand Soils Under Pasture: II. Relation Between Organic Phosphorus Content and Some Soil Characteristics. Soil Sci., Vol. 79, No. 4, 293-299.

(9) Piper, C. S. Soil and Plant Analysis. Univ. of Adelaide, Adelaide, Australia.

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TABLE 1

MECHANICAL ANALYSES

(Values as percentages on oven dry basis)

Lab. No.	Depth inches	Coarse sand	Fine sand	Silt	Clay	Solution loss	Total	Organic matter	Munsell Colour			
									Sample dry		Sample wet	
1234	0-2½	8.5	19.1	25.3	22.2	24.4	99.5	23.2	Dark Brown	10 YR 3/3	Black	2.5 Y 2/0
5	2½-7	11.1	28.8	25.9	23.2	10.5	99.6	9.70	Brown	10 YR 5/3	Dark Greyish Brown	10 YR 3/2
6	7-11	35.0	42.7	17.5	5.8	1.5	102.5	0.81	Pale Yellow	5 Y 7/3	Dark Yellowish Brown	10 YR 4/4
7	11-20	24.4	51.5	17.7	5.2	0.3	99.1	0.09	Light Grey	5 Y 7/2	Greyish Brown	2.5 Y 5/2
8	20-25	38.3	32.5	24.2	5.8	1.1	101.9	0.06	Light Grey	5 Y 7/2	Greyish Brown	2.5 Y 5/2
9	25-30	17.2	29.0	28.8	25.0	1.3	101.3	1.23	Brown	10 YR 5/3	Very Dark Brown	10 YR 2/2
40	30-48	7.0	9.7	24.2	57.9	1.3	100.1	0.59	Yellowish Brown	10 YR 5/4	Dark Reddish Brown	5 YR 3/3
1	48-69	5.0	7.6	11.1	77.0	0.7	101.4	0.20	Yellowish Brown	10 YR 5/4	Dark Reddish Brown	5 YR 3/4
2	69-101	9.4	20.9	36.1	36.5	1.0	103.9	....	Very Pale Brown	10 YR 7/4	Brown	7.5 YR 5/4
3	101+	5.1	18.4	30.9	46.7	0.7	101.8	....	Pale Brown	10 YR 6/3	Dark Brown	7.5 YR 3/2
1251	0-3	4.2	16.2	23.7	30.3	23.1	97.5	20.5	Dark Brown	10 YR 3/3	Black	2.5 Y 2/0
2	3-10	4.9	22.3	35.5	23.2	11.7	97.6	8.9	Brown	10 YR 5/3	Dark Reddish Brown	5 YR 2/2
3	10-22	7.4	35.0	42.0	7.7	4.3	96.4	2.9	Pale Yellow	2.5 Y 7/4	Dark Brown	10 YR 4/3
4	22-36	18.0	44.8	28.2	8.2	1.9	101.1	0.4	Pale Yellow	5 Y 7/3	Dark Yellowish Brown	10 YR 4/4
5	36-48	33.3	48.8	10.6	8.9	0.8	102.4	....	Light Grey	5 Y 7/1	Greyish Brown	2.5 Y 5/2
6	48-54	43.0	39.3	11.0	5.3	0.8	99.4	....	Light Grey	5 Y 7/1	Greyish Brown	2.5 Y 5/2
1294	0-12	10.0	19.0	17.0	42.7	11.0	99.7	9.85				
5	12-18	10.4	19.0	22.2	44.9	3.1	99.6	3.54				
6	18-34	17.4	21.8	23.1	37.4	0.5	100.2	0.9				
7	34-42	15.9	21.2	28.1	35.4	1.0	101.6	....				

Profile 1234-1243 Shallow ash layer (25 in.) over weathered tuff (25 in. to 101 in +).
1251-1256 Deep ash layer (54 in.).
1294-1297 Old profile exposed after removal of ash by erosion (10 per cent. slope).

TABLE 2

EXCHANGE DATA

(All values on oven dry basis)

Lab. No.	Depth inches	Exchangeable Cations m.e.%				Total Cations (=Exch. capacity)	% of Total Ca^{++}				$\frac{Ca^{++}+Mg^{++}}{K^{+}+Na^{+}}$	$\frac{Ca^{++}}{K^{+}}$	Ca removed by NH_4 Ac	Exchange Ca^{++}	Non Exch. Ca^{++} removed by NH_4 Ac.
		†Ca^{++}	Mg^{++}	K^{+}	Na^{+}		Ca^{++}	Mg^{++}	K^{+}	Na^{+}					
1234	0-2½	38.4	11.6	7.1	3.6	60.7	63	19	12	6	4.7	5.4	100.0	38.4	61.6
4	2½-7	13.7	5.5	9.8	3.5	32.5	42	17	30	11	1.4	1.4	32.2	13.7	18.5
6	7-11	5.5	1.1	7.7	0.8	15.1	37	7	51	5	0.8	0.7	6.2	5.5	0.7
7	11-20	3.2	1.8	3.5	1.2	9.7	33	19	36	12	1.1	0.9	3.7	3.2	0.5
1251	0-3	41.2	8.0	5.2	4.8	59.2	70	13	9	8	4.9	7.9	80.5	41.2	39.3
2	3-10	19.7	5.7	3.7	3.6	32.7	60	18	11	11	3.5	5.3	37.5	19.7	17.8
3	10-22	14.7	3.0	3.1	1.1	21.9	67	14	14	5	4.2	4.7	18.9	14.7	2.2
4	22-36	4.5	2.8	3.4	1.4	12.1	37	23	28	12	1.5	1.3	6.3	4.5	1.8
5	36-48	0.9	1.6	2.7	1.8	7.0	13	23	38	26	0.6	0.3	2 9	0.9	2.0
6	48-54	1.0	1.3	2.3	1.6	6.2	16	21	37	26	0.6	0.4	3.2	1.0	2.2

† Exchangeable Ca^{++} obtained by difference, Exchange Capacity — (Mg^{++} + K^{+} + Na^{+})

Lab. No.	Depth inches	CO_2%	as $CaCO_3$%	CO_2 Expressed in m.e.%	Non Exch. Ca m.e.% removed by NH_4 Ac	Non Exch. Ca m.e.% unaccounted as $CaCO_3$
1234	0-2½	0.568	1.29	25.8	61.6	35.8
1235	2½-7	0.193	0.44	8.8	18.5	9.7
1236	7-11	0.009	0.02	0.4	0.7	0.3
1251	0-3	0.495	1.12	22.5	39.3	16.8
1252	3-10	0.185	0.42	8.4	17.8	9.4
1253	10-22	0.069	0.16	3.1	2.2	0

ANALYTICAL RESULTS

(All values on

inches	pH	S.C. mhos $\times 10^{-5}$	Ca removed by NH_4 Ac	Exch. Mg^{++} m.e.%	Exch. K^{+}	C%	N%	C/N	Walkley Black C%	Recovery %	Ignition Loss %	Organic
0-2½	7.30	30.9	100	11.6	7.1	13.4	1.17	11.5	10.0	75	29.1	2
2½-7	7.20	18.5	32.2	5.5	9.8	5.60	0.598	10.4	4.57	81	16.3	9
7-11	7.10	7.0	6.2	1.1	7.7	0.47	0.058	8.1	0.34	72	4.48	0
1-20	6.90	5.2	3.77	1.8	3.5	0.053	....	....	0	....	....	
20-25	6.85	4.9	3.2	1.2	2.6	0.033	....	....	0	....	....	
25-30	6.45	3.6	7.6	3.2	1.7	0.71	....	....	0.52	70	6.90	
30-48	6.30	3.6	7.3	5.1	4.1	0.32	....	....	0.17	50	10.8	
8-69	6.30	4.0	5.6	4.1	3.8	....	....	....	0.11	....	10.9	
9-101	6.20	3.5	4.4	4.8	3.1	....	....	....	0	....	10.9	
01 +	6.15	3.8	5.0	5.5	1.7	....	....	....	0	....	10.2	
0-2	7.1	26.0	76.0	8.6	5.0	10.5	0.990	10.6	7.70	73	24.7	1
2-12	7.0	17.4	48.5	4.0	4.6	6.06	0.635	9.5	4.45	73	16.9	
2-28	7.1	9.5	24.2	4.2	4.2	1.84	....	....	1.47	80	8.80	
28-42	7.1	7.0	10.6	1.7	2.4	....	....	....	0.20	....	5.05	
2-54	6.9	6.4	7.0	2.4	2.4	....	....	....	0.09	....	3.88	
54-66	6.9	4.9	6.8	2.3	2.2	....	....	....	0.06	....	3.71	
66-72	6.6	5.2	4.8	2.2	2.1	....	....	....	0.07	....	2.92	
0-3	7.30	36.2	85.5	11.0	5.0	11.9	1.07	11.1	9.06	76	26.6	1
3-10	7.20	19.8	44.8	5.0	3.5	5.16	0.501	10.3	3.90	76	14.7	
0-22	7.00	9.3	18.9	3.7	3.3	1.68	0.183	9.2	1.35	80	8.75	
22-36	6.90	6.0	8.2	2.7	3.6	....	....	....	0.17	....	4.56	
36-48	7.10	3.8	4.2	1.6	3.1	....	....	....	0.03	....	2.72	
48-54	7.05	4.6	4.9	1.2	2.4	....	....	....	0.04	....	2.58	
0-1	7.10	29.8	60.4	7.4	4.4	9.07	0.960	9.5	7.17	79	22.2	1
1-12	7.00	11.4	23.3	4.2	6.7	1.35	0.17	8.0	1.04	77	9.35	
2-18	7.00	7.0	10.8	2.6	4.4	....	....	....	0.10	....	4.87	
8-24	7.20	3.8	7.4	1.6	2.6	....	....	....	0.06	....	3.57	
24-36	6.90	4.9	6.7	1.2	1.9	....	....	....	0.26	....	5.85	
36-48	6.95	5.2	2.8	0.9	1.6	....	....	....	0.06	....	4.35	
48-54	6.75	7.6	8.7	2.6	2.4	....	....	....	0.35	....	7.08	
54-60	6.70	7.6	11.0	5.6	3.1	....	....	....	0.40	....	8.22	
0-2	7.10	38.0	94.8	6.7	3.6	13.6	1.13	12.0	10.1	74	30.0	
2-6	7.10	15.4	39.2	3.8	2.7	4.21	0.445	9.5	3.12	74	14.0	
6-8	6.90	13.4	28.0	3.1	3.5	2.43	0.280	8.7	1.79	74	10.7	
8-10	6.95	11.3	24.7	2.9	2.8	....	....	....	1.32	....	9.20	
0-14	6.95	8.3	19.2	3.0	4.1	....	....	....	0.39	....	7.17	
4-16	7.20	5.2	11.9	2.8	3.7	....	....	....	0.05	....	4.95	
54	7.50	4.2	3.5	1.9	1.7	....	....	....	0.02	....	2.50	
28-46	6.55	5.5	7.7	3.5	2.0	....	....	....	0.19	....	8.22	
0-2	6.10	9.9	21.3	4.4	0.3	2.42	0.222	10.9	2.01	83	8.55	
2-10	5.70	9.3	14.9	4.2	0.8	1.02	0.127	8.0	0.78	76	6.22	
10-16	5.80	5.2	13.0	3.1	0.4	....	....	....	0.25	....	4.48	
16-24	5.75	7.6	15.0	2.7	0.4	....	....	....	0.20	....	4.65	
24-36	6.10	7.0	17.9	4.4	0.5	....	....	....	0.35	....	6.08	
36-42	6.20	7.6	17.8	4.4	0.7	....	....	....	0.33	....	3.71	
42-72	6.45	6.4	14.7	4.0	0.5	....	....	....	0.09	....	4.75	
0-1	7.00	34.8	81.8	10.4	4.3	13.0	1.29	10.1	9.42	73	28.9	2
1-6	7.00	19.0	46.7	5.8	4.2	6.30	0.713	8.8	4.81	76	16.4	1
6-12	6.90	14.9	38.3	4.2	4.5	4.38	0.534	8.2	3.49	79	14.1	2
12-16	6.90	10.1	19.9	2.5	4.0	1.56	0.188	8.3	1.15	74	8.17	

TABLE 4

PHOSPHORUS ANALYSES

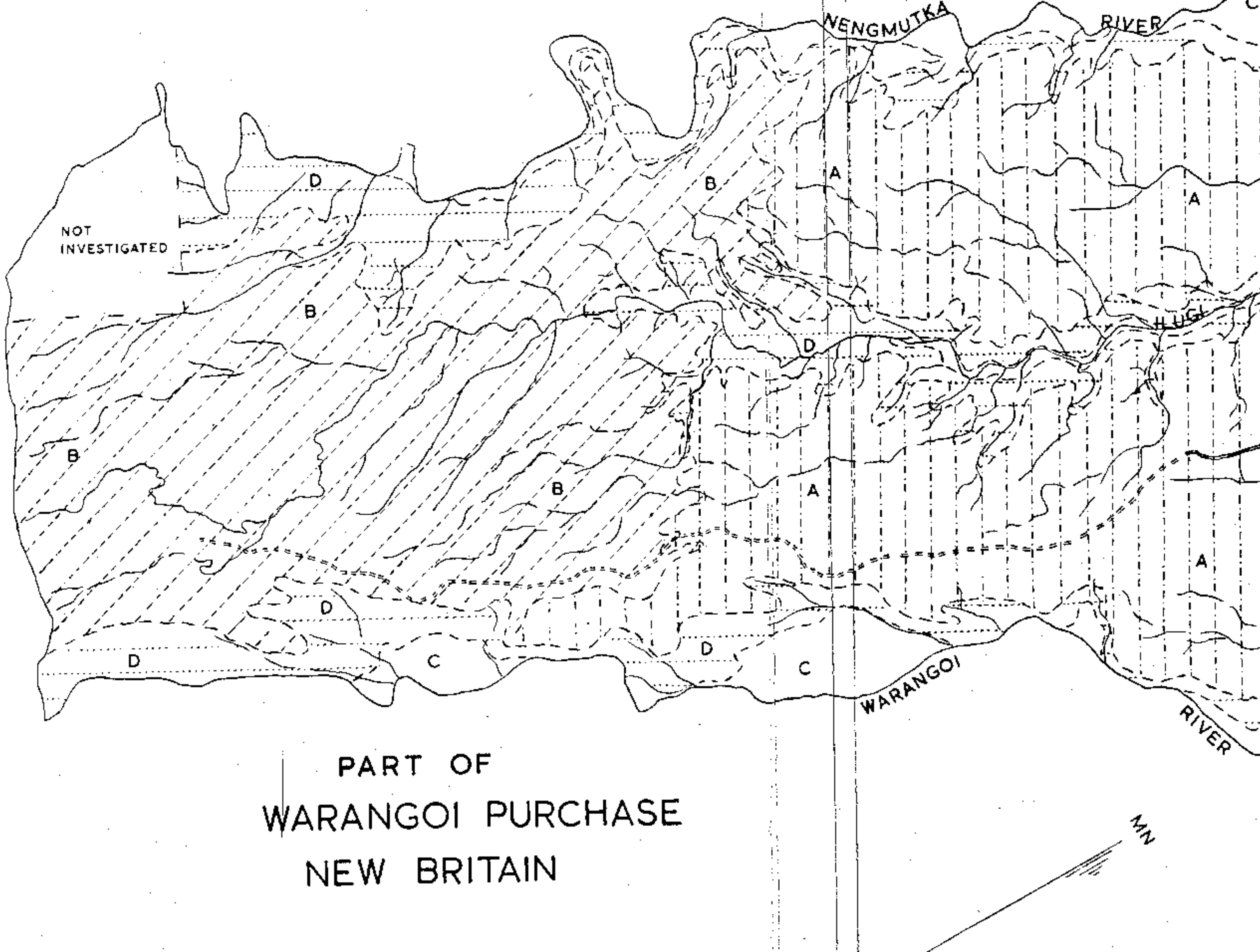
(All values are in parts per million and on oven dry basis)

Lab. No.	Depth Ins.	Total P	P extractable with					Organic P. (by difference)	% Organic P. of total P.
			.5M $NaHCO_3$ at pH 8.5	H_2O	.01N H_2SO_4	.2N H_2SO_4 before ignition	.2N H_2SO_4 after ignition		
1234	0-2½	2860	99	65	288	300 *	2290	1990	70
5	2½-7	1710	44	19	62	285	1200	915	53
6	7-11	585	9	4	162	388	477	89	15
7	11-20	632	3	4	267	640	640	0	0
8	20-25	655	3	4	177	420	470	50	8
9	25-30	320	6	....	11	....	....	....	....
40	30-48	405	13	....	8	....	....	....	....
1	48-69	334	17	....	14	....	....	....	....
2	69-101	356	16	....	7	....	....	....	....
3	101+	262	11	....	5	....	....	....	....

Extraction Solutions :—

0.5M $NaHCO_3$ at pH 8.5 .... 5 gm. sample/100 ml/1 hour shaking time.
H_2O .... 1 gm. sample/100 ml/1 hour shaking time.
0.01N H_2SO_4 .... 1 gm. sample/200 ml/1 hour shaking time.
0.2N H_2SO_4 before ignition .... 2 gm. sample/100 ml/4 hours shaking time.
0.2N H_2SO_4 after ignition .... 2 gm. sample/100 ml/4 hours shaking time.

* 300 ppm extractable with .2N H_2SO_4 before ignition is approximate, since correction was necessary for absorbance due to the substantial amount of organic matter also extracted.



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