Department of Agriculture and Technical Instruction for Ireland.

MEMOIRS OF THE GEOLOGICAL SURVEY OF IRELAND.

THE GEOLOGICAL FEATURES AND SOILS OF THE AGRICULTURAL STATION OF THE DEPARTMENT OF AGRICULTURE AT BALLYHAISE, IN THE COUNTY OF CAVAN,

BY

J. R. KILROE, A.R.C.Sc.I.; H. J. SEYMOUR, B.A., F.G.S.,

AND

T. HALLISSY, B.A.

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DIRECTOR—PROF. GRENVILLE A. J. COLE, M.R.I.A., F.G.S.

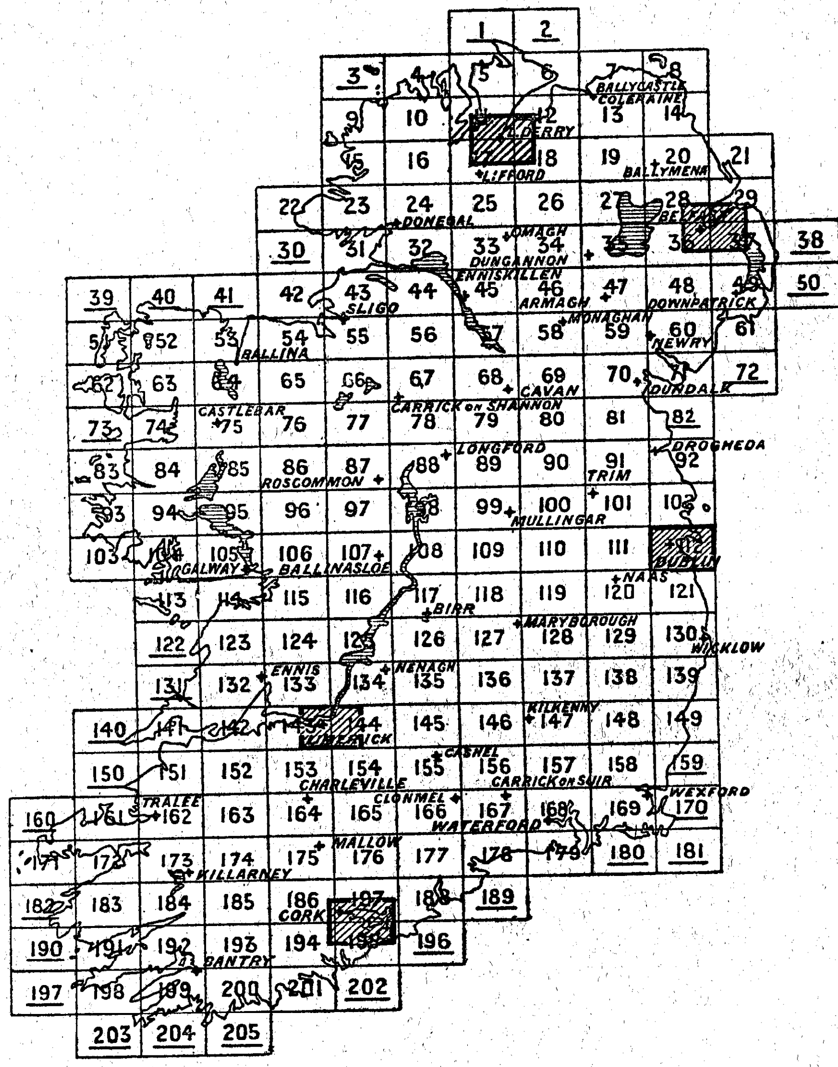
SENIOR GEOLOGIST—S. B. WILKINSON.

GEOLOGISTS—J. R. KILROE, A.R.C.Sc.I.; W. B. WRIGHT, B.A., F.G.S.

T. HALLISSY, B.A. (*Officer in charge of the Collections*).

SUPERINTENDENT OF MAPS—R. CLARK.

DRAUGHTSMAN—M. GAVIN.



Boundaries of the Sheets of the Geological Map on the scale of one inch to one mile. Various prices. Thick lines mark the boundaries of the colour-printed sheets showing superficial deposits, in addition to the underlying rocks; price 1*s*. 6*d*. each.

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PREFACE.

THE present memoir was undertaken in connexion with the preparation of a Soil Map of the Agricultural Station at Ballyhaise, and the two are now issued together, as an illustration of the origin of various types of soil from local drift deposits and underlying rocks. The lands at Ballyhaise are of an agreeably varied character, and the memoir shows what may be done in any limited area where agricultural experiments are likely to be carried on, or where a more accurate knowledge is required as to the distribution of particular soils. It is felt that such soil-mapping should be on a large scale, and should be restricted to areas of educational interest, or where special problems from time to time arise. In a virgin country, however, soil-surveys covering broad untenanted areas are no doubt desirable as a guide to future settlers. The general scheme of work for the present memoir was entrusted to Mr. J. R. Kilroe, who has always connected observations on soils with his work on the Geological Survey. Owing to illness, however, he was unable to conduct the survey of the drift deposits at Ballyhaise, and this work, so necessary for the foundation of the soil-map, was carried out by Mr. H. J. Seymour. Mr. T. Hallissy, after determining the characters of a number of soil-types from the area, mapped the boundaries of these types above the drift boundaries established by Mr. Seymour; and the groundwork of the coloured map now issued was very carefully prepared in the Geological Survey Office by Mr. Gavin, for reproduction by the Ordnance Survey.

The colours used for the representation of soil-types were selected on a natural basis, but, fortunately, this presented little difficulty. It seemed desirable, in the case of the present and future soil-maps, to avoid any clashing with the well-established tints used for rocks of the various geological systems. In Ireland, the larger part of the Jurassic and Cretaceous systems is absent, and thus a number of orange, yellowish, and greenish tints, necessary in England, remain free. These have been arranged in sequence, from orange for gravels down to a deep green-blue for clays, and they will, it is believed, meet all future requirements.

GRENVILLE A. J. COLE,

Director.

Geological Survey Office,

14, Hume Street, Dublin.

March, 1910.

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THE GEOLOGICAL FEATURES AND SOILS

OF THE

AGRICULTURAL STATION OF THE DEPARTMENT OF AGRICULTURE AT BALLYHAISE, IN THE COUNTY OF CAVAN.

CHAPTER I.

GENERAL DESCRIPTION OF THE GROUND.

By J. R. Kilroe.

SURFACE FEATURES.

The Farm attached to this Station consists of about 874 acres, in the County of Cavan, and is situated 4½ miles north by east of the county town. Butler's Bridge lies 2½ miles to the west, and Redhill 3½ miles to the north. The Agricultural Station adjoins the village of Ballyhaise (population 141), three miles from the Railway Station of this name. The village stands in the broad flat valley of the Annalee River, which traverses the farm from east to west, leaving about one-third of it on the north side, and two-thirds on the south. On the north side the farm comprises the townlands of Drumhome and Drumaraw, and parts of Lisnagowan and Carrickmore; and, on the south, those of Annaghduff, Elteen and Drumcrow, and parts of Drummully, Townparks and Raheg. Until recently the Station had been a well-kept private demesne, with a handsome residence and good out-offices. It is picturesquely situated beside sharp bends of the river, the residence overlooking in front a bridge which carries the main road from Cavan northward. Above the bridge, and also overlooked by the residence, are rapids which flow on each side of an island in the river, named Garden Isle. The rapids are exceptional in this portion of the river, its surface being practically unbroken for some two miles above and four miles below Ballyhaise. Around the residence and at a few other points, the river-banks and undulating surface are prettily decked with woods, which add charms to the Station, in pleasing contrast with the uninteresting appearance of the country around. The total area of the farm, together with the areas of wood,* peat,† water and arable ground, as obtained from the Ordnance maps, in some instances approximately, are presented in the following Table:—

* Including bare rock; much of the wood is cut down and in process of replanting.

† In process of reclamation—not reckoned in arable column of Table I.

TABLE I., shewing areas of Townlands, Woods, Peat, Arable Land and Water (River) comprised in the Ballyhaise Agricultural Station.

TOWNLANDS.	Area, acres, &c.	Woods, acres, &c.	Peat, acres, &c.	Water, acres, &c.	Arable,* acres, &c.
	A. R. P.	A. R. P.	A. R. P.	A. R. P.	A. R. P.
N. side—					
Drumhome .	74 0 35	.	.	6 0 26	68 0 9
Drumaraw .	149 2 21	13 0 20	.	7 2 25	128 2 16
Pt. of Lisnagowan	55 0 0	32 2 0	.	.	22 2 0
„ Carrickmore	6 2 35	.	.	0 3 8	5 3 27
S. side—					
Annaghduff .	92 2 4	.	27 0 7	4 3 14	60 2 23
Elteen . .	101 3 2	.	14 3 3	4 2 36	82 1 3
Drumcrow .	98 1 19	8 0 20	.	6 0 15	84 0 24
Pt. of Drumully .	75 1 0	73 1 20	1 3 20	.	.
„ Townparks	60 2 20	10 3 30	.	.	49 2 30
„ Raheg .	159 3 4	8 3 0	.	.	151 0 4
Totals .	873 3 20	146 3 10	43 2 30	30 1 4	652 3 16

Taking a bird's-eye view of the region in which the Station is situated, it is seen that the Annalee valley is one of the largest of those which open into the main valley of the Erne. The latter, including the hollow occupied by Lough Oughter, some four miles distant toward the south-west, is dotted with drumlins,† the longer axes of which are disposed in general conformity with the direction of the main valley. They are separated from each other by branches and windings of the river, small, fantastically-shaped lakelets, and peaty and alluvial tracts. The lakelets are specially conspicuous and important in the area to the south, where they form Lough Oughter, and northward along the course of the Erne below Belturbet. The water level at Baker's Bridge, according to the Ordnance map published in 1880, is 160 feet above datum; the low ground between the drumlins is some 10 to 15 feet higher as an average, while the drumlins rise to heights of 250 to 300 feet above datum.

This description of the ground covers the general characters of the valley-floor for three or four miles in width. The central portion of the tributary valley of the Annalee presents a somewhat similar aspect; its lowest portion, that is the river level between Ballyhaise and Butler's Bridge, is about 170 feet above datum, and the flat alluvial land margining this part of the river is about 5 to 10 feet higher.

* Including premises—Residence, yard, out-houses, mill, and roads.

† The vast number of these hog-backed hillocks in the Erne valley and Ballyhaise region gives the surface a strikingly undulating or irregular, puckered aspect. Their frequency may be judged from the fact that the names of thirteen townlands, in a space of twenty square miles in this region, commence with "Drum." Several of the townlands in the same region have names commencing with "Derry," which testifies to the former prevalence of oak woods

Drumlins are of common occurrence over the Ballyhaise Farm and its vicinity, and are accountable for the naming of four of the townlands, wholly or in part comprised in it.

From the central portion of the valley the gently rising undulating ground slopes upward to some 500 feet on the north and somewhat more than this on the south. A few exceptionally high features occur on this side of the valley, the most important being Shantemon Hill (715 feet), three miles south by east of Ballyhaise, and Slieve Glah (1,057 feet) south-east of Cavan town.

NATURAL DRAINAGE.

The Annalee joins the Erne River about a mile and a half below Butler's Bridge, and contributes to it the drainage of 343 square miles. At the middle point of the Farm it carries the drainage of 299 square miles, 159 of which lie in the county of Monaghan and 140 in that of Cavan. The river-bed lies centrally in the drainage basin; and the latter is bounded by a watershed which follows an undulating course over low hills, varying in height from under 450 feet to over 800 above datum; Slieve Glah, already mentioned, also lies on the watershed, but is of exceptional altitude. Eastward, the watershed or basin boundary runs by Newbliss (one mile south-east of the town); three miles to the southward of Monaghan; passes near Castleblayney, and within less than a mile and a half of Shercock. This line drops to about 350 feet above datum between two drumlins forming the townlands of Devlin and Garradevlin, west of Castleblayney. This divides the waters of the Annalee from those of the Clarebane or Fane River, which flows eastward; and here, therefore, we have indicated the comparatively slight lowering of the country's surface, which would effect a connection between the Irish Sea and the Atlantic, along the Fane and Erne valleys.

The principal initial supply of the Annalee is drawn from Lough Egish, near the eastern margin of the basin, the water-level in which is 532 feet above datum; from this the stream descends through 100 feet in two miles, to the alluvial flat below Laragh. Onward from this point the river flows over comparatively flat ground, traversing some of the numerous lakelets and alluvial flats which dot the lower part of the basin; and it falls 252 feet, that is to 180 feet above datum, in 27 miles of its course, thus possessing an average slope of about 9½ feet per mile. The surface-level is 180 feet above datum from Ballanacargy ford to Ballyhaise, the water being held up at the latter place by shallows, supplemented by a weir at the sharp turn of the river, above Garden Isle, where its bed is formed of rock. From the bridge below the rapids, for some distance, the water level is 170 feet, as previously stated.

With the exception of the alluvial flats near the river and a small peaty tract extending eastward from Oakwood (Drumully), and thence northward, the surface of the Farm is sufficiently undulating to afford good falls for artificial drainage.

WATER-POWER.

The fall of the river, calculated from the above given levels as some 10 feet, taken conjointly with the quantity of water flowing past, represents a vast amount of water-power; and the limited distance of some 360 yards through which the fall takes place affords good opportunity for its utilization. A certain proportion of this power is already applied to drive mills* and dairy machinery placed on the east side of the river nearly opposite Ballyhaise House, the Station residence.

The average rainfall of the district may be taken as approximately 35† inches; and if we set down the discharge as one-fourth of the rainfall,‡ the total annual amount from 280 square miles, which is the approximate drainage area above Ballyhaise, would be about 5,691,840,000 cubic feet, or an average of 15,594,000 cubic feet per day. The variation due to excessive precipitations on the one hand, and to droughts on the other, is to some extent modified by the large natural storage afforded by the numerous small lakes, swamps and flats which dot the central portion of the drainage area, as already mentioned; so that the water-flow in ordinary times should not be much smaller than the above average.

It will be noticed on the map how winding the course of the Annalee is; it is especially so in the vicinity of the Station. The river makes its way zig-zag between promiscuously placed drumlins, and in this region touches the rock only at the head of the Garden Isle rapids, above and below which deep water occurs. Here also it will be noticed that the river seems thrown out of its normal course by the prominent hill of Drumaraw. The placing of the drumlins, by which the solid rock is for the most part concealed, is discussed in Chapter III.; it may here, however, be pointed out that the deep water§ above and below the rocky shallows at Ballyhaise has led the present writer to believe that the river has been deflected from its original course, that it has, in fact, been constrained to ascend its left bank, to make its way round the drumlin. The wide-spreading marshy alluvium above the rapids, in some parts some ten feet higher than the present water-level, marks the site of a recent lake. This appears to have been caused by the natural damming of the river

* There are two "breast wheels;" one of iron 12′ wide and 17′ 6″ in diameter, with a measured fall of 8′ 8″; another older wheel of wood 10′ in width, 17′ 6″ in diameter and 8′ 8″ fall. The effective dimensions are somewhat less than these figures.

† Dr. H. R. Mill has kindly informed us that the average for the rainfall stations at Stradone, 280 feet above datum, Killeshandra, 251 feet above datum, and Belturbet. 202 feet above datum, may be taken as 35 inches.

‡ The proportion for the Thames basin, with a large aggregate area of porous strata, is one-third; and for the Severn basin, where the water is more largely lost by evaporation, the proportion is one-fourth. Reasons for taking the latter proportion for the Shannon in preference to one-third are stated by the present writer in a paper: "The River Shannon, its Present Course and Geological History" (Proc. Roy. Irish Acad., Vol. xvi., Sec. B. p. 80); and the conditions of the Annalee may be compared to those of the Shannon.

§ If borings were made through the alluvial matter forming the river-bed below the bridge, and say 200 yards above the shallows, the rock would be reached probably at a much greater depth than the present depth of the water.

at Ballyhaise, to the height mentioned at least, and while its bed at the Ballyhaise bend was in process of erosion to its present level. Judging from the average slope of the river, and its level at Ballanacargy, the bed here should be about 18 feet lower than it is at the shallows, that is, about 162 feet above datum. This would probably be the level of the rock beneath the river-bed below the bridge, where the river, as here supposed, resumes its original course.

CHAPTER II.

ROCK FORMATIONS.

By J. R. Kilroe.

The solid crust, concealed for the most part by superficial coverings, is visible here and there throughout Oakwood, where it bears but a scanty sprinkling of local detritus between crags of rock. Even here, however, this partial covering contains roundish stones, mingled with angular débris and clay, which indicates that drifted materials are not entirely wanting; and, in hollows, the material which sparsely covers the rock is in many places an accumulation of rain-wash from higher ground. These circumstances will be kept in view when reference is made later on to the *soils* taken from Oakwood, as from other parts of the area.

ORDOVICIAN SYSTEM.

The rock in Oakwood, and at a few other points indicated on the map, consists of gray, brown, purplish or greenish hard, fine-grained sandstone, mostly thin-bedded and flaggy, of Ordovician, *i.e.*, Lower Silurian, age. Determinative fossils have not been found at any point within the Farm, or indeed nearer than Newbliss, eight miles to the north-east. The group of shales there, associated with sandstones similar to those at Ballyhaise, consists of black slate containing *Cœnograptus gracilis*, from which it is concluded that the beds are representative of those in Wales belonging to the Llandilo series. The shales and associated sandstones have assumed a strike which may be followed south-westward toward Ballyhaise, a circumstance upon which our conclusion regarding the age of those at the latter place is based.

Other fossils have been collected at Redhill, three miles north of Ballyhaise, and at Cootehill, ten miles east by north of the Agricultural Station, at both of which points the graptolites showed that the Upper Silurian formation supervenes. Boundary lines, therefore, have been drawn, severing the areas of (Upper) Silurian from that of the Ordovician rocks in this region, neither of which boundaries, however, enters the present map. The nearer one is a zig-zag line which runs south-westward, about a mile to the south-east of the Station.

CARBONIFEROUS SYSTEM.

Limestone occurs about 4½ miles to the south-east, as an outlying mass—technically an "outlier"—separated from the main area of Carboniferous strata, which form the underlying rock of the Erne valley, and out of which that valley has been hollowed. The outlier is to be seen stretching northward from Stradone, five miles to the south-east of Ballyhaise; and, at a point about a mile and a half north by east of the former village, Carboniferous fossils were collected in a quarry between the townlands of Kilnagarbet and Lisegny. Viewing the outlier conjointly with the large area of Carboniferous strata to the north-west and south-west of Ballyhaise, it is inferred that a great thickness of Carboniferous strata once extended across the entire area until its removal by denudation exposed the underlying Ordovician and Silurian rocks, which are now to be seen at Ballyhaise.

The facts just referred to are represented upon the one-inch map of the Geological Survey, sheet 68, which was republished in 1901. On this map it will be noticed that the beds of rock dip in various directions at angles of 35° and 40° in Oakwood and Lisnagowan Hill; elsewhere the bedding-dip is much steeper, being 80° and 85°, and in certain places the sandstones and slate are set vertically. This high dip is the more remarkable when comparison is made with the low angle (5° to 15° or 20°) at which the beds of Carboniferous limestone, shale, and sandstone repose upon the Silurian rocks, both near Stradone and in the vicinity of Cavan. Such discordance of dips is indicative of the unconformity between the two formations, and is therefore suggestive of the interval of geological time which intervened between the epoch marked by the deposition of the Silurian strata, on the one hand, and the formation of the Carboniferous limestone, on the other.

CHAPTER III.

THE SUPERFICIAL AND DRIFT DEPOSITS AT BALLYHAISE.

By H. J. Seymour.

The superficial covering of detrital material which overlies the "solid" rocks of this area is in the main of Glacial origin. What cannot now be classed as boulder-clay has been derived chiefly from the latter by rain and river action, during the long period of time intervening since the Glacial epoch. Prior to the advent of the great ice-sheet over the whole of Ireland, the rocks exposed at the surface suffered from denudation, as they do at the present time, and, consequently, a fair thickness of disintegrated rock material lay on the surface. The stony portion of this deposit, however, was directly derived from the underlying rock, while the clayey matrix represented a still more comminuted condition of the same rock. On the advance of the ice-sheet, this local detritus was pushed along under the ice, sometimes for a considerable distance. The friction of the stones against the rock-floor, and against one another, smoothed and rounded them, while the smaller pieces were ground down to a fine plastic clay. Some of the stones became embedded in the ice-sheet and were transported slowly in a southerly direction for long distances, and hence, on the disappearance of the ice, we find a number of "erratics," as they are termed, of a totally different kind of rock from that occurring *in situ* in the same district.

This presence of foreign stones or erratics is characteristic of boulder-clay, and differentiates it from other detrital material; but most characteristic of all is the occurrence of sub-angular stones, the surfaces of which are frequently polished and grooved, or exhibit "glacial striations." These latter are caused by relative movement of the stones against one another, while embedded in the moving ice. The striæ produced on the rock-floor by a similar process of value as indicating, more or less approximately, the direction of movement of the ice in that particular locality. This direction is also determinable by examination of the erratics, which may often be definitely referred to their parent source. Thus, over a large part of Cavan, blocks of coal have been found in the drift, and the direction of movement of the ice-sheet over this portion of Ireland is consequently inferred to have been from the N.W., *i.e.*, from the area where coal outcrops around Lough Allen. The boulder-clay, formed under the moving ice-sheet in the manner indicated above, and deposited as it slowly melted away, is sometimes spread in sheets of nearly uniform thickness over large areas, as in the central plain of Ireland; but in many other districts, as at Ballyhaise, it is heaped up into mounds, generally elongated in one direction, with fairly steep slopes and U-shaped valleys between. The exact mode of origin of these mounds, or *Drumlins*,* as they are called, is not clearly understood, though various explanations have been put forward from time to time. It is clear, however, that they do not owe their origin to any known process of denudation, and that they have not been carved out of a thick deposit by the action of rivers or other agents. It is fairly certain that the shape of the drumlins is original, and is connected with the movement of the ice-sheet at the time of its maximum development. The probability is that a certain condition of the rock-floor, such as the presence of hummocks obstructing the sole of the glaciers, has had something to do with the phenomenon, for many of the more typical drumlins have a rock-core masked beneath a mantle of boulder-clay. Their formation would appear also to be connected with divergent movements of the ice-sheet locally, such divergence being primarily due to the presence of rock-obstructions, which led to the accumulation of boulder-clay in certain places. The continued movement of the ice-sheet caused it ultimately to over-ride the mass and give it its present characteristic shape.

* See Maxwell H. Close, "General Glaciation of Ireland." Journ. R. Geol. Soc. Ireland, Vol. i. (1866), p. 212.

The drift deposits dealt with in the following notes cover an area of some $2\frac{1}{2}$ square miles in the immediate vicinity of Ballyhaise House. The ground is undulating or moundy in character, owing to the presence of numerous drumlins rising on an average about 100 ft. above the level of the River Annalee, which winds in S-shaped curves between them.

Quite a small proportion of the area is devoid, or nearly devoid, of drift material, and in such places the rugged nature of the surface topography is in marked contrast with the smooth outlines of the surrounding drift-covered areas.

Comparatively level and flat ground occurs in the vicinity of the river and minor tributary streamlets, and also in some isolated hollows between drumlins, marking the sites of former lakelets that have now been drained. On mapping out the drumlins, it becomes at once apparent that in the great majority of cases the longer axes are all orientated in the same direction, roughly N.N.W. to S.S.E. This direction, as is usually the case, coincides almost exactly with the direction of ice-movement in this district, as evidenced by the ice striæ on the rock in the old quarry in the townland of Lisnashanna, S.E. of Ballyhaise House. At this latter quarry some well-marked striæ may be seen, which run nearly magnetic north and south. A little over a mile W. by S. of Ballyhaise village, some very good striations were noticed, running N.W. and S.E., this direction being also that noted at several localities on the published one-inch map of the Geological Survey, sheet 68.

The drumlins may be divided into two-classes, viz.: those which have a rock core with a boulder-clay covering, and those consisting, as far as direct evidence goes, entirely of boulder-clay. The latter kind are characterised by a uniform more or less convex slope on all sides, while the former, in outline from crest to base, typically show an upper and a lower convex slope, with a concave slope between (Plate I.).

The upper portions of these drumlins appear, therefore, as rather steep-sided ridges, rising from the crests of a larger and usually less steep-sided ones. The best example of this class of drumlin occurs in the townland of Drumaraw, about one-third mile N.E. of Ballyhaise House, the rock constituting the core outcropping in the road-cutting south of Lisnagowan House. The Drumhome drumlin has also an obvious rock-core, which is exposed at its southern extremity, and it is noteworthy that it is the only drumlin in the vicinity of Ballyhaise the longer axis of which apparently does not follow the trend of the other drumlins. This appearance, however, is probably deceptive, for a large proportion of the western side of this drumlin has obviously been eroded away by the river, and no doubt it once was more extensively developed than at present towards the north-west, in which case its major axis would approximate closely to the prevailing direction in the district.

PLATE I.—View of drumlin in Raheg, showing change of slope between the upper and lower portions, with an alluvial flat in the foreground.

PLATE II.—View looking east towards Ballyhaise House, showing contrast between drift-covered area (to the left) and bare ground (to the right).

BOULDER-CLAY.

The boulder-clay itself is of the character usual in this area, consisting almost exclusively of sub-angular pebbles of Silurian sandstones and slates, with very few erratics, embedded in a brownish-yellow stiff clay very retentive of water.

North of Ballyhaise House in the vicinity of Broomfield, and between the latter and Lisnagowan House, the boulder-clay is much redder in colour, and is full of a pink or carmine-coloured micaceous shale or slate, which was seen in situ on the old road running through Carrickmore townland. Pebbles of this rock were also seen in the boulder-clay further south, but were comparatively rare, and were not present in sufficient quantity to modify the colour of the clayey matrix. On the whole, this peculiar red boulder-clay is less stony than the brown boulder-clay, as indeed might be expected, seeing that the red slate pebbles of the former weather down much more rapidly than the harder sandstones and shales of the latter.

The denuding action of rain has also modified slightly the former more or less uniform character of the boulder-clay in certain places. This is naturally best observed in the drumlins, the boulder-clay in the upper portion of some being now much more stony than that of the lower slopes, a result brought about by the gradual transference of the clay downwards and its accumulation on the flanks of the drumlin.

The maximum thickness of the boulder-clay in this district is not directly ascertainable, and not more than a ten-foot section was seen anywhere; but it is highly probable that in some of the drumlins it attains a thickness of not less than 80 feet, and probably more in places. Although "*gravel pits*" are noted on the 6-inch Ordnance maps as occurring within the present area, or its immediate vicinity, no material which could be classed as such was found. In one instance on the south bank of the river, 100 yards or so south of Garden Isle, the material excavated was clearly a much disintegrated rock. At the locality to the south-west and outside the area of the farm, some shallow excavations, now overgrown with grass, are still noticeable. From information supplied by a local resident, sand for building was formerly got here "in small veins," the material being evidently intercalated in boulder-clay, and not of the nature of esker or mound gravels.

LOCAL DRIFT.

Where the rock outcrops at the surface, a modified form of drift occurs. This is mainly "local detritus" containing sharply angular fragments of the underlying rock, along with a more or less small proportion of transported material derived from the boulder-clay. The principal deposit of this drift occurs on the western side of the farm, lying on a steep and formerly wooded slope (Drummully townland) (Plate II.); but the most typical material is to be seen occupying a crescent-shaped area in the large field, half-a-mile due west of Ballyhaise House.

PEAT.

Deposits of peat outcrop at the surface in three or four isolated localities on the farm, and underlie alluvium in certain other areas that are probably equally extensive. The principal area occurs on either side of the townland boundary-line between Annaghduff and Elteen; but most of the material has been cut away, only a few remnants being left that exceed six feet in thickness. Peat has also been cut away at the northern end of Drummully townland, from beneath a thin skin of alluvium, and south-east of Lisnagowan House is a small section in a hollow, showing some three feet of peat underlying one foot of clayey alluvium. Shallow borings in the alluvial flat south of Broomfield show that three or four feet of peat underlie most of the comparatively thin alluvium on both sides of the river.

ALLUVIUM.

The deposits of alluvium are confined to the flat ground bordering the river, and seldom exceed 300 yards from edge to edge. They are of two kinds, viz. a loam and a tenacious clay, the latter predominating in extent. A section across the river at almost any point in the district shows a narrow ridge on both banks appreciably higher than the alluvium further from the river. This ridge, which, at first sight, has the appearance of an artificial embankment made to confine flood-waters, has a fairly uniform width of about 15 yards, though here and there it has been spread out to a considerable extent (see map). It is practically continuous, except in a few localities where it has been cut across by tributary streamlets flowing into the river. It usually slopes off gradually, but occasionally fairly abruptly, on the side furthest from the river, into the clayey alluvium which extends up to the edge of the surrounding boulder-clay. The clayey alluvium forms characteristically wet rush-grown ground, while the alluvial ridge is dry and devoid of rushes. Sections through the alluvium of the ridge in various places show that it consists of a reddish-brown coloured loam, and that it overlies the clayey alluvium.

This ridge of loam evidently owes its accumulation in its present position to former recurrent floods in the river, which, as soon as it overflowed its banks, and the velocity of the current became consequently checked, dropped the heavier sediment, mainly sand, which it could no longer carry in suspension. This sediment thus accumulated near the margin of the river. The clay, however, being lighter, was carried further in and was laid down over a more extensive area, and hence the present difference of level of the two deposits.

The alluvium bordering the river attains its maximum development on the eastern edge of the farm, where it occupies an extensive and low-lying flat, liable even at the present day to be covered with water in times of flood. The general character of this area, as well as the relation of the alluvium to the drumlins of boulder-clay, is well shown in the photograph (Plate III.). The junction-line of the alluvium with the boulder-clay

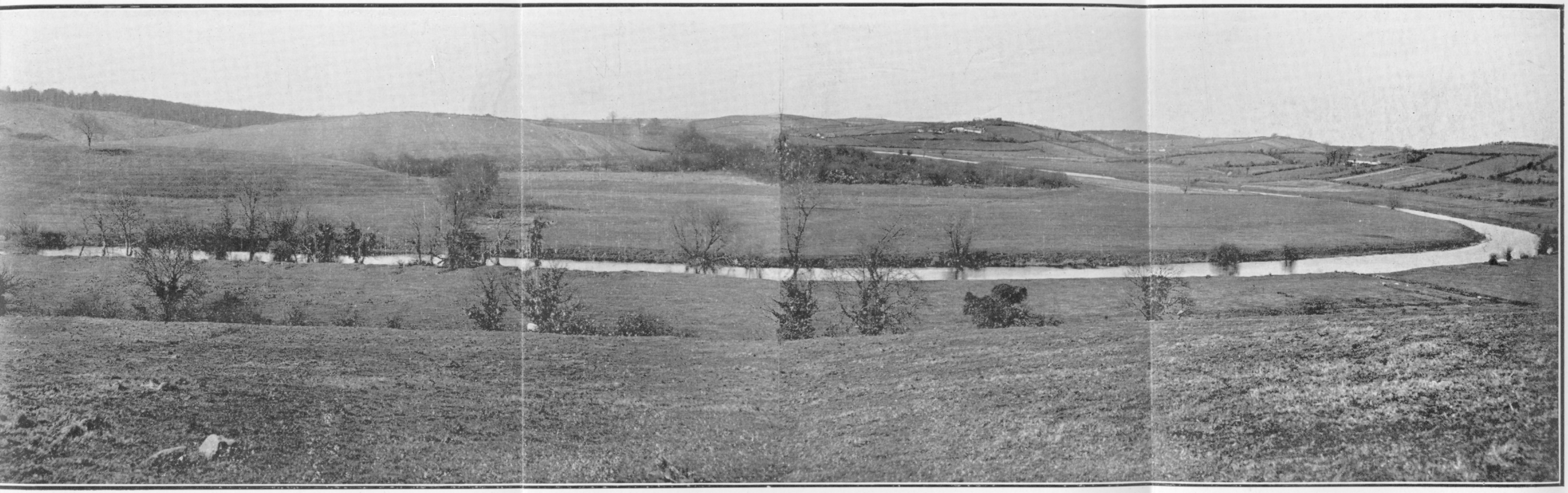


PLATE III.—Panoramic view from the top of the Drumhome drumlin, showing the course of the river Annalee, and the characteristic topography of the district. A drumlin in Annaduff is conspicuous on the left.

is clearly marked in the field, both by the ending off of the rush-grown ground, and also by a slight feature produced by erosion of the boulder-clay by the river, forming a kind of embankment to the spread of alluvium.

Alluvium also occurs in some minor hollows between drumlins, the material being derived from the clay washed down their slopes by rains, during a long period of time, and accumulated at the lowest level.

Among the most recent drifts occurring in this district are the small *delta-fans*, essentially composed of redistributed and washed boulder-clay, eroded by the small streamlets out of their own valleys, and deposited at their junctions with the main valley. These deltas are of very limited extent, and rest on the clayey river-alluvium, forming low mounds with a well-marked scarp at their edges. A rather good example occurs at the northern end of the Drumhome drumlin, and others are noted on the map by an engraved bird sign with Greek delta across it. The small fan at the north end of the Elteen drumlin appears to have been formed by an overflow of water from the peaty area to the west, at a time when the drainage of that area was obstructed on the north, probably in late glacial times. A fan of "hill-wash" occurs to the west of the cross-roads north-east of Ballyhaise House.

The Annalee River for the greater portion of its course in the present district appears to be flowing in a comparatively new channel. In one place it has got down to the rock (south-east of Garden Isle), but has not eroded a channel in it to any marked extent. The course of the river in fact, at least as far as the wooden bridge at the west end of the farm, is almost certainly post-glacial. At the bridge just mentioned, the river-valley is suddenly constricted, and the water flows between steep boulder-clay banks, the bed of the river lying in the same material. On the eastern side of the farm, however, the broad valley in which the river flows suggests that here we have a portion of the original pre-glacial valley, but slightly modified with glacial deposits. The topography here is certainly more "mature" than that in the valley immediately to the west, where the river is now cutting into the rock south-east of Garden Isle.

CHAPTER IV.

GEOLOGICAL ORIGIN OF THE SOILS, AND THEIR REPRESENTATION ON THE MAP.

By J. R. Kilroe.

The latest edition of the Geological Survey one-inch Sheet 68, already referred to (p. 6), represents the glacial and alluvial deposits just described; the former by black stippled dots, within boundaries approximately drawn, over the colour indicating the Ordovician (Lower Silurian) formation, and the alluvial deposits and peat by a light brownish yellow tint. In 1901, in accordance with principles already acted on in England, it was recognized that a more detailed examination and representation of the drift and other superficial accumulations would be advisable, in order to facilitate the advancement of economic interests, especially agricultural, and also from an educational point of view. In pursuance of this object, new maps of several districts have been published since that year, on which the different kinds of superficial coverings are shown, classified according to their nature and origin. On the map of the Dublin district some twelve different classes of soil-forming materials, including shallow local detritus, are represented; on that of Belfast, ten; Cork; ten; Limerick, nine; Londonderry, nine. A still greater number of soil-varieties was noticed during the survey of these deposits; for the mingled materials of the drifts and other deposits have been brought together by geological agencies in such different proportions, that the resulting varieties are in a sense practically infinite. In agriculture, on the other hand, the character of the crops, so far as they are affected by the soil, depends upon certain broad variations, and types of soil have been established in the present memoir on the basis of certain physical characteristics. Their classification will appear in the later portion of this memoir, and will be found in striking accord with one based upon geological differences—differences, in other words, traceable to geological causes.

The writer undertook the classification and description of soils and subsoils for portions of the first four districts mentioned above, but only a limited time was available for the purpose. The results appear in the memoirs accompanying the maps of the various districts. The soils of the Londonderry district received a more systematic examination and fuller description, as appears in the memoir accompanying the map issued in 1909. In the present case, that of the Ballyhaise Agricultural Station, the soils were regarded as of primary importance, and the map accompanying the memoir is a soil-map, rather than one representing the ordinary geology.

It will be observed in the description of the superficial and drift deposits, given in the previous chapter, that they are grouped according to their geological origin under the following names, viz.:—Boulder-clay, Local Drift, Peat, and Alluvium. The map, however, represents nine different types of soil, derived from these deposits. The manner in which the types have been critically fixed appears on pages 26 to 31; but here it may be mentioned that they arrange themselves with a remarkable degree of precision according to the geological divisions established for the drifts. Thus boulder-clay gives us two soil-types; alluvial deposits give four types; "stony soil" on the map corresponds to the scanty covering between crags and bosses in the area represented as practically exposed rock; and the area of soil analytically determined to be "stony loam," and represented as such on the map, coincides with the area occupied by material geologically described as Local Drift. This consists of an admixture of drift and local detritus. Peat, when reclaimed, still appears under the name of peat on the soil map, synonymously with moory soil.

The two kinds of soil formed from boulder-clay are representative of two easily distinguishable kinds of this drift-deposit; so easily distinguishable, indeed, that they might be separated by boundaries in the field, not only on the basis of the different proportions of their stony contents, but by the wetness of the ground (when not artificially drained) that is formed by the less stony variety. Then also the four different kinds of alluvial soils occur under conditions so manifestly distinct that three of them at least might be differently represented within definite boundaries on a soil map. Thus the first, as has been explained on p. 10, forms banks along the river-sides, which are due to the deposition of the coarser material borne along by the river during recurring floods. This material was deposited as the current slackened in spreading inward over the flat land, while the finer matter, carried further, subsided in the still water beyond. In process of time the larger accumulation of coarser material raised the river margin in certain places as much as six feet higher* than the more distant level ground; and a separating line between the two grades of alluvial deposit can without difficulty be traced, and represented on the map. Alluvial deposits between drumlins form a distinct type of soil, and the geological conditions of their origin are accountable for their distinctness. Their materials are more mixed in character than the other alluvial deposits, for they consist of rain-wash carried, from time immemorial, directly from the drumlin slopes. Different layers in this type of alluvium correspond in coarseness to the greater or less erosive power of the different drenchings which they represent. The strong clay type of river-alluvium, as distinguished from the ordinary fine grade river-alluvium, is one revealed by analysis, and not merely by geological observation. On the other hand, deposits which are distinguishable geologically as delta-fans are in virtue of findings in the laboratory grouped under the same soil-type with the coarser river-alluvium.

One or two of these delta-fans are considerably coarser than is usually the case. Attention is directed to this in the detailed description. It may here also be mentioned that the alluvial deposits in several places rest upon the peaty sub-soil or peat. This fact carries the mind back to conditions in which the unevenness of the ground, caused by the deposit of drumlins and other drift-masses as the ice melted away, occasioned hollows where peat accumulated; when the eroding action of the river graded down its bed, the water, having removed numerous impediments, bore along the easily moved drift-materials in the more rapidly descending waters of its frequent floods, and deposited them in its expansions, in swamps, and over peat along its margin.

From the foregoing it will be seen that good geological maps, showing the different classes of soil-forming material, and including the so-called drift deposits, may be made to serve useful

*** As, *e.g.*, near the corner between the wood and the river of Ballyhaise House, as has been ascertained by levelling.**

agricultural purposes. This is especially the case if, as was done in the Londonderry district, types of soil are selected from the different classes of surface-material for examination in the laboratory, the results being ultimately indicated on the map. Detailed descriptions, however, must be reserved for the memoirs accompanying the maps.

A special soil-survey of a limited area, however, leads to greater precision in the establishment of soil-types, and shows the kind of investigation by which the various divisions of a farm may be correctly compared one with another. With this view the survey of the Ballyhaise Station has been carried out.

In the prosecution of this soil-survey, numerous preliminary samples were taken in the field, while the general survey of the ground, with the aid of the Ordnance Survey maps, was being made. These samples were provisionally named during collection, and notes were at the same time made as to the subsoil, depth of the water-table, aspect of the land, etc., some of which appear in Table IV. (p. 44).

In the laboratory, the examination consisted in the separation of the different grades of stones, gravel, sand and smaller particles, which intermingled in each sample, and the estimation of the proportionate quantities of the various grades in each, by methods which are described in Chapter VI. When a sufficient number of samples collected in the first instance had been examined, the soils were classified according to the results of analysis; and the types, roughly fixed upon from general considerations, as previously mentioned, were found to represent with fair precision the average composition of the samples. Inclusive of peat, the soils in all are, as previously stated, of nine types; and, when these were established, boundaries were definitely drawn during a more rigid examination of the farm, delimiting the area or areas occupied by each type. The areas are represented by special colours which are explained in the Index to the map; and, in addition, a system of shading or lettering is adopted which indicates the kind of subsoil. Thus peaty soil over peat is idicated by brown over vertical lines, while peaty soil over a boulder-clay subsoil is shown by the same colour over horizontal lines. Small angular markings, adopted from the maps of the United States Soil Bureau, represent stony soil and subsoil, while the intermingled finer material may be loam (yellowish-brown) or clay (green). The same green is appropriated to less stony boulder-clay soils (with dots), to coarser alluvium (with a bird), and alluvial fans (a bird combined with a Greek delta). When soil rests directly upon Lower Silurian rock it bears the letter *b*, which is used for this rock on the geological maps of the Survey; and when, as in Oakwood, the rock is to be seen at the surface in many places throughout an area, it is indicated by the violet colour appropriated on the Geological Survey maps to the Lower Silurian (Ordovician) system. On the margin of the map are also to be seen typical profiles showing the usual depths of soil and the characters of soil and subsoil. Tables V. and VI. (pp. 46 and 48) show the basis on which the different soil types have been established, and Table II. shows the approximate area occupied by each type.

TABLE II.

APPROXIMATE AREA COVERED BY EACH OF THE NINE SOIL-TYPES.

Type.	N. Side. Acres.	S. Side. Acres.
I. .	0	65
II. .	12	50
III. .	135	240
IV. .	34	87
V. .	32	22
VI. .	3	32
VII. .	23	37
VIII. .	22	0
IX. .	.	52
Totals .	261	585

It will be noticed in glancing over this Table, side by side with the soil-map, that while some 496 acres of the farm are occupied by boulder-clay soils—types III and IV.—127 acres are taken up with rock, local detritus, and stony loams after local drift; and only some 171 acres with four types of alluvial soils. That is to say, boulder-clay soils cover five-ninths of the farm, and alluvium of different kinds covers one-fifth. Nor is this disparity in areas peculiar to the present district. In other districts, for example, those of Dublin, Belfast and Cork, the relative extent of each kind of soil-forming material may be judged from the summarized Table here given, drawn from those prepared by the present writer for portions of those districts selected at random.

TABLE III.

DISTRICT.	Local boulder-clay and rock. Acres.	Boulder-clay. Acres.	Old river and recent alluvium. Acres.	Sand and gravel. Acres.	Intakes and peat. Acres.	Total Area. Acres.
Dublin . .	3,880	15,218	660	776	74	20,608
Belfast .	4,047	15,843	1,667	5,353	91	27,001
Cork .	6,400	5,350	1,575	1,080	245	14,650

CHAPTER V.

THE PURPOSE OF EXPERIMENTAL AND ANALYTICAL DETERMINATIONS.

By J. R. Kilroe.

SOIL-TEXTURE.

The importance of this feature in a description of the soils is well known. It is frequently in practice viewed as the result of mechanical treatment in the way of pulverization or tilth, or as the result of the administration of certain chemical substances causing flocculation of clay particles. The texture is, however, also dependent, perhaps primarily so, upon the proportions in which the fine and coarse components intermingle in a soil. This is the feature of the case with which the present description is chiefly concerned; and, although the ease with which a good tilth is achieved is dependent upon the proportionate occurrence of different grades of material, gravel, sand, etc., the presence of decaying vegetable matter is also of importance in this regard, and requires to be estimated. These circumstances, it is true, may to some extent be judged by the appearance of a soil, and its "feel"; they can, however, be accurately and definitely ascertained only by analysis in the laboratory, which must consequently be the groundwork of just comparisons of one soil with another, and of a true estimate of the physical properties of each. Laboratory determinations have therefore been brought to bear upon the soils collected at Ballyhaise. Those properties which most obviously affect agriculture are their water-holding power, or water-capacity, porosity and air-space, facility for percolation, and capillarity. In addition to these are other considerations of various degrees of importance, already referred to (p. 14) as noted in the field, such as depth of soil, condition and texture of subsoil, depth of the water-table in alluvial soils, surface-slope and aspect.

WATER-CAPACITY.

We may regard stones, gravel, and coarse sand as the earth-skeleton in soils, the interstices of which are filled with finer material, air and water, or, in water-logged soils, water with scarcely any air. Ordinarily, that is, when there are adequate facilities for the passing away of the water by drainage, the amount which the soil is capable of retaining is its water-capacity (sometimes styled "minimum water-capacity"), the moisture in this case forming a thin film, covering each of the particles. It is dependent, therefore, almost entirely upon the aggregate area of their superficies and increases with the number of particles in any given bulk of soil, and, consequently, with their minuteness.

It is obvious that a large proportion of stones, say, material above 1 cm. in diameter, reduces the water-holding power of a soil.

Thus some of the Ballyhaise soils, those derived from local detritus, contain too high a percentage of stones to be good retainers of moisture (e.g., No. 12). The alluvial soils of Ballyhaise, on the contrary, contain, as a rule, a very small percentage of stones; they consist mostly of fine material, and usually have a high water-capacity.

AIR-SPACE.

While the water-capacity is dependent upon the aggregate superficies of the soil-particles, the air-space is synonymous with the aggregate volume of the interstitial spaces. It is obviously somewhat greater in dry than in wet soil, even when the soil is well drained; but as soils are usually moist, the available volume of air space is practically the difference between the absolute interstitial space and that occupied by water in the well-drained soil. The "porosity," or percentage of air-space in air-dried soil, has been ascertained for certain samples, as will appear later in this memoir (p. 35).

PERCOLATION AND NATURAL DRAINAGE.

It is almost needless to point out that the rates of water-percolation, and, indeed, those of the passage of air, through soils are greater in coarse than in fine earths. It may be said that, within certain limits, percolation and the passage of air increase in proportion as the grade of the soil becomes coarser. At first sight one is not prepared to admit how soon percolation practically ceases as the coarser grades diminish in a series of soils; nor, indeed, is it fully realized how readily air passes through coarse sand and gravel, or through soils in a well flocculated condition.

The accompanying diagram (fig. 1), based on results obtained by Wollny,* shows the permeability for water of quartz sand of various grades. The grade in each case is indicated by the numbers at the foot of the columns. The heights of the columns show the volume of water in litres which passes through cylindrical masses of sand, 20 cm. deep by 5 cm. in diameter, in 10 hours under a constant pressure of 10 cm. head of water.

In nature, of course, there is no distinct grouping of soil-grades; and, however much of, let us say, gravel or coarse sand a soil may contain, the interstices may be filled with such fine material that percolation and the passage of the air may be greatly impeded. Thus some of the Ballyhaise boulder-clay soils, though containing so large a proportion of coarse material, are frequently "wet" soils and require draining; while some of the alluvial soils, in which coarse material is almost wanting, are "dry," because they do not contain a large proportion of the finest material.

* "Untersuchungen über die Permeabilität des Bodens für Wasser," Forschungen auf dem Gebiete der Agrikultur-Physik, Vol. XIV.

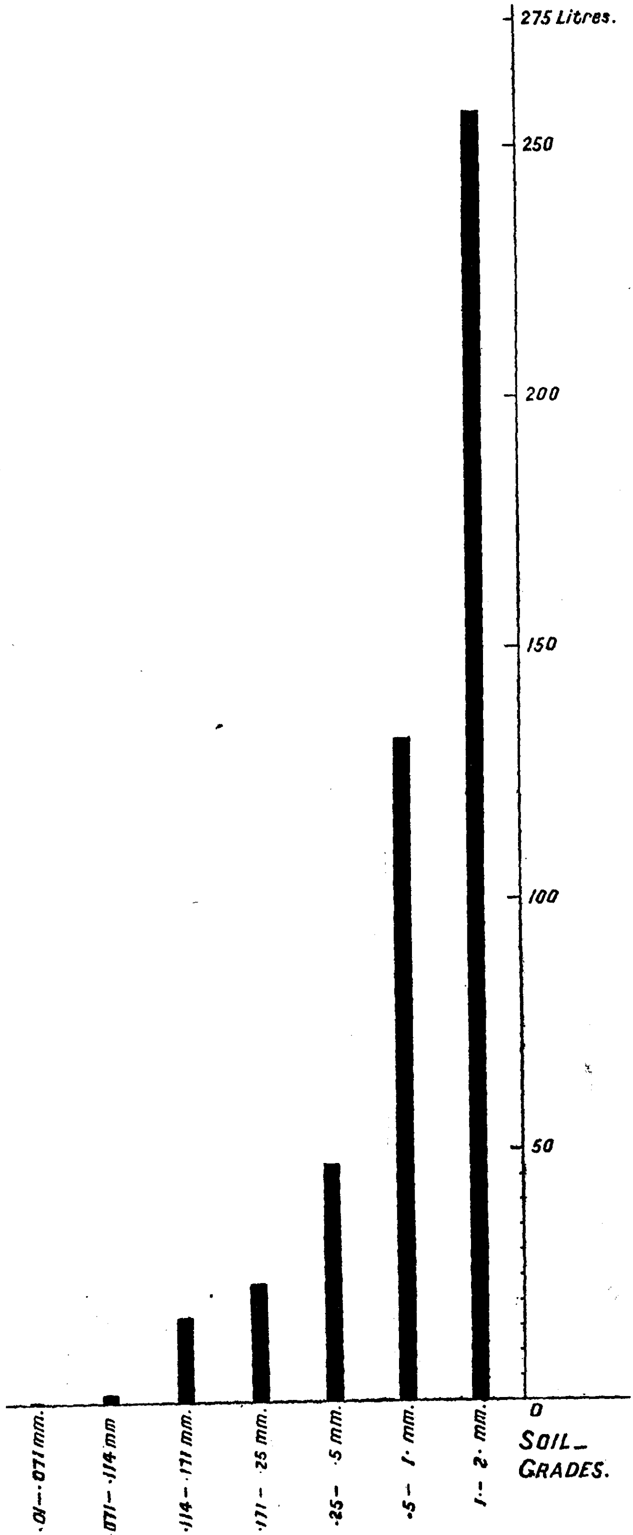

275 Litres.
250
200
150
100
50
0
·01— ·071 mm.
·071— ·114 mm
·114 — ·171 mm.
·171 — ·25 mm.
·25— ·5 mm.
·5 — 1· mm.
1·— 2· mm.
SOIL-
GRADES.

FIG. I.

CAPILLARITY.

It is well known that the height to which water will ultimately ascend in a soil under capillary action, other conditions being equal, is proportionate to the minuteness of the passages along

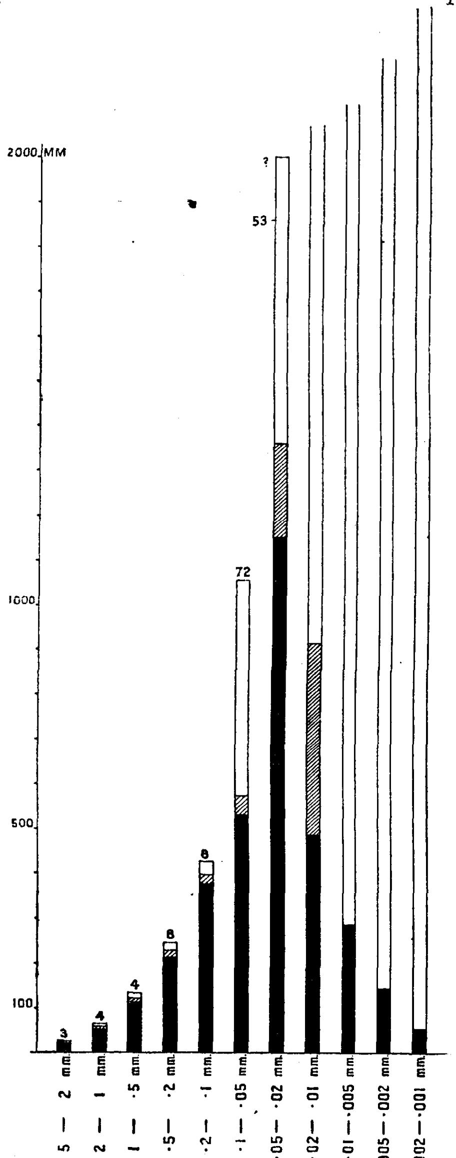


Fig. 2. Columns showing the heights in millimetres to which capillary water will ascend at a temperature of 17°C. in artificially prepared soils formed of quartz-grains of various grades (based on results obtained by Atterberg Kalmar). The black portions of the columns represent the heights reached by water in 24 hours; the black and shaded portions together represent the heights reached in 48 hours; and the completed columns indicate the total heights at which the upward capillary water-movement ceased. The time in days when this occurred is shown by the numbers on the columns.

which the liquid moves; or, in the case of soils, in proportion to the minuteness of the interstitial spaces, which in a soil is dependent, as already remarked, upon the sizes of the particles. To illustrate this, a diagram is here shown (fig. 2), prepared from the results of experiments on capillarity published by Dr. Atterberg of Kalmar.* Different grades of material were taken, and placed in tubes, the lower extremities of which, containing the earths, were immersed in water. The rise of moisture in each was noted in 24 hours, 48 hours, and several days, for each grade of material, and the readings were tabulated. It was found that in an earth in which the particles were from 5 to 2 mm. in diameter there is practically no capillarity; while in one in which they were from .05 to .02 mm., capillarity produces the greatest rise in each of the times mentioned; the rises for 24 hours, 48 hours, and 53 days were 1,153 mm., 1,360 mm., and 1,860 mm., respectively. In the grades between 2 mm. and .02 mm. the rate of rise increased for each of the six grades taken; and in the four finer grades from .02 downward it, on the other hand, declined, the rise ceasing or almost ceasing in the finest clays during the period of observation. This, however, is but the expression of the fact that the rise in the finest material is exceedingly slow; for, when experiments on capillarity are continued, the ultimate amount of rise in this material is found to be very great. In the circumstances presented in practice, those with which we are most familiar, and which most affect agricultural issues, the ultimate rise of the water is not of such importance as the rate at which it rises; for here we are concerned with the transference of nutrient-charged moisture from place to place in the soil, from sources of supply to those of demand by plant-roots; and, in nature we have to do with earths which practically are mixtures of all the grades together with gravel and stones. In these circumstances it is obvious that the more of a grade approximating to the grade .05 to .02 mm. in diameter which the soil may contain, the more beneficial will be its capillary effect; and where the interstices of the earth-skeleton are filled by materials of the finest grades, these will retard the upward movement of the water in proportion to their fineness, other conditions remaining equal (see also p. 36).

A series of experiments has been made with the Ballyhaise soils, and the results of these will be given in Chapter VI.; but it will assist the reader to perceive how the capillarity of earths is affected by certain proportions of sand, gravel, and humus, if the following results of previous experiments, carried out in the Survey laboratory,† are quoted here:—

1. The addition of 20 per cent. of sand of 2 mm. to 1 mm. grades to "fine earth" made scarcely any perceptible difference in its capillarity; although the addition of 10 per cent. of gravel of 3 mm. to 2 mm. grade perceptibly lowered the capillarity.

* "Die rationelle Klassifikation des Sande und Kiese" (*Chemiker Zeitung*, 1905. Bd. 29, No. 15). The present diagram may be taken as replacing that drawn up on a somewhat different plan in the Memoir accompanying the Drift Map of the Limerick District, p. 100.

† Memoir on the Geology of the County around Londonderry (1908).

2. Soils consisting of composite earth particles, 3 mm. to 2 mm., from which all finer matter had been sifted, possessed very weak capillarity, showing about one-third of that manifested by the same material treated as in (3) following.

3. The composite earth-particles similar to those in (2), reduced by gentle crushing to a finely divided state, graded from 1 mm. diameter downward, gave the best results, showing the practical utility of fine pulverization to secure good capillarity.

4. Ordinary "fine earth" grading from 2 mm. downward shows an intermediate degree of capillarity, approximating, however, more nearly to the lower degree of capillarity of (2), than to the higher of (3).

5. A soil artificially prepared with equal parts of 3 mm. to 2 mm., and of 1 mm. downward, gives results almost exactly intermediate between (2) and (3).

6. An earth consisting of composite particles of 2 mm. to 1 mm. in diameter, possesses a capillary power one-third higher than (2).

7. Humous matter in soils obstructs capillarity. A humous soil containing 15 per cent of organic matter was tested before and after ignition, and the capillary power was found in the latter case to be three times that in the former.

In judging of the comparative capillarity of the soils, therefore, from the diagrams hereafter given, account must be taken of the amounts and probable effects of the organic matter which they contain.

SOIL-TEMPERATURE AND ASPECT.

Of the many properties, conditions and circumstances which conjointly account for a soil's productiveness, not the least important is that of temperature; and this in itself is dependent upon several considerations. The most obvious is the heating effect of the sun's rays, which varies with the seasons and aspect. These are elements in the case which will presently be considered. Meantime, other considerations of comparatively minor importance must be mentioned. A first consideration is the specific heat of dry soil—the quantity of heat required to raise it 1° C. in temperature, as compared with that required to raise the same weight of water 1° C. in temperature. A second consideration is the conductive power of dry earth, which carries the surface heat, derived from the sun, downward; and a third is the heating effect due to the decay of vegetable matter residing in the soil. Against these circumstances, productive of soil-heat, must be mentioned the cooling effect due to the evaporation of soil-moisture. A soil greatly charged with water can obtain little benefit from the sun's rays; and the first and second considerations, above mentioned, are ordinarily greatly modified, when we consider the opposing condition of abundant soil-moisture to be removed by evaporation. A fourth consideration is the colour of the soil, since dark soils become raised in temperature more rapidly than light coloured ones on exposure to the sun's rays.

Aspect.

In considering the heating power of the sun's rays, the question of aspect comes particularly into view where the surface is so highly undulating as it is at Ballyhaise. Here a northern slope of more than 12° to the horizontal receives none of the sun's rays in midwinter; that of more than 36° receives none at the equinoxes. Southern slopes, as is well known, are favoured with much sunshine and warmth; the extent to which a slope, say of 15 degrees is favoured in winter, spring, and midsummer may be judged from the diagrams in figure 3. It may here be mentioned that, while easterly and westerly slopes receive equal amounts of sunshine and heat, the former are less favourably situated than the latter; for there tender vegetation, when frozen during the night in early spring, becomes thawed too quickly by the early sunshine, with injury to the tissues. On the south-easterly, southerly, and westerly slopes thaws take place much more gradually, with less danger to vegetation.

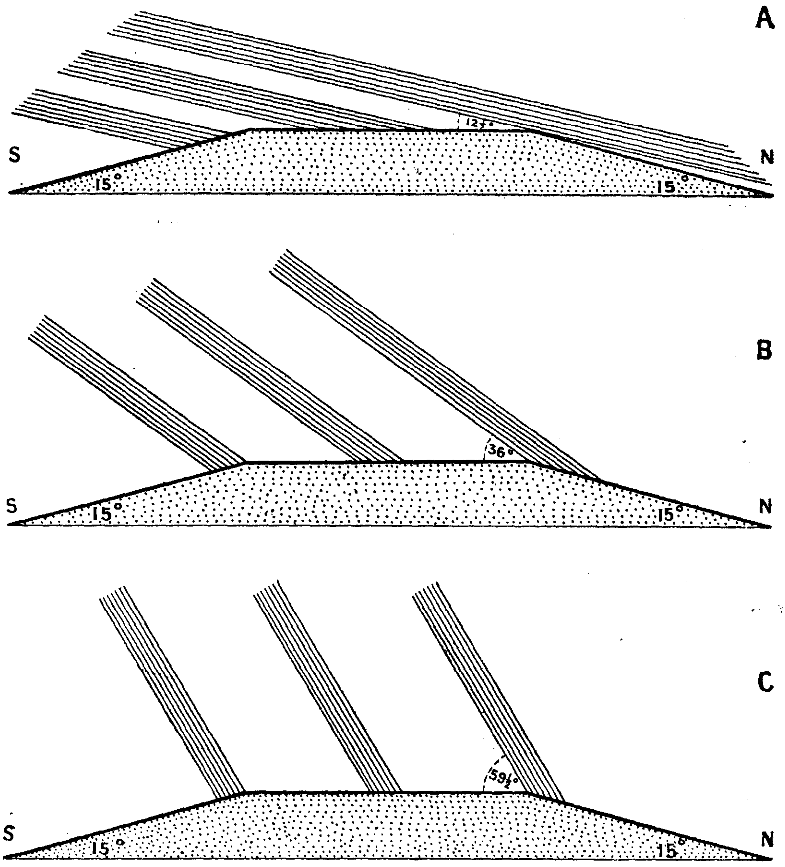


Fig. 3. Distribution of solar rays on level and sloping surfaces at the latitude of Ballyhaise in mid-winter (A), at the equinoxes (B), and in mid-summer (C).

The altitude of the sun at noon for any period of the year may be obtained from the following easily proved statement:—

Altitude = co-latitude $\mp$ declination.

The latitude of Ballyhaise is 54° 3'.; the co-latitude (or difference between the latitude and 90°) is therefore approximately 36°. The declination of the sun is:—

In Midwinter, $23\frac{1}{2}$° S.

At the Spring and Autumn equinoxes, 0°.

In Midsummer, $23\frac{1}{2}$° N.

Hence the altitude at noon in midwinter is $12\frac{1}{2}$°; at the Spring and Autumn equinoxes, 36°; and in midsummer, $59\frac{1}{2}$°. In reading the diagrams (fig. 3) it must be remembered that the heating effect of the beam is inversely proportional to the *space* heated. The diagrams show level ground and northerly and southerly slopes of 15° from the horizontal.

CHEMICAL OBSERVATIONS.

Partial analyses have been made of some of the Ballyhaise soils, and the results are hereafter given, showing the comparative abundance or deficiency of the chief mineral constituents—viewed from the agricultural standpoint. It is well recognised that potash and phosphoric acid exist in soils in available forms for plants; and, this being so, it is obvious that, in economic agriculture, account should be taken of the proportions present that are thus available. This matter is more fully dealt with in pp. 39-42.

Hilgard has called attention to the fact that, when a large proportion of carbonate of lime is present, lower percentages of phosphoric acid and potash are adequate. The same remark applies in the case of nitrogen.

CHAPTER VI.

PHYSICAL AND CHEMICAL CHARACTERS OF THE SOILS OF BALLYHAISE.

By T. Hallissy.

INTRODUCTION.

As is now well known, the physical characters of the soil are of far greater agricultural importance than either its chemical or biological aspects. The ease or difficulty with which a soil can be cultivated, its power of holding water and distributing it according to the needs of the growing crop, its ventilation and, indirectly, its temperature, are all mainly dependent on its physical constitution. The practical agriculturist, indeed, seems to have always regarded the coarseness or fineness of texture as the main factor which regulated the cropping capabilities of the land, so that soils have been described and classified according to their texture into clays, loams, clay-loams, &c., rather than with regard to the chemical ingredients which they contained.

The importance of the physics of the soil came to be recognised by the scientific world early in the last century. Schübler, who appears to have been the first to deal with the subject on a really scientific basis, devotes a good deal of attention to it in his "Grundsätze der Agrikultur-Chemie," which he published in 1830. Since that time, chiefly on the Continent and in America, a very large amount of work has been done in this particular field of inquiry, and quite a voluminous literature has grown up around the subject. Several Geological Surveys now undertake the description of the soils of the districts with which they deal, and record on their published maps information of considerable agricultural value.

Having regard to the dominating importance, in practical agriculture, of the physical constitution of the land, the soils of the Ballyhaise district have been mapped on the basis of their texture as determined by mechanical analysis. Some sixty-one samples of the soil were collected over the ground to be surveyed, and such of them as appeared to be necessary for the description of every variety of soil occurring within the area were submitted to a detailed examination.

SOIL-SAMPLING.

It has been found desirable for the preparation of the map to take "individual" samples, each representative of one particular spot of the ground surveyed, rather than composite ones representative of greater areas. This plan has the great advantage that it admits of the taking of a definite volume of the soil just as it exists under field conditions, furnishing us with data from which, with the real specific gravity of the sample, the actual pore-space may be determined.

A rigid steel-box, $20 \times 10 \times 10$ centimetres, having a capacity of exactly two litres, has been used for collecting the samples (fig. 4). This box has two of its opposite 20×10 cm. sides open, but furnished with suitable lids, and the rims of one of the open sides are made chisel-shaped, so that the box may be easily driven into the soil.* To take a sample a square hole is dug into the ground with a sharp spade, and one of its sides is cut so as to present a smooth perpendicular face. A large block of the soil behind that face is then loosened, lifted bodily out of the hole, and laid flat on the ground with the smooth face upwards. The box, from which the lids have been removed, is now driven with a hammer into this soil-mass, so that a sample representative

* Compare G. Cole, "Aids in Practical Geology," ed. 5, 1906, p. 10; and A. D. Hall, "The Soil," edition of 1904, p. 45.

of the upper two decimetres (practically 8 inches) of soil is secured. The material projecting over the edges of the box is cut off, the lids are replaced, and the contents are finally transferred to a suitable linen bag for conveyance to the laboratory for examination. Samples of the sub-soil may be taken at any

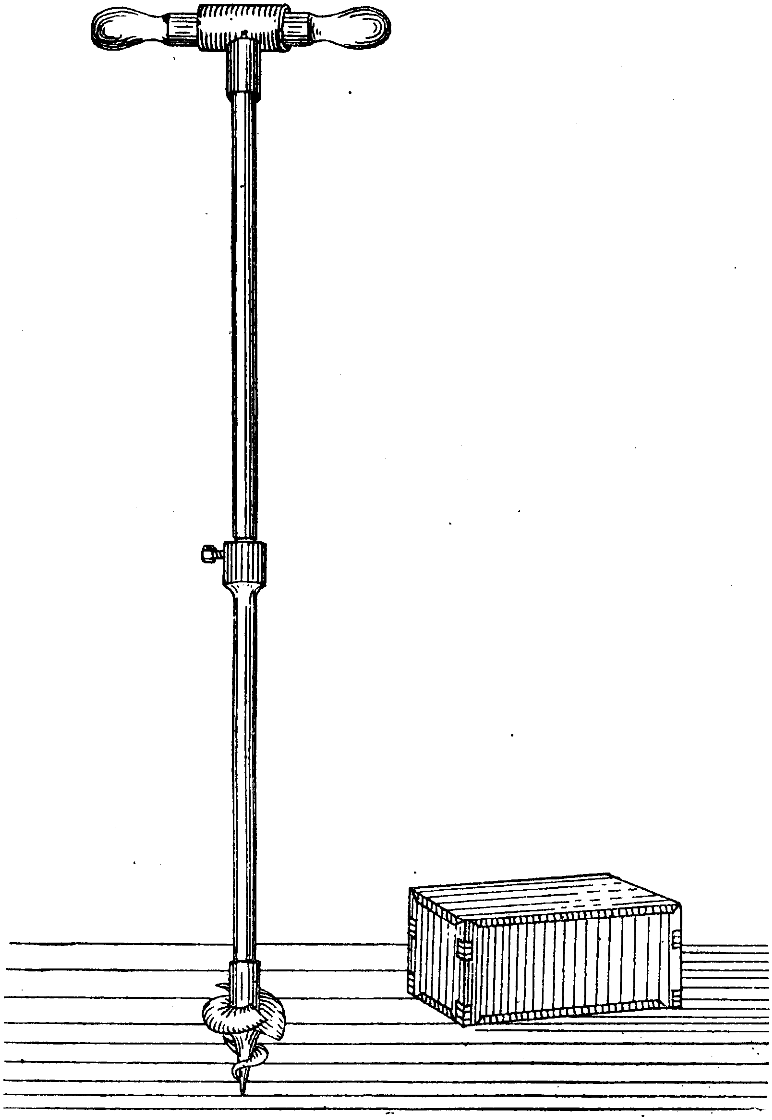


Fig. 4. Soil-sampling box and soil-auger.

depth up to one metre, provided that the soil is not very stony, by means of a soil-auger of the type shown in fig 4. It is remarkable how a simple auger of this type will bring up a core of material unmixed with that of upper layers. The core forms a cylindrical block resting on the blades of the screw.

MECHANICAL ANALYSIS.

The results of a mechanical analysis enable us to form a fair estimate of the texture of a given soil, but it must be remembered that its physical constitution is considerably affected by the presence of large quantities of such substances as humus, carbonate of lime, or oxide of iron, while temporary alterations in structure arise from the formation of aggregates or "crumbs" due to cultural treatment or to various other causes. It is difficult, therefore, to anticipate the behaviour of a soil from its mechanical analysis alone, although certain very important properties, such as resistance to tillage, water-capacity, porosity, and capillarity are closely connected with the physical dimensions of the soil-grains.

Since soil-particles exist of all conceivable sizes and shapes, it has been found necessary for the purposes of analysis to divide them into groups or grades, each grade consisting of grains lying between certain fixed and more or less arbitrary limits. The grades employed for the purposes of the Ballyhaise map will be found on p. 48 of this memoir, the results on pp. 45 to 47.

As the aim of a mechanical analysis is to estimate the natural fundamental texture of the soil apart from the temporary conditions of aggregation arising from tillage, manuring, or other influences, it is necessary to employ some means of reducing the crumbs not held together by a permanent cement to their ultimate single-grained structural condition. The usual methods adopted for this purpose are boiling, pestling, shaking, chemical treatment, or a combination of two or more of these devices. In the preparation of the material for analysis in the laboratory the method adopted at Rothamsted was followed in this instance, and the "fine-earth" (*i.e.*, the portion of the soil that has passed a 2 mm. sieve) was first treated with a dilute solution of hydrochloric acid. This treatment has the effect of dissolving away any cementing carbonate of lime that may be present in the soil; it also breaks up the calcium humate, which likewise helps to maintain a composite structure of the soil-grains. After having been washed free from acid, the soil is boiled, then cooled, and finally ammonia is added with the object of dissolving away the humic substances set free by the acid treatment, and of completing the work of deflocculation (see p. 27, and also note on p. 29 as to treatment of soils containing much calcium carbonate).

The actual separation of the soil into grades is made by the process of sifting in the case of the coarser fractions, and by the beaker or sedimentation method, in the case of the fractions too fine in texture to be separated by sieves.

PRELIMINARY TREATMENT OF THE SOIL AND METHOD OF ANALYSIS.

The soil which has been collected, as above described, is spread out in a shallow dish and allowed to dry at the laboratory temperature. When completely air-dried it is weighed, and one-half its weight is recorded as volume-weight, *i.e.*, the weight, when air-dried, of one litre of the soil collected under field conditions. Portion of this air-dried material is preserved in a suitable sample-bottle, and is labelled and stored for future reference. The remainder of the sample is sifted through a sieve with circular holes one centimetre in diameter. The portion that does not pass through at first is worked up gently with a wooden pestle in a mortar of similar material and again sifted. The stones and coarser vegetable fragments, &c., are thus freed from practically all adherent finer particles. In a similar manner the portion that passes the 1 cm. sieve is sifted through one having circular holes of 2 mm. diameter, and the residue is pestled and re-sifted as before. This process of sifting divides the soil into three portions, each of which is weighed and its weight calculated as a percentage of the whole air-dried soil. The results are recorded as follows:—

Above 1 cm. diameter, ...	...	— per cent.
From 1 cm.—2 cm., ...	...	— ,, ,,
,, 2 mm.—.000 mm.	...	— ,, ,,
		100.

The nature of the stones is determined in the first two grades.

DETAILED ANALYSIS OF THE FINE-EARTH.

The third portion, called the fine earth, is submitted to a detailed mechanical analysis based on the method adopted by Mr. A. D. Hall, F.R.S. The procedure is as follows:—

(1.) 10 grammes of the air-dried fine-earth are weighed out, introduced into a porcelain basin, and treated with excess of N/5 hydrochloric acid for an hour, during which the soil is worked up from time to time with a rubber pestle.

(2.) At the end of an hour the contents of the basin are poured on to a filter and washed free from acid, after which the filter is perforated with a glass rod and the soil washed through with distilled water into a round-bottomed flask of about one litre capacity. The flask is filled about two-thirds full of water and boiled for an hour; it is then cooled and ammonia is added; after being well shaken up, its contents are transferred to a tall glass cylinder with a mark at a height of 15 cm. from the bottom.

(3.) Water is added to the material in the cylinder so as to bring it up to the 15 cm. mark; the contents are then stirred up with a glass rod, and allowed to stand for 24 hours, after which the liquid overlying the sediment is siphoned off. A few drops of ammonia are now added to the precipitate remaining behind in the glass vessel, the material is pestled with a rubber pestle, and water is again added up to the 15 cm. mark. The contents are then allowed to stand for 24 hours as before, the liquid is siphoned off, and these operations are repeated until the liquid comes away quite clear. The separation usually requires from 6-15 decantations, according to the nature of the soil. The liquid siphoned off contains the soluble humus of the soil and all the soil-particles of less than .005 mm. diameter.

(4.) The residue from (3) is transferred to a beaker 10 cm. in height with a mark 7.5 cm. from the bottom. A few drops of ammonia are added, the material is well pestled, and water is added until it reaches the mark. After the contents are well stirred up with a glass rod and allowed to stand for 12½ minutes, the liquid is decanted, and these operations are repeated, until after standing for 12½ minutes there are no longer any particles held in suspension. To complete this separation, from 15-45 decantations are necessary. The decanted liquid contains all the soil-particles between .005 and .01 mm. diameter.

(5.) The sediment left after the last operation is again transferred to the tall cylinder and water is added up to the 15 cm. mark; the material is then well stirred, allowed to settle for 30 seconds, and decanted. This is repeated as often as is necessary, when it will be found that the decanted liquid contains all the particles lying between .1 mm. and .01 mm. diameter.

(6.) The residue from (5) is dried on a water-bath and separated into two grades by means of a 1 mm. sieve. The particles that remain on the sieve constitute the fraction 2-1 mm. diameter, while those that pass through are the grade 1-.1 mm. diameter.

The water in which the soil-particles are suspended is removed in the case of the clayey .005-.000 mm. fraction by evaporation down to dryness on a water-bath, and in all other cases by allowing the particles to subside, and then decanting or siphoning off the water when quite clear. All the fractions are finally dried on a water-bath, *ignited* and weighed. The filter used in (2) is ignited and weighed in along with the fraction .005-.000 mm., and the weight of its ash is deducted.

(7.) To determine the hygroscopic moisture of the soil, 5 grammes of the air-dried fine-earth are weighed out into a small tared dish, and dried in a water-oven at 100° C. for 8 hours, then cooled in a desiccator and weighed. The weighing should be done as rapidly as possible, so as to avoid error from reabsorption of moisture. After weighing, the soil is put back again into the oven, and weighed at intervals of an hour until nearly constant. The loss of weight will represent the hygroscopic moisture.

(8.) To determine loss on ignition, the dry soil used in the hygroscopic moisture determination is ignited in a muffle furnace until all the carbon present disappears. When the ignition is completed, the soil is cooled in a desiccator and weighed. The loss of weight of the dry soil is recorded as loss on ignition.

NOTE.—In soils containing much carbonate of lime, the acid treatment is omitted, and the carbon dioxide driven off by ignition is restored by moistening each fraction with a saturated solution of ammonium carbonate, and then driving off excess of that reagent by heating for about a minute at a dull red heat.

STATEMENT OF RESULTS.

Fraction 2-1 mm.	...	...	—	per cent.
„ 1-.1 mm.	...	...	—	„ „
„ .1-.01 mm.	...	...	—	„ „
„ .01-.005 mm.	...	...	—	„ „
„ .005-.000 mm.	...	...	—	„ „
Hygroscopic Moisture	...	...	—	„ „
Loss on Ignition	...	...	—	„ „

These should add up to a total of approximately 100.00.

INTERPRETATION OF THE RESULTS OF A MECHANICAL ANALYSIS.

The proportion of coarse material (larger than 2 mm. diameter) appears to have an important bearing on the drainage of a soil. On the drumlin boulder-clays of the Ballyhaise area, the fine-earths of which are of an exactly similar nature, the soils of Type III. (see Table IV., p. 44), having over 20% of stones, are consistently well-drained, while those of Type IV., with a smaller stone-content, give evidence in the field of a bad or indifferent natural drainage. The moisture-conditions of a soil are also considerably influenced by the stones which are to be found in its surface-layer, as in this position they tend to conserve the soil-water by checking evaporation. The exhaustive researches of Wollny* throw further light on the influence of stones on the fertility of the land. From his findings it would appear that the mean temperature of a soil increases with its stone-content, while at the same time—and this is an important point—the *variations* of temperature are the more pronounced the greater the percentage of stones. Wollny also shows that the cropping capabilities of the land increase with the proportion of stones up to a maximum which corresponds with a stone content of about 10-20% by volume, after which there is a gradual falling off in fertility.

Apart from these considerations, the material coarser than 2 mm. plays no essential part in the economy of the soil. It represents the least weathered of the soil-constituents, and therefore contributes but an insignificant part of the food materials available for crops. Its capillarity is almost nil, and the total surface which this grade exposes for the holding of water and the providing of a feeding ground for plants is so small in proportion to its mass that it may be left out of account in any further analysis of a sample.

* "Einfluss der Steine auf die Fruchtbarkeit des Bodens," Forschungen auf dem Gebeite der Agrikultur-Physik Vol. xx.

The importance of the fine-earth, however, demands a detailed examination, including as it does almost all the available food-materials possessed by the soil. The power of holding water, which depends mainly on the total surface of the soil-particles, and not on their mineralogical character, becomes appreciable in grains as large as 2 mm. diameter, and increases through all the grades downwards until it reaches its maximum in the .005-.000 mm. fraction. The possession of capillary power may also be said to begin with particles of 2 mm. diameter, and increases in like manner through all the grades downwards to the lowest grade, where its maximum is attained. But as plants require a large supply of water for the purposes of growth, and want it quickly and continuously, the rate of capillary water-movement in the soil becomes of far more practical importance than the total height to which capillary water will eventually attain.

The particles which are capable of the highest capillary rate of water-movement are, of course, the most efficient for restoring in the soil the moisture equilibrium, which is being constantly disturbed in the neighbourhood of the roots of growing plants.

A reference to the columns in Fig. 2 will show that grains of about .05-.02 mm. diameter possess this important property in the greatest degree. As these are included in the grade .1-.01 mm., it is fairly safe to assume that, other things being equal, a soil possessing a high percentage of this grade will display a high rate of capillarity, and should suit a plant of scanty root-development, unable of itself to exploit the soil thoroughly for its water and mineral food-supplies.

The grades below .01 mm. diameter impart most of the clayey characters to a soil, making it retentive, sticky and difficult to work, while the grades between 2 and .1 mm. diameter have a loosening effect and favour percolation or drainage. Of the remaining soil-fractions, the amount of hygroscopic moisture is of no practical account, but the proportion of humus, as roughly indicated by the loss on ignition, exercises a marked influence on the character of the soil by increasing its water-capacity and specific heat, and by retarding the movements of the soil-water.

ESTABLISHMENT OF SOIL-TYPES.

For the determination of the different varieties of soil occurring within the area of the map, the results of the analysis of thirty-five samples, as given in Table V., were taken as the basis for classification. On referring to this table it will be seen at once that several of the soils differ widely in their textural nature, while others give evidence of a close resemblance. But, although no two soils give absolutely similar analyses, it is possible to divide them into groups the members of each of which bear a family likeness to one another. It is evident, in fact, that almost every soil examined, considered with regard to the physical dimensions of its constituent grains, shows an analysis approximating to some one of the eight type-analysis given in Table V., p. 48, so that if peat be included, all the soils of the area studied may be considered as belonging to one or other of nine distinct varieties. These type-analyses do not represent the actual analyses of any of the soils examined, but a sort of average arrived at by an inspection of the results presented in Tables IV. and V.

From these type-analyses the soils have been named, having regard only to the proportion of material below .01 mm. diameter, the amount of ignitable matter, and the proportion of stones (larger than 2 mm. diam.) which they contain. A system of nomenclature on such a basis is necessarily imperfect, but it serves fairly well for the translation of the analytical results into the popular language of the farmer. The names corresponding to the different percentages of fine material are given as follows:—

Name.	Percentage of Material below .01mm. in the fine-earths.
Sand	less than 10 per cent.
Sand approaching sandy-loam	10 to 20 ,,
Sandy-loam	20 to 25 ,,
Sandy-loam approaching loam	25 to 30 ,,
Loam	30 to 35 ,,
Loam approaching clay-loam	35 to 40 ,,
Clay-loam	40 to 45 ,,
Clay-loam approaching clay	45 to 50 ,,
Clay	above 50 ,,

If the fine-earth shows a loss of 15 per cent. or more on ignition, the soil is described as humous clay, humous clay-loam, &c., as the case may be; if it contains 5 per cent. or more of carbonate of lime, the soil is considered calcareous; and if the whole natural air-dried earth possesses 20 per cent. or more of stones the soil is regarded as stony.

MAPPING.

Having established the soil-types by grouping the results of analysis as above described, it now remained to distinguish on the field the boundaries of the soils represented by each type. To accomplish this, borings were made, by means of the soil-auger shown in Fig. 4, at frequent intervals over the ground, and the soil-textures were noted and differentiated according to the judgment of the surveyor. In drawing these boundaries, valuable help was obtained by noting the character of the natural vegetation which the soils supported, and which was usually found to vary as the soils varied. A study of the surface-features of the ground also helped materially towards accomplishing the end in view; it is a safe rule for the surveyor to suspect a change of soil wherever there is a change of slope.* Finally, as has already been mentioned on p. 12, a striking agreement has been found to exist between the drift and soil boundaries, so that, as the survey proceeded, it became evident that assistance of a very material kind was to be obtained from the drift map of the district.

* On the map, in the west of Townparks townland, boundaries have been drawn within an area shown by the colouring as occupied by a uniform soil-type. In this case the boundary marks a distinct change of slope, which in other areas is accompanied by a change of soil-type.

As may be conjectured, no sharp boundary-lines separate one soil-type from another in the field, and this is particularly true of steeply sloping ground. A soil-boundary is really not a line but a zone, which has been produced by the intermingling of the materials from the adjoining soils. The extent of these boundary-zones depends mainly on the features of the ground. In a very level area they may be very narrow bands approximating to lines, but on uneven ground they broaden out into wide belts of an extent depending on the steepness of slope of the ground which the soil at the higher level occupies. A boundary-zone is indicated on the map by extending half-way across the zone the colours representing the soils which contribute to its formation.

It has been stated above that nearly all the soils examined conform to one or other of the nine types already mentioned. There are a few exceptions. Soil 9 has been collected on a very narrow boundary-zone, not represented on the map, and is a mixture of Types III. and V. with an addition of a certain amount of peat from the remains of the peaty deposit which once extended across the hollow of the field from which this sample was taken. This sample, like all samples from a boundary-zone, only represents the soil of the spot on which it was collected.

Soil 50 and a good deal of the eastern side of the swampy flat at the south-eastern corner of the estate have been considerably modified by peaty material washed in probably from an alluvial hollow lying a little to the north.

Soil 55, although its fine earth conforms to the loamy alluvium represented by Type VI., contains a high proportion of stones, which occur mainly as a pavement between the soil and subsoil. These stones were washed in from the rocky ground lying immediately to the south-west, at one stage of the existence of the ancient stream which produced the fan on which the sample has been collected.

SUBSOILS.

The soils of the drumlins, which occupy the great bulk of the area represented on the map, all rest on subsoils which are very typical of the boulder-clays of the district. These subsoils are composed of the same sort of material as the soils they underlie, but are much lighter in colour, having a light greenish-yellow tint from the presence of iron compounds in an incompletely oxidised condition. They lie at depths varying from about seven inches on the top of a drumlin to about sixteen inches on the lower slopes.

The soils of the great alluvial flats on either side of the river all overlie a subsoil of peat. At the point where Soil 60 was taken the peat is found at a depth of one foot, in the neighbourhood of Soil 10 it occurs at a depth of eighteen inches, while in that of Soil 5 it lies at a depth of three feet. On the opposite side of the river, the peaty subsoil of Soil 33 occurs within eighteen inches of the surface, and in the low-level alluvium to the west of Drumhome at a depth of two feet.

The subsoil of No. 49 is somewhat exceptional, as it consists of gravelly material two feet from the surface.

With the exception of the bank of higher alluvium which skirts the river, the immediate subsoils of all these alluvial flats are light-coloured retentive clays containing no coarse materials of any kind; but their poor natural drainage is due as much to the proximity of the permanent water-level as to the texture of the soils themselves. The water-table of the swampy ground by the river on the eastern side of the estate is practically at the surface. On the flats in the neighbourhood of Soils 56 and 5 it lies about two feet from the surface, while at the site of sample 33 it occurs at a depth of eighteen inches.

The subsoils of the type which occurs mainly in the alluvial hollows between the drumlins are commonly light-coloured clays, and lie at depths varying from $2\frac{1}{2}$ feet at the hollow on the most southern extremity of the map to $1\frac{1}{2}$ feet in the hollow north of the road near No. 29, and to nine inches in the hollow lying south-east of No. 22.

The subsoil of No. 20 is also exceptional; it consists of a rather coarse clean gravel at a depth of two feet.

All the soils coloured yellowish brown on the map either rest directly on the solid rock lying a few inches below the surface, or may have intervening between them and the solid rock from a few inches upwards of a yellow ferruginous stony subsoil.

SPECIFIC GRAVITY.

The true specific gravity of a soil is of practical interest chiefly because it furnishes one of the data necessary for the calculation of the amount of porosity, or interspace that exists between the soil-particles which is available for the accommodation of air and water. It is commonly determined on the fine earth of the sample, but it is evident that the results obtained from this method cannot give a true idea of the conditions as they obtain in the field. Accordingly, in this Survey, following the method previously adopted in the Royal College of Science for Ireland, the estimation is made on the air-dried natural soil, and the apparatus used for this determination, shown in Fig 5, is that employed in the Geological Laboratory of the College.

The apparatus consists of a large bottle B, provided with a doubly perforated rubber stopper through which pass two glass tubes, as shown in the figure; one is connected, by means of rubber tubing, with the end of tube **a**, and the other dips into the vessel C, which is provided with a tap. D is a mercury pressure-guage, and A is an aspirator.

To determine the specific gravity of a soil, two litres of water are filled into B, and a mark is placed on the bottle at the surface-level of the water. The bottle is then emptied, and a quantity of soil is accurately weighed out, approximating to, or equal to, that which occupied a litre in the field-condition. This is placed in the bottle, and two litres of water are filled into C, and the connections are made as in the figure. The air is now exhausted from B by means of the aspirator, and, when the exhaustion is as nearly complete as can be accomplished, the pinchcock **d** is opened, and the water allowed to flow into the vessel B, until the two-litre mark is reached. The water remaining behind in the glass vessel C is now drawn off into a graduated cylinder and measured; its volume will be equal to the volume of the soil which had been used in the determination. From these data the specific gravity is calculated in the usual way. In Table VII. will be found the real specific gravities, as determined by the method above described, of six typical soils

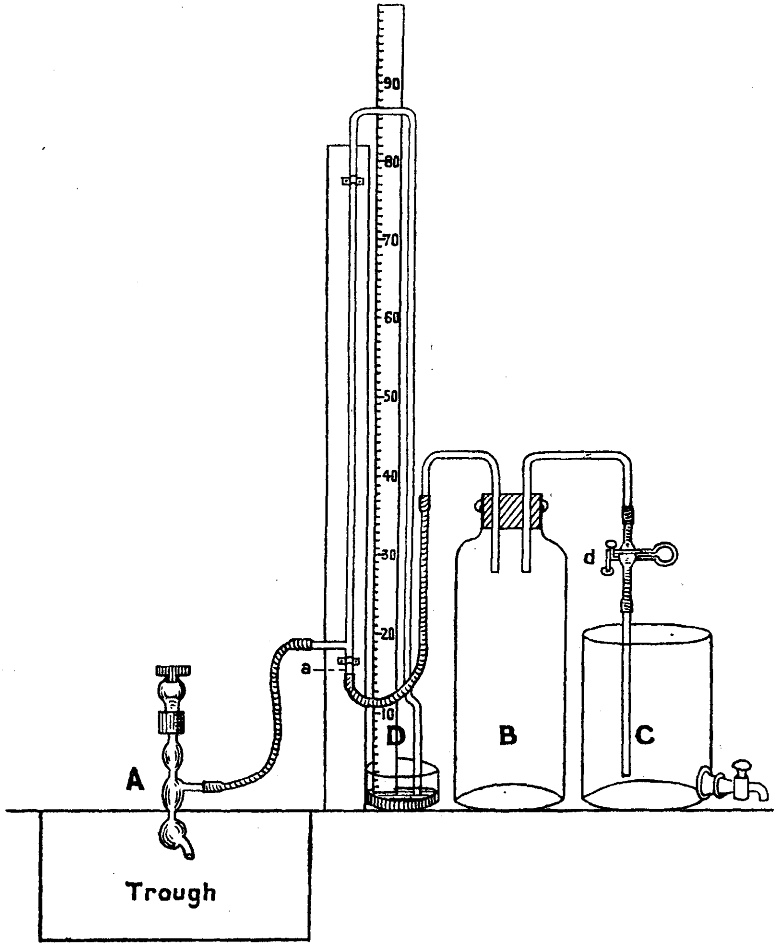


Fig. 5. Apparatus for determining specific gravity and porosity of a soil in its natural unsifted condition.

of the Ballyhaise area. The specific gravity of the majority of these soils approach an average of 2.5, a figure which is, however, much lower than that given in some text-books. This apparent discrepancy arises from the fact that the former figure has been obtained from the *air-dried* natural soils, while the specific gravities given in the text-books have been determined on the *dry* fine earths from which practically all undecayed vegetable matter had been eliminated.

POROSITY.

Since a soil is made up mainly of solid irregularly shaped particles, it is clear that these latter will not pack so closely as to completely fill up all the available space within the soil, but will leave a number of interstices which are collectively known as pore-space.

The amount of interstitial space or porosity varies considerably according to the texture of the soil. The porosity of a sandy soil may be as low as 20% of its volume, while a clay or a humous soil may possess a porosity of 60% or more. In a natural soil the actual porosity may exceed what one may be led to expect from a consideration of the sizes of the particles alone, as the pore-space may be considerably augmented by the presence of humic substances, the loosening caused by tillage, and the holes produced by plant-roots and earth-worms.

TABLE VII.

No. of soil-sample.	Weight, when air-dried, of 1 litre of soil collected under field conditions. This divided by 1000 gives the apparent specific gravity.	Real specific gravity of the soils.	Percentage of Pore-space	
			Calculated on the assumption that the real sp. gr. of the soil is 2.5.	Calculated from the real and apparent sp. grs. as determined.
1	672·5	—	73·10	—
2	1303·5	2·506	47·86	47·98
3	1191·5	—	52·34	—
4	1293·	—	48·28	—
5	944·5	—	62·22	—
7	1163·	—	53·44	—
9	660·5	—	73·58	—
10	882·5	—	64·70	—
12	1075·	—	57·00	—
15	1006·	—	59·76	—
19	838·	—	66·48	—
20	1052·5	—	57·90	—
21	1118·	—	55·28	—
22	1172·	—	53·12	—
23	1237·	—	50·52	—
24	821·5	—	67·14	—
28	1260·	—	49·60	—
29	1272·	2·39	49·12	46·77
30	1030·	—	58·80	—
31	771·5	2·42	69·14	68·12
33	772·	—	69·12	—
34	933·5	2·50	60·26	60·26
36	1072·5	—	57·10	—
42	1038·5	2·34	58·46	55·62
43	1322·5	—	47·10	—
44	1352·	—	45·92	—
45	1366·5	—	45·34	—
48	1414·5	—	43·42	—
49	830·	—	66·80	—
50	448·5	—	82·06	—
52	1155·5	2·50	53·78	53·78
55	1155·5	—	53·78	—
56	1024·5	—	59·02	—
60	609·5	—	75·62	—
61	1046·	—	58·16	—

The porosities given in the fourth column of Table VII. are calculated on the assumption that the real specific gravity of the air-dried natural soils is uniformly 2.5. This figure is probably much too large when dealing with such soils as Nos. 1 and 50, containing a high proportion of vegetable matter; but for the ordinary arable lands of the district it may be taken as approximately correct. By the application of the following formula the porosity is easily calculated from the apparent and real specific gravities of the soil:—

$$\text{Percentage of pore-space} = 100\left(1 - \frac{Ga}{Gr}\right)$$

where Ga is the apparent specific gravity and Gr the real specific gravity. In all these calculations the hygroscopic water is treated as if it were an integral part of the solid soil-material.

A glance at the figures in the fourth column of Table VII. already referred to shows that the soils of this district have the high porosities of clayey or humous earths. It must be remembered in this connexion, however, that a large proportion of interstitial space does not necessarily insure conditions of good aeration. *The contrary is, in fact, often true, for in soils of high porosity, the individual interspaces may be so small as to oppose great frictional resistance to the movements of the soil-atmosphere.*

CAPILLARITY.

Since plants must rely mainly for their supply of water and mineral matter on the movements of the soil-moisture, the rate with which water can be moved about in the soil in all directions has, as already stated, a very decided influence on fertility. Rate of capillary water-movement is conveniently measured, for purposes of comparison in different soils, by the heights to which water ascends, during certain fixed arbitrary intervals of time, in the air-dried fine earths of the samples.

The piece of apparatus represented in Fig. 6 is that used in the Survey Laboratory for this estimation. It consists essentially of a wooden stand supporting ten glass tubes, each one metre long and about 1.5 cm. in diameter. The ends of the tubes dip into a zinc trough containing water, which can be kept at constant level in the trough by means of the constant-level apparatus shown to the right of the stand in the illustration. These tubes, which are filled with the fine earths of the soils whose capillarity is to be determined, are covered at their lower ends with pieces of calico which prevent the soil from dropping out, while at the same time permitting the free ingress of water. The filling of a tube with fine earth so as to avoid stratification of the soil-particles presents a problem of some difficulty. If the tube is filled in the ordinary way by holding it in the vertical position and then pouring in the soil through a funnel, on examination of the soil-column, it will be found to consist of alternate layers of coarse and fine particles, a condition which naturally influences the uniformity of the rate with which the water ascends in the soil-column. To overcome this difficulty the following method of filling the capillarity tubes has been adopted in the Soil-Laboratory of this Survey:—The tube is held in a horizontal position and the fine-earth is introduced into it by means of a long zinc scoop (shown in Fig. 6), which has a diameter slightly less than that of the interior of the tube. When the scoop, filled with the soil-material, has been pushed to the closed end of the tube, the latter is raised to the vertical position and the scoop carefully withdrawn. With skilful manipulation, this method

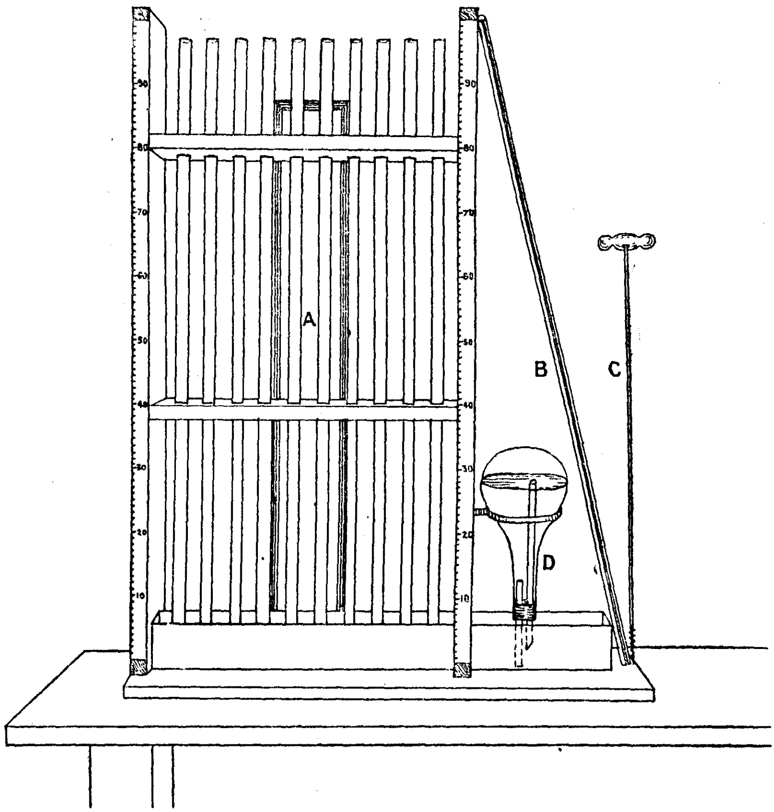


Fig. 6. Apparatus for observing the comparative capillarity of the fine earth of Soils.
A. is a mirror fixed vertically at the back of the stand.
B. is the zinc scoop used for filling the glass tubes.
C. is the corkscrew employed for emptying the tubes.
D. is a constant-level apparatus.

prevents stratification, and secures great uniformity of texture of the soil-column. The tube containing the fine earth is afterwards gently tapped to secure a certain degree of compactness of the material, and is placed in its position in the stand, with its end dipping into the water contained in the trough. At first the water rises very rapidly, but more slowly as the water-column lengthens. The heights to which the water attains above the permanent water-level are read off for seven days at intervals of 24 hours, and the results are plotted as a curve in the way shown in Fig. 7. To facilitate the reading of the heights of the water columns, two metre scales are attached, one fixed to either side of the stand, and a mirror is fastened in a vertical position at the back of the apparatus. A string stretched between the corresponding number of the scales, and held so that the string itself, its reflection in the mirror, and the top of the water-column are in the same plane, will enable the observer, when taking readings, to avoid any possible error due to parallax. The corkscrew shown in Fig. 6 has been found useful in withdrawing the soil from the glass tubes when the estimations are completed.

The soils of the Ballyhaise area do not exhibit wide differences of capillary rate. On examination of the curves shown in Fig. 7, it will be seen how closely they approximate. If these curves be compared with the capillarity curves of the Londonderry district (see the recently published Memoir of the Londonderry District, p. 98) it will be found that the former are much flatter, a fact which is no doubt at least partly due to the larger proportion of clayey material which they contain.

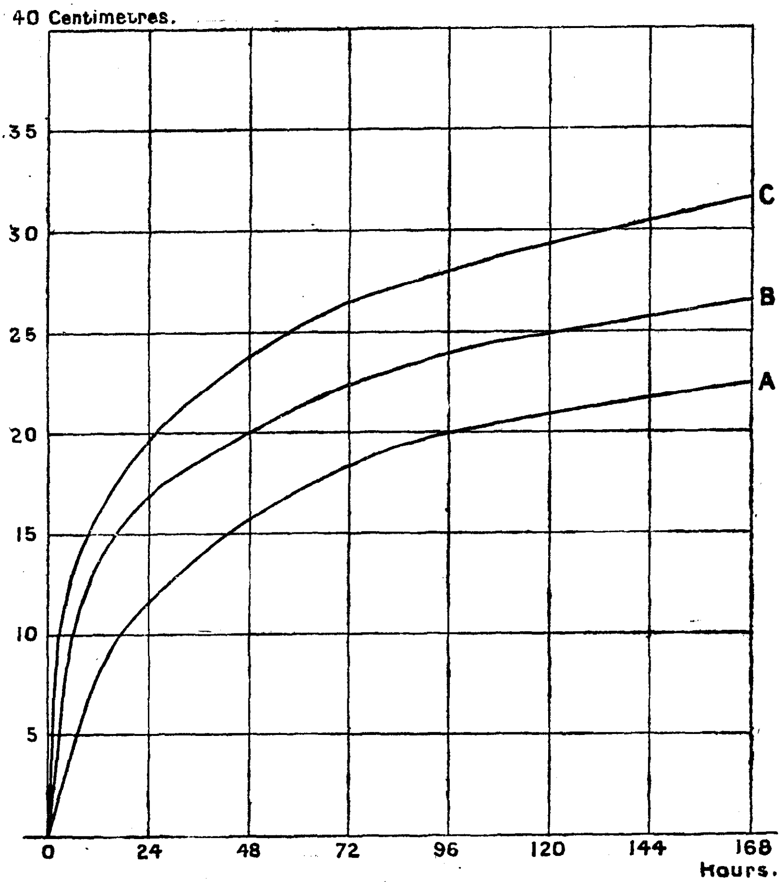


Fig. 7. Curves representing the rates of rise of water by capillary action in the fine earth of different soils.

The curve A, Fig. 7, shows the rate of movement of capillary water in Soil 31, and also fairly represents that of Soils 33 and 46, all of which belong to the lower alluvial types VII. and VIII., and which are characterised by the great proportion of material of diameter less than .01 mm. which they possess. The types represented by the remaining curves are more varied; B is the capillary curve of Soil 12, and fairly corresponds with those of Soils 45, 22, 19, 20, and 41, which belong to types II., III., V., and VI.; while the curve C. represents Soils 1, 2, 3, 4, 23, 32, 42, and 5, which are distributed over types I., III., IV., VI., and VII.

A study of these results shows that, while an observation of the rates of capillary water-movement may serve for the differentiation of soils differing widely in physical constitution, it is insufficient, because of so many disturbing factors like the presence of a large proportion of humus, &c., for classifying them into their agricultural varieties.

CHEMICAL CHARACTERISTICS OF THE SOILS.

While nearly all soils contain the chemical ingredients necessary for plant-growth, they possess them in different proportions, and in differently available forms. It is evident, therefore, that the chemical constitution of soils must be taken into account in any complete description of the latter.

A few soils of the different types occurring in the Ballyhaise area have been analysed to ascertain the available proportions of the principal chemical elements of fertility, viz.: carbonate of lime, phosphoric acid, potash and nitrogen, which they contain. The results of these analyses are given in Table VIII.

TABLE VIII.—CHEMICAL CHARACTERISTICS OF REPRESENTATIVE SOILS.

No. of Soil.	Type.	Percentage of Nitrogen.	Percentage of Phosphoric acid (P_2O_5).	Percentage of Potash.	Percentage of Carbonate of Lime calculated from the determination of Carbon Dioxide.
1	I.	—	·152	1·163	·63
2	II.	—	·226	1·084	·24
3	III.	·302	·117	·881	·315
22	III.	·265	·128	·984	·29
36	III.	·353	·140	1·09	·46
44	III.	·247	·166	·887	·54
34	IV.	·354	·167	·965	·25
20	V.	·305	·168	1·02	·33
30	VI.	·320	·135	·607	·59
5	VII.	·387	·170	·864	·435
33	VIII.	·335	·141	·806	·41

The problem involved in the estimation of the available food-materials of the soil is a complex one, presenting very many practical difficulties, and a bewildering number of methods for its solution has been proposed by agricultural chemists throughout the world. Nearly all the methods in use for the estimation of the available potash and phosphoric acid agree in that they begin with the preliminary treatment of the soil with strong acid. In the method adopted for these estimations in the Survey Laboratory, an acid similar to that employed by Hilgard is used, viz.: hydrochloric acid of specific gravity 1.115, and the soil is digested in this acid for 48 hours. The following are the details of the method:—

Preliminary Treatment of the Soil.

Fifty grammes of the air-dried fine-earth are introduced into a round-bottomed glass flask, and about 175 cc. of hydrochloric of specific gravity 1.115 are added. The contents of the flask are well shaken up, loosely stoppered, and digested for 48 hours on a water-bath. At the end of that time hot water is added, and, after being allowed to stand for some time, the liquid is poured on to a filter. The insoluble residue remaining in the flask is treated three times with hot water, which is poured off through the filter after each washing, and the residue itself is finally transferred to the filter and washed free from chlorides. A little nitric acid is added to the filtrate to prevent the separation of slimy organic material.

The whole filtrate and washings are now brought up to one litre, and from this quantity 200 cc., corresponding to 10 grammes of the soil, are taken for each estimation.

Estimation of Phosphoric Acid.

200 cc. of the above filtrate are measured into a porcelain dish, and evaporated to dryness on a water-bath, some concentrated nitric acid having been added towards the end of the evaporation in order to oxidise all the organic substances and the incompletely oxidised forms of iron which are present. The dry residue is again moistened with concentrated nitric acid, evaporated to dryness, and heated for half an hour in an air-bath at a temperature not exceeding 110-120° C. The residue is finally taken up with hot dilute nitric acid (consisting of equal parts of concentrated nitric acid and water), and is filtered and washed with a small quantity of boiling water. Ammonium molybdate is added to the filtrate, and the mixture is allowed to stand for at least 6-12 hours at a temperature of 40-60° C. The remainder of the estimation is carried out according to the usual method for the determination of phosphoric acid; or the process may be considerably shortened by proceeding in the following manner:—

Two smooth filters are pared down till of equal weight, and are folded, one of them being placed inside the other. The precipitated phosphomolybdate is thrown on to the inner filter, a small quantity of 1 in 20 nitric acid being used to wash it in, and a few drops of distilled water are poured on the upper edges of the filter to displace the acid liquid which had been used in the washing.

The precipitate and filters are now introduced into a water-oven and dried at a temperature of 90° C. When quite dry, the filters are separated, and the precipitate is weighed, the outer filter being placed as counterpoise on the scale-pan along with the weights. The weight so determined multiplied by the factor .0373 gives the quantity of phosphoric acid in 10 grammes of the soil.

Estimation of Potash.

200 cc. of the original filtrate are taken and evaporated to dryness, the organic matter and iron compounds having been oxidised with nitric acid as in the phosphoric acid estimation. The residue is taken up with hydrochloric acid, and is filtered; the filtrate is again evaporated to dryness, after which it is heated in an air-bath at a temperature not exceeding 110-120° C. for half an hour. Finally the dried residue is moistened with concentrated hydrochloric acid, taken up with water, and again filtered. The potash is determined in this filtrate by any of the usual methods. Tatlock's method will be found a short, convenient, and reliable one for this purpose; the estimation is made as follows:—

The above filtrate is introduced into a porcelain basin, excess of platinum chloride is added, and the mixture is evaporated to a pasty consistence on a water-bath. This residue is washed with a little platinum chloride to remove sulphates, phosphates, &c., and the double chlorides of platinum with calcium, sodium, magnesium, &c., which are all soluble in excess of this reagent. The washings are poured through a tared filter, and the residue is again washed by decantation with absolute alcohol (96% pure) until the latter comes away quite colourless. After the filter has been washed with warm alcohol until the yellow colour disappears, the crystals left in the dish are transferred to the filter, and the whole is then dried in a steam-oven and weighed. The weight, less the weight of the filter, multiplied by .193 gives the amount of potash in 10 grammes of the soil.

Estimation of Nitrogen and Carbonates.

Nitrogen has been determined by a modification of the Kjeldahl method, as described by Ingle ("Manual of Agricultural Chemistry," pp. 93-97), and the estimation of carbonate has been carried out after the method of Amos, described in the Journal of Agricultural Science (Vol. I., Oct., 1905). All the combined carbon dioxide of the soils is calculated as carbonate of lime.

Results of the Estimations.

These are set out in Table VIII. (p. 39). As one might expect from the fact that, with the exception of peat, practically all the material of the district has been directly or indirectly derived from the fine-grained Silurian sandstone which underlies the superficial deposits of the area, the proportions of the essential elements of fertility occurring in the soils dealt with in this memoir show a striking similarity. Judged by the standards of Hilgard*, the percentage of potash which these soils contain indicates that they are rich in that ingredient, while their supplies of phosphoric acid and nitrogen are also well up to the average. With the exception of the soils numbered 2, 3, 20, 22, and 34, in which the proportion of carbonate of lime is low, the supply of lime in the soils examined is about that of a normal clay. This statement is made on the basis of Professor Maercker's rating of soils by plant-food percentages, according to which the percentage of lime in a normal clay-soil is from .25-.50%, equal to from .44-.88% of the carbonate.

Mr. A. D. Hall† considers that liming produces effects of a beneficial kind on land which contains less than 1% of the carbonate. On this basis it is fairly safe to assume that the soils of the Ballyhaise district would be much benefited by an application of lime.

* "Soils: their Formation, &c," New York (1906), pp. 354 and 355.
† "The Soil," 2nd Edition (1908), p. 261.

TABLE IV.—Descriptions and Mechanical Analyses of Soils

No. of Sample.	No. of Soil-Type.	Situation and Aspect.	Origin of Soil.	Description of Soil
1	I.	Rugged slope, exposed N. aspect, .	Local detritus, . .	Humous Loam
2	III.	Bleak top of drumlin, . . .	Glacial drift,. . .	Stiff Stony Loam
3	III.	East slope of drumlin, . .	do.	do.
4	III.	Tailing-out of drumlin, N.E. aspect	do.	do.
5	VII.	Flat near river, ...	Alluvium, . . .	Clay
7	III.	Exposed W. slope of a hill, . .	Glacial drift,. . .	Stiff Stony Loam
9	Mixed type.	Hollow between gently sloping hills, .	Drift, alluvium and peat,	Humous Loam
10	VII.	Bare flat, ...	Alluvium, . . .	Humous Clay
12	II.	Flat bare hill-top, . . .	Glacial drift and local detritus.	Stony Loam
15	IV.	Sheltered gentle slope, . . .	Glacial drift,. . .	Loam
19	V.	Sheltered hollow at foot of drumlin,	Peat and local drift .	Humous Clay Loam
20	V.	Hollow between drumlins, . .	Alluvium, . . .	Strong Loam
21	Mixed type.	Sheltered hollow, . . .	Glacial drift, and modified glacial drift.	Strong Loam
22	III.	Bare top of drumlin, . . .	Glacial drift, . .	Stiff Stony Loam
23	IV.	East sheltered slope of drumlin, .	do. . . .	Loam
24	VII.	Hollow at the foot of a drumlin, .	Alluvium, . . .	Humous Clay
28	IV.	Gentle slope of drumlin, N. aspect,.	Glacial drift,. . .	Strong Loam
29	V.	Hollow at the foot of a drumlin, .	Alluvium, . . .	Clay Loam
30	VI.	Sheltered flat near river, . .	Alluvium, . . .	Strong Loam
31	VII.	do., . . .	do., . . .	Humous Clay
33	VIII.	do. . . .	do. . . .	Strong Humous Clay
34	IV.	Bottom of E. slope of drumlin, .	Glacial drift,. . .	Strong Loam
36	III.	Bare top of a drumlin . . .	do., . . .	Stiff Stony Loam
42	VI.	Flat near river, ...	Alluvium, . . .	Loam
43	III.	Exposed top of drumlin . .	Glacial drift,. . .	Stiff Stony Loam
44	III.	E. slope of a drumlin, . . .	do., . . .	Stiff Stony Loam
45	III.	Bottom of drumlin, E. aspect, .	do. . . .	Stiff Stony Loam
48	III.	Bare top of a drumlin, . . .	do., . . .	Stiff Stony Loam
49	VII.	Bare flat near river, . . .	Alluvium, . . .	Clay
50	VII.	do., ...	do., . . .	Humous Clay
52	II.	Rocky hummock, W. aspect, shelt'd	Local and glacial drift .	Humous Stony Loam
55	VI.	Lumpy ground above level of alluv.,	Delta fan, . . .	Stony Loam
56	VI.	Flat at the foot of a drumlin, .	do., . . .	Stiff Loam
60	VII.	Flat near river, ...	Alluvium, . . .	Humous Clay
61	II.	Rocky ground just above alluvium,	Local and glacial drift, .	Humous Stony Loam

collected within the area of the Ballyhaise Agricultural Station.

Description of Subsoil.	Depth of Sub-soil.	Drainage	Nature of Stones found in the Soil.	Percentage of Material. Above 1 cm. diam.	1 cm.—2 mm. diam.	Below 2 mm. diam. (Fine earth).	No. of Sample.
Solid rock, . .	10″	Good	Silurian sandstones and slates,	3·72	5·06	91·22	1
Boulder-clay, .	6″	Good	Silurian standstones, slate and quartzite.	11·19	11·64	77·17	2
do. . .	7″	Good	Silurian sandstones, . .	12·64	9·17	78·19	3
do., . .	13″	Good	do., . . .	22·59	6·84	70·57	4
Alluvial clay on peat	Peat at 36″	Good	do., . . .	·29	·39	99·32	5
Boulder-clay, .	14″	Good	Silurian sandstones and shales	22·28	8·36	69·36	7
Peat, . . .	14″	Bad	Micaceous sandstone and quartz.	·50	2·34	97·16	9
Clay on peat, . .	18″	Indiff.	Silurian sandstones, . .	·00	·11	99·89	10
Solid rock, . .	7″	Good	do., . . .	34·11	11·33	54·56	12
Boulder-clay . .	12″	Bad	Silurian sandstones and shales	6·47	5·98	87·55	15
Peaty clay, . .	18″	Indiff.	Silurian sandstones and quartz	13·26	2·74	84·00	19
Gravel . . .	24″	Good	Silurian sandstones . .	5·86	3·11	91·03	20
Stiff boulder-clay .	16″	Fair	Sil. sandstones and red shales,	4·88	5·06	90·06	21
Boulder-clay, .	8″	Bad	Sil. sandstones and shales, .	10·23	9·66	80·11	22
do., . .		Bad	Silurian sandstones . .	3·02	7·55	89·43	23
Clay, . . .	12″	Bad	do., . . .	·99	1·70	97·51	24
Boulder-clay, .	10″	Bad	do., . . .	8·67	3·01	88·32	28
Clay, . . .	14″	Good	do., . . .	1·60	2·51	95·89	29
Similar to the soil, .	30″	Good	do., . . .	·00	·19	99·81	30
Clay over peat, .	10″	Bad	do., . . .	·06	·27	99·67	31
Clay over peat, .	Peat at 18″	Fair	Micaceous shales, . . .	·00	·11	99·89	33
Boulder-clay . .	13″	Bad	Silurian sandstones and quartz,	3·09	3·71	93·20	34
do., . .	7″	Good	Silurian sandstones, . .	16·08	15·51	68·41	36
Yellow sticky clay, .	30″	Good	Micaceous shales and quartz, .	·39	1·17	98·44	42
Boulder-clay, .	8″	Good	Silurian sandstones, . .	16·95	7·86	75·19	43
do., . . .	15″	Good	Micaceous sandstones, shales and quartz.	24·84	5·18	69·98	44
do., . .	10″	Good	Schistose shales and dolerites	15·64	4·70	79·66	45
do., . .	8″	Good	Silurian sandstones . .	7·58	15·16	77·26	48
Clay with gravel, .	24″	Bad	do., . . .	·11	·22	99·67	49
Clayey peat, . .	24″	Bad	do., . . .	·34	4·37	95·29	50
Stony ferruginous loam	12″	Good	do., . . .	46·66	8·28	45·06	52
Strong clay, . .	7″	Good	do., . . .	23·06	3·09	73·85	55
Similar to soil over dark clay.	12″	Good		·00	·08	99·92	56
Peat, . . .	12″	Good	do. . . .	·09	·59	99·32	60
Solid rock, . .	12″	Good	do., . . .	32·88	4·88	62·79	61

TABLE V.—Mechanical Analyses of

No. of Sample.	Description of Soil.	2—1 mm. Diam.	1—·1 mm. Diam.	·1—·01 mm. Diam.
1	Humous loam . .	0·54	10·81	27·11
2	Stiff stony loam . .	3·86	23·81	22·50
3	do. . .	3·15	23·59	23·54
4	do. . .	2·62	25·79	24·70
5	Clay	0·10	2·13	22·58
7	Stiff stony loam . .	2·96	20·57	25·05
9	Humous loam . .	0·92	5·15	18·51
10	Humous clay . .	0·31	1·92	26·18
12	Strong loam . .	5·47	18·26	22·18
15	Loam	2·75	21·25	26·43
19	Humous clay loam .	1·59	12·57	21·83
20	Strong loam. . .	1·90	16·58	25·29
21	Strong loam . .	2·79	23·16	21·83
22	Stiff stony loam . .	6·13	21·64	21·25
23	Loam	2·43	21·91	26·51
24	Humous clay . .	0·61	5·52	20·26
28	Strong loam . .	1·87	22·20	23·78
29	Clay loam . . .	1·90	17·50	22·78
30	Strong loam . .	0·04	14·51	30·87
31	Humous clay . .	0·73	3·90	21·66
33	Strong humous clay .	0·06	0·62	17·46
34	Strong loam . .	1·23	19·97	25·03
36	Stiff stony loam . .	5·60	23·30	22·46
42	Loam	0·42	14·38	33·58
43	Stiff stony loam . .	4·43	24·67	22·94
44	Do. . . .	2·17	25·41	25·14
45	Do. . . .	·17	23·22	23·67
48	Do. . . .	6·19	24·98	20·04
49	Clay	0·00	2·93	25·39
50	Humous clay . .	0·93	5·86	15·32
52	Humous stony loam .	4·57	19·03	24·91
55	Stony loam . . .	0·75	12·25	34·10
56	Stiff loam . . .	0·35	12·56	30·85
60	Humous clay . .	0·14	0·77	16·98
61	Humous stony loam .	1·17	18·41	32·11

the "Fine-earths" (below 2 mm. diam.).

·01—·005mm. Diam.	Below ·005 mm. Diam.	Hygroscopic Moisture.	Loss on Ignition.	Total.	No. of Sample.
22·01	15·46	5·54	17·67	99·14	**1**
21·55	17·27	3·16	9·84	101·99	**2**
23·15	12·86	3·08	9·78	101·15	**3**
23·21	11·33	3·10	9·80	100·55	**4**
39·92	22·88	6·44	13·14	101·19	**5**
22·24	13·12	5·14	12·28	101·36	**7**
21·52	19·04	8·21	27·94	101·29	**9**
31·99	20·77	3·54	15·76	100·47	**10**
18·19	11·30	7·32	18·08	100·80	**12**
19·58	12·82	3·36	14·91	101·10	**15**
21·13	16·95	4·80	23·92	102·79	**19**
20·43	18·51	6·02	12·52	101·25	**20**
23·71	14·75	2·90	10·72	99·86	**21**
20·66	18·56	4·46	9·50	102·20	**22**
24·22	15·64	3·26	9·80	103·77	**23**
29·45	25·32	3·75	17·51	102·42	**24**
25·90	14·49	2·30	10·04	100·58	**28**
25·63	17·86	3·38	12·03	101·08	**29**
28·33	13·07	5·30	10·50	102·62	**30**
35·22	18·99	4·32	16·24	100·86	**31**
31·85	31·42	4·76	17·50	103·67	**33**
23·13	17·11	3·32	12·80	102·59	**34**
20·26	17·46	3·04	10·52	102·64	**36**
22·47	13·50	5·00	12·44	101·79	**42**
18·96	16·59	3·06	10·00	100·65	**43**
22·17	14·74	2·98	9·06	101·67	**44**
24·64	14·78	2·84	9·32	99·64	**45**
23·27	16·45	2·10	8·80	101·83	**48**
35·19	20·76	4·58	14·00	102·85	**49**
20·49	17·49	7·94	35·16	103·19	**50**
20·58	13·96	3·60	16·34	102·99	**52**
23·81	15·65	3·26	12·40	102·22	**55**
24·12	18·49	3·82	12·12	102·31	**56**
33·13	23·07	5·02	24·46	103·57	**60**
20·98	11·53	3·14	15·22	102·22	**61**

TABLE VI.—Analyses of Soil-Types.

Grades	Types.								
	I. Soil-pocket on Lower Silurian rock	II. Stony Loam	III. Loam approaching Clay-loam (stony type)	IV. Loam approaching Clay-loam (less stony type)	V. Clay-loam	VI. Alluvial loam approaching clay-loam	VII. Clay	VIII. Clay approaching strong clay	IX. Peat.
Above 1 cm. diam. . .	4	50	22	5	Various	0	0	0	
From 1 cm.—2 mm. diam. .	5			5		0	0	0	
Below 2 mm. (Fine-earth), .	91	50	78	90	84—95	100	100	100	

Analyses of Fine-Earths.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
Hygroscopic Moisture . .	6	7	4	4	5	5	5	5	Peat
Loss on Ignition . . .	18	18	10	10	14	11·5	15	17·5	
2—1 mm. diam.	0·5	5·5	3	3	2	0·5	0·5	0·0	
1—·1 mm.	11	18	23	23	16	14·5	4	0·5	
·1 — ·01 mm. . . .	27	22	23	23	23	31	21	17	
·01 — ·005 mm. . . .	22	18	23	23	23	24	32·5	30	
·005 — ·000 mm. . . .	15·5	11·5	14	14	17	13·5	22	30	
Total . . .	100	100	100	100	100	100	100	100	

INDEX.

(325.) Wt.3067—S.73. 3. 3. 600. 6/'10. C.&Co. G.4.

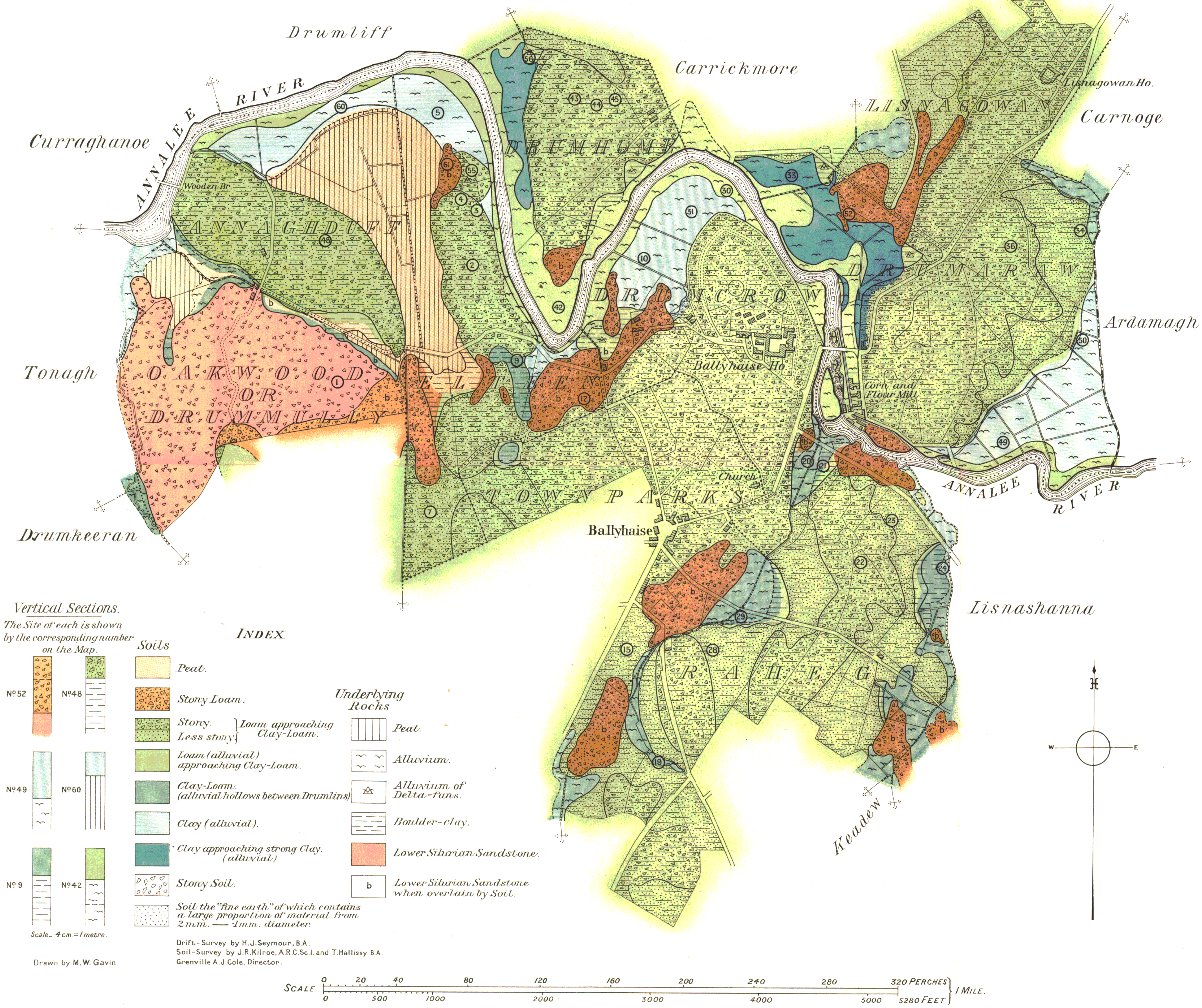
Soil Map

OF THE

BALLYHAISE AGRICULTURAL STATION, C° CAVAN;

DEPARTMENT OF AGRICULTURE AND TECHNICAL INSTRUCTION FOR IRELAND.

Geological Survey of Ireland. 1908.



Printed at the Ordnance Survey Office, Southampton, 1909.

DEPARTMENT OF AGRICULTURE AND TECHNICAL INSTRUCTION FOR IRELAND.

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