The Rendzina soils of the Magnesian series in Durham

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"THE RENDZINA SOILS OF THE MAGNESIAN SERIES IN DURHAM."

Thesis submitted for the Degree of Master of Science.

by

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in the Department of Geography, Durham Colleges,
University of Durham.

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CONTENTS

INTRODUCTION

The rendzina is a sedentary, azonal type of soil which is usually developed from a calcareous parent material. Under the influence of Russian pedologists the name rendzina was applied to all soils developed as the result of the weathering of calcareous rocks. It is now known, however, that the weathering of such rocks results in the formation of a wide variety of soil types. The soil profile is now taken to be of more significance than parent material in the designation of rendzina soils. By conventional nomenclature the rendzina profile only includes A, C, and D horizons, there being no B, or illuvial, horizon. Thus not all calcareous parent materials weather to form a rendzina type of soil. Nevertheless, pedologists unanimously recognise the dominant influence of the parent material in the development of a typical rendzina profile. However, the soil type has not been studied in sufficient detail for the present evidence to be conclusive. Rendzina profiles are rarely developed as a result of the weathering of the Carboniferous Limestone in Northern England. Thus it seems probable that the particular combination of other factors may be necessary for the development of rendzina soil types.

In the literature on rendzina soils there are numerous contradictions regarding their properties. The cause of such differences of opinion seems to result from workers generalising rather than particularising over their findings. It is inevitable that workers in different environments should have varying opinions on the properties of a particular type of soil and such controversies are discussed.

Kubiena states that soil science is now more of a soil sample science than a soil science, arguing that the methods of soil analysis have been mastered but that a firm basis for classification is now required. Such a basis can only be achieved after numerous soil samples have been analysed and the findings correlated. Soils are not mere collections and mixtures of inert material but are remarkable dynamic systems. By their very nature they are diversified in their properties and no matter how many samples are analysed it will only be possible to correlate soils of a certain type within set limits. The soil scientist unfortunately will not be able to define his 'species' with the same exactitude as the botanist or zoologist. Yet a valid basis for the classification of world soil types cannot be approached until many more representative samples have been analysed and described.

Kubiena states that the methods of soil analysis have now been mastered. This, however, is only partially true. No method for a particular soil analysis has been found which is suitable for all types of soils. Invariably the pedologist must modify standard methods of analysis to suit the particular soils on which he is working. Thus neutral ammonium acetate can be used for the determination of the exchange capacity of soils. Such a method is of little value in the case of some alkali soils because of the fixation of appreciable amounts of ammonium in the soil, resulting in a reduction of the determined exchange capacity of the soil. Other methods of soil analysis have been devised to overcome such difficulties, and it would appear that the statement of Kubiena is a valid one. However, the soil is in a delicate state of equilibrium and it is not known to what extent [illegible] two different methods of analysis disrupt that equilibrium. It would seem no two sets of results, determined by different methods of analysis, may be correlated with any justification. It is only when soils are analysed using precisely similar methods that such correlation becomes valid. It is believed therefore that conformity to analytical procedure is as valuable as the results obtained, and for that reason the exact methods of analysis used are included in this work.

In County Durham the Permian Limestone outcrops over an area of approximately 230 square miles. The limestone varies in physical and chemical composition, and all types between a calcareous limestone and a dolomite are found. Theoretically the rock constitutes a parent material from which rendzina soils could develop. Over much of the area of outcrop, however, the limestone is covered with varying thicknesses of glacial drift material which mask the effects of the limestone on soil development. It is only where the glacial drift material is thin that typical rendzina profiles have developed, drift-free soils being rarely found. The physical background of the region is described because of the probability of factors other than parent material being of importance in the genesis of rendzina soils. Field descriptions of twenty representative soil profiles are included in the text. These profiles were sampled and subjected to mechanical, physical, and chemical analyses in the laboratory. The analytical results are recorded and used as a basis for an agricultural evaluation of the soils.

CHAPTER I

TOPOGRAPHY AND DRAINAGE

In the County of Durham the Magnesian Limestone outcrops over a roughly triangular area extending from South Shields in the north, to Langton in the west, and to West Hartlepool in the east. The western margin of the limestone, where it lies above the Coal Measures of the Mid-Wear valley, is marked by the scarp slope of a down-like escarpment. This slope, though not readily recognised on a topographical map of the area, forms a well-marked feature on the ground. To the east the area is bounded by the sea. The southern margin, where the Permian is faulted beneath the Triassic rocks of the Tees lowlands, is covered by thick deposits of glacial drift, and is not therefore marked by any notable topographical feature.

From Trow Point in the north, the escarpment trends in a south south-westerly direction as far as Coxhoe, where it bends to the south west. Between Westerton and Langton it once again runs in a south south-westerly direction. South of Westerton the limestone outcrops along the lower slopes of an eastward projecting Pennine spur of Carboniferous rocks. This spur forms part of the interfluve between the Wear and the Tees. In this region the limestone forms no distinctive topographical feature.

In general, the highest land is to be found along the crest of the escarpment. North of Coxhoe the ground surface slopes eastwards towards the North Sea, but south of Coxhoe it slopes southwards towards the River Tees. The escarpment is cut by two major gaps. These are both post-glacial in origin and include the Wear Gorge at Sunderland, and the Ferryhill overflow channel (vide Chapter 5).

North of Sunderland the limestone has weathered into a series of low, rounded hills. Most of the land in this area is below 250 feet O.D. but Downhill (350602) rises to 307 feet O.D. and Beacon Hill (395639) rises to 277 feet O.D. The latter is formed from Upper Concretionary Limestone but Downhill is composed of Middle (Fossiliferous) and Lower Limestone. South of Boldon a scarp slope can be distinguished on the western outcrop of the limestone. Such a slope cannot be seen on the low, rounded hills to the north. Sometimes, as at Old Cassop (330393), the Yellow Sands, outcropping beneath the limestone, form a small secondary scarp.

South of Boldon the scarp edge is marked by a line of hills all of which rise above 500 feet O.D. The escarpment reaches its maximum elevation of 646 feet O.D. at Warden Law (370506). Here, however, the limestone is capped by a 150 feet thick kame-like deposit of sand and gravel, and therefore the limestone at this point is found at an elevation of 496 feet O.D. Though most of the summits are at elevations of between 500 feet O.D. and 550 feet O.D., there are some which are greater than 600 feet O.D. These latter hills are in the area west of Trimdon and in the area west of Thornley. In general, the base of the limestone outcrops at a height of 400 feet O.D. (the line of outcrop and the 400 feet contour being co-incident in many places) and the crest of the escarpment is thus about 250 feet above the 320 feet surface of the former glacial Wear lake.

South of the Wear gorge the topographical form of the limestone may be considered to be a dissected plateau. The western edge is marked by a steep scarp slope but the dip slope is very dissected. Superimposed profiles taken from west to east across the region show that the surface slopes gently down the dip slope of the escarpment towards the North Sea. This slope, however, is not uniform. It appears to be graded to a height of about 100 feet above the present sea-level, as if the lower slopes (i.e. those below 100 feet O.D.) had been truncated along the line of the present coast. This results in the cliffs along much of the Durham coast rising precipitously from the sea to heights ranging from 50 feet O.D. to 150 feet O.D. The truncation could have been caused by normal marine action, or it could have been caused by the glacial erosion of the south-moving Scandinavian ice-sheet during the Ice Age.

Maling (1) has shown that several surfaces can be recognised on the plateau. These are formed at the following heights:-

1. 600' O.D. - only a few summits.
2. 500'-550' O.D. - some accordance of summits and this is recognised as the principal hill-top surface of the Magnesian Limestone.
3. 400'-450' O.D. - the greater proportion of the middle escarpment is between these heights.
4. 300'-350' O.D. - land at these heights extends as a narrow belt running down the eastern side of the escarpment, and also as a broad belt running round its southern edge.
5. 200' O.D. - land at this height is found north of the Wear gorge and also on the eastern extremity as a thin coastal margin.

These surfaces are too irregular and vary too greatly to be classified as erosion surfaces. It is more likely that they represent normal sloping surfaces on the dip slope of the escarpment.

Irregularities in the surface of the dip slope of the escarpment are probably the result of variations in the degree of hardness of the underlying limestone. This is particularly true of a line of low rounded hills running from north to south down the eastern margin of the dip slope. They include Tunstall Hills (392545), Dalton-le-Dale (402484), Cold Hesledon (417467), Hordon (431415), and Danesly Hill (436390). Tunstall Hills are at an elevation of just over 350 feet O.D. and the rest of the hills listed are just above 400 feet O.D. in height. They are all underlain by the Middle Permian Reef Limestone. Many of the minor surface irregularities are the result of variations in the thickness of the glacial drift which covers the limestone.

The drainage systems of the Permian escarpment were greatly modified during the Pleistocene Glaciation Period. Before the Ice Age the escarpment was drained to the west by obsequent scarp slope streams, and to the south and east by consequent dip slope streams. Glacial drift material was deposited in the pre-glacial valleys as the ice advanced, and as it retreated from the area. The wide 'hopes' of the dip streams were not completely filled with glacial drift material and their courses are followed by the post-glacial dip streams. The latter streams, in their lower courses, have cut deep gorge-like denes (2). The narrow, steep-sided, lower courses of the streams contrast markedly with the more open upper courses. The stream valleys, probably initiated during the Miocene Period, are not yet re-adjusted to the present sea-level and are still eroding their courses downwards into the limestone.

As the crest of the escarpment lies towards the western edge of the outcrop of limestone the obsequent scarp slope streams are of shorter length than the consequent dip slope streams. The streams which drain the western slopes of the escarpment are now only trickles of water. Many of them are not large enough to warrant a name on the O.S. 2½ inch Topographical Map. These streams flow in wide well-marked valleys which are deeply indented into the scarp edge of the limestone. This is especially true of the Coxhoe Beck and of the Sherburn Beck. In pre-glacial times the valleys of the scarp streams were lengthened by the process of backward erosion. Today, many of the streams originate as springs at some distance from the head of the valley. Thus it is unlikely that the valleys were formed as a result of erosion by the streams at present flowing in them; they must have been formed when the surface drainage was greater than at present observed. These valleys give the edge of the escarpment a very ragged indented appearance. It is noteworthy that Smailes (3) states that the irregular shape of the escarpment has prevented the development in this area of the strip parishes such as are found in Lincolnshire.

The highest points on the escarpment are along the western edge and the scarp edge streams have cut backwards through this higher land. Thus the interfluve between the North Sea drainage to the east and the Wear to the west, is at a height of between 450 feet O.D. and 500 feet O.D. and runs from north to south, some two to three miles distant from the scarp edge.

The drainage pattern round South Hetton (380453) is worthy of special mention. Apart from the Ferryhill gap, this is the only region south of Houghton-le-Spring where the escarpment is cut by channels less than 400 feet O.D. in height. From South Hetton the Coldwell Burn flows westwards and a tributary of the Dalton Burn flows eastwards. The headwaters of both of these streams originate at a height of about 380 feet O.D. This is below the level of 420-430 feet O.D. which, according to Maling (1), is the maximum level the Wear Lake could have reached. A small depression runs at a height of 380 feet O.D. from East Wood (365445) to Elemore Vale (358457) and is about one mile in length. Clay deposits are found on the floor of the Elemore depression and deposits of sand are found on the upper parts of the Coldwell valley. It is probable that these two valleys were formed as small overflow channels during the early stages of the drainage of the Wear Lake, and before the main outlet of the Ferryhill gap was opened.

The southern slopes of the escarpment are drained by tributaries of the Tees. It is in this region that the covering of glacial drift material is thickest. This has resulted in a very poorly defined drainage system. The streams flowing across the region must wind their courses round a maze of low, rounded hillocks. This is typified by the meandering course taken by the River Skerne. The low-lying and poorly drained land round Bradbury Carrs (310260) probably originated as the bed of a post-glacial lake. It was formed when the waters of the Wear Lake, draining southwards by the overflow channel at Ferryhill, were impeded by a moraine. Raistrick (4) states that this moraine was deposited by the Tees ice-sheet. Waters from the lake were eventually able to drain south through the Aycliffe Channel, now occupied by the River Skerne.

The area round Cleadon is drained by the River Don, a tributary of the River Tyne. This is the only part of the Durham Permian escarpment which is drained by the Tyne. North of the Wear gorge there is very little surface drainage because of the narrowness of the escarpment and its low elevation.

Although some of the rain water which falls on the Permian escarpment is drained by surface streams much of it sinks underground. The Magnesian Limestone is one of the heaviest water-bearing formations in England (5). Some of the water seeps along relatively impervious beds of the limestone and re-appears at the surface as springs. Thus springs are found round the edges of many of the hills on the escarpment, as well as along the foot of the scarp slope. Much of the water is able to drain through the limestone by means of numerous cracks and fissures called 'feeders.' This water is held either in the Yellow Sands or, where these are absent, in the underlying Carboniferous rocks.

The Permian limestone has few dry valleys so characteristic of the Chalk country; nor has it the swallow holes of the Carboniferous Limestone. However it does show areas of intermittent drainage. On the scarp slopes there are also many examples of streams which disappear underground for short distances.

The underground water of the Permian has proved a great handicap to coal-mining operations in the concealed part of the coal-field. Many mines have been flooded and in some cases abandoned, in other cases costly pumping devices have had to be introduced. For example, when Murton Colliery was sunk, 10,000 gallons of water per minute were pumped from the adjacent Yellow Sands. During the sinking of Blackhall Colliery feeders from the Magnesian Limestone supplied 14,000 gallons per minute and the pumps were unable to cope with such a volume of water. Sinking operations could only be resumed when the water was sealed off from the shaft by forcing concrete under pressure into the rock.

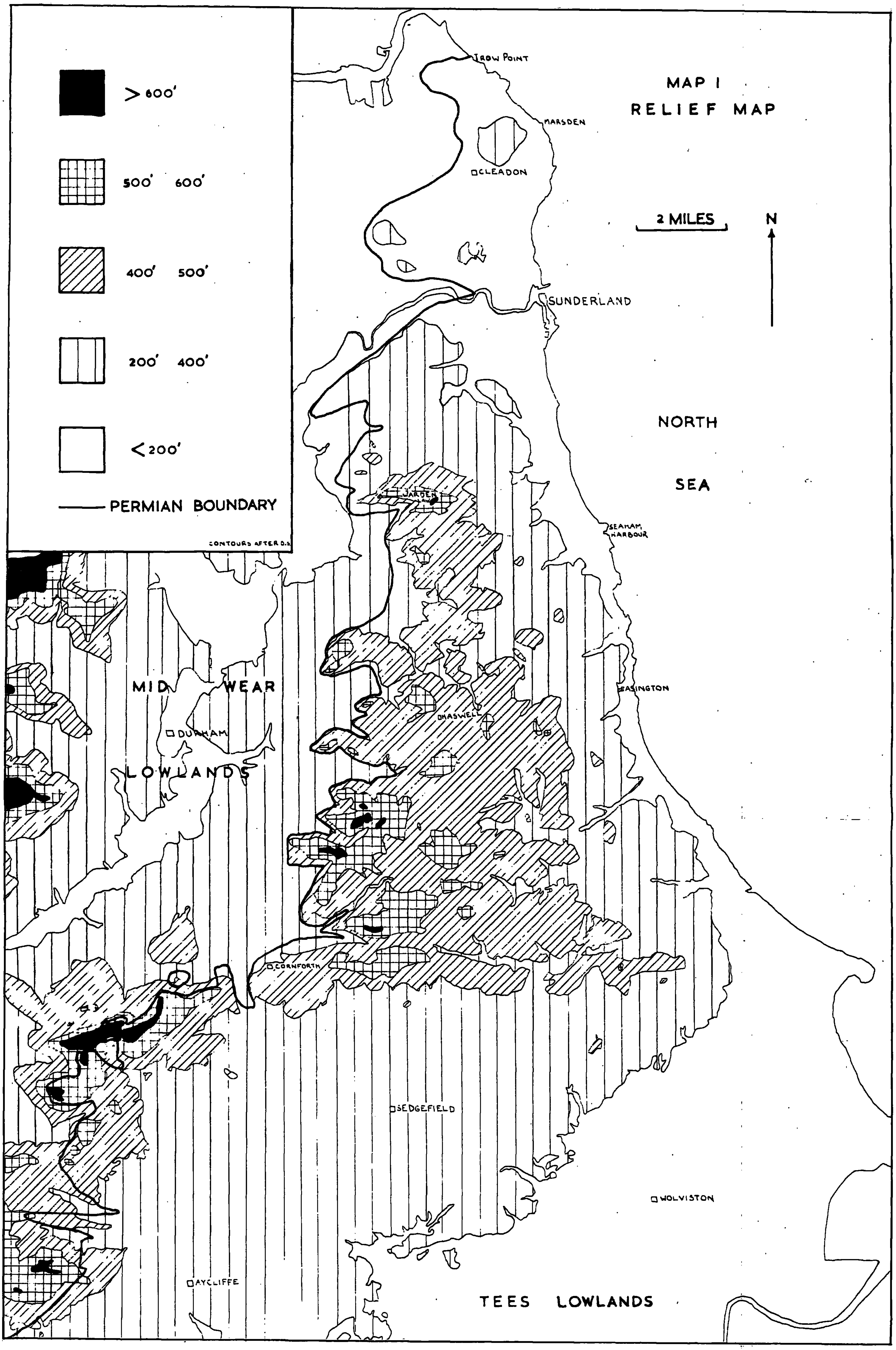
Though this underground water is a drawback to mining activities, it is of great value to the Water Boards. Sunderland, South Shields, and Durham Water Boards all utilise water from the Permian rocks for their domestic and industrial supplies. Castle Eden Pit and Mainsforth Colliery have both been re-opened as sources of underground water. Before such water can be used for domestic purposes it must first be treated to improve its taste and to remove some of its impurities. Such treatment is uneconomical if analysis shows that the content of salts exceeds:-

Sodium sulphate	1100 ppm.
Sodium chloride	1800 ppm.
Sodium carbonate	500 ppm.
Magnesium sulphate	500 ppm.

Analyses of water from Page Bank Colliery, Mainsforth Colliery, and Fishburn Colliery, serve to show differences between water from Carboniferous rocks of the Wear Valley and water from the Permian rocks. Page Bank (234355) is sited on the north bank of the River Wear. Analyses are regularly carried out by the Durham County Water Board chemist. They show typically that the water from the collieries sited on the Permian rocks contains slightly more calcium and magnesium than that of Page Bank. Furthermore, the latter contains very much more sodium, sulphate, and chloride.

Woolacott (6) reports that Sunderland water contains an average of 110 ppm of calcium oxide, 64 ppm magnesium oxide, 38 ppm sulphate, and

12 ppm carbon dioxide. As the industrial area of Wear-side obtains all its water from the Permian formation, large quantities of calcium and magnesium must annually be dissolved out of the Magnesian Limestone. It is noteworthy that Clapham (7) states that the Rhine carries in solution into the sea the equivalent of 370 tons of limestone per year.



MAP 1

RELIEF MAP

CHAPTER 2

CLIMATE.

The climatic data, on which the following observations are based, are taken from recordings made at the Durham University Observatory(8) At this Observatory meteorological observations have been kept since 1847. It is, however, situated six miles away from the East Durham Plateau. It is sited on a well-exposed ridge in a shallow basin and at a height of 336 feet above sea-level. The Observatory is 12½ miles distant from the sea and, being at the centre of a shallow basin, slightly cooler minimum temperatures are to be expected than on the Magnesian Escarpment. Nevertheless, though the station cannot be considered an ideal one on which to base climatic data for the Plateau area, it suffices to show the main climatic features of the region. Furthermore, it is considered that parent material rather than climate plays the dominant rôle in the genesis of the soils under discussion, and therefore exact climatic details are not of paramount importance.

Records since 1847 reveal that the region has an average daily temperature of 47.2°F with an average daily maximum temperature of 53.5°F and an average daily minimum temperature of 40°F. July, usually the warmest and sunniest month of the year, has average daily maximum and minimum temperatures of 67°F and 50°F respectively. The corresponding temperatures for January, the coldest month of the year, are 42.5°F and 32.5°F. It is noteworthy that, whereas July shows warmest average daily as well as the warmest maximum and the warmest minimum temperatures ever recorded, January only shows cooler average daily conditions; lower extreme maximum and minimum temperatures have been recorded in both February and December.

The average monthly temperatures from November to March are all below 42°F. Winters on the North East Coast are considered to be raw and cold, especially when compared with the milder conditions experienced at places of similar latitude to the west of the Pennines. This is illustrated by the fact that the January mean temperature on the south west coast of Cumberland is generally above 41°F but rarely rises above 39°F on the lowlands of Northumberland and Durham. As a result snow occurs on the North East Coast at low altitudes more frequently than in any other part of England and Wales. Records show that snow can be expected on eighteen mornings each year, generally between January and March.

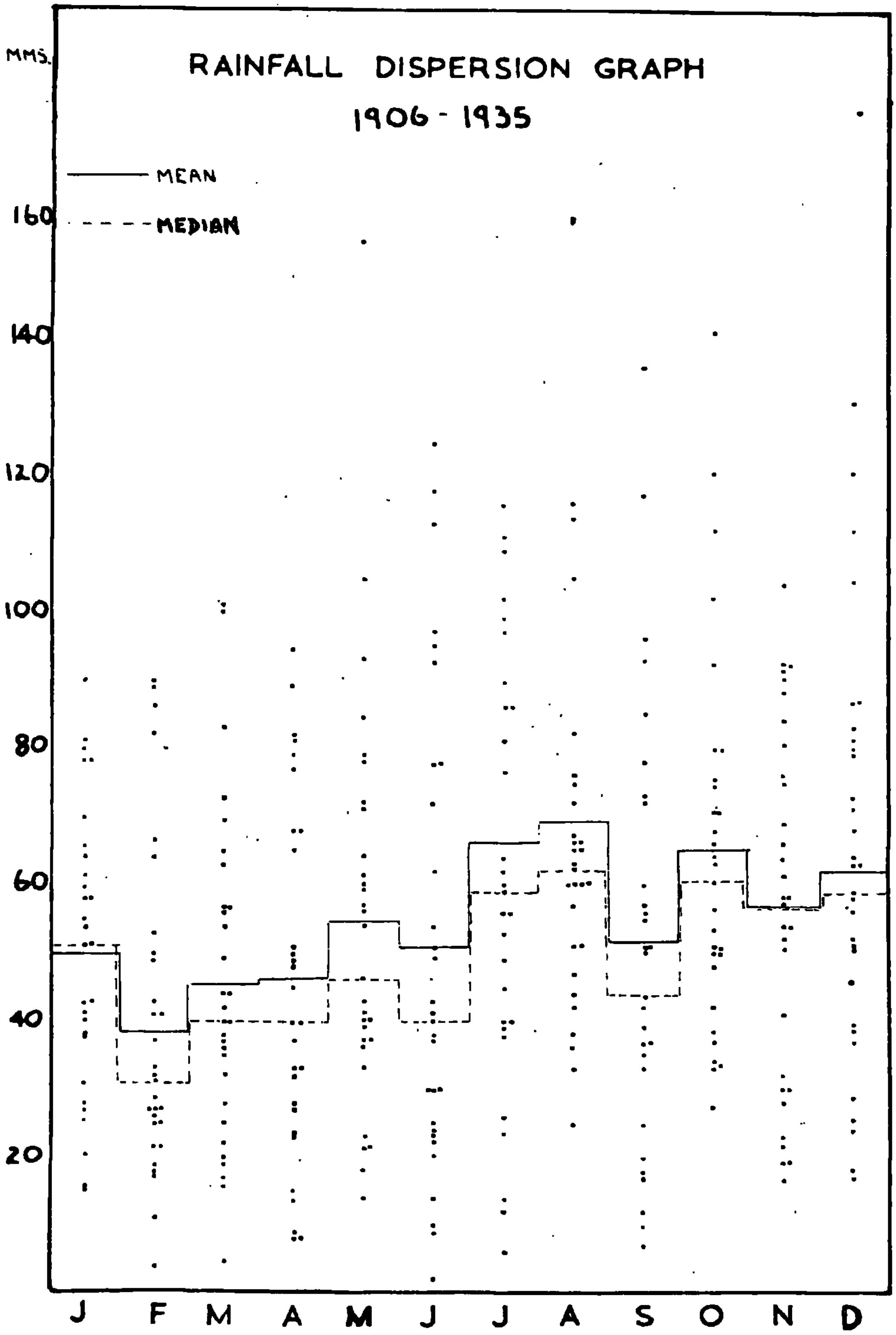
The area has an average of only 1383 hours of sunshine per year. May, June, and July have averages of 180, 183, and 167 hours respectively, whereas January only has an average of 49½ hours and December an average of only 47½ hours. Low cloud on the North East Coast is often associated with northerly to easterly winds. This low cloud appears to be formed in the following way. In most months the coldest waters round the British Isles seem to be found on the west side ofthe North Sea between Aberdeen and the Humber (9). Warm air of Continental origin drifting over these waters is chilled forming a thick layer of low cloud which drifts for a variable distance inland. Such cloud will be particularly prevalent in late spring when the temperature differences between land and sea are greatest. The cold layer would appear to be 1000-2500 feet deep. The low cloud seems to be of some significance to soil morphology (vide Chapter 7). Days when the sky is completely overcast, and when there is a light northerly to north easterly wind, are to be expected on five to ten occasions each year between late April and the end of June, but rarely after the beginning of July. On such days the cloud is formless and the air is damp and chilly.

The North East Coast lies within a rain shadow area because it is on the leeward side of the Pennine Uplands which are the dominating topographical feature of Northern England. The prevailing wind is from the west. Thus at Scafell, west of the Pennines the annual rainfall is 150 inches, but that for Durham is only 25.2 inches. The driest year on record at Durham was 1949 when there were 18.6 inches, and the wettest year was 1930 when there were 34.9 inches. The Magnesian Limestone Escarpment, rising 300 feet or more above the level of the Mid-Durham Lowlands, is of sufficient elevation to cause greater precipitation than that recorded at the Observatory. Coastal areas, and much of the escarpment, are also subject to instability showers of hail, sleet, or snow, associated with the polar current which often develops in the early spring along the west side of the North Sea. Thus the annual rainfall of much of the escarpment is over 30 inches. July and August, each with an average rainfall of over 2.5 inches are usually the wettest months of the year, although only slightly wetter than October and November. February and April are the driest months and each has an average rainfall of little over 1.5 inches.

The amount of rainfall in any one month shows a wide variation throughout the years. This is especially true of the greater than average figures and this can be seen on the rainfall dispersion graph (Fig. 1). The rainfall means, therefore, are consistently higher than the medians for each month.

Winter water shortages are generally the result of slight summer rainfall, especially if this is followed by less rain than usual in October and November. Bailey (10) considered that the greatest droughts were associated with a cold north-easterly wind, which often begins in March, and prevails until the end of June. Water shortages are especially noticeable on the rendzina soils of the East Durham Plateau. This is not only a result of the free-draining nature of the soils themselves but also of the permeability of the underlying parent material.

The prevailing wind throughout the year is from the south west quadrant but in December, January, and February, northerly winds may be of significance. Reference has already been made to the cold north-easterly winds which often prevail during the months of March, April, and May. Such winds tend to prolong the winter and thus delay the spring-sowing of crops, the germination of seeds, and the commencement of growth of grass.


RAINFALL DISPERSION GRAPH
1906 - 1935
MMS.
MEAN
MEDIAN
160
140
120
100
80
60
40
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J
F
M
A
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J
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S
O
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FIG. 1

CHAPTER 3

VEGETATION

For centuries much of the area underlain by the Permian Limestone has been utilised as agricultural land. The warm, well-aerated, easily worked, soils that have developed from the limestone, or have developed in areas where the glacial drift is thin, have been regularly ploughed either for arable crops or for long leys. The cultivation of the area resulted in the removal ofthe natural vegetation of the limestone soils. More of the vegetation was removed when houses were built, when roads and railways were constructed, and when quarries and sand-pits were dug into the sides of the escarpment. Surface workings and colliery waste tips have been the cause of the destruction of vegetation over wide areas(1).

By the beginning of the 20th century there were few areas on the limestone where the vegetation remained undisturbed. Such areas included slopes too steep to be ploughed, and small patches of woodland and scrub. The narrow, gorge-like denes of the dip slope streams were unsuitable for agricultural purposes because of the steepness of their valley sides.

1. Until 1800 it was believed that the coal seams deteriorated beneath the Magnesian Limestone, a belief based on the fact that coal outcropping from under the Magnesian Limestone at Ferryhill was of inferior quality. William Smith was first to recognise that coal seams lying under the Permian rocks could be worked and the first colliery shaft was sunk through the Permian succession at Monkwearmouth in 1826. A second shaft was sunk at Murton in 1838. Since 1838 about 40 shafts have been sunk through the Permian rocks.

The denes remained areas of natural beauty within a region which was becoming increasingly industrialised and urbanised. The steep valley sides were covered with trees and with a natural undergrowth of grasses, ferns, and flowering plants, including many species rare to the district. The flora in some of the denes was further disturbed as a result of the opening of the Easington to West Hartlepool road and also as a result of the construction of the Hartlepool to Sunderland and the Hartlepool to Ferryhill railways. Debris and noxious fumes from the collieries which had been sunk at Easington, Horden, and Blackhall, caused further destruction of the flora of the area. Despite these setbacks much of the Castle Eden Dene, the whole of Hawthorn Dene, and much of Hesledene, remain covered with a natural type of vegetation. Harrison (11) states that 'with the cessation of promiscuous tipping of waste from collieries the flora of many of the minor denes shows encouraging signs of recovery.' Disused quarries provide a refuge for some of the plants which might otherwise have been exterminated from the area. It is ironical that the opening of the quarries resulted in a destruction of the flora and yet their disused sites often provide refuges for many species. Once the quarry becomes disused plants begin to grow in soil material found in cracks and fissures on the limestone surface. Gradually a thin soil is formed where more and more plants are able to survive.

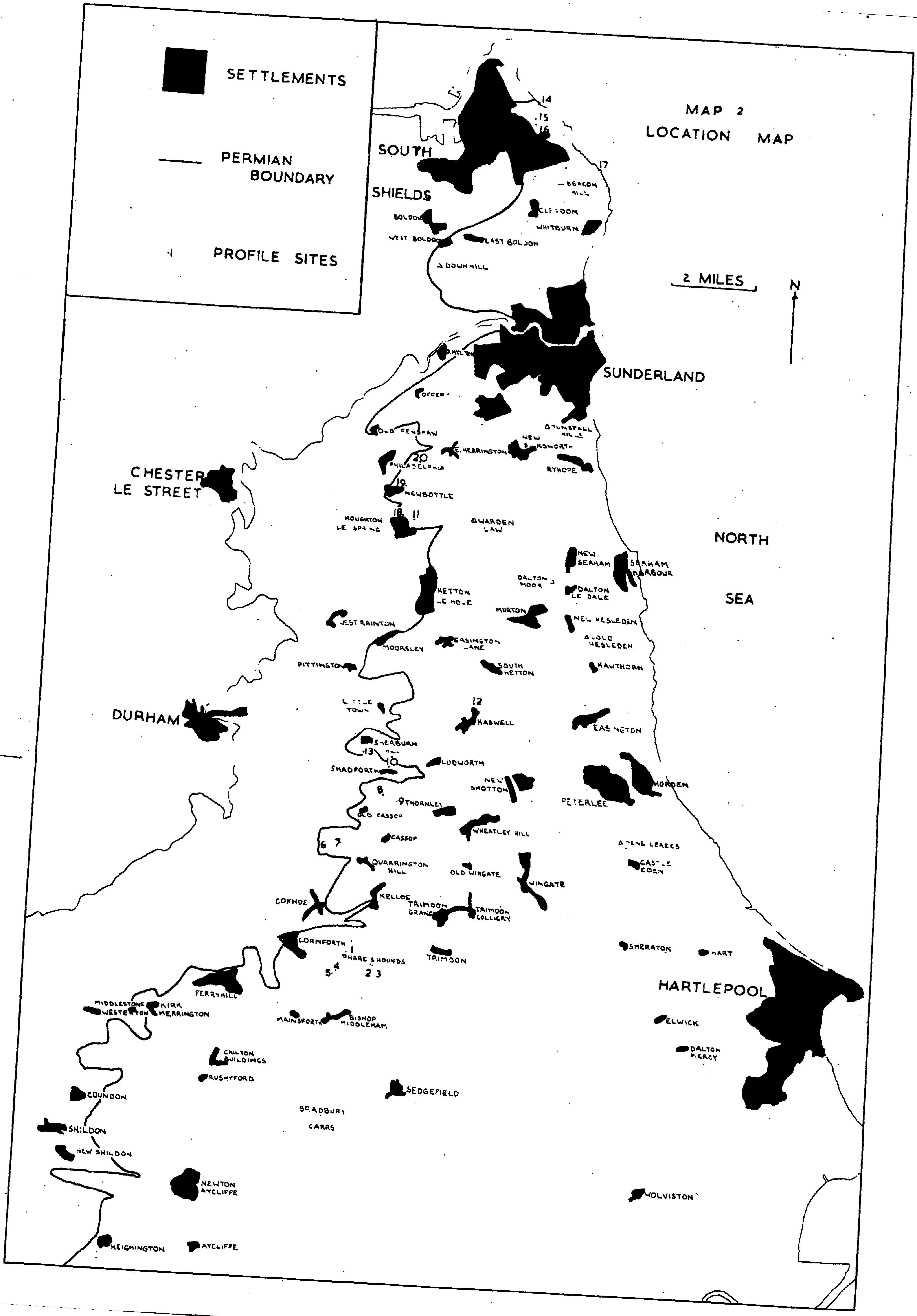
During the Pleistocene Glaciation Period the whole of the Magnesian Limestone Escarpment was covered by ice-sheets. This almost certainly resulted in the complete destruction of the flora of the area along with the removal of the soil. No plants could have survived the cold conditions experienced during this time. Although it was formerly suggested that Crossfell had remained a refuge for plants during the Ice Age, most botanists now believe that even this area was devoid of life.

In the warmer conditions following the glacial period the area was recolonised by plants from the continent and also by plants from refugia in Britain. Thus Heslop Harrison (loc-cit.) suggests that many of the common species of the Durham flora have a two-fold origin. After the Ice Age southward migrations of plants, from refugia in Scotland, and northward migrations of plants, from refugia in Southern England and the Continent, met and intermingled in the Durham area. Harrison bases this suggestion on the fact that hybrid insects are to be found in Durham which feed on certain plants. The hybrids are the result of interbreeding by sub-species of the insect from Scotland with others from Southern England and the Continent. Since the insects feed on specific plants any migrations of the insects must have been accompanied by migrations of the plants. Cited examples include the Brown Argus Butterfly (*Aricia medon*) whose larvae feed on the rockrose (*Helianthemum nummularium*), the Common Blue Butterfly which feeds on Lotus corniculatus, and the Dark Green Fritillary (*Argynnis aglaia*) which feeds on the Viola species. Other plants found in Durham are of a southern origin and are near their northern climatic limit in Britain. They include Upright Brome grass (*Bromus erectus*), White Bryony (*Bryonia dioica*), and Green-winged Orchis (*Orchis morio*).

Extensive woodland is rarely found on the Magnesian Limestone escarpment. This absence is partly a result of the nature of the soils and partly a result of the extent of cultivation. The rendzina soils are characteristically shallow and therefore do not provide the soil depth required for the extensive root development of trees. Moreover, such soils are well-aerated and dry. Thus during a dry season water is rapidly lost either by drainage or by evaporation. Duchaufour (12), when discussing the rendzina soil type states, 'Lacking the water reserves they do not constitue a good forest soil.' Woodlands are confined to areas where the soils are deep enough and moist enough to support tree growth, but which have not been brought into cultivation. Such areas include some of the steep hill slopes, especially the sides of the denes. Many of the woods are located on soils developed from drift material. Ash is the dominant tree in the woods and also in the hedges separating the fields while sycamore, birch, and beech are also found. It is interesting to note that on the Chalk rendzina soils of Southern England, ash is often an earlier coloniser than beech, but the climax vegetation is beech. In Durham, however, the situation is different. There are small stands of beech to be found, as for example at the Hare and Hounds Inn (333339), but generally ash is the chief species. This difference between the northern and southern woodlands is almost certainly a result of climatic differences. A less likely reason is that the vegetation of the north has not reached its climax. The scrub layer of the woods on the limestone escarpment includes hawthorn, elder, hazel, and guelder rose. There is very little ground vegetation as this is unable to compete for moisture with the trees once the latter have become established.

Rough pasture is found covering soils which are not suitable for arable land, and too shallow or too dry to support the growth of trees.

The vegetation consists of a variety of species of grasses and flowering plants. Many of these plants are calcicoles and include such species as Hairy Violet, Milkwort, Kidney Vetch, and Common Rock-rose. The rough pastures often give rise to scrubland in which ash is often the first coloniser. Hawthorn is also found and is generally second to ash in importance. Other species include elder, bramble, gorse, and holly. The heights of the various species depend largely on the time during which the scrub has developed. They may only be a foot or so in height in the younger scrubs, but as high as twenty feet in the older scrubs. However, the semi-natural vegetation of rough pasture, scrubland and woodland, covers only a limited area of the limestone escarpment. The biggest proportion of the land is used for agricultural purposes, houses, or industrial sites; and over such areas the natural vegetation has been destroyed.



MAP 2 LOCATION MAP

CHAPTER 4

SOLID GEOLOGY

'Par leurs propriétés fondamentales - notamment leur complex absorbant saturé - les Rendzines se rapprochent des sols calcimorphes de steppe, mais leur genèse n'est pas d'origine climatique; elle est liée à la richesse en calcium de la roche-mère, sous forme de carbonate (roches calcaires)'. Duchuafour (12) thus emphasises the importance of the parent material in the formation of rendzina profiles. Sigmond (13) states that the rendzina owes its origin primarily to the active calcium of the parent material and Glinka (14) classifies them as being endodynamomorphic i.e. their character is determined by internal forces - the parent rock. Thus it would appear that pedologists unanimously recognise the dominant influence of the parent material in the development of a typical rendzina profile; the other soil forming factors, climate, topography, vegetation, and time, play a secondary rôle. The Magnesian Limestone of Durham includes a triangular area of 230 square miles. Over much of this region, however, the solid geology is overlain with varying thicknesses of alluvial, glacial, and fluvio-glacial deposits. It is only on outcrops of the limestone, or where the cover of drift material is very thin, that rendzina profiles have developed. Elsewhere the effect of the limestone is masked by drift deposits and typical rendzina profiles are not developed. Thus both the solid and the drift geology of the area are of great importance and will be discussed in turn.

Following the post-Carboniferous (Hercynian) earth movements there was a long period of denudation resulting in much of the North East Coast being reduced to almost a peneplain. The area was covered by sands and dunes bordering the German Zechstein Sea. Epeirogenic earth movements allowed the advance of the waters of this sea into the North East Cuvette. The sands were planed down by the incoming waters and thus formed the basal beds of the Permian rocks now recognised in Durham. These sands are termed the Yellow Sands and they filled in hollows in the pre-Permian[1] land surface and therefore occur under the limestone as pockets of varying depths. The roundness of the sand grains and the absence of mica flakes indicate that they originated by erosion under arid conditions. Bedding structures show that the sands were later re-sorted by the waters of the advancing Permian Sea. In Durham the Permian deposits are of marine origin and were deposited in the Zechstein Sea. Elsewhere in Britain, however, they are predominantly of continental origin.

The Permian basin in the North East was bounded to the west by the Pennine area and to the south by an anticline of Lower Carboniferous rocks, lying across the south of Durham. Within this basin the first deposit to be laid down was the Marl Slate consisting of a finely laminated calcareous and dolomitic mud. The absence of ripple-marks, of sun-cracks, and of false bedding, suggests a fairly deep off-shore origin where tranquil conditions prevailed. The Marl Slate is equivalent to the German Kupferschiefer and underlies the whole Magnesian Limestone area of Durham, varying in thickness from three to eight feet. Exposed surfaces are a blue-grey colour. Eventually the anticlinal ridge in the south of the County was breached by the waters of the Permian Sea and deposits of a limestone facies were laid down continuous from Durham to Central England.

1. The origin of the term 'Permian' is from rocks of that age found near Perm in Western Russia.

In parts the limestones which were deposited are highly fossiliferous. Fossil evidence has played an important part in distinguishing the sequence of deposition of the rocks. The divisions of the Permian as shown in Table I are taken from the work of Woolacott on the Magnesian Limestone of Durham (6). It must be realised that, within the zones tabulated, uniform conditions do not prevail; wide variations within the rock are to be expected.

TABLE I

DIVISIONS OF THE PERMIAN

	East of Reef		West of Reef
Red Upper Beds	Marls, red marly false-bedded sandstone, thinly fossiliferous, dolomitic limestone, and beds of salt, anhydrite, and gypsum. Only in South Durham. 300 feet thick.		
Upper Limestone	Oolites (originally gypsiferous) of Roker and Hartlepool. 100 feet thick.		Gypsiferous oolites (proved by borings in South Durham).
	Concretionary limestone. Bedded concretionary dolomite and calcareous rock. 250 feet thick.		Upper limestone not understood west of the reef.
	Flexible Limestone 12 feet thick.	Unbedded dolomites and calcareous shell bank of Bryozoan Reef 300 feet.	Segregated limestones. Dolomitic limestone 240 feet. Dolomitic oolite. Fossiliferous dolomite. Granular oolite.
Middle Limestone	Yellow bedded dolomite and segregated limestone 150-200 feet thick.		
Lower Limestone	250 feet of yellow bedded dolomites and dolomitic limestones with which are interbedded in the south of the County lenticles of grey calcareous limestone. These beds thin rapidly north of Sunderland.		
Marl Slate	3-8 feet of thinly-laminated dolomitic and calcareous marl.		
Yellow Sands	Pockets of loose sand of varying depths filling pockets in the pre-Permian land surface.		

The sequence shows that the Lower Magnesian Limestone was laid down under uniform conditions of deposition. The Permian Sea then became shallower. Finally, when all of the calcium carbonate and magnesium carbonate had been laid down, the more soluble salts of anhydrite, gypsum, salt, and potassium chloride, were precipitated. The critical temperature for anhydrite and gypsum is 97°C. Thus for the two minerals to crystallise the local temperatures must have been above 97°C, a temperature greater than the hottest place on earth at the present time. At this time conditions approached those of the true desert of Triassic times.

The Lower Limestone reaches a maximum depth of 250 feet and thickens rapidly from north to south. It is only 20 feet at Marsden but 250 feet beneath Humbledon Hill. The rock is regularly bedded, the beds increasing in thickness to over one foot in the lower layers. The beds are often full of geodes, generally lined with calcite crystals, hence it is often termed the 'Geodic Limestone'. The prevailing colour of these beds is yellow but brown, grey, and whitish bands occur. Sometimes the rock is spotted black with crystals of manganese dioxide. The rock is generally compact and often sub-crystalline, but rarely friable. It generally weathers to a dark brown colour. The Lower Limestone is distributed on the western side of the Magnesian formation.

The Middle Limestone includes a great mass of highly fossiliferous unbedded rocks as well as some bedded rocks. It reaches a maximum thickness of 300 feet and forms a distinct line of hills from High Barnes to Hawthorn. Though highly fossiliferous these beds contain the greatest proportion of magnesium of any in the Series. The Middle Limestone is seldom concretionary but has been rendered crystalline locally along fissures. Some areas are highly calcareous owing to the leaching out of magnesium carbonate in the presence of calcium sulphate. Colours vary from yellow to brown but in limited areas e.g. Tunstall Hill, the rock is very dark owing to the presence of manganese dioxide. The limestone thins to the east and is replaced by bedded rocks which are unfossiliferous and highly brecciated. The Middle Limestone is sometimes termed the Reef Limestone because much of it was deposited as a broken reef with a series of reef knolles. Abnormal conditions prevailed during the deposition of the Middle Limestone as indicated by the progressive extinction of species on ascending the reef. The junction between the Lower Limestone and the Middle Limestone is marked by an unconformity.

At the base of the Upper Limestone there is a thinly bedded yellow limestone, about 12 feet thick, known as the Flexible Limestone. The latter is confined to the northern area, east of the Middle Limestone reef. The Flexible Limestone possesses the property of flexibility and contains a high proportion of magnesium carbonate. The Upper Limestone includes marls which are highly magnesian, soft, and powdery, and it also includes compact blue-stones containing very little magnesium. The peculiar and controversial 'cannonball' limestones of Fulwell are included in these beds. The upper beds are thin-bedded, unfossiliferous, and in places oolitic.

In composition the Magnesian Limestone is variable. Calcium carbonate and magnesium carbonate together generally constitute 90-99 per cent of the limestone. Analyses made by Browell and Kirkby (15) show the percentage of calcium carbonate to vary from 38 to 99 and that of magnesium carbonate to vary from 1 to 50. The rock is rarely a true dolomite (calcium carbonate 54.35 per cent and magnesium carbonate 45.65 per cent) but occasionally approximates to a pure limestone. These workers claim 'the differences in chemical composition are largely due to the action of segregation after deposition.' They further claim 'the light coloured, friable beds contain the most magnesia, while the dark compact beds are the most calcareous'. Trechmann (16) disagrees with this latter contention and states that it applies only to the sulphate-free and oxidised rocks appearing near the surface. It is, however, these beds which are of particular interest to the pedologist. Moreover, the method of recording results as percentages of calcium carbonate and magnesium carbonate of the former workers, is of more use to the worker in soils than Trechmann's method of recording percentages of dolomite and of calcium carbonate. In general, it would appear that the friable beds contain the most magnesium carbonate whilst the crystalline and compact beds contain the most calcium carbonate. Although the light yellow beds are generally richer in magnesium and the darker browns and greys are more calcareous, hue is less reliable as an indication of chemical composition than is texture.

The limestones contain an appreciable amount of iron, occurring either as the oxide or as the carbonate. Iron oxide imparts a pale buff colour to the rock. Silica and aluminium rarely constitute a high percentage of the limestone except in the case of shaly partings in the Lower Limestone. Clapham(17) suggests that limestones containing calcium silicate are easily broken down by the carbonic acid present in percolating water. Calcium carbonate is thus removed as the soluble bicarbonate and silica and magnesium carbonate remain. Such rocks are of limited occurrence and are of little importance to the pedologist.

The small amounts of insoluble residue found in all of the limestones, except in some of the more marly varieties, shows that at the time of deposition the coastline must have been far distant from the present area of outcrop of the rock. The heavy mineral assemblage found in the Magnesian Limestone shows that the distributive province contributing material to the Permian Sea embraced a variety of rock types. These included acid and basic igneous rocks, pegmatites, and metamorphic rocks. Crampton (18) states that the presence of monazite, zircon, apatite, and sphene, suggests the derivation of the material from acid igneous rocks, whilst topaz and tourmaline show that it may be derived from pegmatites. Evidence of the derivation of material from basic igneous rocks is given by the presence of rutile, pyroxenes, and amphiboles. Garnet, zoisite, and staurolite could originate from metamorphic rocks. The distributive province almost certainly included the Caledonian ranges. The above minerals occur together with quartz and felspar - generally of the albite-oligoclase type.

Clusters of calcite crystals were found at Raisby Quarry, Coxhoe. These were remarkable in that they contained numerous inclusions of chalcopyrite ($Cu\,Fe\,S_2$), some of which had been oxidised to malachite ($Cu\,CO_3 . Cu\,(OH)_2$). The crystals are of very local occurrence in Durham. It is interesting to note that chalcopyrite also occurs in the Kupferschiefer of Mansfeld, Germany, where it is probably of sedimentary origin.

The Permian, or Magnesian, Limestone of Durham has attracted much attention. As early as 1883, Lebour remarked that 'probably no other British rock offers so many types of structure displayed in a finer continuous section'. Very simply the exposure can be described as an escarpment of dolomitic limestone dipping gently to the south and east. However, the detailed geology of that escarpment is extremely complex. The limestones show wide variation in colour, texture, macroscopic and microscopic structure, and also in chemical composition. The physical differences are not solely a result of varying chemical composition but are in part the result of differences in formation. Furthermore physical, chemical, and structural changes in the rock have occurred subsequent to its deposition. Trechmann, Wolacott, Lebour, Browell, Kirkby, Garwood, and many other distinguished workers have been concerned with the Limestone. Despite their efforts many problems involving the Series are yet to be solved, notably the mode of formation of the rock. Two explanations have been suggested:-

1. It may have been formed as a result of the molecular replacement of calcium by magnesium in a limestone. This explanation seems to be most accepted. The original calcareous rock is visualised as having sunk beneath a sea saturated with magnesium salts. Molecular replacement of calcium by magnesium and consequent shrinkage of the rock then occurred and produced a dolomite. This shrinkage would explain the numerous small cavities found in many of the limestones. Trechmann (16) and Guy (19), however, suggest that the removal of gypsum, or some such substance, in solution, accounts for these cavities. This hypothesis is supported by the fact that, where the limestone is exposed at the surface or where it lies below a

permanent water table gypsum is absent. But where the rock is protected from water then gypsum is found.

2. It may have been deposited as a dolomite. The great drawback to this theory is the remarkable variation in composition found throughout the limestones. Dolomites and pure calcareous limestones are often found side by side with sharp dividing lines between them. A dolomitic reef may be entirely surrounded by limestone or vice versa. Sometimes a mass of one rock may extend as a ridge through the other, with nearly vertical boundaries. Such irregularities would hardly be expected had the dolomite been deposited in situ.

Many of the problems and controversies relating to the Magnesian Limestone are geological and, in particular, geochemical. They include the following:-

a. the actual mode of formation of the limestones.

b. whether or not gypsum and anhydrite were original constituents of all divisions.

c. The peculiarities of the cannonball limestone of the Fulwell district of Sunderland.

d. The origin of cellular structures within the limestone.

The pedologist is interested in the present form of the rocks and is not directly concerned with these problems. Thus the question as to whether or not gypsum was a significant constituent of the original limestones, and was subsequently removed, has no bearing on the soils now developed. For this reason such problems will not be discussed any further.

Except in the case of the marls the insoluble residue rarely constitutes more than 5 per cent of the rock. Thus, once the magnesium carbonate and calcium carbonate has been leached away the remaining soil material is very thin. Furthermore, some of this material may be removed by the eroding action of wind and water. As a result the rendzina soils, developed solely from the Magnesian Limestone, are themselves of shallow depth. They are mainly developed from the Lower Limestones, the latter outcropping on the scarp edge. It is from here that most of the drift deposits have been eroded away. Elsewhere the soil profiles are developed from a mixture of drift deposits and residual material from the Magnesian Limestone, and may not therefore be of the rendzina type. It is noteworthy that Akimtzev (20) found that an average depth of 12" of soil had developed on the walls of the Dennay tower in 230 years. The tower is part of the Kamenetz fortress which was built in 1362 in the Ukraine. The walls of the tower, on which the soils have developed, were built with slabs of calcareous limestone.

CHAPTER 5

DRIFT GEOLOGY

The most distinctive feature, which shows that ice at one time covered the whole of East Durham, is the widespread occurrence of deposits of glacial drift material; evidence of erosion supports this conclusion. Superficial deposits cover more than three-quarters of the area of the Permian bed-rock. As with the bed-rock they vary greatly in composition, texture, and mode of origin. Sands, clays, and gravels are to be found in close proximity to one another, and these may be of glacial, fluvio-glacial, alluvial, or aeolian origin. Most of these deposits were laid down during, or shortly after, the Pleistocene Glacial Period.

Subdivisions and correlations of the drift deposits are difficult owing to the rareness of clear exposures of any depth. Descriptions of these deposits give different sequences showing that there were from one to five glacial episodes. Woolacott recognises five episodes but Raistrick contends that there were only three. The latter worker states that episodes three and four of Woolacott include clays from contemporary ice-sheets deriving their material from different sources, while the fifth episode is not represented in East Durham.

The sequence shown in Table II is after Raistrick (21).

TABLE II

Glacial Sequence	Northumberland and Durham
4.	Artic Peat (Crossfell)
3.	Birtley Laminated clays and the sands and gravels of Plawsworth etc. Cheviot-Scottish ice swings on to the coast. Lakes down the coast with sands and laminated clays, as at Bedlington. Early stages of ice retreat in the West Durham Fells.
2.	Occasional sands. Pennine and Cheviot ice passing nearly due east to the North Sea (Main Lower boulder clay). North Tyne and some Cheviot ice moving south into the Tyne Valley.
1.	Sands (so-called Loess of Trechmann). Scandinavian clay on the coast south of Warren House Gill.

In East Durham glacial erosion is recognised by occasional striations on rock surfaces. Striae on the Magnesian Limestone run parallel to the coast and were mainly caused by the southward moving Tweed-Cheviot ice-sheet. Boulder clay and fluvio-glacial deposits are much more widespread than the striations and provide ample evidence that the area was once covered by ice-sheets. Erratic boulders have been collected from all parts of the county and many of them identified and their source region recognised (22). They have played an invaluable part in the interpretation of events during the Pleistocene.

Trechmann (23) found patches of boulder clay, containing debris from the sea floor and also characteristic Norwegian erratics such as rhomb-porphyry and nordmarkite, at Warren House Gill, at Hawthorne Dene, and at adjacent coastal areas. This material was rammed into fissures in the Magnesian Limestone and had not been left merely as a surface deposit after the ice had melted. A piece of South Norwegian Laurvikite was found when the railway viaduct at Castle Eden was built. The glacial material in the limestone fissures was protected from subsequent erosion and is evidence that Scandinavian ice impinged on the Durham coast very early in the glacial period. Trechmann considers that there is an unconformity, representing an inter-glacial period, between these deposits and the later products of Scottish and English glaciation. During this interglacial period there was some valley erosion, calcretion of conglomerates, loess concretions, and, at Beacon Hill, local uplift and slickensliding (2). Raistrick (4) reports that there was a period of weathering of the Scandinavian drift with the formation of a loess-like material, before ice-streams from the Pennines reached the North East coast. Woolacott (24), however, states that there is no evidence of any inter-glacial period.

Following a slight retreat of Scandinavian ice the area was then covered by ice of British origin. Some observers believe that northern ice i.e. from the Cheviots, Tweed, and East Scotland, twice advanced over the region, with an intervening stage during which western ice, from the Lake District and the south-west of Scotland, and local ice, from the Pennines and Cheviots, reached the coast. Others believe the region to have been affected by a single British glaciation, during which there were changes in the direction of ice movement. Erratics have been found and associated with all of the source areas mentioned above. The former explanation of ice movements would appear to be the most satisfactory.

Tweed and Forth ice was prevented from moving directly eastwards by Scandinavian ice which filled the North Sea basin. As a result the Scottish ice was deflected southwards, as a buffer stream between the Scandinavian ice and the growing Pennine glaciers. The Tweed ice was joined by glaciers formed on the Cheviot massif. The drifts of these two ice streams are distinguished by the erratics contained in the drift material. The erratics of the Tweed are dominated by Silurian greywackes and those of the Cheviot by porphyrites. The Tweed ice originated in the south west of Scotland, as is shown by the presence in the drift of erratics of the Dalbeattie and the Criffel granites.

Lake District ice was forced eastwards owing to the congestion of Scottish glaciers in the Irish Sea and Carlisle Basin, and crossed the Pennines via the Tyne and Stainmore gaps. The more northerly of these two flows joinednthe southward flow of the Tweed-Cheviot ice-sheets.

The boundary between the Lakeland ice and the Tweed-Cheviot ice may have been somewhere across the Magnesian Limestone Escarpment. This hypothesis is substantiated by the fact that no Cheviot or Tweed erratics have been found in the Middle Wear Valley. The eastward movement of Lake District ice across Stainmore and down into the Tees lowlands is marked by erratics of Shap granite.

The erratics of igneous rock types such as Criffel granite, Cheviot porphyry, Shap granite, Skiddaw granite, and the Threlkeld microgranite, are the most useful in determining the exact direction of ice movements. Such rocks, however, are included within a mass of local Carboniferous sedimentary material. The latter constitutes most of the drift material found on the Permian escarpment and includes fragments of Carboniferous limestone, sandstone, ironstone, and coal. Over most of the area the drift is sandy or gravelly in texture and true tenacious boulder clays are rarely found.

The drift is either thin or completely absent on the edge of the escarpment but it thickens to the south. Thus at Cotefield Close the drift is 106' thick and at Sheraton it is 187' thick (25). Observations show that the whole of the Permian escarpment was once covered with drift. But in places, chiefly along the scarp edge, much of this drift has been removed by subsequent denudation.

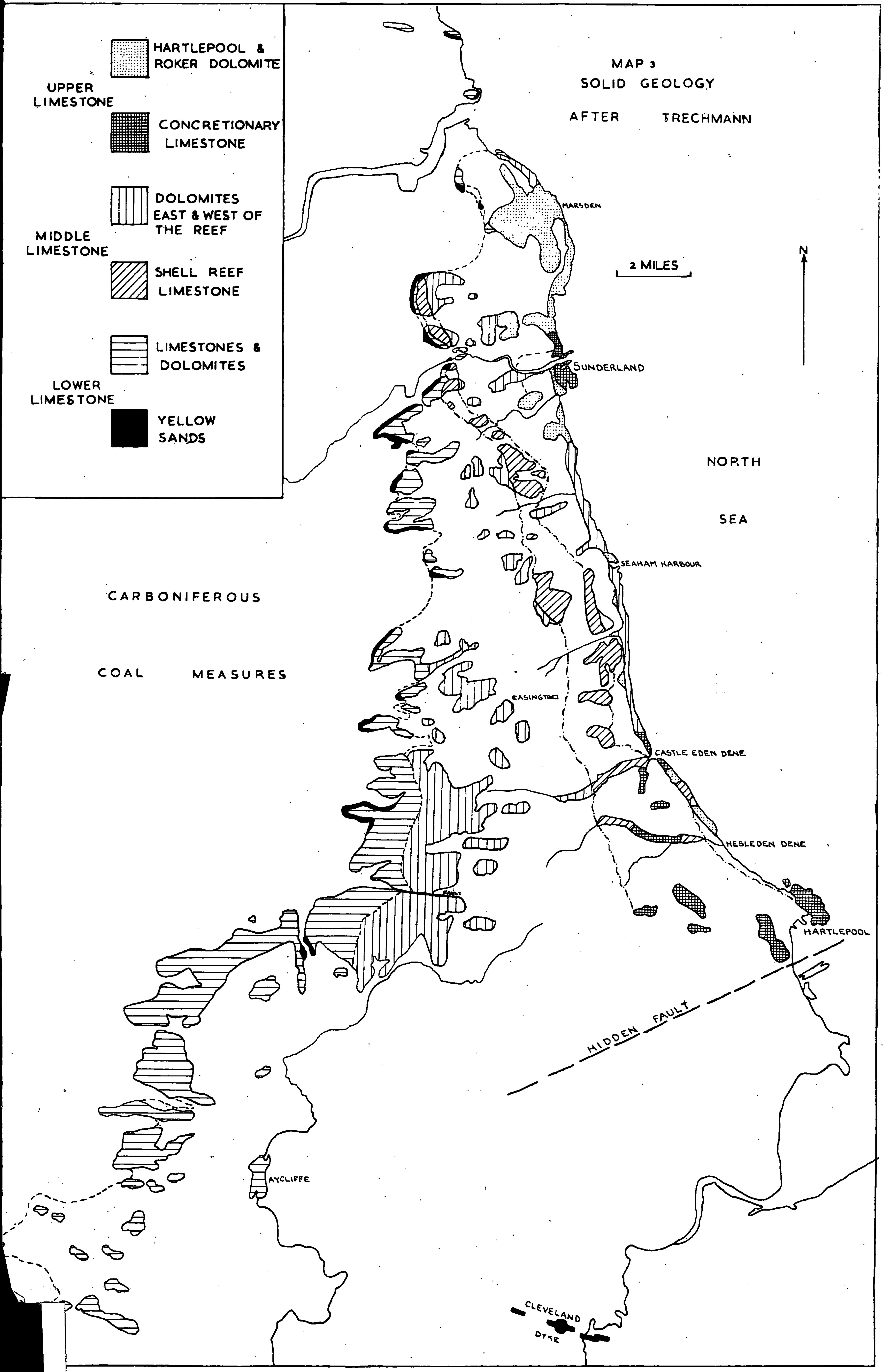
The main drift is purple or blue in colour and contains abundant boulders, mostly of local Carboniferous rocks. On the coastal plain, between this deposit and an upper boulder clay there is a series of sands and gravels. The upper deposit is variable in colour and contains few large pebbles. These pebbles are more varied and not of such local origin as those of the lower deposit. The two deposits are separated by an unconformity even when there are no intervening sands and gravels. Above the upper deposit is a series of sands, gravels, and morainic deposits, laid down as the ice retreated. The 150 feet thick kame-like deposit of sand and gravel which caps Warden Law (646 feet O.D.) originated as the ice retreated. Many of the lower summits are probably of similar origin.

The first ice-streams to melt in the warmer conditions at the close of the Ice Age were those of the smaller Pennine valleys. Meltwaters from these glaciers were hemmed in, between Lake-Tyne ice to the north and north west, Cheviot ice to the east, and Tees-Stainmore ice to the south. As a result the meltwaters collected in the Mid-Wear Lowlands and formed a vast lake. The bed of this former lake is marked by what is now known locally as the 320 feet surface, through which the Wear has cut its present valley. The lake persisted for some time after the Cheviot and Tees ice-sheets had retreated, the Permian escarpment preventing its drainage. At this stage, the low ground north of Sunderland must still have been covered with ice, to prevent the drainage of the lake. Waters from the lake eventually escaped southwards by cutting a channel through the escarpment near Ferryhill. Maling(1) postulates that the channel at Ferryhill was originally a wind gap at 430 feet O.D. at the same time a low col, or pre-glacial depression, across the northern edge of the escarpment was opened. This allowed the reversal of the drainage of the Wear Lake. It resulted in the cutting of a gorge at Sunderland which was developed as the post-glacial course of the River Wear. The pre-glacial Wear had followed the valley of the Team Wash and had been a tributary of the River Tyne.

The pre-glacial floor of the drift-filled Team Wash is as much as 141 feet below the present sea-level. At Dunston, near the junction of the Wash and the River Tyne, the pre-glacial valley floor is 169 feet below the present sea-level. Thus, before the Glacial Period, the land must have stood higher in relation to the sea-level than it now does. Since that time there have been several changes in sea-level. Caves found in Cleadon Hills at a level of 140 feet are said by Howse (1879) to have been formed as a result of marine erosion. This was accepted by Woolacott(1905), Trechmann (1952) and Anderson (1954).

Woolacott also recognised raised beaches at 140 feet O.D. on Tunstall Hills, Fulwell Hills, and an area south of Dawdon. Howse considered that the Cleadon Hills were an island at the time when these beaches were formed. A raised beach was discovered by Woolacott in 1912, at Easington. It is at a height of 60 feet O.D. and is described by Trechmann (26) as being post-glacial in age. Beaches at a level of 100 feet O.D. are to be found along the Durham coast. Some of the beach gravels contain shells of <u>Cyprina islandica</u> and <u>Littorina littorea</u>. Eastwood (27) states that, because of the differences of levels at which such deposits are found, the deposits are probably sea-bottom material which was dragged across the coastal belt during the Glacial Period. Raistrick (4) points out that had beaches been formed at 140 feet then most of the mid-Durham lowlands must have been flooded by the sea at the same time. But there are no deposits inland to suggest that this was the case. Thus little can be found to substantiate the theory of Howse.

Deposits of vegetable remains including tree trunks of pine, hazel and birch, are to be found at Hartlepool, Whitburn, Seaton Sluice, Cresswell, Amble, and Howick. These mark areas of forest growth which were submerged by the sea.


MAP 3
SOLID GEOLOGY
AFTER TRECHMANN
UPPER LIMESTONE
HARTLEPOOL & ROKER DOLOMITE
CONCRETIONARY LIMESTONE
MIDDLE LIMESTONE
DOLOMITES EAST & WEST OF THE REEF
SHELL REEF LIMESTONE
LOWER LIMESTONE
LIMESTONES & DOLOMITES
YELLOW SANDS
MARSDEN
2 MILES
N
SUNDERLAND
NORTH SEA
SEAHAM HARBOUR
CARBONIFEROUS COAL MEASURES
EASINGTON
CASTLE EDEN DENE
HESLEDEN DENE
HARTLEPOOL
HIDDEN FAULT
AYCLIFFE
CLEVELAND DYKE

CHAPTER 6

RENDZINAS - GENERAL

Black, sticky, clay soils, developed from a calcareous or gypsiferous parent rock, were termed Rendzinasbby the agrarian people of Poland. The name rendzina was first used in the literature in 1896 by Sibirtzeff. It is thought to be derived from the Polish verb 'rhedzic' (to tremble), and the term would therefore owe its origin to the sound heard when the soil was being cultivated. When the underlying limestone was visible at the surface, the Poles called the soil 'shraph' because the sound emitted by this soil on being cultivated was similar to snoring.

Rendzina soil types from a wide range of places have been described. These include such areas as South Australia, the Seychelles Islands, United States of America, Russia, Poland, Turkey, Czechoslovakia, Yugoslavia, Italy, Spain, France, England, and Norway. The soils have developed from different types of parent material. Calcium rendzinas have developed from limestones, dolomites, chalks, and flysch rocks. Magnesium rendzinas have been described from Czechoslovakia and they are developed from a parent material of serpentine, while gypsiferous rendzinas, developed from a gypsum-rich parent material are described from Poland. Most of the parent materials of the rendzina soils are between Permian and Cretaceous in age. The rendzina is found developed under Equatorial, Mediterranean, North West European, Continental, and Alpine climatic conditions.

The influence of Russian soil workers led to the name rendzina being applied at one time to all soils developed as a result of the weathering of calcareous rocks. However, soils developed from calcareous parent materials have morphologies far too diverse to justify such a common genetic designation. Moreover, such a nomenclature is contrary to the modern method of soil classification based on the soil profile. Stevens (28) bases his classification of the soil types formed from calcareous parent materials on the hardness of the limestone and also on the climatic conditions under which the soil is formed. The classification of Stevens is given in Table III. Brown earth, chernozem, and podsol soil types may all be developed from calcareous parent materials. In the Mediterranean region the weathering of a calcareous rock usually leads to the formation of a Terra Rossa type of soil. In County Durham the soils developed from the Carboniferous Limestone differ from the soils developed from the Magnesian Limestone. Thus, in classifying a soil as being of the rendzina type, it should first be established that the profile of the soil is typical of a rendzina, rather than to infer that the soil is a rendzina because it has developed from a calcareous parent material.

Some soil workers have noticed characteristic features in those soils with which they have been concerned. They have recorded these characteristics, not as peculiarities of their particular soils, but rather as generalisations of the rendzina soil type. As a result, in the literature on rendzina soils there are many contradictions regarding the properties of these soils. This is exemplified with reference to reports by the various workers on the natural vegetation of the soils. Sigmond (13) states that the rendzinas are formed under a forest type of vegetation. He adds that the rendzina profile is more related to that of the chernozem soil, developed under a steppe grass vegetation, than to a forest profile.

TABLE III

PARENT MATERIAL	CLIMATE			
	HUMID	SUB-HUMID	SEMI-ARID	ARID
Soft or Powdery Calcareous Material	Rendzina		Grey calcareous soils	Brownish-grey calcareous desert soil.
Hard or Nodular Calcareous Material	Brown Forest soil	Terra Rossa	Brown soils, red-brown soils, solonised brown soils.	Red calcareous desert soils

Duchaufour (12), however, states that the rendzina does not make a good forest soil because of its dryness. Principi (29) supports this statement and notes that trees could not be grown on the rendzina soils of the Italian Umbria region. Furthermore Lutz and Chandler (6) state that rendzina soils in Alabama, Mississippi, and Texas, will only support a natural vegetation of prairie grasses and legumes, whereas adjacent red and yellow podzolic soils, which are derived from acid parent materials, will support a forest type of vegetation. They add that even under humid climatic conditions, where the climate favours the development of a forest type of vegetation, the natural vegetation of the rendzina is principally grass. Kubiena (31) describes soils, which he classifies as being of the rendzina type, supporting either forest or grassland vegetation. Therefore the natural vegetation associated with a rendzina soil is probably dependent on local climate and topography.

Hilgard (32) states that areas underlain by a dolomite rock are sterile. This statement is substantiated by the occurrence in Europe of areas where a dolomitic country rock has been weathered to a sandy dolomitic desert, from which plants are unable to obtain nutrients. In the United States, Magnesian Limestone underlies barren areas in several States. The occurrence of such areas seems to justify the contention that dolomite is a poor soil former. Why the presence of magnesium carbonate should interfere with the beneficiary effects of calcium carbonate is not understood. The rendzina soils found in Durham are amongst the most fertile to be found in the county and they cannot be classed as barren or sterile. However, though the Durham Permian Limestone contains magnesium carbonate it is rarely present in amounts equal to the dolomitic ratio. Thus the name of Magnesian Limestone is more appropiate than Dolomitic Limestone.

Principi found no difference between the soil profiles developed from a limestone and those developed from a dolomite. Miklawski (quoted in 13), however, differentiated the Polish rendzinas into thirteen classes depending on the type of parent material from which the soils were derived. Kubiena distinguishes eighteen different types of rendzina profiles and takes no single factor as a basis for classification.

Kotzmann (33) states that rendzinas are most typically derived from the weathering of a pure limestone or a dolomite, but that all intermediate stages can be found between a rendzina and a podsol. Glinka and most Russian pedologists regard the rendzina as a transitional soil which will eventually become a podsol. Podsolisation commences when all of the calcium carbonate has been leached out of the original rendzinas profile. Rendzina profiles have been converted into podsols on the Permian escarpment of Durham. The conversion is the direct result of planting conifers in soils that were originally rendzinas. The decomposition of acid pine needles contributed to the podsolisation of these soils. Miklashewski, however, denies that podsolisation could ever result from a true rendzina under natural conditions. Central European workers link the rendzina soil with the chernozen. In fact, Stebutt (quoted in 13) classifies the rendzina as an intrazonal chernozem. Duchaufour states that the rendzinas merge into the brown earth soil group. Obviously all of these workers have associated the rendzina soil with the particular major soil group with which they are familiar. Probably the best classification of the rendzina is that given by Thorp and Smith (34) who classify it in the Calcimorphic Suborder of the Intrazonal Soils. Thus the morphology of a particular rendzina will approach that of the zonal soil of that particular region. Lutz and Chandler state that it is the calcium carbonate present in the rendzina profile which impedes the development of the zonal soil type.

Despite the number of controversies over the rendzina soil type, pedologists are in agreement over several characteristic features of the soil. The most outstanding of these features concerns the soil profile. There is an absence of a B, or illuvial, horizon. Thus by conventional nomenclature the rendzina profile only includes A, C, and D horizons, though sometimes the C, Horizon is absent. The A_o horizon is a thin humic layer which lies above the mineral soil. It usually includes fragments of dead plants which have not been decomposed. Other A horizons may be distinguished on the basis of differences of colour, texture, structure, or some other criterion. Such horizons are named from top to bottom A_1 A_2 A_3 ..... These horizons have one feature in common namely that they are all eluvial or leached horizons.

C horizons are those composed of unconsolidated material essentially similar to that from which the soil was formed. The D horizon is the underlying solid rock. A D horizon is also one which cannot be considered as parent material but may influence profile development as would be the case if an impermeable band of clay underlay the soil profile.

The rendzina profile is typically shallow, usually 6 - 12" in depth. The soil reaction is either neutral or slightly alkaline. There is little differentiation throughout the profile of the mineral fractions of the soil. Although the rendzinas are found to vary texturally from clays to sandy loams, there is little textural differentiation between the horizons within the same profile. Parent material is the dominant factor in the genesis of the rendzina profile but climate, vegetation, topography, and time, may all exert an influence on profile development.

Calcium is generally the dominant exchangeable cation but in the case of some rendzinas developed from dolomitic limestones magnesium may be present in a greater proportion than calcium. Soil humus accumulates in the upper layer of the soil and is very dark in colour. The humus often forms a distinct A_0 horizon. The quantity of humus present in the soil decreases with depth. The dark colour of the humus is thought to be the result of specific bacterial action in the presence of free calcium carbonate. Many bacteria prefer to live in soils which contain calcium carbonate. Calcium carbonate also promotes the aggregation of the mineral fractions of the soil into a crumb or granular structure. McIntyre (35) states that free ferric oxide may also be present in the profile and can help in the aggregation of the mineral grains.

Free calcium carbonate is usually absent from the upper horizons of the soil profile as a result of downward leaching. However, fragments of limestone are usually found in the lower horizons increasing in size and number with depth. Very often the rendzina profile includes a C_1 horizon in which limestone fragments make up the bulk of the soil material.

Limestones and dolomites, from which rendzinas develop are usually porous and well-fissured. The soils are rarely influenced by ground water and are almost always free-drained. Because soil moisture affects soil temperature the rendzinas are generally warm soils. Erosional forces act along the limestone fissures resulting in steep slopes on the limestone formations. The soils developed on these slopes may be subjected to great changes in temperature because of their aspect.

The colour of the rendzina soil is often found to vary from one locality to another. Black, dark brown, brown, yellow, red, and grey, are common colours found in the rendzina type of soil. Even with the presence of only a small amount of humus the soil colour of the upper horizons is often very dark. The subsoil is always lighter in colour than the top soil and generally the soil becomes lighter in colour with depth.

CHAPTER 7

RENDZINAS - DURHAM

The rendzina soils developed from the Durham Magnesian Limestone show variations in their physical and chemical properties. Such variations are to be expected for two reasons:-

1. The limestones from which the soils have developed vary both in physical and chemical properties.
2. The soils include varying proportions of glacial drift material, which is itself variable in composition.

The rendzina profiles were characteristically shallow, fifteen inches being the deepest recorded. The continuous erosion of soil material by fluvial and aeolian agencies inhibits the development of deep profiles and thus prevents the rendzinas from reaching a state of pedological maturity. In areas where there was an accumulation of soil material (viz. Chapter 8) the thickness of the deposits masked the effect of the underlying limestone and reduced the influence of the limestone on soil development. Thus, in these areas, a brown earth type of profile was developed.

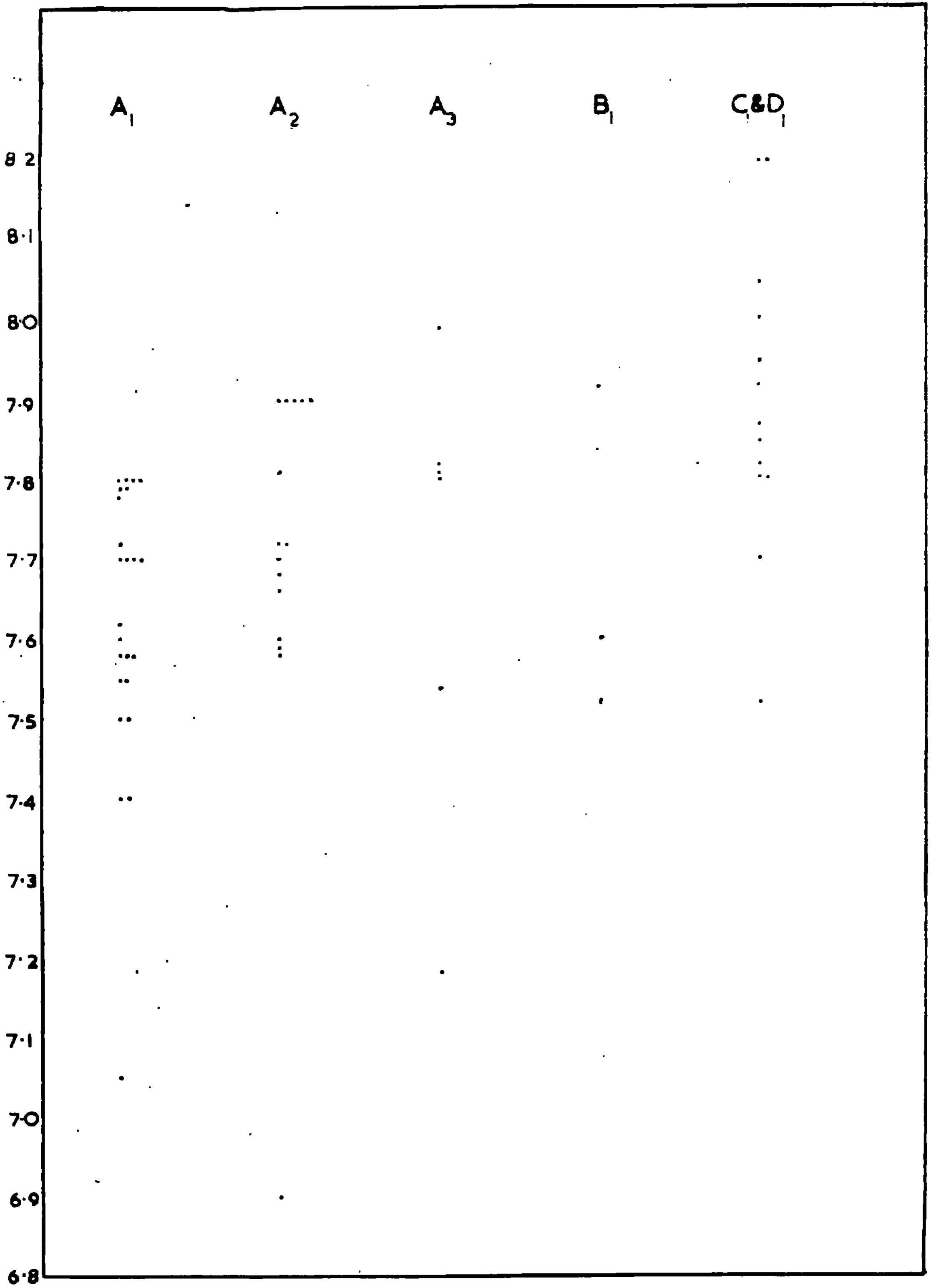
Results of the mechanical analysis are given in Table VII. In most of the samples analysed the recovery was more than 95%. This indicates that the method employed was suitable for the soils studied. The texture of the rendzinas varied from loamy sand to silty loam but there was no general textural differentiation throughout the horizons of the profiles. The lower horizons, however, tended to contain a slightly higher percentage of clay and silt than did the upper horizons. In most cases this increase was insufficient to give the horizons different textural classifications. The slight enrichment of the lower horizons with silt and clay would result from mechanical eluviation by percolating rain water. Furthermore the upper soil horizons contained a greater proportion of drift material. Hence the coarse sand fraction of these horizons included rounded grains of quartz and coal fragments, which had not been derived from the underlying limestone, but owed their origin to the superficial deposits of glacial drift. Because much of the drift material was restricted to the upper horizons, they had a slightly coarser texture than the lower horizon. Sometimes the presence of coarse quartz grains and coal fragments conferred on the soil a gritty feel. Such soils differed in textural feel from other soils of the same textural classification, which did not contain very coarse sand fractions.

In general, the soil material of each horizon included at least 60 per cent of sand, coarse sand accounting for 5 to 15 per cent of the total. The percentage of clay varied from 1 to 27 and the percentage of silt from 3 to 28. Profile 10 is worthy of special mention. The sandy A_1 horizon was two inches deep and was an aeolian deposit, the sand grains being carried by the wind from an exposure of Yellow Sands in an adjacent quarry. The formation of this horizon demonstrated the effect of wind erosion on soil formation on the escarpment. Profile 12 was typical of the brown earth soils developed in areas of deeper soil material. These soils revealed a textural differentiation throughout their profiles, thus distinguishing them from the rendzina profiles.

In the rendzina soils there was a gradual change in colour with depth of profile. The upper horizons were generally dark brown or dark grey brown whereas the lower horizons were yellow brown. Though the change in colour between the upper and lower soil horizons was a gradual one, the distinction between the soil and the underlying parent material was striking.

Thus there was a marked contrast between the grey brown or yellow brown of the soil and the pale yellow of the parent material. This colour contrast was especially marked in soils developed over sandy pockets of uncemented limestone, as was the case in Profile 16. Dark colour of the soils is usually caused by the presence of humus. Calcium carbonate is thought to be associated with the formation of a black type of humus (36). Thus, the rendzina soils are often surprisingly dark in colour, even with only a moderate humus content. Ramann (37) suggests a further factor with calcareous soils. He states that the difference in colour between soil and subsoil may result from the downward translocation of ferric hydroxide; the iron is leached from the upper soil horizons and deposited in the subsoil. McIntyre (35) states that the presence of iron in the soil can influence the aeration of the soil by promoting aggregation of the soil particles into crumbs. Such aeration would affect the rate of formation of humus from organic matter and would thus affect the soil colour.

The rendzina soils were well-aerated as a result of the development of a strong crumb structure and in some cases a granular structure was developed. Apart from organic matter, calcium carbonate, moisture, and ferric oxide (see above), all help in the formation of a strong structure. Tansley (38) states that "calcium, when the dominant metallic ion, imparts physical and chemical stability to the whole weathering complex, aggregating the fine colloidal particles into compound particles, giving a crumb or granular structure". The aeration of the soils and the permeability of the underlying limestone results in the soils always being freely drained.



pH VALUES OF THE SOIL HORIZONS

FIG. 2

The soil reaction varied from pH. 7.05 to 8.2. Thus the soils are neutral or slightly alkaline. The pH of each horizon was plotted on Fig. 2. The graph demonstrates the gradual increase of pH with depth of soil sample. Thus the median pH values for each horizon are as follows:-

A_1 7.62; A_2 7.7; A_3 7.81; C_1 7.85.

The low value of 7.05 recorded for the A_1 horizon of Profile 20 could be explained by the influence of an adjacent pine wood. The composition of pine needles would result in a more acid type of humus than is produced from the decomposition of the natural vegetation of the rendzina soils. The pine needles could be blown on to the rendzina soils and on decomposing produce a less alkaline soil than that normally found. It will be noted that the pH recordings for horizons A_2 (6.9) and A_3 (7.18) of Profile 9 are both low when compared respectively with the pH values for other A_2 and A_3 horizons. This would be expected, however, because Profile 9 was not typical of the rendzina type of soil. This profile included a B horizon and was representative of the brown earth type of soil towards which the rendzinas evolved.

The concentration of carbon dioxide in the soil air effects the pH of the soil sample. The higher this concentration then the lower will be the soil reaction. Witney and Gardner (quoted from 39) have shown that this reduction in pH is proportional to the logarithm of the carbon dioxide pressure. Plant roots maintain a high concentration of carbon dioxide surrounding them. Because of this the effective pH affecting the plant root system is lower than that of the soil sample when determined in the laboratory. This lowering of the pH by plants is of great importance.

Many plants suffer from phosphate and trace element deficiencies if the pH of the soil in which they grow rises above 8. Thus by maintaining a high concentration of carbon dioxide round their roots they are able to reduce the pH of the adjacent soil and hence, to some extent, make available phosphate and trace elements in which they would otherwise be deficient. There is an upward movement of calcium carbonate from the limestone parent material by evaporation and by plant and animal activity within the soil. This continual addition of calcium carbonate prevents the development of acidity anywhere in the profile.

The percentage loss on ignition for each sample is shown in Table VIII. Values range from 35.5 per cent to 5.6 per cent. As could be expected the greatest losses were recorded in the upper soil horizons and the percentage loss decreased with depth of soil sample. The loss recorded included organic matter and any hygroscopic moisture or combined moisture present in the samples. The carbonates were reformed during the analysis and therefore did not contribute to the loss recorded. The percentage loss on ignition can only give an approximation of the organic content of the soils. When referred to soils of a single type such figures may give a significant indication of their organic content. Undoubtably, in the case of the soils studied, this was not possible, because of the presence of small fragments of coal admixed with the soil. These coal fragments were of glacial origin and were rarely more than a quarter of an inch in diameter. (Cf. 40). The fragments were unevenly distributed throughout different soil profiles and also throughout individual profiles. Such fragments would contribute to the loss on ignition whenever present in a sample. Although amounts of organic matter and of hygroscopic moisture would be relatively similar in each sample because the soils were all of a similar genetic type, the amount of coal present in the samples varied widely and erratically. Thus the great differences (35.5 per cent to 5.6 per cent) between percentage loss on ignition are largely a result of the uneven distribution of coal fragments throughout the horizons. The glacial drift material, among which the coal was deposited, was largely confined to the upper soil horizons.

Percentage of organic carbon was determined by the Walkley and Black method. It is assumed that soil organic matter contains 58 per cent of carbon. Thus the percentage of organic matter was calculated by multiplying the percentage of organic carbon by 1.724 (100:58). Percentage of organic carbon varied from 11.6 to 0.78, and these data give corresponding values for the soil organic matter of 19.76 and 1.34 per cent. There was a decrease in percentage of organic carbon, and therefore of organic matter, with depth of profile. The degree of humification of the organic matter appeared to be high, probably a result of adequate aeration in the soil. Thus apart from live roots and recently dead plants, little plant structure could be observed. The recently dead plant material sometimes formed a thin A_0 horizon at the top of the soil profile. There was some degree of humus accumulation in the upper soil horizons but this was not pronounced in the soils studied.

Percentage of nitrogen in the soil samples varied between 1.03 and 0.07. There was usually a decrease in percentage nitrogen with depth of soil profile. Thus percentages of both carbon and nitrogen decreased with increase in soil depth. When the carbon:nitrogen (C:N) ratio was calculated for each horizon it became apparent that the decrease in percentage carbon was not always equivalent to the decrease in percentage nitrogen. Thus in some instances the decrease in percentage nitrogen and in the percentage carbon was accompanied by a decrease in the C:N ratio, whilst in other instances it was accompanied by an increase in the C:N ratio.

Duchaufour (12) suggested a figure of from 10 to 12 for the C:N ratio of the upper horizons of rendzinas covered by grass. The ratio decreased from 8 to 10 with depth. The C:N ratios of the soils studied showed more variation than this. The ratios for the upper horizons varied between 18.6 and 8.5 whilst the ratios for the lower horizons varied between 20.7 and 4.5. The presence of coal fragments in the soil horizons could well result in increases in the percentage carbon content of the samples. In the Walkley and Black method an attempt is made to exclude carbon in the form of coal, graphite and inorganic carbon, from the analysis. Because of the low percentage of nitrogen found in the soils, however, even a small increase in the percentage carbon resulting from the presence of coal, would cause a significant increase in the C:N ratio, which would have no significance.

The available potash and available phosphate status of the soils were also determined. There was variation in status not only throughout individual profiles but also between one profile and another. In general, it was found that both the phosphate and potash status of the soils was within the medium to very high range. Thus the soils were not deficient in these nutrients. There appeared to be no relationship between the available nutrient status, and either the texture, the content of organic matter, or the soil reaction. The soils studied were rarely cropped and therefore their high nutrient status may be a result of accumulation rather than of any inherent ability of the soils to provide an adequate supply of these nutrients. The phosphate status

of the soils was usually

higher than the potash status. The availability of phosphate to plants is dependent on soil reaction and many plants suffer from phosphate deficiencies if the pH of the soil rises above 8. The pH of the soils was rarely above 8 and, as most of the soils were under pasture, the plants would be able to maintain a concentration of carbon dioxide round their roots and hence effectively reduce the soil reaction. It is noteworthy that Profile 9, which was sited within the area which Bailey (10) classed as poor infertile clays, had a low potash status and a low phosphate status.

The exchange capacity of the rendzinas varied between 15.51 and 34.57 milligram equivalents per 100 grams of soil. Although the contribution of the individual exchangeable cations varied with depth of soil there was a general decrease in total exchange capacity with depth in every profile except Profile 10. The organic matter, as calculated from the carbon figures, of the profiles was also found to decrease with depth of profile. Thus the exchange capacity of the rendzinas appears to depend primarily on their humus content and not on the amount of clay material present in the profile. In Profile 10, the increase of exchange capacity with depth of soil was a result of the A_1 horizon of aeolian sand which modified the natural profile. The adsorbing complex was saturated with cations other than hydrogen and calcium was the predominant cation. Calcium generally accounted for from 55 to 70 per cent of the total exchangeable cations but the percentages varied from 40.9 to 76.9. Exchangeable calcium varied throughout the profiles from 11.2 to 21.1 milligram equivalents per 100 grams of soil. There was a general decrease in the quantity of exchangeable calcium with depth of soil, but the percentage contribution of calcium to the total exchange capacity of the soils increased with depth.

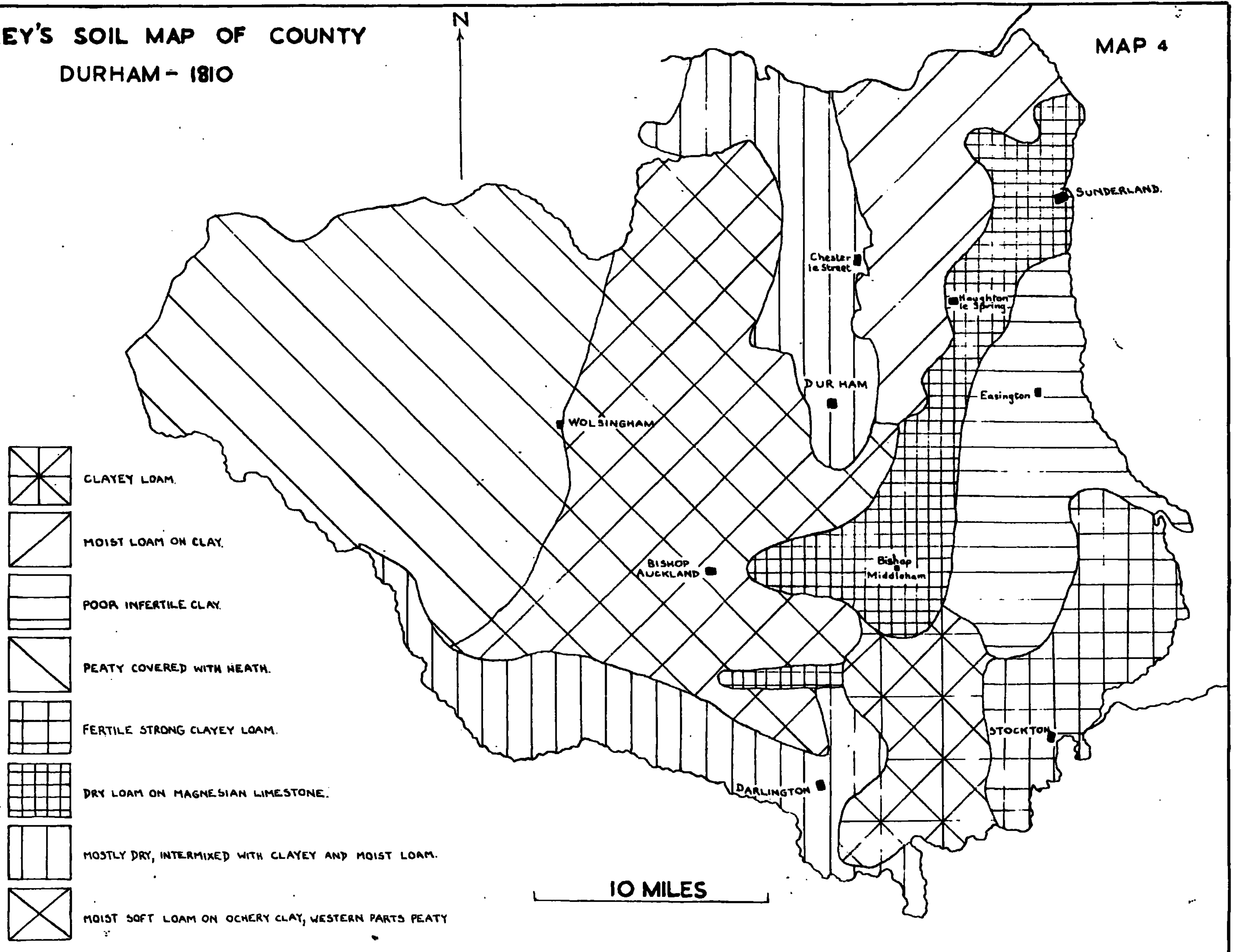
Exchangeable magnesium varied between 3.0 and 14.8 milligram equivalents per 100 grams of soil. In general, magnesium decreased in milligram equivalents and also in percentage of the total exchangeable cations with depth. Calcium was always found in excess of magnesium on the exchange complex.

Percentage of exchangeable sodium was usually less than percentage of exchangeable magnesium but greater than percentage of exchangeable potassium. Exchangeable sodium varied between 0.76 and 8.09 milligram equivalents per 100 grams of soil. In most samples, however, there was less than 4 milligram equivalents per 100 grams of soil. Exceptions to this were Profiles 14 and 17. Both of these profiles were sited on the sea coast, Profile 14 on a sea stack at Trow Point, and Profile 17 on the cliff edge at Marsden Village. The greater amounts of exchangeable sodium found in these profiles undoubtedly resulted from their proximity to the sea. Sodium carried in sea spray and sea mist would be deposited in the soil and thus enrich the sodium content. The percentage sodium of the total exchangeable cations was generally between 5 and 10. Profiles 14, 15, 16, and 17, which were all sited near to the sea, have percentages of exchangeable sodium greater than 10, which is sufficiently high for the soils to be classified as saline alkali. Thus it would appear that proximity to the sea is the most important factor controlling the exchangeable sodium content of these soils. Mention has already been made of the thick layer of low cloud which drifts for variable distances inland over the East Durham Plateau. The cloud is especially prevalent in late spring and the particles of moisture forming it will certainly contain sodium salts from the sea water. As the warm air passes over the cold land surface moisture will be precipitated as a result of condensation. Thus sodium ions will be introduced into the soil profiles.

Exchangeable potassium only occasionally exceeded 2 milligram equivalents per 100 grams of soil. Thus the total exchangeable cations usually included less than 5 per cent of potassium. There was a decrease in amounts of exchangeable potassium with depth of profile.

MAP 4

BAILEY'S SOIL MAP OF COUNTY DURHAM - 1810



CHAPTER 8

DISTRIBUTION OF RENDZINAS IN DURHAM

In 1810, Bailey (10) compiled a soil map of the County of Durham. (See Map 4). Eight soil types based on textural classification were recognised. Even at this early date, Bailey differentiated between the soils developed along the edge of the Magnesian Limestone escarpment and those developed further east and south on the dip slope.

During the Pleistocene Period glacial drift was deposited over the whole of the limestone escarpment. Since this time the drift has been reduced in thickness by denudation and especially by fluvial erosion which is most effective on steep slopes. In general, the steepest slopes on the Magnesian Limestone are found along the crest of the escarpment. Thus most of the glacial drift has been eroded from this area, and indeed in places the underlying limestone is exposed at the surface. As a result, the cover of drift is thin along the edge of the escarpment but progressively thickens down the dip slope towards the sea to the east and towards the Tees Lowlands to the south.

The variations in thickness and composition of the glacial drift are associated with variations in soil types over the Magnesian escarpment. The influence of the limestone on soil development and morphology is largely dependent on the thickness of the glacial drift. As already pointed out, in areas where the cover of drift is considerable the limestone has little effect on soil genesis. The rendzina soil type is thus only developed where the glacial drift is thin or absent, though drift-free soils were rarely found. Coal fragments, sandstone and ironstone pebbles, indicative of drift deposits, were found even in the shallowest profiles studied. The soils described as being of the Rendzina type were those in which no B horizon could be recognised. It was estimated that drift material accounted for something less than fifty per cent of the total soil material in these soils.

The largest area of rendzina soils is between West Cornforth and Thornley. This area includes the higher land of the escarpment. Probably only a thin cover of glacial drift was originally deposited over this area. Moreover, the area has the highest rainfall per annum on the escarpment and therefore the removal of drift material as a result of fluvial erosion would be greatest. Elsewhere on the escarpment rendzina types of soil are developed only in small patches. They are usually found on the higher ground at the crests of many of the hillocks along the escarpment e.g. Cleadon Hills and Cold Hesledon. (See Map 5). Material eroded from the crests of the hills is washed down on to the lower slopes. As a result a brown forest type of soil is usually developed on the lower hill slopes, where soil material is much thicker.

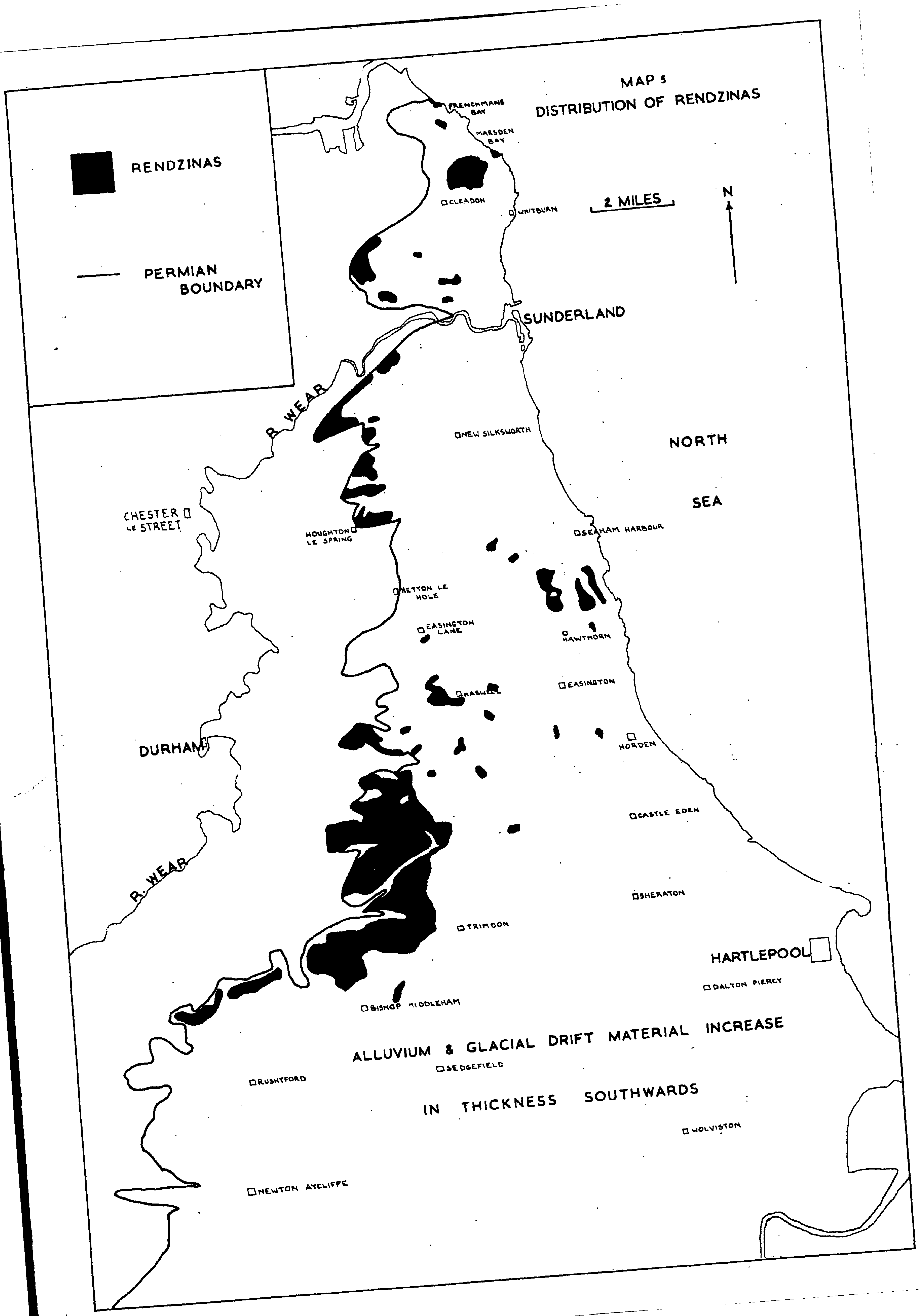
True rendzina types of soil, i.e. those developed solely from the Magnesian Limestone are at present developing in disused quarries. Here the thin cover of drift material was removed as a result of quarrying and when work ceased benches of limestone were exposed to pedological processes. Waste heaps from the quarries are a further source of parent material on which rendzina soils can develop. The soils formed in these areas are immature since insufficient time has elapsed to allow of their full development; their profiles are rarely more than one or two inches in depth. Although such soils are of limited importance to the agriculturist they are of some interest to the pedologist. They provide information regarding the mode of formation of rendzina soils and also of the colonisation of rendzina soils by plants.

CHAPTER 9

AGRICULTURAL POTENTIAL

Bell (41), in 1856, stated that the soils developed from the Magnesian Limestone were 'light and dry, and capable of producing a good cover of grass'. Since then advances have been made in the fields of soil analysis, crop requirements, and farm management. Analysis of the soils (see Chapter 7) shows that they are reasonably fertile. They are slightly alkaline in reaction and therefore are well suited to crops such as clover, lucerne, turnips, beans, peas, and barley. It should be noted, however, that most agricultural crops prefer a soil reaction which is slightly acid i.e. pH about 6.5. The soils generally have a high status of both "available" phosphate and "available" potash. Many workers have discussed the low availability of phosphate in calcareous soils. Thus, in the soils studied, phosphate may have been present in an available form or else $^N/2$ acetic acid may have extracted phosphate from the soils beyond the true availability of that nutrient.

No measurement was made of trace elements present in the soils. Russell (39) states that many plants suffer from trace element deficiencies if the pH of the soil is above 8. Thus manganese is converted into insoluble manganese oxides, which are not available to plants. Chlorosis, resulting from the low availability of iron, is one of the characteristic problems of calcareous soils. Chlorosis, resulting from a possible deficiency of magnesium would not appear to be evident in the soils studied. Salisbury (42) found that the availability of molybdenum is promoted by an alkaline reaction but the availability of boron, manganese, iron, and aluminium, is decreased. It is noteworthy that the teart



MAP 5
DISTRIBUTION OF RENDZINAS

pastures found on some of the heavy Lower Lias clays of southern England result from excessive concentrations of molybdenum in the soil. In rendzina soils the fact of poor productivity and plant disease could be expected to be associated with trace element deficiencies and not with such factors as structure, texture, the availability of major nutrients (Cf. above paragraph), or the organic content of the soils.

Diseases often associated with calcareous soils include:-

Disease	Crop	Cause
Take All	Cereals	Ophiobolus
Common Scab	Potatoes	Actinomyces
Heart Rot	Turnips	Boron deficiency
Grey Speck	Oats	Manganese deficiency
Marsh Spot	Beans	Manganese deficiency

Magnesium compounds may have injurious effects on plants. Hilgard (32) states that in soils formed from dolomites the presence of magnesium carbonate can interfere with the usual beneficial effects of calcium carbonate, but the reason for this is not fully understood. Magnesium is a constituent of chlorophyll and is therefore an essential nutrient for all green plants. Moreover, it is thought to play an important rôle in the transport of phosphate in the plant. To prevent the injurious effects exerted on the plant by an excess of magnesium, it appears that exchangeable calcium must be present in the soil in greater amounts than exchangeable magnesium. Plants appear to have individual preferences for a particular exchangeable calcium to exchangeable magnesium ratio. Also, Turuta, and Katayama found that oats grow well with a calcium: magnesium ratio of 1:1 but cabbages prefer a ratio of 2:1 (Quoted from 32).

When exchangeable magnesium does exceed exchangeable calcium this may result in the formation of infertile soils. Thus Hilgard (32) states that areas where dolomitic country rocks predominate, the soils are remarkably sterile. In Durham, however, the Magnesian Limestone rarely approaches the chemical composition of a true dolomite. Calcium carbonate is invariably present in ~~the~~ greater amounts than magnesium carbonate. This is reflected in the soils and the percentage exchangeable calcium was always found in excess of the percentage exchangeable magnesium. Thus plants growing on the Durham rendzinas rarely suffer from ill-effects resulting from there being an excess of exchangeable magnesium in the soil. In fact, ground magnesian limestone is transported from the Steetley and Raisby Quarries, sited near Coxhoe, to Ayrshire. The limestone is then used as field dressing to reduce soil acidity. For many years it was thought that magnesian limestone was injurious to crops when used as a field dressing. About 1800, the Rev. Turner of Newcastle (10) analysed two samples of Limestone from Weardale (Carboniferous) and two samples from East Durham (Permian). He found that the Weardale Limestone, which never had harmful effects on crops when used as a field dressing, contained no magnesium, whereas the Permian Limestone, which sometimes had harmful effects, did contain magnesium. He sums up his findings by saying that 'the quantity of magnesia is proportionate to the bad character of the limestone'. The injurious effect of magnesian limestone was largely a result of the rate at which it was applied to the land. The dressing rate was rarely less than 5 tons per acre and such heavy dressings caused the development of alkaline conditions in the soils so treated. Moreover, magnesium oxide is less soluble and takes up carbon dioxide less readily than does calcium oxide. Thus when magnesian limestone is applied to a soil it remains active and caustic in that soil longer than an equivalent dressing of quicklime (43). Recent research has shown that when the magnesian limestone is applied at a rate equivalent to the lime requirement of a soil, it is at least as effective in promoting the growth of crops as a non-magnesium type of limestone (44). It is regrettable that the old prejudice against the use of magnesian limestone should still persist in some localities.

The rendzina soils being usually alkaline rarely reveal any lime requirement. However, Bailey (10) states that in East Durham farmers formerly thought it necessary to lime all fallow fields. Indeed such a condition was often included in a tenancy agreement and anyone not complying with this was thought to be exhausting his land. Usually 'two cartloads' of lime per acre were applied. There were no agricultural advisory workers at that time and farmers had to resort to methods of trial and error in determining the best treatment for improving their land. Mr. Bamlet of Haverton Hill limed part of a field and left the rest unlimed. He found that the best crops grew on the unlimed land and that crops were poor on the limed land for two years after treatment. Now, of course, farmers are able to have their soil analysed and the lime requirement more accurately estimated.

The rendzinas are light in texture and the underlying limestone is very porous; as a result, the soils are free draining and tend to dry out. Water shortages may have noticeable effects on growing crops. Russell has shown that the quality of wheat is usually highest in dry years and that of barley in wet years, providing the rain falls in the months of May and June.

Probably the most important limitation on the agricultural utilisation of the rendzina soils is their shallow depth. The profiles are generally less than twelve inches deep and many are too shallow to be ploughed. Even the deepest soils are rarely of sufficient depth to allow the growth of root crops. When ploughed, the soils studied had a stony appearance, resulting from the disturbance of the C horizon of weathered limestone fragments. These fragments had been upheaved by the plough and had been distributed throughout the profile instead of being confined to a single horizon as found in undisturbed profiles. A typical rendzina field, after ploughing, is shown on Plate 6, and it is noticeable that the limestone fragments cover a considerable proportion of the area. Sometimes slabs of the underlying limestone are broken off from the country rock by the plough. The slabs may be two or three feet in length and they must be removed from the field if they are not to cause future damage to farm implements. Many such slabs can be found around the edges of fields having a rendzina type of soil.

Because of the shallow depth of their profiles the rendzina soils are mainly used for the growth of cereal crops and grass. Wheat, clover, oats or barley and, if the soil is deep enough, turnips or potatoes, are grown in rotation. Typical rotations are:-

1.	2.
Potatoes	Roots
Wheat	Barley (or wheat)
Swedes	Seeds
Barley	Seeds
Seeds	Oats
Seeds	
Oats	

The shallower soils are kept under long ley pasture or under permanent grassland. Thus the field in which Profile 20 was sampled had not been ploughed for at least thirty years.

PLATE 1. Intermittent drainage on the dip slope of the limestone escarpment.

PLATE 2 Lower Limestone underlain by Yellow Sands.

PLATE 3 Clusters of calcite crystals with inclusions of chalcopyrite and malachite - sample taken from Raisby Quarry, Coxhoe.

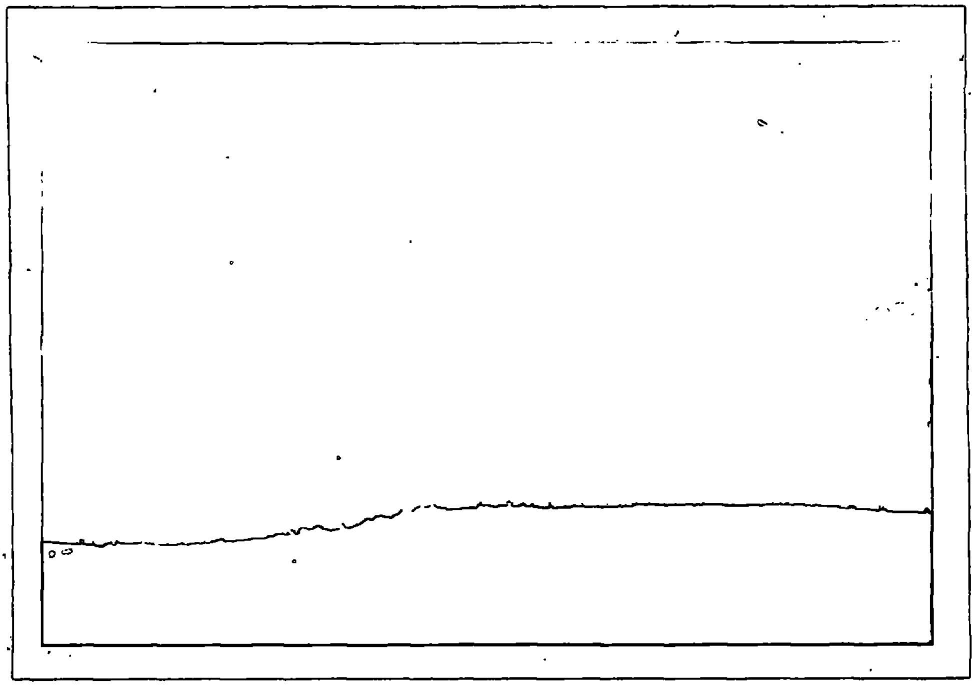


PLATE 4. Scarp edge of the Magnesian Limestone with minor scarp of Yellow Sands.

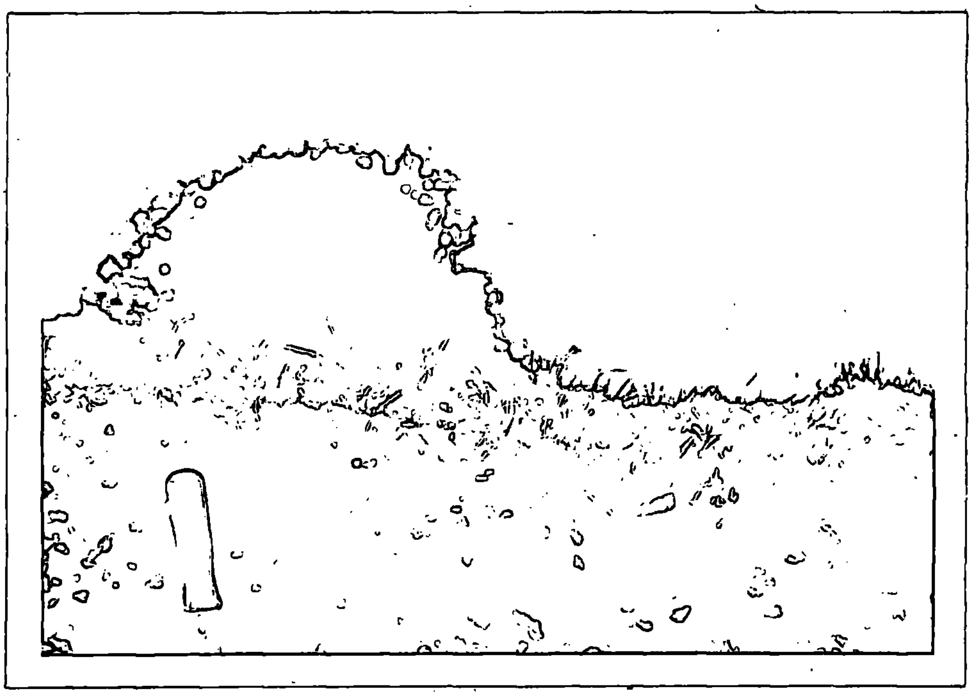


PLATE 5. Typical rendzina profile showing fragments of Magnesian Limestone.

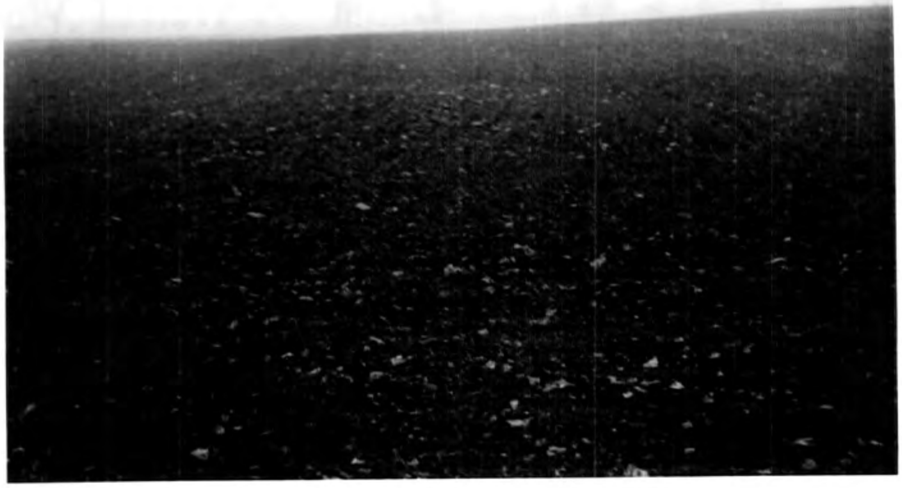


PLATE 6. Rendzina soil after ploughing, showing disturbance of limestone fragments.

PLATE 7. Detailed view of above field.

CHAPTER 10

FIELD DESCRIPTIONS OF PROFILES

Profile 1.

Grid reference - 45/332340.

Site - Hare and Hounds quarry situated on the crest of the escarpment at a height of 470'. The quarry has long been disused and is overgrown with vegetation. The land slopes away fairly steeply to the north-west and is free-drained.

Vegetation - Meadow grass, perennial rye grass, meadow flowers, scrubland with ash, elder, brambles, and hawthorn, close by.

A_1	0-3"	Dark grey brown loam with a mat of plant roots throughout. Good crumb structure but breaking down readily, when rubbed between the fingers to give a fine silty mass. No free calcium carbonate fragments but coal fragments, up to $\frac{1}{2}$" diameter, present throughout the horizon; a definite layer, 1" thick, of coal fragments found at the base of the horizon.
A_2	3-9"	Yellow brown loamy sand with rootlets throughout. Crumb structure only markedly developed round the rootlets; elsewhere single grain structure. Sub-angular limestone fragments less than $\frac{1}{2}$" diameter, and also occasional coal fragments found. Transitional to A_3.
A_3	9-13"	Light yellow brown loamy sand in which only the longer tap roots and their associated rootlets were found. Lighter in colour than A_2 and entirely single grain.

A_3	9-13"	Darker soil washed down from the A_2 horizon could be seen lining worm and root-holes. Limestone fragments and particles present throughout the horizon and much more numerous than in A_2.
C_1	13-24"	Yellow sandy layer containing many small limestone fragments. No structure developed and very few roots apparent. A fragment of micaceous sandstone was found at a depth of 2½" and measured 4"x3"x½". It probably originated from the local Coal Measures and, taken in conjunction with the presence of coal fragments, indicated the presence of glacial drift material in the soil.

Profile 2.

Grid reference - 45/339354.

Site - Garmondsway Moor Quarry, dug into the western edge of a minor erosion spur on the upper dip slope of the escarpment, at a height of 465'. The quarry is now disused. Land slopes away fairly steeply to the west and south and is free-drained. Springs are found round the western and southern edges of the spur at heights below 400'. The springs mark the junction of the limestone and patches of alluvium and boulder clay. Water from the springs united to form the Stony Beck, a minor tributary of the Skerne. Glacial material, in the form of micaceous sandstone pebbles and gravel with sandstone boulders, was found on the lower slopes of the spur. Several rabbit burrows, some with recent droppings round them were found round the edge of the quarry.

Profile 2

Vegetation - Meadow grass, perennial rye grass, sweet vernal grass, bedstraw, and plantain. The vegetation was kept short by sheep grazing. Hawthorn bushes, many only about 1' high, numerous.

A_1	0-1"	Dark grey brown silty loam tending towards a loamy sand. The dark colour was the result of humus and undecomposed plant remains. The fine silty soil had little structure and was held by a mat of roots and fibres. Quartz grains and flakes of mica could be seen but there was an absence of coal fragments and also of fragments of limestone.
A_2	1-4½"	Brown to dark brown loam. Roots were present throughout the horizon and limestone fragments increased in size and number with depth. Many large worm-holes, some up to ⅜" in diameter, were found. A crumb structure was developed, becoming almost granular round the plant root holes. The crumb structure was easily broken down by rubbing the soil between the fingers. A fragment of massive quartz 1"x¾"x¾" was found at a depth of 2". Transitional to A_3.
A_3	4½-14½"	Yellow brown loam which differed from A_2 in being of lighter colour andoof slightly less sandy texture. Limestone fragments were far more numerous than in A_2 and increased in size with depth, until they were

A_3	4½-14½"	they were/ about 2" in diameter at the base of the horizon. Crumb structure well-developed especially round root-holes. Roots penetrated the horizon and both large and small worm-holes were found. The boundary between A_3 and C_1 well marked but pitted and irregular.
C_1	14½-29½"	Weathered parent material, consisting of a pale yellow silty loam. Large flag-shaped limestone fragments up to 6" diameter present throughout. The powdery matrix was pitted with very small solution holes. Roots penetrated only the upper few inches and the root-holes were layered with darker soil material washed down from A_3. There was a complete absence of structure.
D	29½"-Depth	Sandy, orange yellow limestone which weathered to a whitish yellow. It was thin bedded in 2" bands. Minute dark spots in the rock were found to be crystals of manganese dioxide.

<u>Profile 3</u>.

<u>Grid reference</u> - 45/339$\overset{354}{334}$

<u>Site</u> - The sample was taken 20' to the south of sample 2. Aspect, slope, vegetation, and drainage, similar to Profile 2. Despite their proximity and the similarity of conditions under which they have developed, the two soils had different morphologies. There was no evidence of glacial material in Profile 3 and it would appear that the soil had developed entirely from the underlying limestone. The sample was taken at an elevation of 460'

Profile 3

A_1	$0-1\frac{1}{2}$"	Grey brown loamy sand in which there was no structural development, the soil being held by a mat of fine roots and much undecomposed plant material. Light yellow limestone fragments, less than $\frac{1}{8}$" in diameter, gave the soil a spotted appearance.
A_2	$1\frac{1}{2}-4$"	Light grey brown loamy sand containing small limestone fragments which were less than $\frac{1}{4}$" in diameter. Roots passed throughout the horizon and down into C_1. No structure developed. Worm-holes present throughout A_1 and A_2. A_2 was separated from C_1 by a definite stone layer of rounded limestone fragments less than $\frac{1}{2}$" diameter.
C_1	4"-Depth	Weathered parent material identical to C_1 in Profile 2.

Profile 4

331329

Grid reference - 45/329331

Site - Highland Quarry now disused. Situated on a small hillock at an elevation of 450'. The land sloped gently down to the north and was free-drained.

Vegetation - Cocksfoot. A hawthorn thicket formerly covered the area but this had been cleared some 80 years ago to facilitate quarrying. Remnants of the once extensive thicket can still be seen to the south and east of the quarry. Vegetation regularly burnt.

A_1	0-5"	Brown to dark brown loamy sand with a mat of roots throughout. Some structure was developed but this readily broke down between the fingers. Small stone fragments, less than ¼" in diameter. Numbers of earthworms and black beetles were seen.
C_1	5-7"	Brown yellow weathered parent material, consisting of small rounded and pitted fragments of limestone, set in a sandy matrix. Crumbs of soil material from A_1 were seen in the C_1 horizon. The gritty orange yellow limestone weathered in places to a light grey colour.

Profile 6

Grid reference - 45/324383

Site - Sample taken at a height of 550' near the top of the southern side of an east-west spur projecting from the main limestone escarpment. The ground rose gently to the crest of spur in the north and sloped away steeply to the south. The soil was free-drained. Rusty and brown rounded sandstone pebbles as well as angular limestone fragments were found on the upper surface of the profile. Iron nodules up to ½" in diameter were common throughout the profile, while occasional coal fragments, less than ¼" in diameter, were found. Thus, although the A horizon was only 10½" deep there was ample evidence that the area was once covered with glacial drift.

Vegetation - Perennial ryegrass, meadow grass, common moss. Sheep were grazed in the area.

A_1 0-1½" Very dark grey brown loamy sand with roots throughout. Gritty feel when rubbed between the fingers largely resulting from the presence of sizeable quartz grains. A good granular structure developed.

A_2 1½-7" Dark brown loam in which only tap-roots were found. Quartz grains and occasional small rounded limestone fragments most of which were less than 2" diameter. Earthworms and black beetles were found throughout the profile. Plant tap-roots and associated side-roots penetrate the weathered parent material.

Profile 6

D_1	10½"-Depth	Parent material of yellow white limestone (which weathered to a pale yellow colour). The thin bedded, compact, rock is one of the basal members of the Permian Limestones as it outcrops only 50' above an exposure of the Yellow Sands. There were small cavities in the rock but none of these were seen to be infilled with calcite.

Profile 7

Grid reference - 45/327379

Site - The sample examined was 400 yards to the south east of Profile 6, and was situated on the edge of a quarry from which the Yellow Sands are worked. Above the Yellow Sands were 20' of Lower Magnesian Limestone.

Vegetation - Cocksfoot.

A1	0-4"	Brown to dark brown loam with a well-developed granular structure. Small sandstone pebbles and occasional limestone fragments found throughout the horizon.
A_2	4-9"	Yellow brown clay loam with a weak crumb structure and roots penetrated the horizon.
A_3	9-12"	Yellow brown loam with a granular structure and numerous large air spaces. In one of these air spaces a chrysalis was found.
C_1	12-20"	Very pale brown loam with numerous limestone fragments.

Profile 8

Grid reference - 45/337402

Site - Sample taken from the crest of the escarpment on Strawberry Hill, at an elevation of 555'. The adjacent field had been ploughed when the sample was taken and was sown with a crop of mangolds. Ploughing had upturned many limestone fragments of various sizes. The field from which the sample was taken had never been ploughed as was seen by the undisturbed nature of the limestone fragments in the D_1 horizon. The land sloped away gently from the sample site in all directions except the west, where it rose slightly. The soil was free-draining.

Vegetation - Perennial ryegrass and white clover. Cattle were grazing.

A_1 0-1" Brown to dark brown heavy loam with roots throughout. Rounded sandstone pebbles up to 4" diameter, coal fragments, and particles of limestone, less than ½" diameter present. The sandstone and coal were obviously glacial in origin, but the small limestone fragments, dispersed as they were throughout the horizon, indicated that the soil had probably been formed insitu. This could well be the case if the finer glacial till had been eroded and if only the larger heavier material i.e. the sandstone and coal pebbles, had escaped erosion. A mat of roots was seen to bind the soil and earthworms were numerous. The soil had little structure but broke into hard

Profile 8

A_1	0-1"	lumps on digging. This was a reflection of the amount of clay in the soil. Furthermore, the constant grazing of the land by cattle would lead to compaction of the soil. (The mechanical analysis show that this sample contained the highest proportion of clay for an A_1 horizon). Both in A_1 and A_2 sand and clay occurred in patches. The darker clay patches could be distinguished readily from the lighter sand patches. The clay patches were compacted into large hard lumps which gave an infertile appearance.
A_2	1-7"	Yellow brown clay loam distinguishable from A_1 by a slightly higher proportion of clay, a lighter colour, and the fact that only main tap-roots were found.
D	7"-Depth	Yellow brown compact Lower Magnesian Limestone, the upper few inches of which were much fragmented. Brown yellow clay material washed down from the A_1 and A_2 horizons into fissures between the limestone fragments.

Profile 9.

Grid reference - 45/344398

Site - Sample taken from a quarry on the western side of Witch Hill at the top of Silent Bank. From the sample site (elevation 610') the land sloped gently to the west, north and south, and rose to the east. There was a marked variation of colours in the adjacent soils and it was difficult to find a sample representative of the area. Colours varied from a dark brown to a striking orange red. The red coloration was undoubtably the result of the presence of free iron oxide. Pockets of the underlying limestone were unusually rich in iron compounds, and such lenses stood out on weathered limestone surfaces because of their striking red colour. Much of the soil material was of glacial origin and sandstone pebbles were common, espedially at a depth of 3". The profile had a mottled appearance owing to the downward movement of dark coloured clay particles and the upward movement of rusty brown coloured iron compounds. These processes were most evident in the vicinity of plant roots. Very large earthworms were present throughout the profile but were few in number.

Vegetation - Perennial ryegrass.

A_1	0-1½"	Brown to dark brown loam with a strong crumb structure. A mat of lateral roots and tap-roots held the soil together.
A_2	1½-6½"	Dark grey brown loam very similar to A_1 but penetrated only by tap-roots. In both A_1 and A_2 many quartz grains could be seen.

A_3	6½-9½"	Dark yellow brown clay loam, mottled with material from A_2. A weak crumb structure was developed in the darker material washed down from A_2 but not in the clay fraction.
B_1	9½-14"	Strong brown clay which developed a nutty structure. This structure was formed when the clay dried after having been moistened and the particles coagulated into hard lumps. Plant roots penetrated the horizon by passing through cracks between the clay lumps.
D	14"-Depth.	Soft, friable, pale yellow, limestone.

<u>Profile 10</u>

<u>Grid reference</u> - 45/342416

<u>Site</u> - The sample was taken from the edge of a sand pit near Shadforth, on a southwest facing scarp slope. Yellow Sands are being worked in the sand pit. The sands are about 150' thick, lying beneath 30' of Lower Magnesian Limestone. The profile site was at an elevation of 470' and the ground sloped away steeply to the south west. The area is free-drained.

<u>Vegetation</u> - Sheep's fescue, cranesbill, and hawthorn scrub. There was evidence of a considerable rabbit population in the area.

A_1	0-2"	Light yellow brown sand with single grain structure. The horizon formed a distinct layer and was formed as a result of sand being blown over the area from the pit below.

A_1	0-2"	The horizon corresponded to the depth of lateral root development, the roots being tightly matted within the horizon while only the longer tap-roots penetrated to lower levels. The sand was very loose and readily fell away from the root mass when the plants were pulled from the soil.
A_2	2-4½"	Very dark grey loamy sand in which there was a strong development of crumb structure. Sand grains from A_1 were present in the horizon. There were also small (½" diameter) rounded coal and sandstone fragments. Thus, although the A and C horizons were together only one foot deep there was evidence of glacial drift material. Limestone fragments were present but only as minute particles.
A_3	4½-7½"	Brown to dark brown loam in which sandstone and coal fragments were found together with numerous limestone fragments, the latter forming 50% of the bulk of the soil. A weak crumb structure was developed and few roots were found within the horizon.
C_1	7½-11½"	Yellow loam in which limestone fragments predominated over soil material. The clay material had been washed down between the limestone fragments from the upper horizons. Very few roots penetrated into this layer.
D	11½"-Depth	Yellow Lower Magnesian Limestone. The limestone was thinly bedded and contained solution holes which were lined with calcite crystals.

Profile 11

Grid reference - 45/345506

Site .- The soil above Houghton Cut included a great amount of glacial drift material, consisting of small rounded pebbles of coal, ironstone, and sandstone. During excavations for the Cut, benches were formed on which typical rendzina profiles have developed. Even these profiles included some glacial material which had clearly been washed down from higher levels. The soils were very immature and had been formed within the past hundred years.

Vegetation Sheep's fescue and couch. There were many patches of bare soil. Plant roots were quite sturdy and there was no mat of fine rootlets such as observed in some of the other profiles described. Many of these roots branched out as they reached the C_1 horizon.

A_1	0-3"	Dark yellow brown loam with a weak crumb structure which could easily be broken down when rubbed between the fingers. Round the plant roots the soil was slightly darker and had a stronger crumb structure. Small limestone fragments gave the soil a spotted appearance.
C_1	3-7"	Pale yellow powdery structureless horizon. Darker patches occurred owing to clay material being washed down from the A_1 horizon.

Profile 11

D Parent material consisted of a yellow limestone with white streaks. It weathered to a grey coloured material and was thin-bedded. Some signs of minor folding were to be seen in the beds.

Profile 12

Grid reference = 45/375437

Site - This profile was not considered to be that of a typical rendzina soil. It was included as a representative sample of many of the soils found on the East Durham Plateau. These soils are derived from boulder clay but the profile, has been influenced by the underlying Magnesian Limestone. Although the bulk of the soil material is glacial in origin the soil exhibits many of the physical and chemical characteristics of the rendzina profile. There were few large pebbles in the glacial drift. The sample site was on fairly level ground, at an elevation of 460'. The soil was free-drained.

Vegetation - Perennial ryegrass, cocksfoot, plantain, and daisy.

A_0 0-1½" Dark brown loamy sand with weak crumb structure. The dark colour of the soil was due to the considerable amount of humus found within the horizon. The soil was held by a mat of plant roots.

A_1 1½-9½" Dark grey brown sandy loam with a strong crumb structure. The soil had a gritty feel when rubbed between the fingers. Earthworms were present throughout the horizon. Small coal and rock fragments gave evidence of glacial drift.

A_1	1½- 9½"	The boundary between A_1 and B_1 was irregular.
B_1	9½-21½"	Yellow brown silty loam tending to be loamy. A granular structure wa noticeable owing to structure was noticeable owing to the mineral grains aggregating as the soil dried out. Few coal fragments.
C_1	21½-31½"	Pale yellow weathered Magnesian Limestone. The limestone had weathered into a fine sandy layer. This horizon formed a marked contrast to B_1 but the boundary between the two horizons was irregular.
D	31½"-Depth	Very pale yellow bedded dolomite (which weathered to a grey colour). Pink streaks and bands in the rock suggested areas of ferric oxide concentration.

Profile 13

Grid reference - 45/333419

Site - The sample was taken from the top of an east to west spur on the scarp edge, at an elevation of 510'. The area was free-drained. Rounded sandstone pebbles and coal fragments proved the presence of glacial drift material in the soil.

Vegetation - Sedges with meadow grass.

A_o	0-1"	Very dark brown loamy sand. There was a mat of plant roots and much humic material. Coal fragments and quartz grains could be recognised in the soil material.
A_1	1-4"	Very dark grey brown leam which felt soft to the touch. A strong crumb structure was developed.
A_2	4-11"	Dark yellow brown loam with a strong crumb structure tending to be granular in places.

C_1	11-13"	Dark yellow brown loam. Limestone fragments 2" in diameter were as abundant as weathered material. The latter included material washed between the limestone fragments from upper horizons.
D	13"-Depth	Parent material consisted of a thin-bedded, yellow grey limestone. Solution holes within the limestone were lined with calcite crystals. The limestone was about 50' thick and rested on a thick bed of Yellow Sands.

Profile 14

Grid reference - 45/387665

Site - The sample was taken from a sea stack at Trow Point, near South Shields, at a height of 30'. The adjacent coastal area was covered with a thick deposit of boulder clay varying from a few inches to 30' in thickness. The glacial drift was fairly uniform in composition and in general rested directly on the limestone rock, there being no intervening layer of fragmented limestone. Pebbles within the boulder clay included sandstone, ironstone, hard shiny coal, and a variety of igneous rock types. Occasional fragments of Magnesian Limestone were found which were quite angular indicating their local origin. Despite the thick deposits of boulder clay the flat land was free-drained, which reflected the sandy texture of the glacial material.

Vegetation. - Sheep's fescue

A_1	0-2"	Dark yellow brown loam. The humic layer showed little structure.
A_2	2-7"	Dark yellow brown loam differentiated from the A_1 horizon by its strong crumb structure. The horizon was penetrated by a mat of plant roots.
B_1	7-21"	Brown to dark brown clay loam separated from A_2 by a definite layer of angular limestone fragments. Few plant roots passed down into this horizon which exhibited a platy type of structure.
D	21"-Depth	Thin-bedded, yellow limestone. The beds were rarely more than 1" thick and the limestone was broken into large slabs as a result of marine erosion. Underlying the bedded limestone was a massive type of limestone which weathered into angular lumps. The surfaces of the latter were honeycombed with numerous small holes. The massive limestone was brecciated and had a mottled appearance. It appeared to include two different types of limestone - a grey crystalline and a yellow brown variety. Pieces of the crystalline variety were included in the yellow brown, the latter probably being richer in magnesium.

Profile 15.

Grid reference - 45/390655

Site - The sample was taken from the east side of Harton Down Hill at an elevation of 140'. The land sloped away steeply to the 75' coastal platform in the east. The hill had a hummocky surface giving the appearance of having once been quarried. The soil was very thin and there was no indication of material of glacial origin in the profiles. This may be the result of the site being above the main level of deposition from the coastal ice sheet or, more probably, the erosion of any boulder clay which had been deposited.

Vegetation - Perennial ryegrass and petty whin.

A_o	0-$\frac{1}{4}$"	Grey to dark grey loamy sand. The layer included much humic material and plant debris.
A_1	$\frac{1}{4}$-3"	Dark grey silty loam varying to loamy sand. The soil was aggregated into coarse crumbs. Roots and earthworms were found throughout.
A_2	3-15"	Grey brown silty loam varying to loam. There was some mottling owing to darker material being washed downwards from A_1. This was especially noticeable round plant roots and wormholes. Limestone fragments increased in size and number towards the base of the horizons.
D	15"-Depth	Very thin-bedded platy limestone. The upper beds were about $\frac{1}{2}$" thick and the lower beds were about 6" thick. The brown yellow limestone became more massive with depth.

Profile 15.

D	15"-Depth	The limestone was unfossiliferous and the few solution holes in it were lined with calcite crystals.

Profile 16.

Grid reference - 45/390655

Site - Within the parent material of sample 15, described above, there were pockets of a light yellow sandy material. Evidently these were a result of local differences in lithology of the limestone. A sample of the soil developed over one of these pockets of sand was taken and the profile is described below. It was different from that developed over the platy limestone of Profile 15.

A_0	0-$\frac{1}{4}$"	Dark grey brown silty loam varying to loamy sand. The horizon included much humic material and plant debris so that the soil felt soft to the touch.
A_1	$\frac{1}{4}$-3"	Dark grey brown silty loam varying to loamy sand. A strong crumb structure was developed.
C_1	3-12"	Pale yellow silty loam with some small limestone fragments. Predominantly single grain with few crumbs.
C_2	12"-Depth	Pocket of loose sandy limestone. The cement of the original rock had obviously disintegrated leaving a sandy mass of rock material.

Profile 17.

Grid reference - 45/406644

Site - The sample was taken on the edge of the cliff near Marsden Village. The height of the site was 60' and the ground was level. Boulder clay, found elsewhere along the coastal stretch, was absent at this point.

Vegetation - Sheep's fescue

A_1	0-3"	Very dark brown loamy sand with a strong crumb structure. The soil felt soft to the touch despite its texture and the presence in it of numerous white sand grains. The horizon was penetrated by a thick mat of roots hairs.
A_2	3-9"	Dark brown silty loam with fewer root hairs than A_1. Rock fragments present.
D	9"-Depth	Pale yellow brecciated limestone. The limestone weathered into small rounded fragments similar in appearance to the cannonball limestone of Fulwell.

Profile 18.

Grid reference - 45/340505

Site - The profile was taken from an old quarry bench on the upper section of a south facing slope. The surrounding terrain was covered with a thin layer of boulder clay in which were found small well rounded pebbles of sandstone, ironstone, coal, and a variety of igneous rocks. Above the quarry the glacial material had been converted into a good arable soil. This consisted of 12" of dark brown sandy loam, grading into the light yellow brown parent glacial material. The colour of the top soil was the result of frequent ploughing and manuring. The glacial material had been removed when quarrying was begun and therefore the soil described below is that which has subsquently developed on the limestone bench.

Vegetation - Sheep's fescue, cocksfoot, mayweed, dandelion, gorse, and hawthorn bushes.

A_1	0-4"	Very dark brown silty loam tending to a loamy sand. Roots were found throughout the horizon and there was a strong crumb structure developed. Free calcium carbonate was present as fine particles but not as limestone fragments.
A_2	4-12"	Dark yellow brown silty loam tending to a loamy sand. Only occasional roots penetrated the horizon. Limestone fragments were numerous.
D	12"-Depth	Parent material consisted of a yellow, thin-bedded, subconcretionary, limestone. The rock was much fractured and included pockets of marl.

Profile 18

D 12"-Depth Underlying the upper beds was a more uniform limestone, somewhat mottled with white streaks. The beds of the latter were about 1' thick and it became more massive with depth.

Profile 19

Grid reference - 45/341517

Site - The sample was taken from the middle region of a north facing scarp slope at a height of 350'. The land was free-drained.

Vegetation - Meadow grass, cocksfoot, clover, and daisy.

A_1 0-2" Very dark grey brown silty loam tending to a loamy sand. There was a strong crumb structure and an absence of limestone fragments. A fine mat of rootlets were found throughout.

A_2 2-12" Dark yellow brown silty loam tending to a loamy sand. Although rounded limestone fragments were found in this horizon, the soil rested on the solid limestone rock and there was no marked zone of soil with weathered limestone fragments. A strong crumb structure was developed.

D 12"-Depth Pale yellow well bedded limestone in which individual beds ranged from a few inches to one foot in thickness. Occasional solution holes were found and these were usually lined with calcite crystals. Fractures in the upper layers of the rock were generally filled with a light yellow brown clay, washed down from the A_2 horizon.

Profile 20.

Grid reference - 45/347528

Site - The sample was taken at a height of 410' on the upper slopes of Herrington Hill. The lower slopes of the hill were covered with glacial material which included pebbles of sandstone, coal, ironstone, Carboniferous Limestone, and lumps of crystalline calcite. The latter were most unusual and were found only in this one area. They consisted of fine needle shaped calcite crystals arranged in radial fashion. The crystals may be of local origin, a hypothesis supported by the coating of magnesian limestone observed on their surface. The glacial material had been eroded from the upper slopes of the hill, where the sample was taken.

Vegetation - Perennial ryegrass, meadow grass, and common moss, hawthorn, gorse, and rose bushes. About twenty yards south of the sample site was the edge of a plantation of young fir trees. The latter had been planted on the steep slopes of the scarp edge.

A_1	0-3"	Very dark brown loamy sand. Mainly single grain structure with a few crumbs. The sandy texture of the soil was especially obvious in the field because of the coarse nature of the sand. The horizon was penetrated by a mat of fine plant roots.
A_2	3-15"	Dark brown loamy sand which included limestone fragments. Few plant roots present.
D	15"-Depth	Lower Magnesian Limestone similar in appearance to that found at Houghton and described for Sample 18.

CHAPTER 11

METHODS OF ANALYSIS

Conformity of procedure is the basis of dependable soil analysis. Many workers record the methods employed for a series of analyses in rather vague terms. Thus, although it is true that "available" phosphate is determined colorimetrically, the time factor is most important and a definite time must be allowed for colour development. In order to avoid confusion the exact techniques used in the analyses carried out are described. A description of the developmental work on the methods is also included.

Soil Reaction (pH)

The reaction of each soil sample was determined directly it reached the laboratory. 5gm. of the soil which had passed through a 2 mm. sieve were placed in a 50 ml. beaker and 25 ml. of distilled water added giving a soil:water ratio of 1:5. The suspension was stirred for one minute using an electric stirrer fitted with a glass paddle. The pH of the suspension was then determined on the E.I.L. pH Meter with a glass electrode and a calomel reference electrode. It will be noted that in the method employed the pH of the soil suspension is determined since the liquid is not decanted after stirring. Each sample can be treated in exactly the same manner, and the time interval between stirring and reading of pH is identical in each case. This is not so when a mechanical shaker is used and the pH determined on the supernatant liquid. The pH meter was set with a buffer solution of 7 before the soil suspension readings were recorded. Whenever a series of readings were being taken the meter was checked at regular intervals against the buffer solution.

Once the reaction of the soils had been determined the bulk samples were spread on to tin trays and allowed to dry out in the laboratory. The air-dry samples were then crushed with a pestle and mortar, care being taken to avoid breaking any stone fragments which were present. The samples were then sieved through a 2mm. sieve, bottled, and carefully labelled. The analysis described below was carried out on the 'fine earth' sample i.e. the soil which had passed through the 2 mm. sieve.

Colour

Colour was matched with the Munsell Soil Colour Charts and recorded by the Munsell notation (45). In this method the different colours are distinguished on the basis of Hue, Value, and Chroma. The symbol used for Hue is the letter abbreviation of the dominant colour or colours e.g. R - red, Y.R. - yellow red; this is preceded by a number which is between 0 and 10. Within each letter range the hue becomes more yellow and less red as the numbers increase.

The Value notation, from 0 - absolute black, to 10 - absolute white is indicative of the lightness of the colour.

Chroma marks the strength of colour or departure from a neutral of the same lightness. Chromas of nought are neutral grays and the chroma increases at equal intervals to a maximum of 20, which is rarely approached in a soil.

Figures are given in the order of Hue, Value, and Chroma. Thus for a colour of Hue 7.5YR, Value 5, and Chroma 6, the notation is 7.5YR5/6.

Loss on Ignition

10 gms of fine earth were accurately weighed into a silica crucible, ignited over a bunsen flame, and then placed in a muffle furnace at about

450°C for 30 minutes. The sample was then removed from the muffle furnace, cooled, and moistened with ammonium carbonate to reform the soil carbonates:-

$$CaO + (NH_4)_2\,CO_3 \xrightarrow{\hspace{3em}} CaCO_3 + 2NH_3 + H_2O$$

The ammonia formed and excess ammonium carbonate were driven off by placing in an oven for 12 hours at a constant temperature of 105°C:-

$$(NH_4)_2\,CO_3 \xrightarrow{\text{Heat}} 2NH_3 + CO_2 + H_2O.$$

The sample was then cooled in a desiccator. The crucible plus the ignited soil were weighed and then the crucible was carefully cleaned and reweighed. These weights were recorded. The loss on ignition of the sample was calculated as a percentage using the weight of ignited soil and the weight of the original sample:-

$$\%\ \text{Loss on ignition} = \frac{(\text{Weight of soil taken} - \text{Weight of ignited soil})\text{x}100}{\text{Weight of soil taken.}}$$

This method gives some measure of the organic matter present in the soil. It has, however, the disadvantage of including in the final figure hygroscopic moisture and also elemental carbon and graphite; all of these will tend to give too high a value for organic matter.

Organic Carbon

The organic carbon content of the soil was determined using the 'wet oxidation' method of Walkley and Black (46). The method is based on the use of chromic acid. The temperature required for oxidation results from the heat of dilution of the sulphuric acid. There is therefore less heating than in Schollenberger method where the sample is heated over a bunsen. Only the more active organic matter is oxidised and soil humus is largely differentiated from extraneous sources of organic carbon such as graphite and charcoal.

1 gm. of soil was weighed into a 500 ml. conical flask. 10 ml. of normal potassium dichromate solution were pipetted into the flask, followed by 20 ml. of concentrated sulphuric acid. The flask and contents were gently shaken for one minute and then stood on an asbestos mat for 30 minutes. The contents were now diluted with 200 ml. of water, and 10 ml. of phosphoric acid and 1 ml. of 0.5 per cent diphenylamine indicator were added. The excess dichromate was titrated with 0.5N ferrous sulphate solution until one drop caused a colour change from blue to green.

$$\% \text{ Organic Carbon} = \frac{\text{Number of Ml. of normal potassium dichromate reduced } x10x.0039}{\text{Weight of soil taken.}}$$

A blank titration was carried out to standardise the ferrous sulphate solution by using the same procedure as above but omitting the soil.

Nitrogen.

The soil nitrogen was determined by the Kjeldahl digestion method and subsequent distillation with the Markham Micro - Kjeldahl apparatus.

Digestion:- 20 gms. of fine earth were weighed into a Kjeldahl flask and 50 mls. of distilled water added. After allowing to stand for 30 minutes eight Kjeldahl tablets (Boot's Special Formula No. 3763 - Copper Sulphate 20.0 parts, Selenium 0.05 parts, Anhydrous Sodium Sulphate A.R. 100.0 parts. All to 2.5 gms.) and 35 mls, of concentrated sulphuric acid were poured into the flask. Great care was taken over the addition of the acid to avoid excessive frothing. The flask was then placed on the Kjeldahl rack in a fume cupboard and heated, commencing with a low flame over a sand-tray. The latter was removed only when frothing in the flask had ceased. The flame was then turned up and heating was continued until the contents of the flask turned a blue or, more often, a straw colour, and then for a further 45 minutes. More acid was added whenever necessary to maintain the level of acid in the flask. Whenever excess frothing occurred during heating, the flame was extinguished and only re-lighted when the flask had cooled. When digestion was completed the digest was diluted with distilled water, cooled, washed into a 250 ml. graduated flask, and then made up to the mark with distilled water.

Distillation:- The Markham apparatus was first adjusted with distilled water, the flame being regulated so that distillation was proceeding at the rate of one drop per second. 10 mls. of dilute sulphuric acid (10 per cent) were now poured into the outer funnel, carefully allowed to run into the boiling chamber, and boiled for two or three minutes. The steam generator was cooled by gently squirting it with water, thus causing the acid to be sucked out from the boiling chamber into the outer jacket, from whence it was drained by opening the waste clip. This procedure served to wash the apparatus. 10 mls. of the soil digest were then pipetted directly into the boiling chamber and 10 mls. of sodium hydroxide were poured into the outer funnel. A conical flask containing 10 mls. of boric acid was held under the condenser. The sodium hydroxide was allowed to run slowly into the boiling chamber, a small quantity being retained in the outer funnel to act as a seal to the glass stopper. The conical flask was raised so that the tip of the condenser was below the level of the boric acid, the waste clip was closed, and the solution distilled for two minutes. After this time the flask was lowered but the next 10 drops of distillate were collected. The distillate was then titrated with $\frac{N}{100}$ hydrochloric acid until its colour just turned pink, comparison of colour being made with a standard in which distilled water had been used instead of the soil digest. The distillation was repeated until two results differed by less than 0.2 mls. of added $\frac{N}{100}$ hydrochloric acid. The percentage nitrogen was calculated from the formula:-

$$\% \text{ Nitrogen} = \frac{0.35 \times \text{Number of mls. of acid required.}}{\text{Weight of soil taken.}}$$

Mechanical Analysis.

The mechanical analysis of the soil samples was carried out using a Bouyoucos hydrometer. This hydrometer is calibrated to read in grams of soil per litre of suspension at 20°C. The method is similar to that used by T. J. Marshall at Adelaide University (47). It should be noted that calcium carbonate and other soluble salts were not removed from the soil before the mechanical analysis.

50 gms. of soil were weighed into a shaking bottle and 200 ml. of water added together with 25 ml. of 5 per cent sodium hexametaphosphate (50 gms. of sodium hexametaphosphate + 5.724 gms. of sodium carbonate per litre, buffered to a pH of 9). The suspension was shaken continuously in a mechancial shaker for 10 hours, and then washed into a litre measuring cylinder. Water was added to the litre mark. The cylinder was shaken end over end for one minute and the hydrometer placed carefully into it. One or two drops of amyl alcohol were added when required to break excess froth. After shaking the suspension was allowed to stand for 4 minutes 30 seconds before the hydrometer reading and temperature of the water were recorded, similar readings being recorded after the suspension had stood for five hours. The hydrometer is calibrated at

20°C and therefore a temperature correction must be made to the readings taken. 0.3 unit was added for every degree Centigrade that the temperature of the suspension was above 20°C and 0.3 unit subtracted for every degree C. the temperature of the suspension was below 20°C. The first reading gave the weight of clay plus silt of the sample held in suspension, the coarse sand and fine sand having fallen below the level of the hydrometer. The second reading gave the weight of clay in the sample since after five hours all the other fractions had settled.

The clay fraction was then discarded and the sand and silt fractions were washed into a 0.2 mm. sieve, placed over a 400 ml. beaker. The silt and fine sand fractions were washed through the sieve into the beaker. The coarse sand, still retained in the sieve was transferred to a filter paper, oven-dried at 105°C, and weighed.

The silt and fine sand fractions were separated by decantation. Water was added until it reached the 10 cm. mark on the beaker. The soil material was then allowed to settle for about five minutes, the exact time depending on the temperature of the water and determined from Table IV on the following page.

TABLE IV

THE TIME OF SEDIMENTATION AT DIFFERENT TEMPERATURES

INTERNATIONAL SYSTEM.

Temperature	Fine Sand Decantation Depth 10 cm	
Deg. C.	Mins.	Secs.
8	6	40
9	6	30
10	6	20
11	6	10
12	6	0
13	5	50
14	5	40
15	5	30
16	5	20
17	5	10
18	5	0
19	5	0
20	4	48
21	4	40
22	4	30
23	4	30
24	4	20
25	4	15
26	4	10
27	4	5
28	4	0
29	3	55
30	3	50
31	3	45
32	3	40
33	3	35

TRIANGULAR DIAGRAM FOR DETERMINATION OF

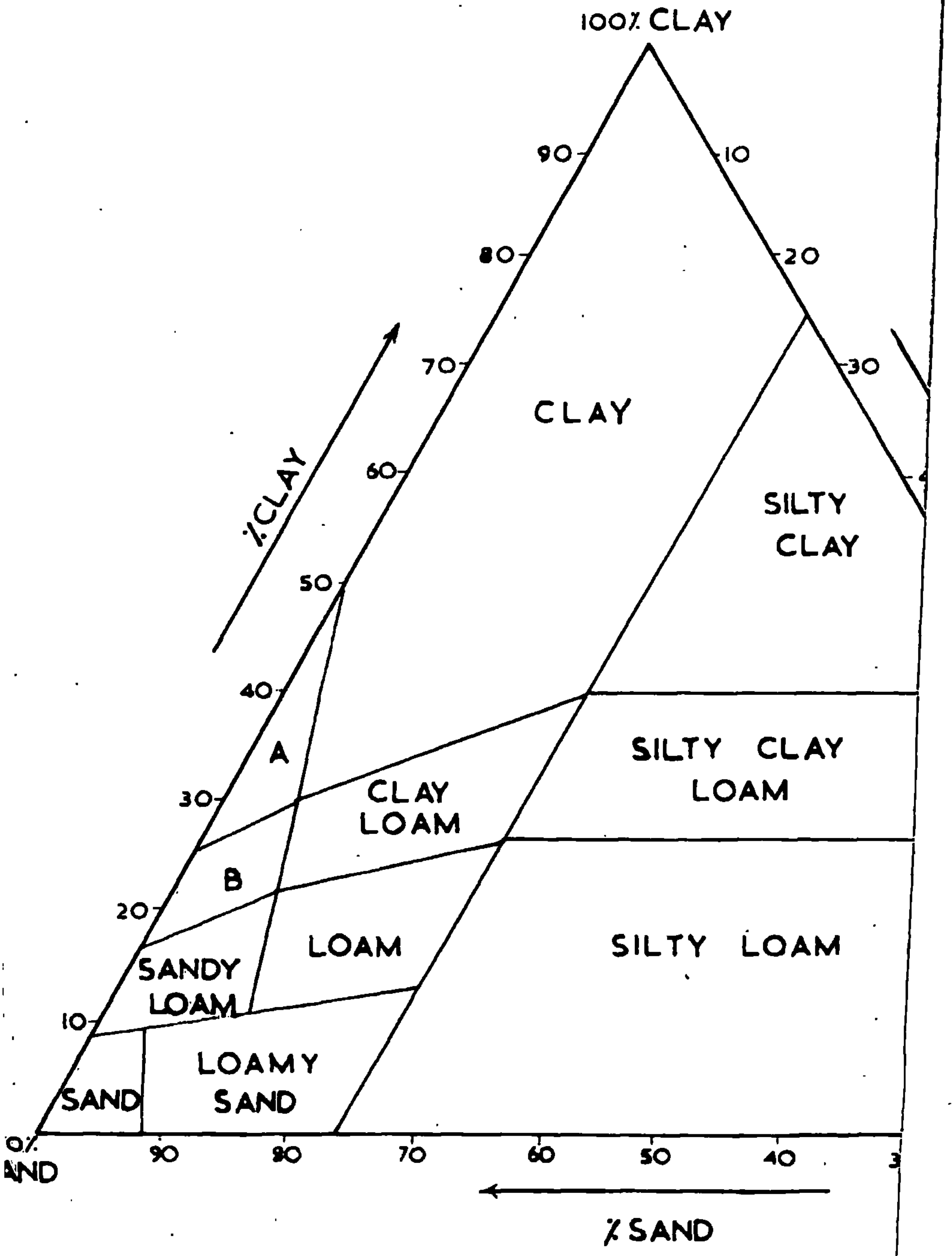


FIG. 3

A :- SANDY CLAY

B :- SANDY CLAY LOAM

After this time the fine sand fraction would have reached the bottom of the beaker, and the water with silt held in suspension, was poured away. The process of sieving and decanting was repeated until the water was clear after being allowed to stand for the sedimentation period.

The fine sand fraction was then washed from the beaker on to a filter paper, oven-dried at 105°C. for 12 hours and weighed.

The four fractions i.e. coarse sand, fine sand, silt and clay, were then calculated as percentages of the weight of the original quantity of soil used. The percentages were then plotted on the triangular diagram (Fig. 3) and the corresponding textural class of each soil was thus determined. In general the soil texture determined from the mechanical analysis was in agreement with the field assessment.

AVAILABLE PHOSPHATE AND POTASH

Various attempts have been made to measure the 'available' phosphate and potash status of soil, i.e. that which can be readily taken up by a plant and not that which, as in the case of phosphorus in apatite minerals, is unavailable. Results obtained depend on the extractant used. Until recently, Morgan's reagent, made up from 100 gms. of sodium acetate dissolved in water plus 30 mls. of concentrated glacial acetic acid, diluted with distilled water to one litre and adjusted to a pH of 4.8, was found to be the most successful. A set of standard solutions of phosphate in Morgan's reagent were made up consisting of 0,5, 10, 15... .. 50 ppm phosphate. These were treated with ammonium molybdate using the following reagents to reduce the phosphomolybdate complex:-

1. p-methylaminophenol sulphate powder.
2. stannous chloride.
3. 1-amino -2-napthol -4-sulphonic acid.

In an acidic medium of molybdate and phosphate ions the yellow coloured phosphomolybdate ion is formed and for the analysis of small amounts of phosphate, the latter is reduced to phosphomolybdic blue. The stannous chloride reducing agent (0.1 gm of tin boiled in 2ccs. of concentrated hydrochloric acid to dissolve it and diluted to 10ccs. with distilled water) was found to be unsatisfactory, since no two sets of readings with the standard solutions agreed. The error was due to the molybdic acid reacting with the reducing agent to give a blue colour even when no phosphate was present. The other two reducing agents reduce only the phosphomolybdate and hence can be used in the colorimetric test for phosphates.

p-methylaminophenol sulphate reducing powder, made up by mixing intimately 277 gms. of sodium bisulphite, 11 gms. of sodium sulphite, and 10.4 gms. of p-methylaminophenol sulphate, is indefinitely stable in storage. The volume of reductant used is slightly in excess of that needed and small variations in the amount of powder taken will not affect the test. 2 mls. of standard solution were mixed with four drops of molybdate reagent (10 gms. of ammonium molybdate dissolved in 250 ml. of distilled water and, when cool, mixed with 150 mls. of concentrated sulphuric acid.) One level scoop, holding from .05 gms. to 0.1 gms. of reducing powder were added and the tube swirled to dissolve the powder. The blue colour developed was measured on the colorimeter using a red filter (Eel Filter NO. 205). Results obtained were not satisfactory and this may be explained in two ways:-

1. The reducing powder was not mixed sufficiently intimately.
2. Differences in amounts of reducing powder added caused erroneous results.

By using a solution of the reducing powder exactly the same amount of reductant could be added each time and also the constituents of the powder were much more intimately mixed.

Even with this modification the results were unsatisfactory. This was owing to two reasons:-

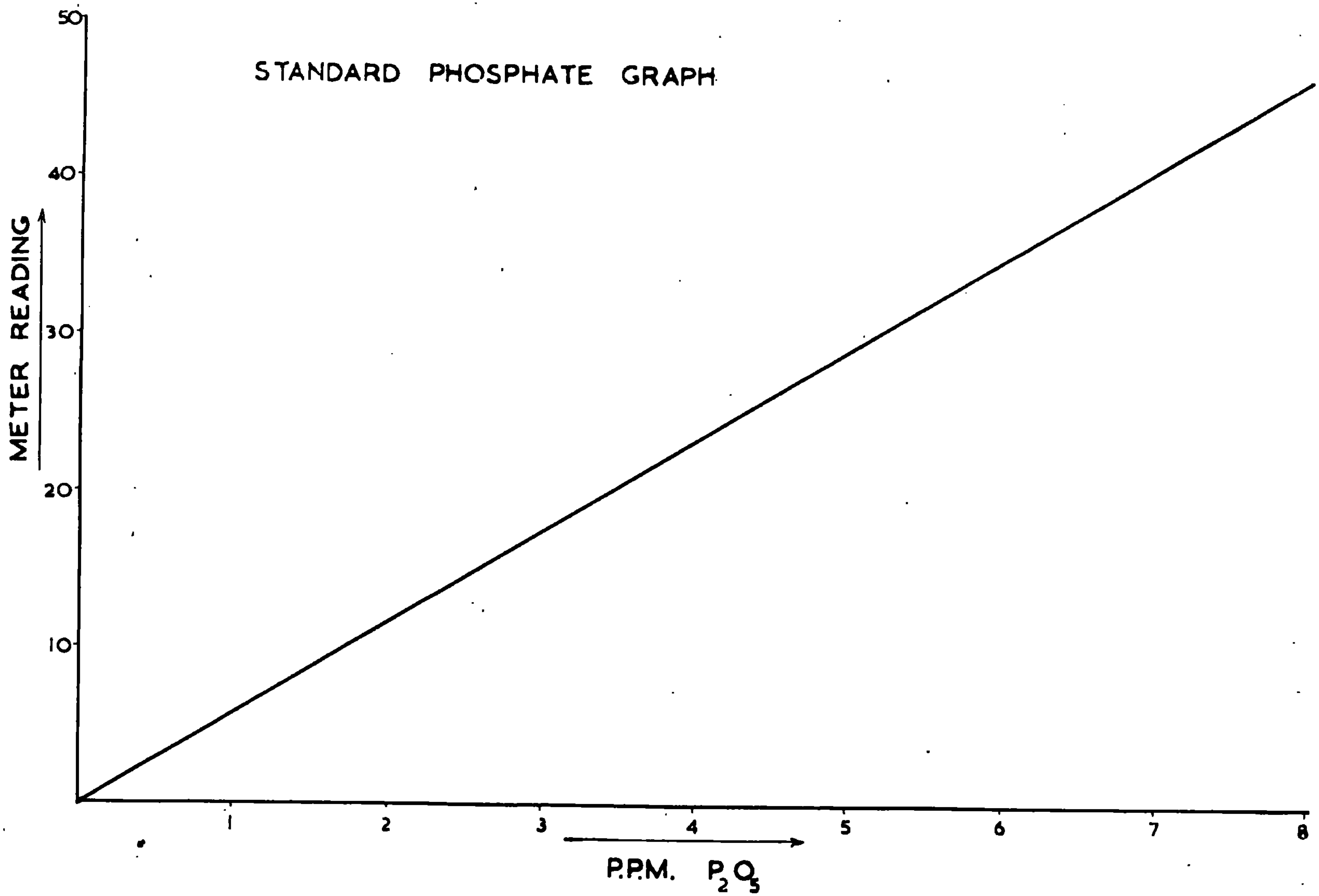
1. By taking readings on the colorimeter at five minute intervals, it was found that the intensity of the colour for any one standard increased for at least 70 minutes, even though it was reported in (48) that the colour was fully developed after five minutes.

2. The rate of colour development varied from standard to standard and for any two samples of the same standard. This precluded the possibility of fixing a particular time at which the readings should be taken.

The third reducing agent was 1:2:4 amino-naphthol-sulphonic acid; 0.2 gms. acid, 12 gms. sodium metabisulphite, and 2.4 gms. sodium sulphite, were dissolved in 100 mls. of distilled water. 1 ml. of standard solution was pipetted into an Eel tube followed by 9 ml.s of distilled water, 0.5 mls. of ammonium molybdate and 4 drops of amino-naphthol-sulphonic acid solution. These were well mixed by shaking. From the results obtained it was thought that the solutions were far too dilute. The amount of standard phosphate was increased to 10 mls. and distilled water was omitted but still no measureable colour developed. It was now realised that the pH of the solution was too high and therefore six drops of sulphuric acid were added and the colour intensity measured after 20 minutes. A measurable blue colour developed. To determine the optimum quantity of sulphuric acid to be added, 10 samples of the standard solution were taken and varying quantities of sulphuric acid (1 to 10 drops) were added. Results obtained indicated that 3 drops of acid were sufficient to develop the colour and that no decrease in colour intensity could be detected with 10 drops. An arbitrary level of 6 drops was therefore chosen. Again it was found that colour developed with time and that there was no convenient interval after which it could be definitely stated that development was complete. The change in intensity, however, over a given period of time was found to be far less than when using p-methylaminophenol sulphate as the reducing agent.

In order to conform with the analytical procedure of the Northern Agricultural Advisory Service the extracting reagent was changed from Morgan's reagent to $^{N}/2$ acetic acid (57.1 mls. of concentrated acetic acid diluted to 2 litres in distilled water). 2.5 gms. of fine earth were weighed into a shaking bottle and 100 mls. of $^{N}/2$ acetic acid added using an automatic burette. (The ratio of extractant to the weight of soil used with Morgan's reagent was 5:1). The bottle and contents were shaken for 45 minutes on the reciprocating shaker. The extract was filtered through a No. 541 Whatman filter paper and phosphate and potash determined on the filtrate.

Phosphate was determined by pipetting 10 mls. of the filtrate into an Eel colorimetric tube. 1 ml. of ammonium molybdate was added and the tube shaken. Six drops of amino-naphthol-sulphonic acid were added and the tube again shaken. The solution was then allowed to stand for 20 minutes before the intensity of colour developed was measured on the colorimeter. The instrument was set at zero witha blank solution in which $^{N}/2$ acetic acid was used instead of the 10 mls. of filtrate as above.



STANDARD PHOSPHATE GRAPH

FIG. 4

Care was taken when running a series of samples that solution was not carried from one tube to the next while shaking. Since the available phosphate is expressed as a status and not as an absolute value, it was found that as many as 10 samples could be handled at once without variations in the time of colour development producing significantly different results. The developed colour was then compared with that developed on a set of standards (Fig. 4).

Potash was determined directly on the Eel flame photometer using the $^{N}/2$ acetic acid extract. The instrument was set at 50 with a 10ppm standard potash solution and at zero with $^{N}/2$ acetic acid.

The phosphate and potash status of the soil was obtained using Table V

TABLE V

The Phosphate Status of Soils

mgm/100 gms. P_2O_5	
0 - 1.8	Very low (V.L.)
1.8 - 3.0	Low (L.)
3.0 - 6.0	Medium (M)
6.0 - 10.0	Medium high (M.H.)
10.0 - 17.0	High (H.)
Over 17.0	Very high (V.H.)

The Potash Status of Soils

mgm/100 gms. K_2O.	
0 - 6	Very low (V.L.)
6 - 12	Low (L.)
12 - 20	Medium (M)
20 - 30	Medium high (M.H.)
30 - 40	High (H.)
Over 40	Very high (V.H.)

Exchangeable Cations

'Exchangeable cation analysis of saline and alkali soils are subject to difficulties not ordinarily encountered with other soils e.g. those from humid regions' (49). The difficulties mentioned above are most certainly encountered in analyses of calcareous soils, even under humid conditions, although no doubt they are increased in the case of saline and alkali soils. The rendzinas of the East Durham Plateau are developed from Magnesian Limestone and fragments of the parent material (calcium carbonate and dolomite), present in the soil samples, create difficulties in the determination of exchangeable calcium and magnesium. Though these fragments of calcium carbonate and dolomite are less soluble than calcium and magnesium salts present in saline and alkali soils, and though they do not cause excessive slow permeability to aqueous solutions and alcohols, nevertheless they are dissolved in sufficiently large quantities to give significantly greater apparent values of the exchangeable calcium and magnesium status of the soils. Jacobs (50) mentions the difficulty of attempting to measure the magnesium status of soils without extracting amounts of non-exchangeable magnesium.

Neutral ammonium acetate, a common extractant of exchangeable cations, reveals a great disadvantage when used to leach alkali soils. Appreciable amounts of ammonium may be fixed by some alkali soils, and this results in a reduction of the determined value for cation exchange capacity of those soils.

This fixation of ammonium does not interfere with the extraction of exchangeable cations. Jackson, however, states the extracting calcareous soils with ammonium acetate dissolves calcium and magnesium extensively from calcite and dolomite (51). Kelley concluded that exchangeable calcium and magnesium determinations for calcareous soils were meaningless and preferred to estimate their sum as the difference between the total exchange capacity expressed in m.e. and the determined values for the m.e. of exchangeable sodium and potassium (52).

However, this gives no indication of the ratio of exchangeable calcium to exchangeable magnesium of a particular soil. Bower et al (49) also disregarded the quantities of calcium and magnesium extracted by ammonium acetate if the soil was calcareous or gypsiferous. Peech (53) estimated exchangeable calcium in calcareous soils as exchange capacity less exchangeable potassium, sodium, and magnesium.

Various workers have suggested methods for the determination of exchangeable calcium and magnesium in calcareous soils. Proposals include the following:-

1. Use of 40-80 per cent alcoholic solutions of ammonium acetate (54). It has since been shown that calcium carbonate and dolomite are to some extent soluble in such leachings.

2. Corrections for the solubility of calcium carbonate in the leachings (55). In the first soil leachate ealcium obtained includes exchangeable calcium and also calcium dissolved from calcium carbonate fragments. The second leachate is assumed to contain only soluble calcium from rock particles. There is no reason to suppose, however, that the amount of calcium dissolved from rock particles in the first and second leachings will be the same, and on these grounds the method is unsatisfactory.

3. Use of alkaline solutions such as sodium carbonate (56) or barium chloride-triethanolamine extraction solution.

Bower et al (49) have shown that carbonates are less soluble in normal sodium acetate of pH 8.2 than in normal ammonium acetate of pH 7.0 to the extent:-

	N. Na.Ac.	N. Am. Ac.
Calcite	1.62 m.e.	17.1 m.e.
Dolomite	0.75 "	9.4 "
Magnesite	0.15 "	1.44 "

In both solutions solubility of calcite>dolomite>magnesite.

An attempt was made to determine exchangeable calcium and magnesium by precipitation as the oxalate after leaching with a solution of normal sodium acetate of pH 8.2. 5 gms. of soil were placed in a leaching funnel and leached with 250 mls. of normal sodium acetate solution. 5 mls. of the leachate were pipetted into a conical flask and evaporated to dryness on a water bath. The residue was moistened with hydrogen peroxide and again taken to dryness. This process was repeated until the residue was colourless, which showed that the organic matter had been oxidised. The residue was taken up in 5 mls. of distilled water and 20 mls. of saturated ammonium oxalate and then warmed. After allowing to cool for one hour the mixture was filtered through a fritted glass crucible, the filtrate being retained for determination of magnesium. The calcium oxalate precipitate in the crucible was dissolved in hydrochloric acid and diluted to 100 mls. with distilled water. Calcium in the dilution was determined on the flame photometer, the instrument being set at 100 with a standard solution of 50 ppm calcium.. It was found, however, that little of the calcium was recovered and that most of it was washed through the fritted glass crucible with the magnesium extract. The time allowed for formation of the calcium oxalate was increased but with no more success. Eventually the method was abandoned and barium chloride-triethanolamine was adopted as an extracting solution.

25 mls. of about eight normal commercial triethanolamine were diluted to 250 mls. with distilled water and partially neutralised with hydrochloric acid to adjust the pH to 8.1. This solution was diluted to 500 mls. with distilled water and then mixed with 500 mls. of 0.4 N barium chloride solution, the resulting solution being protected from the carbon dioxide of the air. 5 gms. of soil were placed in the leaching funnel and leached with 250 mls. of the barium chloride-triethanolamine solution, barium carbonate coating the surfaces of calcite and dolomite fragments and rendering them insoluble. 5 mls. of the leachate were pipetted into a thick-walled centrifuge tube, and 1 ml. of concentrated glacial acetic acid and 2 mls. of saturated ammonium ~~acetate~~ oxalate added. The mixture was digested on the water bath for two hours and then centrifuged to separate the precipitate of barium and calcium oxalate from the supernatant liquid, the latter being poured off. 5 mls. of 0.1 N sulphuric acid and 1 ml. of dilute hydrochloric acid were added to the precipitate. The sulphuric acid was added to ascertain that all of the barium had been precipitated and the hydrochloric acid was added to dissolve the calcium oxalate. After digesting for half an hour and centrifuging more sulphuric acid was added drop-wise to make sure that no barium remained in solution. Normal potassium permanganate was added to the solution until in excess as indicated by a permanent pink colour. Hydrogen peroxide was now added until the pink colour disappeared. The solution was digested for another hour and centrifuged, the liquid portion being poured into a 10ml. graduated flask and made up to the mark with 0.1 N sulphuric acid. The amount of calcium in parts per million in the latter dilution was determined on the flame photometer. The instrument was set at 100 with a standard 50 ppm calcium solution.

Calcium was then expressed in milliequivalents per 100 grms. of soil.

Determination of exchangeable magnesium.

J. B. Hester (57) used an alcoholic solution of Titan Yellow for determination of exchangeable magnesium while H. A. Lunt et al (58) used Thiazole Yellow. Both of these dyes are affected by the presence of iron, aluminium, and calcium, an obvious disadvantage for the extracts of the soils under discussion. M. Taras (59) developed a simple magnesium test using an alcoholic solution of Brilliant Yellow, which is unaffected by the presence of relatively small amounts of iron and aluminum but, more importantly, the presence of calcium intensifies the development of colour. Saturated lime water is used to adjust the pH of the solution being tested and also compensated for the calcium error.

The magnesium reagent was made up by weighing 0.01 grms. of powdered Brillian Yellow (Cl 364) into a 100 ml. volumetric flask, dissolving and diluting to the 100 ml. mark with a 1:1 mixture of reagent grade methanol and distilled water. One part of this solution was mixed with 19 parts of fresh, clear limewater and this solution was used to determine magnesium as follows:-

2 mls. of the barium chloride triethanolamine solution leachate were pipetted into a colorimetric Eel tube. 5 mls. of magnesium reagent were added and the mixture shaken. The intensity of colour developed was measured on the colorimeter and compared with that developed on a set of standard solutions of known magnesium content.

Various proportions of Brilliant Yellow solution to limewater were used and the 1:19 mixture was found to be the most satisfactory. This latter mixture, as can be seen from Fig. 5, allows for readings of up to 25 ppm to be taken with reasonable accuracy. The magnesium content of the

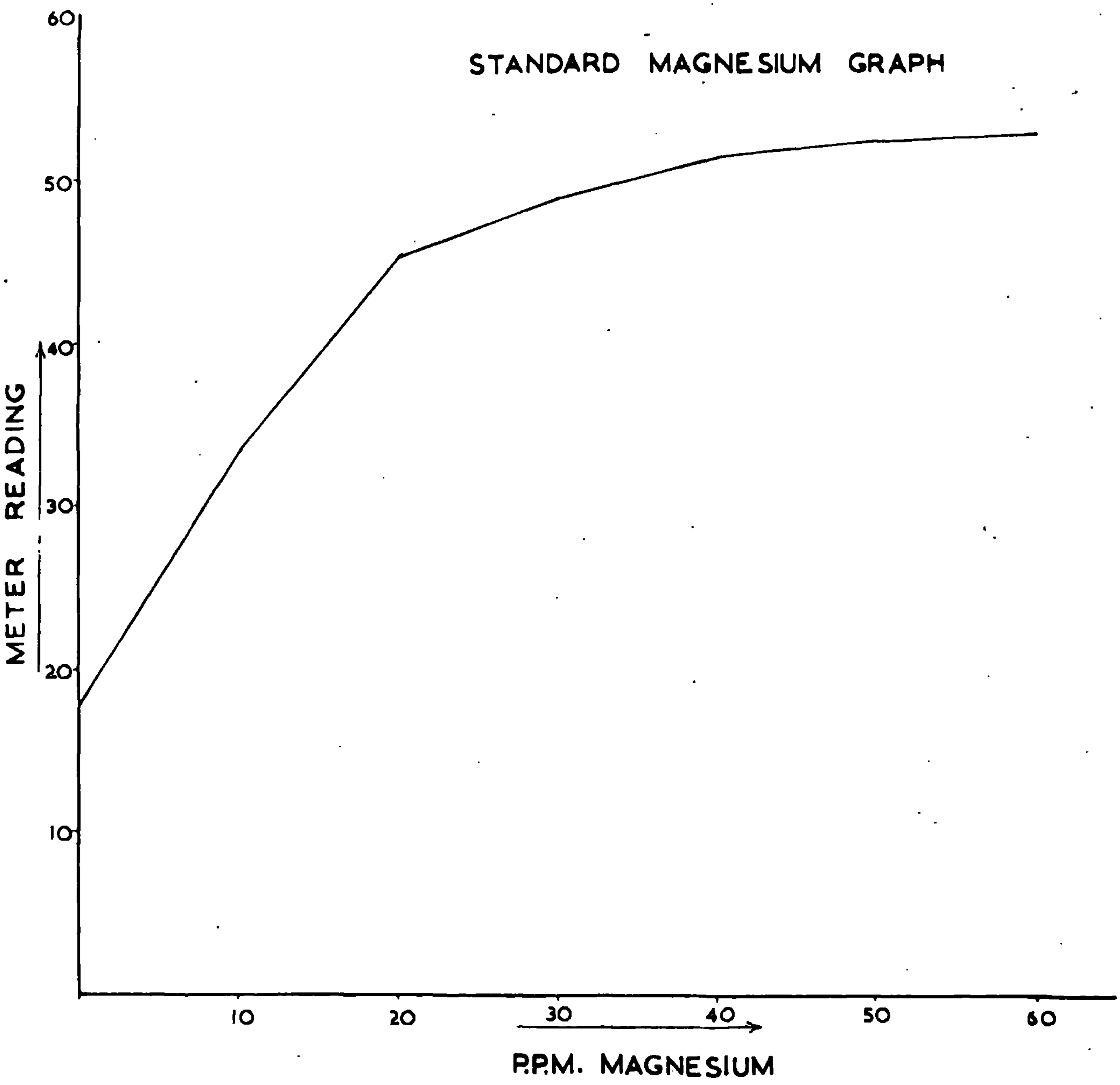

STANDARD MAGNESIUM GRAPH
METER READING
60
50
40
30
20
10
10
20
30
40
50
60
P.P.M. MAGNESIUM

FIG. 5

2 ml. leachates of the soils studied, all fell well within the 0-25 ppm range. Magnesium was read off the graph as ppm and was then expressed as milli-equivalents per 100 grms. of soil.

Total Exchange Capacity.

5 gms. of soil were accurately weighed out and placed in a leaching funnel. The soil was leached with 250 ml. of normal sodium acetate, whereby the exchangeable cations on the clay-humus complex were replaced by sodium ions. Excess sodium was then washed away by leaching with 250 mls. of industrial alcohol. The sodium acetate and alcohol leachates were discarded. As a result of the above treatment the exchange complex of the soil was saturated with sodium ions, which were then replaced by leaching with 250 mls. of normal ammonium acetate. This third leachate was collected in a 250 ml. volumetric flask and made up to the mark with ammonium acetate. The amount of sodium in the solution was measured on the flame photometer, the instrument being set at 100 with a solution of 50 ppm sodium. Results were then expressed as milli-equivalents of sodium per 100 grms. of soil. This corresponded to milli-equivalents of exchange capacity per 100 grms. of soil.

The chief errors of the method are:-

1. All cations may not be replaced by sodium ions after leaching with normal sodium acetate, thus giving a low exchange capacity.
2. Washing of excess sodium acetate with alcohol might not be complete, though this seems unlikely when 250 mls. of alcohol are used.
3. Hydrolysis of sodium ions can occur when washing with alcohol. The exact medium, between excess sodium being washed from the soil and exchangeable sodium being removed by hydrolysis,

should be reached. This is probably the most important error and causes low readings for exchange capacity.

4. All of the sodium may not be replaced by ammonium in the final leaching, and this would again result in low readings for exchange capacity.

The results obtained showed that the exchange capacity, as calculated from the addition of the individual cations, was about 20% below the exchange capacity as determined in the method described above. Considering the experimental errors involved, it was decided to assume the exchange capacity to be satisfactory and the indivividual cations were corrected accordingly.

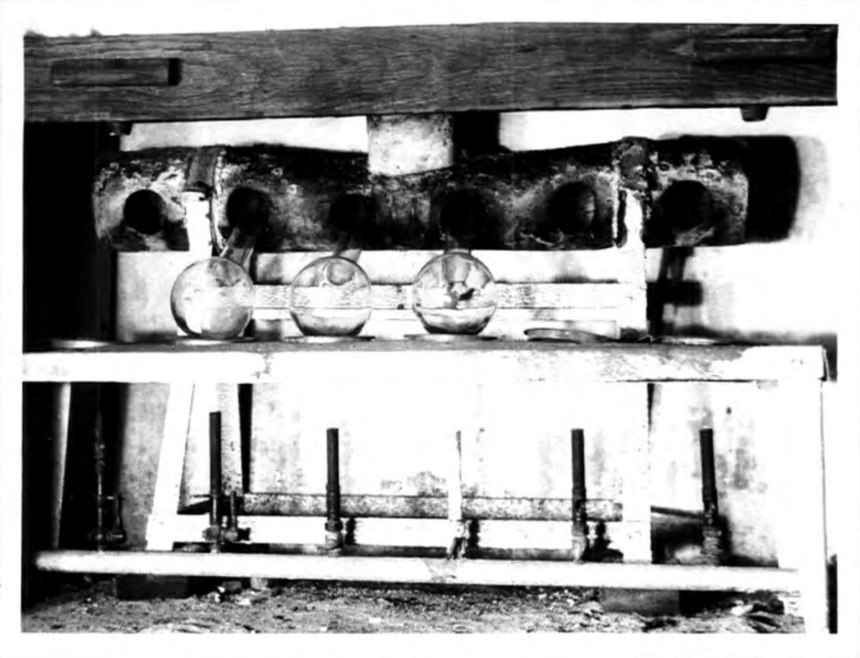


PLATE 8. Digestion appamatus for nitrogen determination.

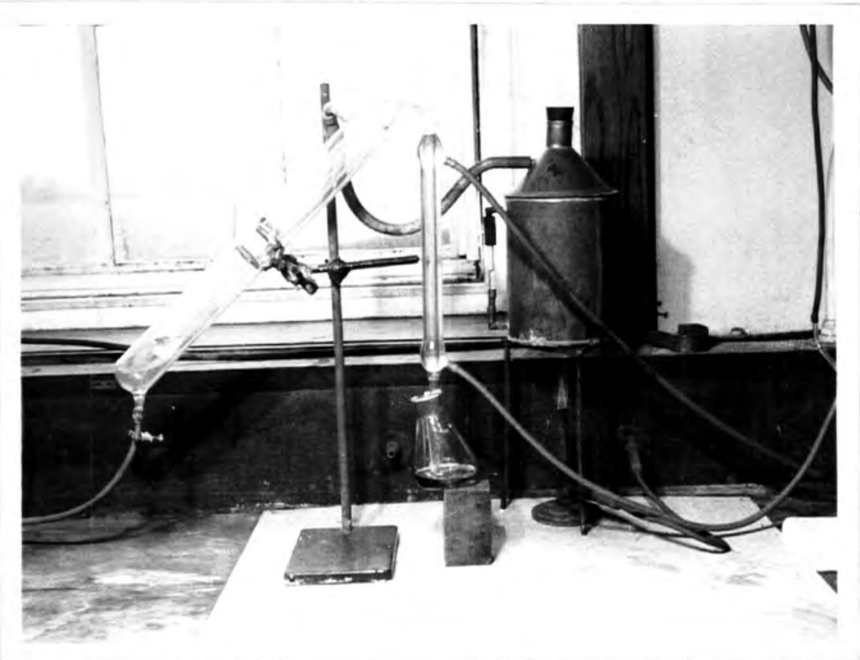


PLATE 9. Markham apparatus for distillation in nitrogen determination.

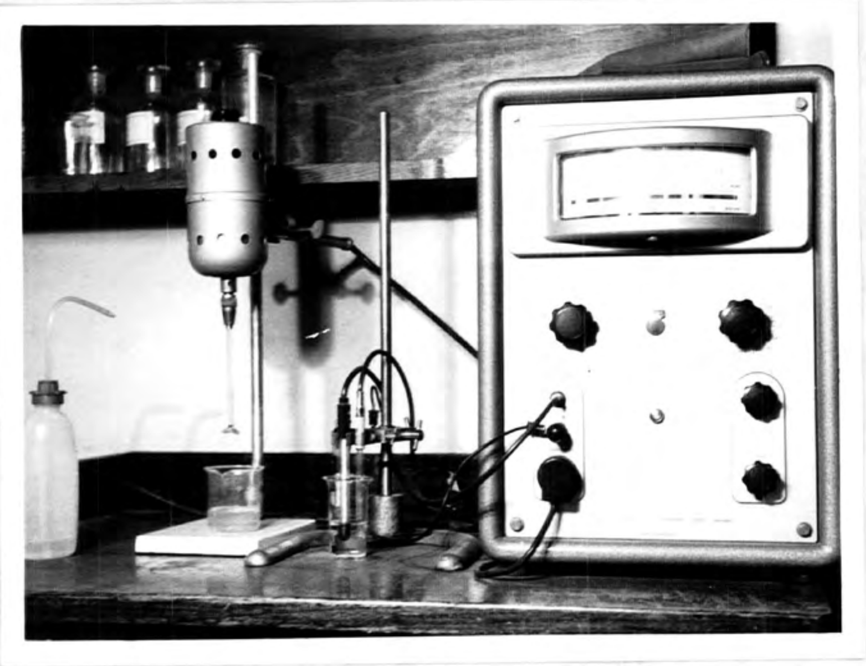


PLATE 10. E.I.L.pH Meter and mechanical stirrer.

PLATE 11. Mechanical shaker and centrifuge apparatus.

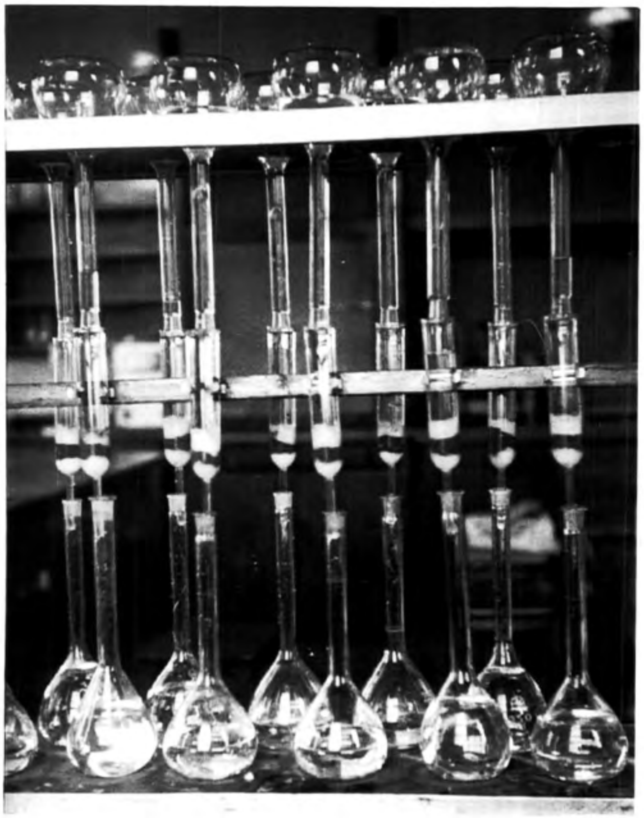


PLATE 12.

Leaching funnels for the determination of exchangeable cations.

PLATE 13. Flame photometer.

TABLE VI

LOCATION OF PROFILES, DEPTH OF HORIZONS AND SOIL COLOUR

Profile and Horizon		Grid reference	Altitude	Colour		Depth
				Munsell	Visual	
1	A_1	45/332340	470'	10YR 4/2	Dark Grey Brown	0 - 3 "
	A_2			10YR 5/4	Yellow Brown	3 - 9 "
	A_3			10YR 6/4	Light Yellow Brown	9 - 13 "
	C_1			10YR 8/6	Yellow	13 - 24 "
2	A_1	45/339334	465'	10YR 4/2	Dark Grey Brown	0 - 1 "
	A_2			10YR 4/3	Brown-Dark Brown	1 - 4½"
	A_3			10YR 5/4	Yellow Brown	4½ - 14½"
	C_1			2.5Y 8/4	Pale Yellow	14½ - 29½"
3	A_1	45/339334	460'	2.5Y 5/2	Grey Brown	0 - 1½"
	A_2			2.5Y 6/2	Light Grey Brown	1½"- 4 "
4	A_1	45/329331	450'	10YR 4/3	Brown-Dark Brown	0 - 5 "
	C_1			10YR 6/6	Brown Yellow	5 - 7 "
5	A_1	45/329329	450'	10YR 4/3	Brown-Dark Brown	0 - 15 "
6	A_1	45/324383	550'	10YR 3/2	Very Dark Grey Brown	0 - 1½"
	A_2			10YR 3/3	Dark Brown	1½"- 7 "
	A_3			10YR 3/4	Dark Yellow Brown	7 - 10½"
7	A_1	45/327379	550'	10YR 4/3	Brown-Dark Brown	0 - 4 "
	A_2			10YR 5/4	Yellow Brown	4 - 9 "
	A_3			10YR 5/6	Yellow Brown	9 - 12 "
	C_1			10YR 7/4	Very Pale Brown	12 - 20 "
8	A_1	45/337402	555'	10YR 4/3	Brown-Dark Brown	0 - 1 "
	A_2			10YR 5/6	Yellow Brown	1 - 7 "
	D			10YR 6/6	Brown Yellow	7" +

TABLE VI (CONT.)

Profile and Horizon		Grid Reference	Altitude	Colour		Depth
				Munsell	Visual	
9	A_1	45/344398	610'	10YR 4/3	Brown-Dark Brown	0 - 1½"
	A_2			10YR 4/2	Dark Grey Brown	1½ - 6½"
	A_3			10YR 4/4	Dark Yellow Brown	6½ - 9½"
	B_1			7.5YR 5/8	Strong Brown	9½ - 14 "
	D			2.5Y 8/4	Pale Yellow	14"+
10	A_1	45/342416	470'	2.5Y 6/4	Light Yellow Brown	0 - 2 "
	A_2			10YR 3/1	Very Dark Grey	2 - 4½"
	A_3			10YR 4/3	Brown-Dark Brown	4½ - 7½"
	C_1			10YR 7/6	Yellow	7½ - 11½"
11	A_1	45/345506	410'	10YR 4/4	Dark Yellow Brown	0 - 3 "
	C			5Y 8/4	Pale Yellow	3 - 7 "
12	A_o	45/375437	460'	10YR 3/3	Dark Brown	0 - 1½"
	A_1			10YR 4/2	Dark Grey Brown	1½ - 9½"
	B_1			10YR 5/4	Yellow Brown	9½ - 21½"
	C_1			5Y 8/4	Pale Yellow	21½ - 31½"
13	A_o	45/333419	510'	10YR 2/2	Very Dark Brown	0 - 1 "
	A_1			10YR 3/2	Very Dark Grey Brown	1 - 4 "
	A_2			10YR 3/4	Dark Yellow Brown	4 - 11 "
	C_1			10YR 4/4	Dark Yellow Brown	11 - 13 "
14	A_1	45/387665	30'	10YR 3/4	Dark Yellow Brown	0 - 2 "
	A_2			10YR 3/4	Dark Yellow Brown	2 - 7 "
	B_1			7.5Y 4/4	Brown-Dark Brown	7 - 21 "
	D			2.5Y 8/4	Pale Yellow	21+"

TABLE VI (CONT.)

Profile and Horizon		Grid reference	Altitude	Colour		Depth
				Munsell	Visual	
15	A_o	45/390655	140'	10YR 4.5/1	Grey-Dark Grey	0 - $\frac{1}{4}$"
	A_1			10YR 4/1	Dark Grey	$\frac{1}{4}$ - 3 "
	A_2			10YR 5/2	Grey Brown	3 -15 "
16	A_o	45/390655	140'	10YR 4/2	Dark Grey Brown	0 - $\frac{1}{4}$"
	A_1			10YR 4/2	Dark Grey Brown	$\frac{1}{4}$ - 3 "
	C_1			2.5Y 8/4	Pale Yellow	3 -12 "
17	A_1	45/406644	60'	10YR 2/2	Very Dark Brown	0 - 4 "
	A_2			10YR 3/3	Dark Brown	3 - 9 "
18	A_1	45/340505	350'	10YR 3/2	Very Dark Brown	0 - 4 "
	A_2			10YR 3/4	Dark Yellow Brown	4 -12 "
19	A_1	45/341517	350'	10YR 3/2	Very Dark Grey Brown	0 - 2 "
	A_2			10YR 4/4	Dark Yellow Brown	2 -12 "
	D			10YR 6/4	Light Yellow Brown	12"+
20	A_1	45/347528	410	10YR 2/2	Very Dark Brown	0 - 3 "
	A_2			10YR 3/3	Dark Brown	3 -15""

TABLE VII

SOIL MECHANICAL ANALYSIS

Profile and Horizon		Clay	Silt	Fine Sand	Coarse Sand	Total	Texture
1	A_1	14.0	20.0	55.73	9.52	96.25	Loam
	A_2	8.4	14.1	62.51	11.25	96.26	Loamy Sand
	A_3	4.0	22.0	62.88	8.24	97.12	Loamy Sand
	C_1						
2	A_1	2.0	24.8	57.80	12.49	97.01	Silty Loam-Loamy Sand
	A_2	11.2	21.0	52.77	9.62	94.59	Loam
	A_3	12.7	24.5	49.78	11.95	98.93	Loam
	C_1						
3	A_1	7.4	18.0	65.51	8.78	99.69	Loamy Sand
	A_2	5.4	17.0	61.56	13.56	97.52	Loamy Sand
4	A_1	9.4	7.0	60.25	20.18	96.83	Loamy Sand
	C_1						
5	A_1	9.4	13.6	52.03	22.00	97.03	Sandy Loam
6	A_1	8.4	15.0	56.84	17.67	97.91	Loamy Sand
	A_2	12.4	17.0	51.84	13.33	94.57	Loam
	A_3	17.2	11.0	53.46	16.00	97.66	Loam
7	A_1	14.0	18.0	54.1	11.6	97.7	Loam
	A_2	24.0	16.4	46.66	9.0	96.06	Clay Loam
	A_3	21.0	21.0	44.46	11.28	97.74	Loam
	C_1						
8	A_1	21.2	20.0	45.6	10.59	97.39	Loam
	A_2	27.0	18.8	40.63	9.88	96.31	Clay Loam
	D						

TABLE VII (CONT.)

Profile and Horizon		Clay	Silt	Fine Sand	Coarse Sand	Total	Texture
9	A_1	13.6	12.0	55.58	13.22	94.40	Loam
	A_2	20.0	12.0	53.66	11.33	96.99	Loam
	A_3	23.0	11.6	48.35	12.48	95.43	Clay Loam
	B_1	38.0	9.6	40.02	8.96	96.58	Clay
	D						
10	A_1	4.6	3.0	51.39	38.62	97.61	Sand
	A_2	8.0	8.0	54.8	25.52	96.32	Loamy Sand
	A_3	17.0	12.2	57.6	9.2	96.0	Loam
	C_1						
11	A_1	17.0	12.0	45.2	21.4	95.6	Loam
	C_1						
12	A_0	6.5	16.5	56.48	11.14	90.62	Loamy Sand
	A_1	14.0	21.0	49.0	14.3	98.3	Loam
	B_1	18.0	26.0	42.2	10.6	96.8	Silty Loam-Loam
	C_1	1.0	45.0	50.9	1.3	98.2	Silty Loam
13	A_0	7.0	12.0	54.62	16.4	90.02	Loamy Sand
	A_1	11.0	15.0	48.66	18.7	93.36	Loam
	A_2	16.0	14.0	49.14	14.96	94.1	Loam
	C_1	15.0	15.0	49.72	17.06	96.78	Loam
14	A_1	15.0	12.0	46.18	13.76	86.94	Loam
	A_2	20.0	15.0	40.36	13.98	89.34	Loam
	B_1	29.0	14.0	37.64	14.44	95.08	Clay Loam
	D						

TABLE VII (CONT.)

Profile and horizon		Clay	Silt	Fine Sand	Coarse Sand	Total	Texture
15	A_o	9.0	22.0	53.7	11.12	95.82	Loamy Sand
	A_1	7.0	27.0	52.98	9.52	96.5	Silty Loam-Loamy Sand
	A_2	15.0	25.0	42.06	14.94	97.0	Silty Loam-Loam
16	A_o	6.5	27.6	56.2	5.34	95.64	Silty Loam-Loamy Sand
	A_1	6.0	24.6	58.3	5.3	94.2	Silty Loam-Loamy Sand
	C_1	3.0	41.0	51.2	2.6	97.8	Silty Loam
17	A_1	7.4	22.3	54.6	9.83	94.13	Loam Sand
	A_2	10.2	24.7	46.8	13.64	95.34	Silty Loam-Loamy Sand-Loam
18	A_1	5.0	22.4	56.4	9.5	93.3	Silty Loam-Loamy Sand
	A_2	7.0	24.6	54.8	7.8	94.2	Silty Loam-Loamy Sand
19	A_1	4.3	25.8	53.8	8.6	92.5	Silty Loam-Loamy Sand
	A_2	7.4	24.5	55.4	8.1	95.4	Silty Loam-Loamy Sand
	C_1						
20	A_1	4.2	22.1	63.4	6.3	96.0	Loamy Sand
	A_2	10.4	21.1	51.5	13.8	96.4	Loamy Sand

TABLE VIII

SOIL REACTION, LOSS ON IGNITION AND C:N RATIO

Profile and horizon		pH	Loss on Ignition %.	Carbon	Organic Matter	Nitrogen	C:N Ratio
1.	A_1	7.72	20.73	5.40	9.31	0.294	18.35
	A_2	7.81	8.33	2.28	3.93	0.158	14.43
	A_3	7.99	5.64	0.78	1.34	0.070	11.15
	C_1	8.0					
2	A_1	7.7	21.00	11.46	19.76	0.616	18.6
	A_2	7.72	15.73	4.02	6.93	0.280	14.4
	A_3	7.82	8.25	2.32	4.00	0.20	11.6
	C_1	7.8					
3	A_1	7.7	18.05	5.24	9.03	0.56	9.4
	A_2	7.59	11.69	4.51	7.77	0.36	12.5
4	A_1	7.78	21.57	8.47	14.60	0.52	16.3
	C_1	7.8					
5	A_1	7.6	13.23	4.07	7.02	0.28	14.5
6	A_1	7.4	23.06	8.52	14.69	0.921	9.25
	A_2	7.58	17.90	5.40	9.31	0.756	7.14
	A_3	7.81	15.06	5.07	8.74	0.453	11.19
7	A_1	7.62	14.57	5.22	9.00	0.518	10.08
	A_2	7.72	8.86	1.57	2.71	0.296	5.3
	A_3	7.54	12.65	2.91	5.02	0.205	14.19
	C_1	7.82					
8	A_1	7.8	15.22	4.56	7.86	0.432	10.55
	A_2	7.9	11.59	3.35	5.78	0.2	16.75
	D	8.2					

TABLE VIII (CONT.)

Profile and Horizon		pH	Loss on Ignition °/.	Carbon	Organic Matter	Nitrogen	C:N Ratio
9	A_1	7.79	18.02	6.38	11.0	0.38	16.8
	A_2	6. 9	12.32	4.12	7.10	0.37	11.1
	A_3	7.18	8.79	2.83	4.88	0.20	14.1
	B_1	7.52	17.18	3.37	5.81	00.30	11.2
	D	8.2					
10	A_1	7.58	6.75	2.55	4.40	0.30	08.5
	A_2	7.6	18.91	5.12	8.83	0.60	8.5
	A_3	7.8	14.90	4.77	8.22	0.23	20.7
	C_1	7.87					
11	A_1	7.79	7.66	3.90	6.72	0.30	13.0
	C_1	7.7					
12	A_o	7.5	24.79	9.12	15.72	0.60	15.2
	A_1	7.7	17.09	4.23	7.29	0.46	9.2
	B_1	7.92	11.66	2.01	3.47	0.18	11.2
	C_1	7.95					
13	A_o	7.4	32.85	9.45	16.29	1.03	9.2
	A_1	7.58	27.60	6.72	11.59	0.63	10.7
	A_2	7.66	19.64	4.42	7.62	0.46	9.6
	C_1	7.52	20.36	2.18	3.76	0.48	4.5
14	A_1	7.55	16.30	6.47	11.15	0.63	10.3
	A_2	7.68	14.03	4.6	7.93	0.34	13.5
	B_1	7.6	8.48	1.92	3.31	0.13	14.7
	D	8.05					

TABLE VIII (CONT.)

Profile and Horizon		pH	Loss on Ignition °/.	Carbon	Organic Matter	Nitrogen	C:N Ratio
15	A_o	7.8	17.91	7.32	12.62	0.52	14.1
	A_1	7.8	13.99	6.23	10.74	0.41	15.2
	A_2	7.9	7.73	2.95	5.09	0.18	16.0
16	A_o	7.7	14.23	5.75	9.91	0.45	12.8
	A_1	7.8	8.44	3.52	6.07	0.29	12.1
	C_1	7.92					
17	A_1	7.5	29.10	7.42	12.79	0.44	16.8
	A_2	7.9	17.31	5.69	9.81	0.51	11.2
18	A_1	7.55	32.85	7.76	13.38	0.78	10.0
	A_2	7.7	21.92	5.82	10.03	0.57	10.2
19	A_1	7.58	26.57	6.85	11.81	0.71	9.6
	A_2	7.9	13.55	3.81	6.57	0.45	8.5
	C_1	7.85					
20	A_1	7.05	35.55	6.29	10.84	0.68	8.6
	A_2	7.9	20.94	5.73	9.88	0.63	9.1

TABLE LX

EXCHANGEABLE CATIONS OF SOILS

Profile and Horizon		Milliequivalents /100g. of soil.					°/. of Total			
		Total	Na.	K.	Ca.	Mg.	Na.	K.	Ca.	Mg.
1	A_1	24.78	1.36	1.20	15.96	6.26	5.49	4.84	64.41	25.26
	A_2	18.48	0.92	0.29	12.75	4.51	4.98	1.57	68.99	24.40
	A_3	15.51	0.83	0.10	11.25	3.33	5.35	0.64	72.53	21.47
2	A_1	29.13	2.22	3.62	14.44	8.86	7.62	12.43	49.57	30.42
	A_2	24.56	1.51	1.18	13.99	7.88	6.15	4.80	56.96	32.08
	A_3	22.83	1.70	0.58	14.85	5.70	7.45	2.54	65.05	24.97
3	A_1	23.48	2.15	2.87	13.14	5.32	9.16	12.22	55.96	22.66
	A_2	21.09	1.85	1.07	13.09	5.08	8.77	5.07	62.07	24.09
4	A_1	32.17	3.57	1.95	21.08	5.56	11.10	6.06	65.53	17.28
5	A_1	25.65	3.55	1.31	16.43	4.36	13.84	5.10	64.05	17.00
6	A_1	30.87	1.80	6.31	16.71	6.05	5.83	20.44	54.13	19.60
	A_2	29.57	1.64	3.18	16.90	7.85	5.55	10.75	57.15	26.55
	A_3	29.35	1.83	1.05	18.79	7.68	6.24	3.58	64.02	26.17
7	A_1	27.00	1.67	1.43	18.57	5.33	6.19	5.30	68.78	19.74
	A_2	23.04	1.32	0.78	16.52	4.42	5.73	3.39	71.70	19.18
	A_3	23.90	2.04	0.90	15.99	4.97	8.54	3.77	66.90	20.79
8	A_1	27.39	1.90	0.86	17.49	7.14	6.94	3.14	63.86	26.07
	A_2	27.01	1.61	0.90	17.88	6.62	5.96	3.33	66.20	24.51
9	A_1	29.23	3.98	1.95	16.60	6.70	13.62	6.67	56.79	22.92
	A_2	26.08	2.46	0.50	17.39	5.73	9.43	1.92	66.68	21.97
	A_3	23.70	2.32	0.36	16.68	4.34	9.79	1.52	70.38	18.31
	B_1	25.87	3.00	0.47	16.89	5.51	11.60	1.82	65.29	21.30

TABLE IX

EXCHANGEABLE CATIONS OF SOILS

Profile and Horizon		Milliequivalents /100g. of soil.					% of Total			
		Total	Na.	K.	Ca.	Mg.	Na.	D.	Ca.	Mg.
10	A_1	18.38	0.76	1.00	13.50	3.12	4.13	5.44	73.45	16.97
	A_2	27.39	1.69	1.33	17.15	7.22	6.17	4.86	62.61	26.36
	A_3	27.83	1.47	0.98	20.08	5.30	5.28	3.52	72.15	19.04
11	A_1	19.19	0.96	0.36	14.75	3.12	5.00	1.88	76.86	16.26
12	A_o	30.66	2.68	1.03	18.14	8.81	8.74	3.36	59.17	28.73
	A_1	23.71	1.57	0.31	15.93	5.90	6.62	1.31	67.19	24.88
	B_1	20.65	1.37	0.19	15.03	4.06	6.63	0.92	72.78	19.66
13	A_0	33.92	2.04	1.45	15.59	14.84	6.01	4.27	45.96	43.75
	A_1	30.23	1.80	0.98	16.89	10.56	5.95	3.24	55.87	34.93
	A_2	27.82	1.66	0.79	18.93	6.44	5.97	2.84	68.04	23.15
	C_1	27.39	1.17	0.51	19.50	6.21	4.27	1.86	71.19	22.67
14	A_1	29.35	6.89	2.54	12.00	7.92	23.48	8.65	40.89	26.98
	A_2	26.30	4.69	1.60	11.88	8.13	17.83	6.08	45.17	30.91
	B_1	22.17	1.72	1.12	11.50	7.83	7.76	5.05	51.87	35.32
15	A_o	28.03	3.13	1.63	19.87	3.40	11.17	5.82	70.89	12.13
	A_1	25.44	3.56	0.93	17.29	3.66	13.99	3.66	67.96	14.39
	A_2	22.83	2.52	0.39	16.69	3.23	11.04	1.71	73.11	14.15
16	A_0	27.39	3.62	2.02	17.19	4.56	13.22	7.37	62.76	16.65
	A_1	21.59	4.35	0.99	13.25	3.00	20.15	4.59	61.37	13.90
17	A_1	30.43	7.35	2.00	14.00	7.08	24.15	6.57	46.01	23.27
	A_2	25.45	8.09	1.46	12.13	3.77	31.79	5.74	47.66	14.81

TABLE IX (CONT.)

Profile and Horizon		Milliequivalents /100g. of soil.					°/. of Total			
		Total	Na.	K.	Ca.	Mg.	Na.	D.	Ca.	Mg.
18	A_1	28.91	3.11	1.31	14.75	9.74	10.76	4.53	51.02	33.69
	A_2	27.00	1.72	0.33	13.38	11.57	6.37	1.22	49.56	42.85
19	A_1	28.70	2.20	1.63	14.25	10.62	7.67	5.68	49.65	37.00
	A_2	22.61	2.70	0.63	13.86	5.69	11.94	1.59	61.30	25.17
20	A_1	34.57	2.61	1.33	17.88	12.75	7.55	3.85	51.72	36.88
	A_2	27.17	1.43	0.71	15.88	9.15	5.26	2.61	58.45	33.68

TABLE X

AVAILABLE NUTRIENTS AND CARBONATES

Profile and Horizon		Available Nutrients				Insoluble Residue	Calcium AS $CaCo_3$	Magnesium AS $MgCO_3$
		Potash		Phosphate				
		m.e./100g.	Status	m.e./100g.	Status			
1	A_1	19.20	M-M.H.	7.40	M.H.			
	A_2	4.80	V.L.	3.00	L.-M.			
	A_3					13.38	59.47	27.15
	C_1					1.20	66.00	32.80
	D					0.59	84.53	14.88
2	A_1	6.72	L.	13.6	H			
	A_2	16.32	M.	8.0	M.H.			
	A_3	7.68	L.	7.0	M.H.			
	C_1					1.84	66.18	31.98
	D					0.77	85.42	13.81
3	A_1	38.40	H.	11.4	V.H.			
	A_2	20.16	M.-M.H.	6.6	M.H.			
4	A_1	24.00	M.H.	12.8	H			
	C_1					13.41	59.30	28.29
	D					0.50	74.29	25.21
5	A_1	18.24	M.	27.4	V.H.			
	D					0.37	63.94	35.23
6	A_1	90.24	V.H.	28.2	V.H.			
	A_2	42.24	V.H.	7.6	M.H.			
	A_3	11.92	L.	8.2	M.H.			
	D					0.83	57.98	42.02

TABLE X (CONT.)

Profile and Horizon	Available Nutrients				Insoluble Residue	Calcium AS $CaCo_3$	Magnesium AS $MgCO_3$
	Potash		Phosphate				
	m.e./100g.	Status	m.e./100g.	Status			
7 A_1	22.08	M.H.	9.0	M.H.			
A_2	13.44	M.	4.8	M.			
A_3	15.36	M.	6.6	M.H.			
C_1					18.38	47.79	33.83
8 A_1	15.36	M.	16.0	H.			
A_2	12.48	M.-L.	13.2	H.			
D					26.57	44.28	29.15
					0.50	57.99	41.51
9 A_1	16.32	M.	7.6	M.H.			
A_2	8.64	L.	1.6	V.L.-L			
A_3	7.68	L.	0.8	V.L.			
B_1	7.68	L.	2.6	L.			
D_1					2.73	48.83	48.44
D_2					0.17	71.70	28.13
10 A_1	28.80	M.H.	9.8	M.H.			
A_2	35.52	H.	5.6	M.			
A_3	20.16	M.H.-H.	4.6	M.	41.33	43.73	14.94
C_1							
11 A_1	9.60	L.	4.6	M.			
C_1					7.34	50.78	46.88
D					0.16	62.95	36.89

TABLE X (CONT.)

Profile and Horizon		Available Nutrients				Insoluble Residue	Calcium	Magnesium
		Potash		Phosphate				
		m.e./100g.	Status	m.e./100g.	Status		AS $CaCo_3$	AS $MgCO_3$
12	A_o	18.24	M.	18,6	V.H.			
	A_1	15.36	M.	9.0	M.H.			
	B_1	5.76	V.L.	8.2	M.H.			
	C_1					2.34	50.78	46.88
	D					0.68	64.63	34.69
13	A_o	28.80	M.H.	21.4	V.H.			
	A_1	14.40	M.	16.0	H.			
	A_2	11.92	L.-M.	9.4	M.H.			
	C_1	10.56	L.	10.0	M.H.-H.			
14	A_1	54.72	V.H.	13.6	H.			
	A_2	33.60	H.	4.2	M.			
	B	25.92	M.H.	2.1.	L.			
15	A_o	32.64	H.	24.8	V.H.			
	A_1	18.24	M.	23.8	V.H.			
	A_2	7.68	L.	25.2	V.H.			
	D					1.65	53.64	44.71
16	A_o	37.44	H	22.4	V.H.			
	A_1	20.56	M.H.-M	18.0	V.H.			
	C_1					4.92	68.18	26.90
17	A_1	45.12	V.H.	12.0	H.			
	A_2	24.00	M.H.	9.0	M.H.			
	D					0.65	91.71	7.64

TABLE X (CONT.)

Profile and Horizon	Available Nutrients				Insoluble Residue	Calcium AS $CaCo_3$	Magnesium AS $MgCO_3$
	Potash		Phosphate				
	m.e./100g.	Status	m.e./100g.	Status			
18 A_1	23.04	M.H.	12.4	H.			
A_2	8.64	L.	5.4	M.			
D					0.25	54.32	45.43
19 A_1	38.40	H.	25.6	V.H.			
A_2	6.72	L.-V.L.	15.2	H.			
C_1					13.36	55.34	31.30
D					3.84	66.27	29.89
20 A_1	28.80	M.H.	5.4	M.			
A_2	17.28	M.	6.8	M.H.			
D					0.21	72.77	27.02

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