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TITLE The Stratigraphy And Morphology of Pleistocene Deposits In County Waterford (with Special Reference To The Ballyvoyle Till)

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THE STRATIGRAPHY AND MORPHOLOGY OF PLEISTOCENE DEPOSITS

IN

COUNTY WATERFORD

(WITH SPECIAL REFERENCE TO THE BALLYVOYLE TILL).

by

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ABSTRACT

Quinn, I.M. The stratigraphy and morphology of the Pleistocene deposits in County Waterford with special reference to the Ballyvoyle Till.

The Ballyvoyle Till (Watts, 1959) was originally described by Wright and Muff (1904) as a boulder clay deposited by southerly-moving ice of inland, northern origin. They regarded this advance as having post-dated one of Irish Sea origin along the south coast. While Watts (1959) considered that the two ice masses were broadly contemporaneous. Synge (1977) suggested that the glacigenic sequence predated the deposition of the underlying raised beach and was subsequently soliflucted downslope to its present stratigraphic position overlying the raised beach unit.

Five lithostratigraphic units are recognised in County Waterford. The sequence (in ascending order) is interpreted as an interglacial raised beach deposit, overlain by a gelifluctnear deposit (head) associated with onset of cold conditions, followed by a glacigenic sequence which was subsequently subjected to periglacial conditions only in the upper 1.5 m. Two major lithostratigraphic units are recognised within the glacigenic sequence: a laminated and massive silty diamicton (Whiting Bay Member, Ballycroneen Formation) and a sandy, stony massive diamicton (Ballyvoyle Member, Bannow Formation). The former is confined to the south coast and is regarded as a meltout and lodgement till facies of Irish Sea basin provenance respectively. It is overlain by the latter which is found throughout the county and is interpreted as a lodgement till facies associated with a southerly movement of ice from the midlands. It is concluded on the basis of the lithostratigraphic evidence that movement of terrestrially-based ice onshore was followed by an offshore movement of ice of northern provenance in eastern County Waterford.

The earlier observations of Wright and Muff (1904) are substantiated and developed. Synge's (1977) slumped hypothesis is refuted. The entire interglacial and overlying *in situ* glacigenic sequence in County Waterford is assigned to the most recent interglacial and glacial respectively, following normal stratigraphic procedure (Hedberg, 1976). The traditional stratigraphic framework (Mitchell *et al.*, 1973) as applied to the lithostratigraphy of the glacigenic sediments in County Waterford, is rejected in favour of the simpler stratigraphic model (Warren, 1979, 1985).

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I first of all wish to thank my two supervisors Dr R.H. Bryant and Dr. W.P. Warren for their patient and critical contribution towards the undertaking and completion of this thesis.

I wish also to thank Prof. G.S. Boulton for introducing me to Arctic glaciers; Dr. J.J. van der Meer for directing me towards Alpine glaciers; Prof. M. Downes and Paddy Prendergast for encouraging the user-friendliness of the Vax computer at St. Patrick's College, Maynooth; Ed Buckmaster for his cartographic advice; the staff in the National Library and the libraries attached to the Geological Survey of Ireland and St. Patrick's College, Maynooth; the Geological Survey of Ireland, in the person of Dr. W.P. Warren, for financial assistance in the form of temporary field assistantships and help with particle size analyses, the loan of a microscope and the use of library, research and cartographic facilities; Prof. G.F. Mitchell, Dr. R.H. Bryant and Dr. W.P. Warren for helpful discussions in the field; the late Dr. F.M. Synge for his stimulating ideas and Dr. W.P. Warren for his tireless criticism of preliminary drafts of the thesis.

Finally I thank my family, particularly, Declan, Martha and Rachel, and friends, for their support in carefully administering alternating doses of encouragement and distraction on a daily basis over a protracted period.

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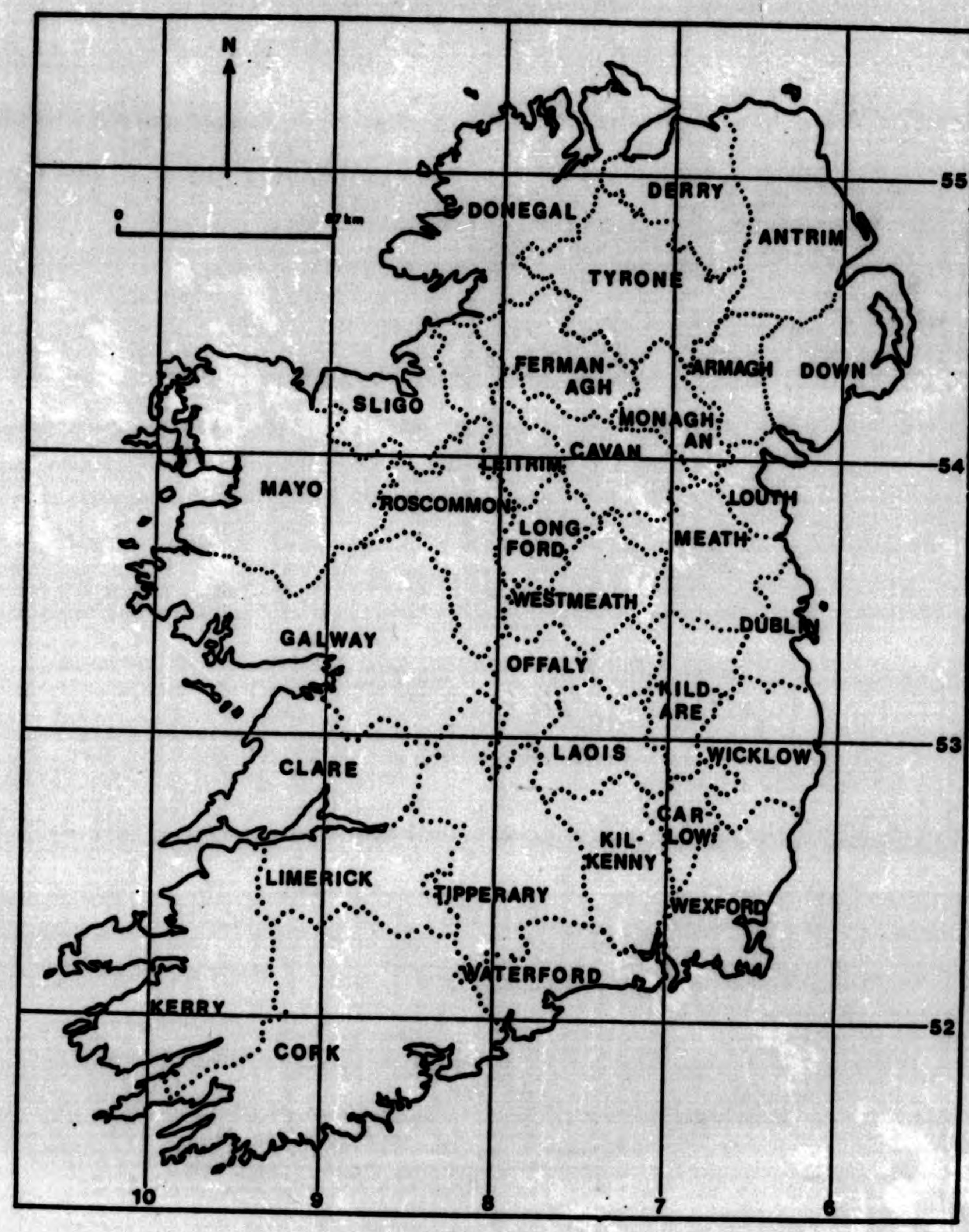


Frontispiece. Counties and coordinates in Ireland.

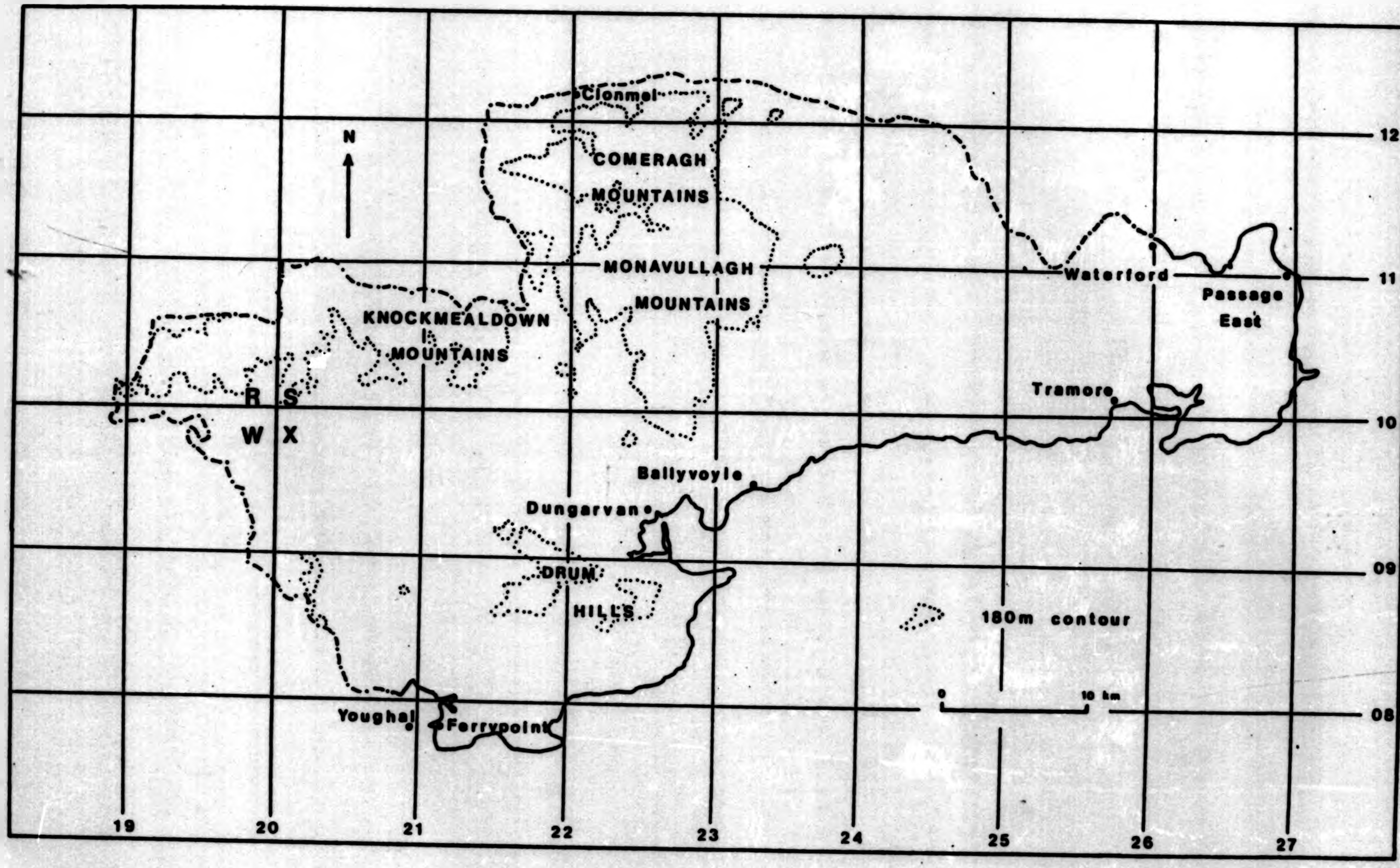


Figure 1 Location map.

CHAPTER ONE

INTRODUCTION

1.1. Introduction

This thesis examines the informally named Ballyvoyle Till (Watts, 1959) in County Waterford (Figure 1). Research was largely concentrated on establishing whether the Ballyvoyle Till exists as a distinct stratigraphic unit. In order to carry out this objective the Ballyvoyle Till is firstly described at its stratotype, Ballyvoyle (X 335 949), in terms of lithological characteristics. Horizontal and vertical variations in the Ballyvoyle Till are then examined on a similar basis. Thus, having defined the basic stratigraphic unit, the spatial and stratigraphical relationship between the Ballyvoyle Till and surrounding Pleistocene sediments including those of Irish Sea basin provenance (Wright and Muff, 1904), local glacial sediments from the Knockmealdown and Comeragh Mountains (Du Noyer, 1865; Lewis, 1894 etc.), and neighbouring Bannow (Synge, 1964), Mothel (Watts, 1959), Knockakeen (Mitchell, 1976) and Garryvoe (Mitchell, 1960) tills are investigated. The stratigraphic relationships between the Ballyvoyle Till and the raised beach, head (Wright and Muff, 1904), and organic deposits (Mitchell, 1948; Watts, 1959) in the southern part of the county are also

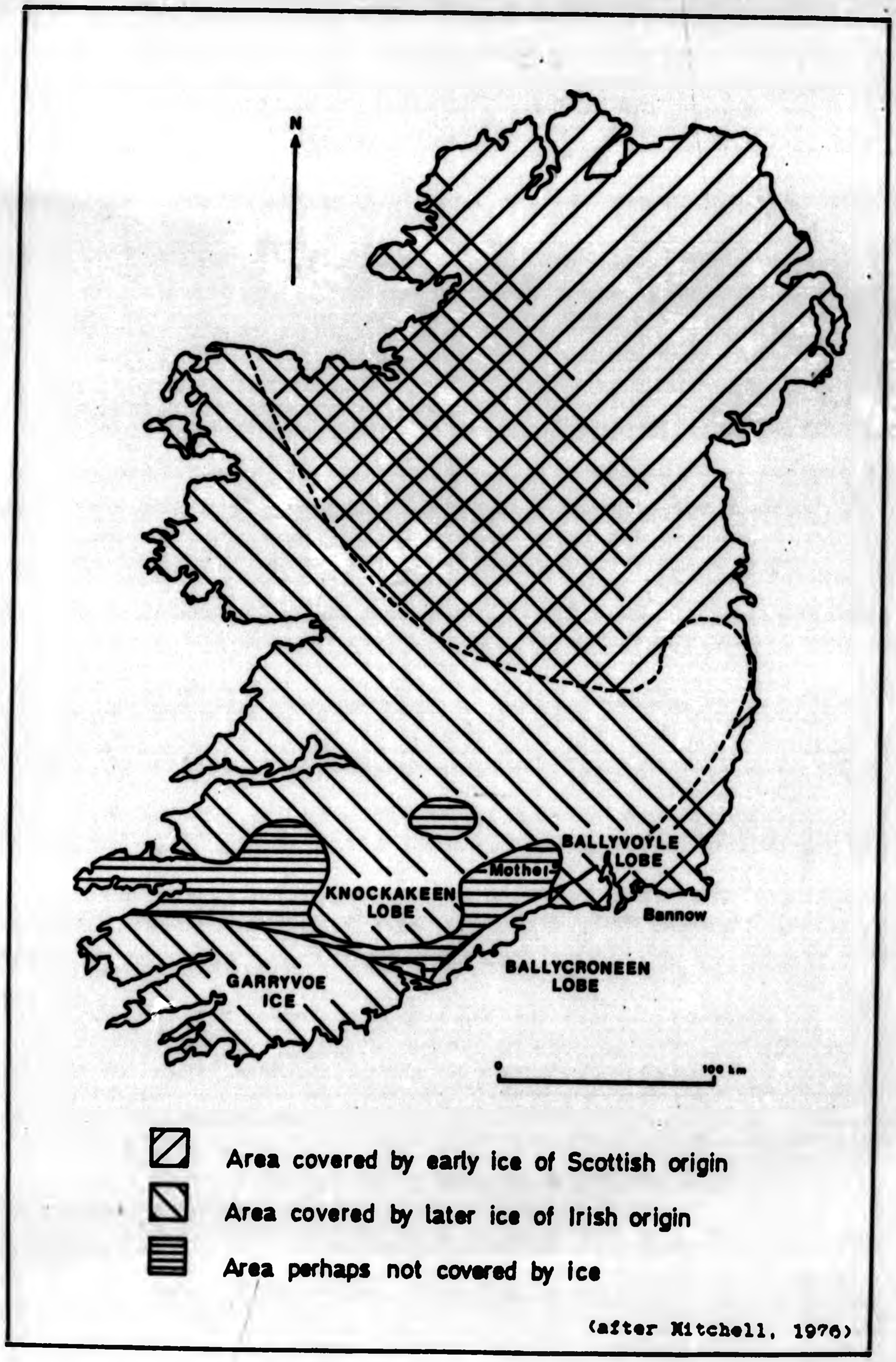


Figure 2 Potential sources of glacigenic sediments in County Waterford

investigated (Figure 2). Finally, the assessment of the stratigraphic status of the Ballyvoyle Till in relation to adjoining nonconsolidated sediments provides a basis for the establishment of a lithostratigraphic, biostratigraphic and chronostratigraphic framework for the Quaternary sediments in part of County Waterford.

1.2. Location of the Study Area

The study area is comprised of approximately 600 km^2, one third of the total area of County Waterford (1837 km^2) (Figure 3). Observations and results of field mapping were recorded on twenty seven of the forty six inch/1:10560 O.S. maps which cover the county (Figure 3). The coastal strip stretching from Passage East on the western side of Waterford Estuary at the mouths of the Rivers Barrow, Nore, Suir and Blackwater, to Ferrypoint on the eastern side of Youghal Harbour at the mouth of the Munster Blackwater was initially surveyed with a view to establishing the nature and extent of the Quaternary sediments, particularly those of the Ballyvoyle Till, in the coastal exposures.

Fieldwork then proceeded inland in order to investigate the provenance, spatial and stratigraphic relationships of the unconsolidated sediments as defined in the course of

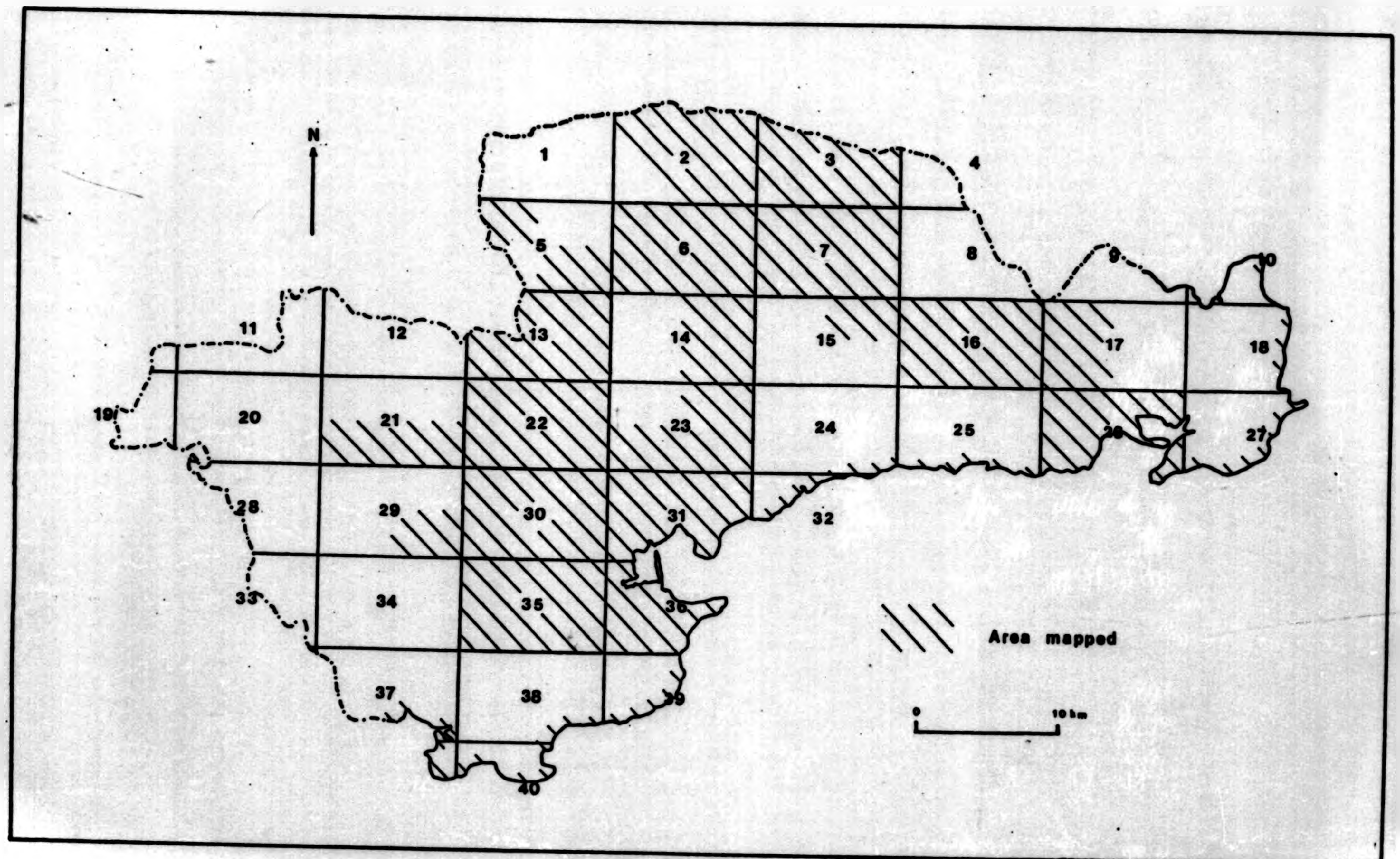


Figure 3 Area mapped at scale of 1:10000.

research at the coast. Two broad transects across the county were selected:

a) a north-south transect which stretches northward to the River Suir from the coast around Dungarvan. The area covered includes the relatively low ground on either side of the Comeragh Mountains and the higher ground of the Drum Hills to the south; and,

b) a north-west/south-east trending transect across the county extending from the environs of Clonmel in the north to Tramore Bay in the south.

1.3. Solid Geology

1.3.1. Introduction

A fairly detailed knowledge of the solid geology of the area is a prerequisite for an understanding of its effect on the landscape in terms of relief which in turn would have influenced and would have been influenced by glacierisation. A thorough awareness of the nature of lithological variation, outcrops and their location is also essential for establishing provenance and transport patterns as reflected in the erratic content of unconsolidated sediments.

Two aspects of the solid geology combine together to produce a basic contrast between the east and west of the county: lithological composition and tectonic influence. A glance at either a topographical or a geological map of the county will serve to highlight this contrast. There is a neat, discrete distinction between the relatively low lying relief in the eastern half of the county and the upland areas to the west. The former is associated with the older Lower Palaeozoic Ordovician and Silurian shales, slates and volcanic sequences. These rocks were subjected to Caledonian tectonic activity which took place along the colliding north-east and south-west trending margins of the continental plates surrounding the Iapetus Ocean (Naylor *et al.*, 1980). This is reflected in County Waterford by the presence of the remnants of a volcanic island arc characterised by large shield volcanoes lying to the south-east of a sedimentary arc. The Caledonian influence in the geological structure is typified by the north-east and south-west trend of the fault-controlled boundaries of the subsiding submarine basins which lay parallel to the margins of the colliding continental landmasses. In contrast, the upland areas in the western half of the county coincide with Upper Palaeozoic Devonian strata. These, together with the underlying Lower Palaeozoic strata were subjected to Hercynian earth movements, as also were the overlying Carboniferous limestones. The folded strata of the Devonian and Carboniferous Systems resulted in an east-west aligned structural grain with Old Red Sandstone cropping out in the mountainous areas and Carboniferous limestone underlying the floors of the intervening synclinal valleys. Only one cleavage (predominantly axial-planar to the folds) is present in the Upper Palaeozoic strata. [In the Lower Palaeozoic rocks of the Caledonides the Variscan earth movements resulted mainly in normal north-south faults in County Waterford (Penney, 1980a)]. The Comeragh and Monavullagh Mountains form the central spine of the county with the Knockmealdown Mountains lying to the north-west. They are separated from the Drum Hills to the south by the Dungarvan syncline and are bounded on the north by the limestone lowland of the Carrick-on-Suir syncline. Hercynian tectonic activity is reflected in the east-west trend of the fold axes in both synclines.

1.3.2. Ordovician

The oldest rocks crop out in the eastern half of the county. They belong to the Ordovician system, which was characterised by periods when sedimentation and volcanism both alternated and coincided with each other. The stratigraphic sequence includes deep and shallow water marine sandstones, mudstones and limestones which are intercalated with and intruded by the products of intermittent and persistent submarine volcanicity (Stillman *et al.*, 1973, 1974). The Ordovician shales were first described and mapped by Holdsworth (1834) and later, as part of the Transition Series, by Weaver (1838). The rocks of eastern County Waterford were comprehensively mapped in the years 1848 to 1851 by Wilson of the

Geological Survey. This work was revised by Du Noyer and the maps were published in 1856. Then the work was later revised by Jukes (1859) and the memoirs were published in 1865. Further revision by Kilroe (1899, 1900) followed and these publications coincided with additional observations published by Reed (1899, 1900) who recognised the three lowest units in the stratigraphic sequence. The Ordovician shale and volcanic sequence in County Wateford forms part of a broad belt which extends south-westward from the Dublin area and flanks both sides of the granite uplands in the Leinster Chain (Hallissy, 1939).

The sequence for south-east County Waterford is based on exposures in the vicinity of Tramore where it is 4000 m thick and is divided into five formations (Carlisle, 1971; Downes, 1974; Mitchell *et al.*, 1972; Schiener, 1974, Stillman *et al.*, 1974):

5. Upper Tramore Volcanic Formation
4. Garraun Shale and Tuff Formation
3. Middle Tramore Volcanic Formation
2. Tramore Limestone Formation
1. Lower Tramore Shale and Volcanic Formation.

The oldest beds seen are the Lower Tramore Shale and Volcanics which are 300 m thick. They are composed of highly deformed distal turbidite sandstones and slates

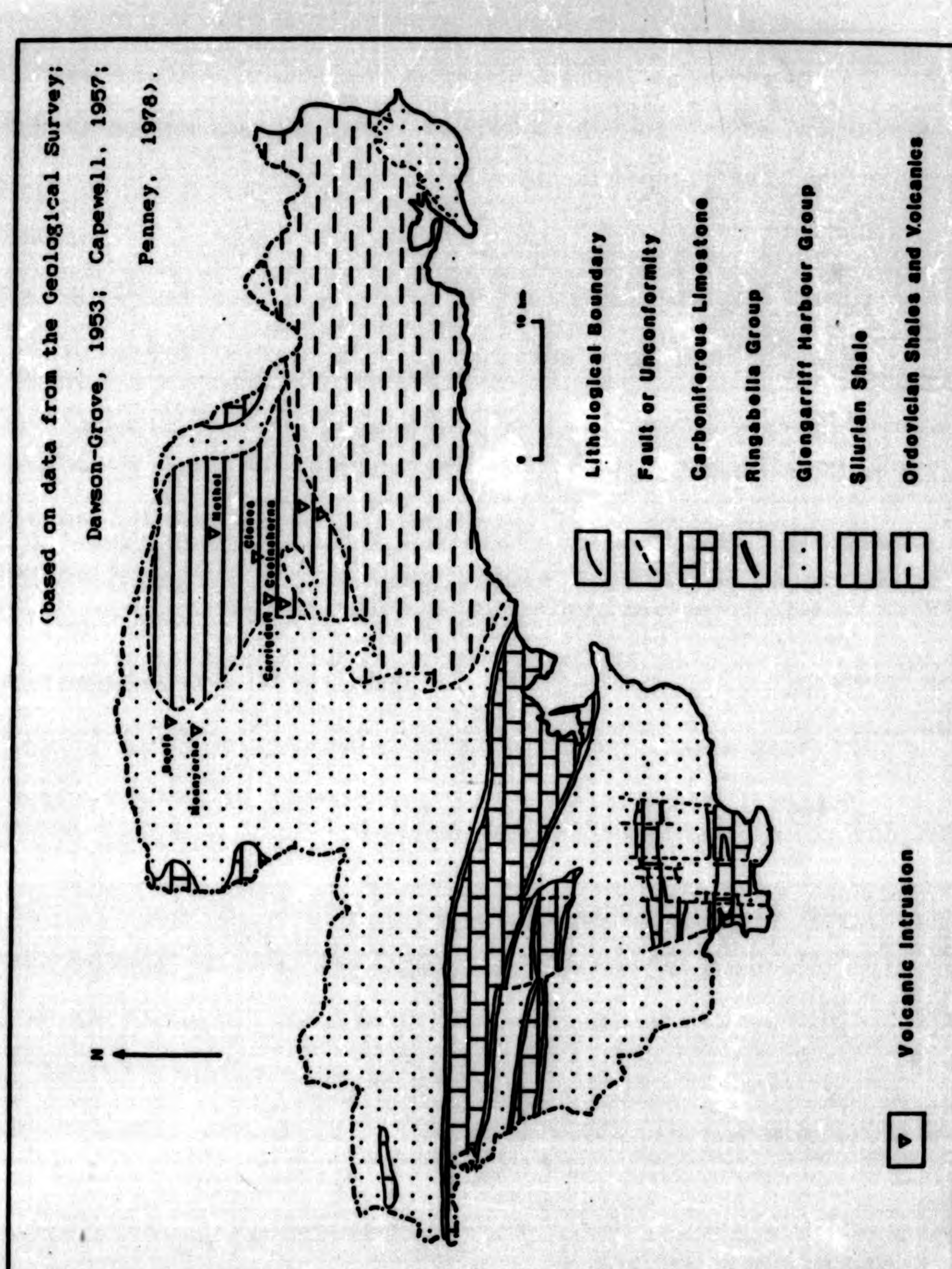


Figure 4 Generalised geology of County Waterford

which crop out to the east of Tramore and are intercalated with intermediate to basic volcanics (andesites). These rocks, although unfossiliferous, are correlated with the pre-Middle Llandeilo Ribband Group (Bruck and Stillman, 1978) (Figures 4 and 5).

The Tramore Limestone Formation is seen to rest unconformably on the underlying strata. Calcareous siltstones are interbedded with thin beds of nodular limestone and are correlated on the basis of their fossiliferous content with Bala-Caradocian sediments. The succession further north is somewhat different where shales and acid tuffs crop out. Downes (1974), as reported in Stillman (1978), "shows that the shales extending east from Kilmacthomas are probably equivalent to the lower part of the Tramore succession, the Tramore Limestone facies apparently not extending far to the north." These shales were actually mapped as part of the Tramore Limestone Formation (Stillman *et al*.., 1978) (Figure 5). However, Penney (1980a) regarded the east Waterford sequence as younging northward. He assigned these shales to the Ross Formation (see section following) as they both overlie and are interbedded with acid tuffs of the Middle Tramore Volcanic Formation.

The Middle Tramore Volcanic sequence (the Lower Tramore Volcanic Group of Mitchell *et al*, 1972; and the Carrigaghalia Series of Reed, 1899 and Hallissy, 1939)

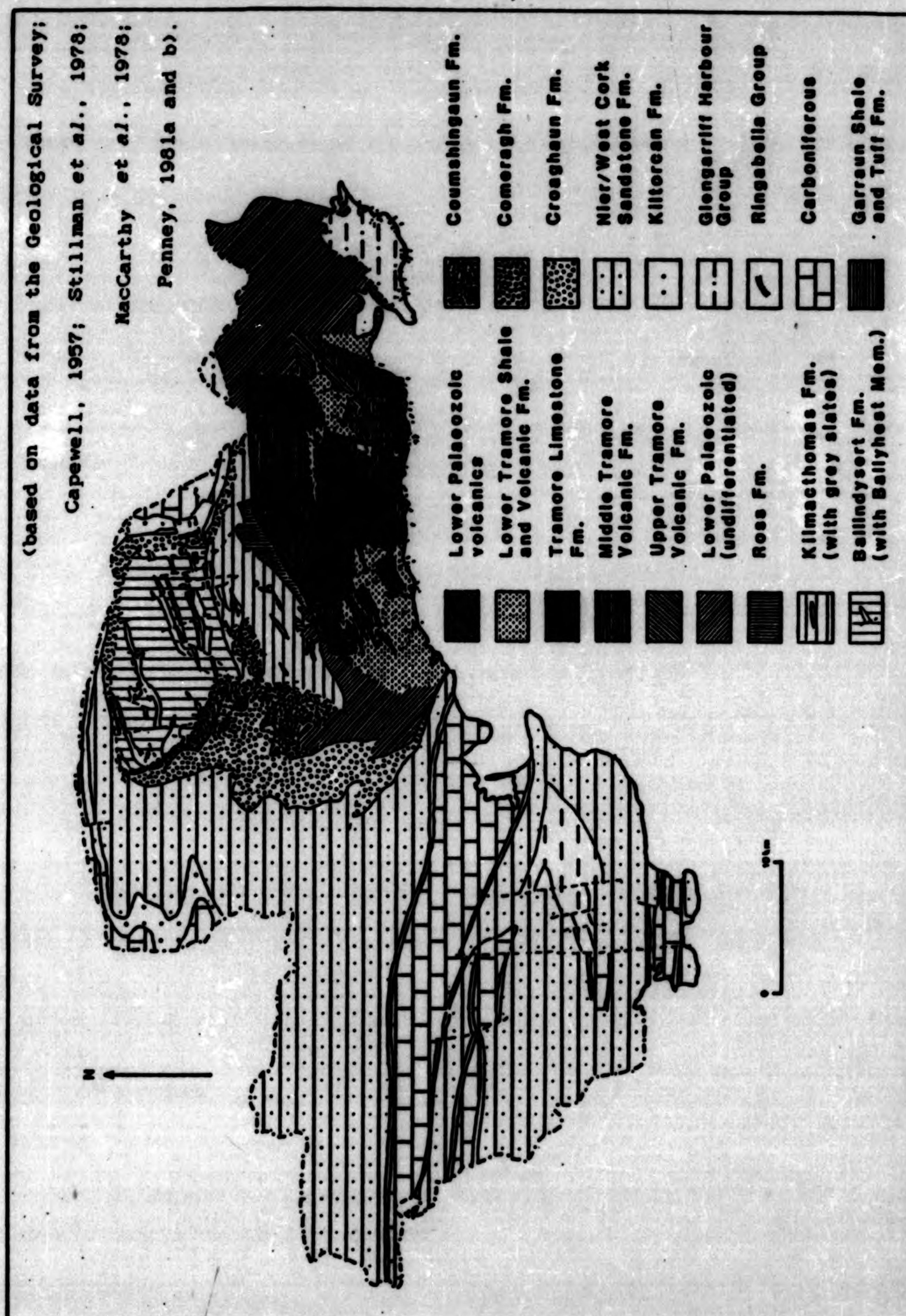


Figure 5 Geology of County Waterford

rests conformably on the underlying strata. The thickness of the formation varies from 650 to 2000 m in the south where it is thickest. The volcanic sequence includes rhyolites, andesites and both subaerial and submarine tuffs derived from volcanic centres to the south and south-west of Bunmahon.

The Tramore sequence is capped by the Garraun Shale and Tuff Formation where sedimentation occurred in faulted localised basins in the area around Fenor between Dunhill and Tramore.

The Upper Tramore Volcanic Formation is represented by the products of a final phase of volcanicity which took the form of a return to tholeiitic and more alkaline intrusions (Schiener, 1974; Stillman, *et al.*, 1978; Phillips, 1980). These intrusive rocks were probably associated with Caledonian folding at the close of the Silurian or early Devonian times as they are seen to cut the rhyolites associated with sediments of Llandeilo/Bala age (Hallissy, 1939).

1.3.3. Silurian

Slaty rocks of this age have been laid bare on the Rathgormuck Plateau by denudation of the eastern end of the Armorican ridge of the Comeraghs to the south of the River Suir in north-eastern County Waterford. According to

Penney (1980a) the sequence is 3000 m thick and rests conformably on and interfingers with the underlying Ross Formation. The sequence in north-east County Waterford comprises:

3. Ballindysert Formation	(1900 m thick)
2. Kilmacthomas Formation	(1100 m thick)
1. Ross Formation	(0-800 m thick)

The Ross Formation is composed of dark grey slates and thin greywacke beds interbedded with acid tuffs. These rocks crop out to the north-east of Kilmacthomas.

The turbidites of the Kilmacthomas Formation crop out to the south and east of Croughaun Hill. They are interbedded with acid tuffs, particularly, in the lower part of the sequence and in the south. This sequence indicates the waning of volcanic activity and is attributed with an Upper Wenlock/Llandovery age.

The Ballindysert Formation includes basin plain type turbidites which crop out in the north east of the county. They are interfolded with a coarse turbidite which fines distally to the north (the Ballyhest Member) and crops out around Mothel and Aughnabrone.

All the beds of the conformable sequence described above dip at high angles. Sometimes there is pronounced cleavage with certain beds yielding slates suitable for roofing purposes in the past (Hallissy, 1939).

A much smaller Silurian inlier crops out in Muggort's Bay to the south of Helvick Head. The shales are cut by a dyke south of Seaview House and there are indications of a second dyke at the northern end of the outcrop (Wynne, 1861).

1.3.4. Devonian

The rocks of the Devonian system are well exposed in the western half of County Waterford to the west of Ballyvoyle Head, in the Comeraghs and in the ridge which extends eastward along the south bank of the River Suir. The Old Red Sandstone of the nineteenth century Geological Survey have been described by Capewell (1957), MacCarthy *et al.* (1978), Penney (1980b) and Boldy (1982). The sandstones and conglomerates form a conformable sedimentary sequence over 2000 m thick in the west. A total thickness of 4000 m is estimated for the Devonian strata in the Comeraghs which rest unconformably on the underlying Lower Palaeozoic rocks.

The sequence as seen in west Waterford forms part of the Glengarriff Harbour Group and is divided into the following formations (MacCarthy *et al.*, 1978):

3. Coomhola Formation (28-203 m thick)

2. West Cork Sandstone Formation (1900 m + thick)

1. Templetown Conglomerate Formation (109 m thick)

In the Comeragh Mountains and the eastwardly extending rim, the sequence as mapped by Capewell (1957) and Penney (1980b), is divided into four formations:

4. Kiltorcan Formation (230-555 m)

3. Nier Sandstone Formation (0-2210 m)

2. Comeragh Conglomerate-Sandstone Formation (120-610 m)

1. Coumshingaun Conglomerate Formation (0-850 m)

The three uppermost formations of both groups are lithostratigraphically correlatable with each other based on descriptions of the sequence at Ballyvoyle Head (Capewell, 1957; MacCarthy *et al.*, 1978).

The lowest formation in the Comeraghs, the Coumshingaun Conglomerate Formation, usually crops out as a red breccia composed largely of Lower Palaeozoic fragments as in the backwall of the cirque at Coumshingaun. Two volcanic members are also recognised within this formation: the Carrigduff Volcanic Member and the Coolnahorna Volcanic Member (Penney, 1978). Both members are composed of green vesicular lava and have very localised outcrops on the east-facing escarpment of the Comeraghs to the north of

Coumshingaun.

The Coumshingaun Conglomerates are overlain conformably by the Comeragh Conglomerate-Sandstone Formation, which, like its correlative, the Templetown Conglomerate Formation, is composed of quartz pebble conglomerates, red sandstones and siltstones. The backwalls of the Comeragh cirques afford excellent exposures in these westward dipping strata (Anonymous, 1820; Weaver, 1838 etc.).

Outliers of conglomerates and mudstones crop out in the area around Dunmore East and at Knockavelish Head. These are correlated with the Templetown and overlying Harrylock Formations on a lithological basis. Contacts with the surrounding Lower Palaeozoic rocks are faulted and there is no upward transition into rocks of the Carboniferous system (Dewey and Rast, 1965; Ori and Penney, 1982).

The Croughaun Formation crops out on the south side of the hill of the same name. It is composed of steeply dipping well bedded conglomerates and has a distinctive green colour. It is considered by Penney (1980b) to overlie quartz pebble conglomerates and is therefore interpreted as a lateral correlative of the Comeragh Conglomerate-Sandstone Formation, although Capewell (1957), followed by Gardiner (1963), considered it to be older than the Coumshingaun Conglomerate Formation.

The Comeragh Conglomerate-Sandstone Formation grades upward into the flat bedded red sandstones of the Nier Sandstone Formation which crops out on the west and south side of the Comeraghs and is best exposed at Ballyvoyle Head. Two localised basic volcanic intrusions occur at Boola and Moanyarha respectively. In their eastern extension across the north of the county, the sandstones of the Nier Formation pass laterally into the underlying conglomeratic formation and there is an abrupt vertical transition into the overlying Kiltorcan Formation (Penney, 1980b).

The Kiltorcan Formation is characteristically composed of white or yellow sandstones and green or grey mudstones with abundant red sandstones. Their outcrops occur around the edges of the sandstone uplands, particularly, to the north of Ballymacarbry, parallel to the River Suir and in the extreme south, on the west side of Ballyvoyle Head. The base of the formation was recognised petrologically, by Penney (1980b), as the incoming of feldspar detritus associated with the unroofing of the Leinster granite to the north; whereas MacCarthy *et al.*, (1978) regard the base of the correlative Coomhola Formation at Ballyvoyle Head as the "incoming of thick sandstones" in which a coloration differentiation due to the presence of detrital feldspars occurs higher up in the sequence (MacCarthy, 1983).

The Glengarriff Harbour Group:

The Templetown Conglomerate Formation comprises poorly sorted pale purple breccio-conglomerates and a rhythmic alternation of medium sorted pale red purple, pebble and cobble, sheet conglomerates and greyish purple sheet mudstones. The representative section is at Ballyvoyle (X 348 592)(MacCarthy *et al.*, 1978).

The base of the West Cork Sandstone Formation is taken at the contact between conglomerate-dominant and mudstone-dominant sequences. Red colours predominate in the finer lithologies, while green and grey colours are generally associated with the coarser ones.

The Coomhola Formation is represented in western County Waterford by the Dysert Member which contains heterolithic units which crop out around Ardmore. Grey sandstones and grey siltstones predominate and display a general fining-up sequence into the overlying Carboniferous strata.

1.3.5. Carboniferous

Rocks of this age are divided into the Ringabella Group and the 'Carboniferous Limestone'. The former group is roughly equated with the 'Lower Limestone Shales' of the Memoirs and consists of two formations in western County Waterford (MacCarthy *et al.*, 1978):

2. Courtmacsherry Formation (19.6 m thick)

1. Kinsale Formation (370 m + thick)

The base of the Kinsale Formation is taken as the first "significant clay-dominant mudstone unit" (Gardiner and Horne, 1976) which rests conformably on the underlying Glengarriff Harbour Group and the transition is visible at Whiting Bay and at Crushea (Ardmore Bay). The transition at Whiting Bay is marked by a quartz pebble conglomerate, termed the Garryvoe Conglomerate Formation, at the top of the underlying Glengarriff Harbour Group (MacCarthy *et al.*, 1971).

The base of the conformably overlying Courtmacsherry Formation is taken as the lowest limestone in the sequence and is visible at Whiting Bay (MacCarthy *et al.*, 1978). The formation consists of alternating bioclastic limestone and locally calcareous mudstone with isolated sandstones and crops out at Whiting Bay and Crushea (Smyth, 1939).

These beds pass conformably up into the 'Carboniferous Limestone' which crops out in the synclines at Dungarvan, Ardmore, Whiting Bay and Clashmore with reef limestones overlying dark grey cherty limestone. Outcrops of these cherty limestones to the east of Dungarvan are interbedded with dolomite (Smyth, 1939; Dawson-Grove, 1953).

1.3.6. Conclusion

The alternation of marine and terrestrial conditions accompanied at times by both prolonged and intermittent volcanism and tectonic activity in County Waterford have resulted in a complex geological history. The concomitant wide lithological variation is reflected in the erratic content of the unconsolidated sediments which have been transported by various agents over such a complex basement. However, lithological composition of the unconsolidated sediments will not reflect a simple carry-over effect. The relationship between the total composition of any unconsolidated sediments and the terrain traversed by them may be complicated by the following five processes:

a) Erratic content may contrast sharply with local underlying lithologies over which the sediment has been transported due to the absence or weakness of the admixture process. This is particularly evident where relatively cohesive silty diamictic sediments containing clays, shells, flints and far-travelled erratics have been transported on-shore. Thus, the lithological composition of the unconsolidated sediments is a function of the carry-over rate which in turn is governed by the nature of the sediments being transported and by the transporting mechanism itself.

b) Lithological composition and erratic content may reflect vertical as well as lateral variation at any one section due to complex depositional or sedimentological processes e.g. lag deposits may be introduced into a transported mix via vertical lowering through the sedimentary column as is probably the case with the distribution of massive conglomerate and sandstone erratics which abound in the sediments resting on the Lower Palaeozoics around the margins of the Devonian outcrop. Further complications in tracing the origin of erratic content could be introduced by the effects of the weathering out of "erratic" clasts from breccia-conglomerates.

c) Relative content of a particular lithological type will depend on its erodibility and survival ability in a transported medium i.e. flint and quartz pebbles tend to survive as erratic clasts even through many cycles of erosion due to their resistance.

d) Lithological or erratic content may be altered subsequently due to the influence of post-depositional processes e.g. weathering and leaching of carbonates and calcareous clasts in the upper horizons of unconsolidated sediments. Subsequent admixture of "erratics" may result from human agricultural or cultural activities.

e) Finally, owing to the repetition of alternating outcrops of east-west aligned Upper Palaeozoic and north-east/south-west aligned Lower Palaeozoic rocks along a north-south profile i.e. the path of the dominant transporting mechanism (*vide infra*), the task of assigning individual transported clasts to actual outcrops for the

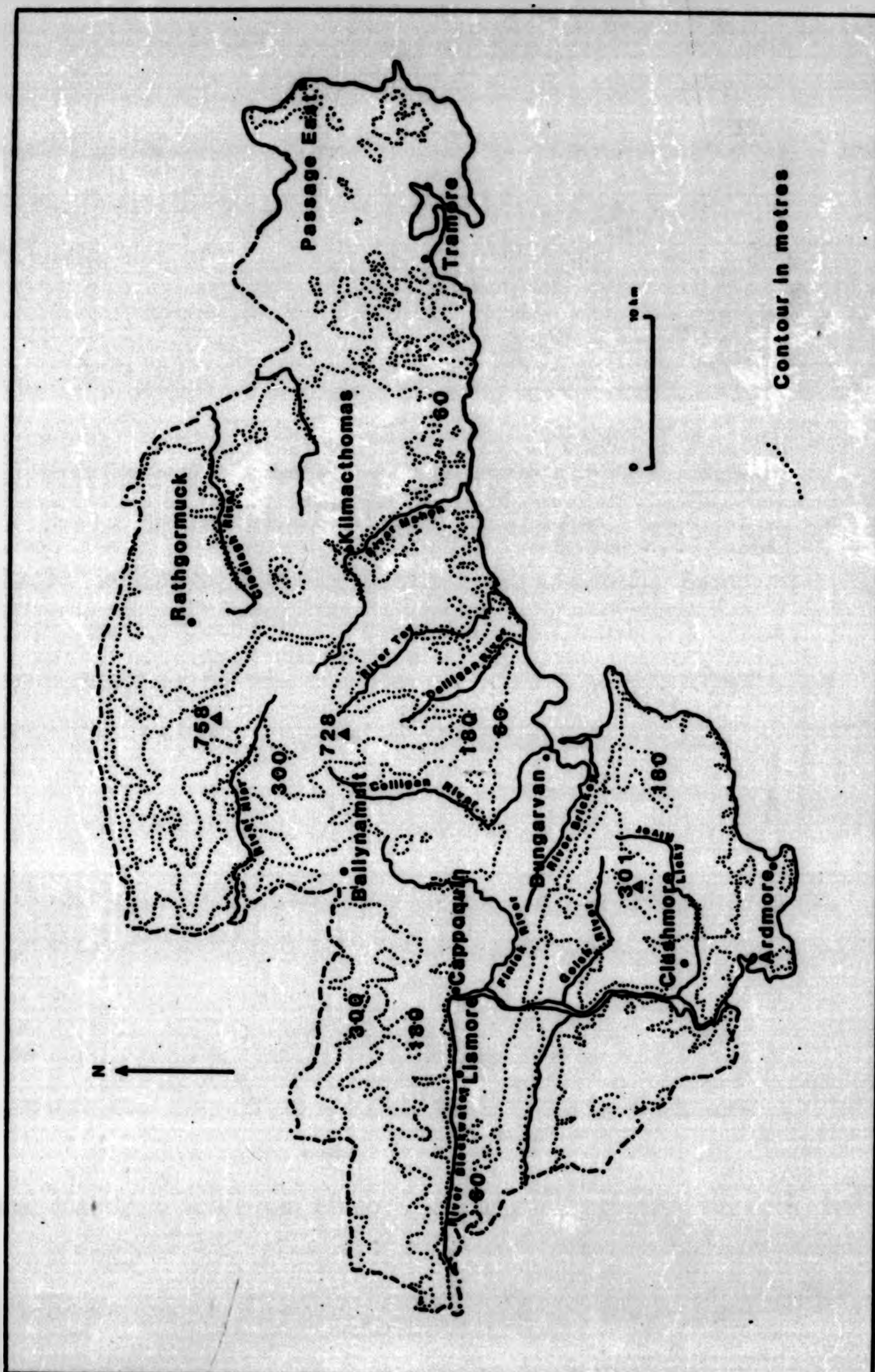


Figure 6 Physiography of County Waterford.

purposes of lithological content analysis becomes virtually impossible. For this reason broad categories for lithological types were employed as being most suitable to the scale of research adopted.

1.4. Topography

1.4.1. Relief

Du Noyer (1865) wrote of the part of County Waterford east of a line from Ballymacarbry to Ardmore that "There are few districts in Ireland where the geological structure of the ground has more clearly influenced its main physical features". He observed that the "lowest ground is almost entirely occupied by the Carboniferous Limestone. The next in elevation has been formed on the Lower Palaeozoic rocks, especially when they have been associated with trappean beds. The third level is on the same formation where they are purely schistose; and the highest ground is covered by the overlying Old Red Sandstone".

The Comeragh, Monavullagh and Knockmealdown Mountains in the western and central parts of County Waterford are underlain by Devonian Old Red Sandstone which provides the most extensive and highest relief element in the landscape. The Comeragh /Monavullagh range is separated from the Knockmealdown Mountains to the west by the Ballynamult Gap (183-214 m O.D.). The Drum Hills with their east-west trending ridges form the southern counterpart of the northern uplands. Elevation of the highest peaks ranges from 796 m O.D. at Knockmealdown, through 792 m O.D. at Knockanaffrin in the Comeraghs and 726 m O.D. at Seefin in the Monavullagh Mountains to 302 m O.D. at Carronadavderg in the Drum Hills. The cirque indented eastern escarpment of the Comeragh Mountains with the easterly extension at Croughaun Hill and the rim to the north of the county around the southern limb of the Carrick-on-Suir syncline all provide Devonian upland relief which overlooks the next highest relief element in the landscape (Figure 6).

The Rathgormuck plateau to the south and east of the Devonian uplands forms the second highest relief element in the county and is underlain by Lower Palaeozoic Ordovician and Silurian slates and shales affected by the Caledonian orogeny. The surface of the plateau lies between 92-122 m O.D. and extends southward across the Lower Palaeozoic shale and volcanic rocks where it becomes increasingly lower and is dissected into isolated volcanic hills such as the Ballyscanlan Hills (134 m O.D.) to the south-east of Kilmacthomas.

The lowest ground coincides with the east-west oriented Carboniferous synclines of the Dungarvan-Cappoquin valley, Ardmore and Clashmore in the south and the Suir valley in the north.

1.4.2. Drainage

"It is remarkable that over the area occupied by the Lower Palaeozoic rocks, the forces of denudation have excavated valleys and formed hills directly across the general stratification, and totally uninfluenced by the comparative hardness or softness of the beds". (Du Noyer, 1865).

The discordant drainage in eastern County Waterford which is referred to above is particularly well exemplified by the lowest reaches of the River Suir where it cuts across underlying strata of Devonian Old Red Sandstone and Lower Palaeozoic shales, just north of Waterford city, before entering the sea at Waterford estuary. The discordance displayed by the River Suir is mirrorred in the courses of the Rivers Tay, Dalligan and Mahon, whose subparallel courses follow a south-easterly direction in wide open valleys over Caledonian structures in the underlying Lower Palaeozoic rocks.

In contrast, the drainage of western County Waterford displays a striking concordance with the underlying geological structures cutting "into the very lowest shaly and soft portions of the deposit. The Old Red sandstone beds which rise directly from beneath the limestone have also yielded on the lines of their deposition and least resistance". (Du Noyer, 1865). The courses of the Nier, Colligan and Finnisk which drain the western slopes of the Comeragh/Monavullagh range follow the maximum topographic slopes to drain into the Carboniferous lowlands. The courses of the Goish and Licky Rivers in the Drum Hills follow the synclinal structures while the eastern end of the Dungarvan syncline is drained concordantly by the River Brickey. Only the Munster Blackwater which forms the western boundary of the county provides the exception. Having flowed concordantly eastward for the greater part of its course, it makes a right angled turn at Cappoquin and flows discordantly southwards across three east-west trending sandstone ridges just before it enters the sea at Youghal. There is some suggestion that this north-south stretch of the river does in fact coincide with a similarly oriented fault (Jukes, 1861).

1.4.3. **The Coastline**

The form of the present coastline is notably governed by geological composition and structure with precipitous cliffs and headlands coinciding with resistant sandstone and volcanic materials, while the embayments and sandy beaches are associated with Ordovician shale and Carboniferous limestones.

Working south and west from Passage East on the west side of Waterford Estuary, the litholgy changes from Old Red

Sandstone to Lower Palaeozoic rocks which are coincident with an embayment punctuated by a minor headland at Newtown where volcanic rocks crop out. The embayment of Woodstown Strand is eroded into a Lower Palaeozoic horst inlier (Dewey and Rast, 1965). The southern boundary is faulted against an outlier of Devonian sandstone which forms the prominent Knockavelish and Creadan headlands and presents a cliffed coastline along the south coast which continues westward as far as Brownstown Head on the east side of Tramore Bay (Ori and Penney, 1982). The bay itself is eroded into the south-western continuation of the Silurian shales and slates which crop out in the embayment between Passage East and Newtown Head on the east side of Waterford Estuary.

Great Newtown Head, on the west side of Tramore Bay is formed of dolerite and the east-west trend of the coastline continues westward to provide a dip section in the Ordovician shales and volcanics (Stillman *et al.*, 1978) which is regarded by Dewey and Rast (1965) as marking a fault zone traversed at intervals by north-south faults. The direction of the coastline changes significantly to coincide with the outcrop of Old Red Sandstone at Ballyvoyle Head.

From this point westward to the cliffs at Mine Head the coastline is clearly influenced by the alternation across the strike, from sandstone on the west side of Ballyvoyle

Head to limestone in Dungarvan Harbour, back to sandstone around Helvick Head on the south side of Dungarvan Bay. The minor embayment at Muggort's Bay, (as already stated in section 1.3.3.) is coincidental with an outcrop of Lower Palaeozoic shales which have been intruded by volcanic material at two points.

From Mine Head to Crushea, the steeply cliffed coastline parallels the east-west strike of the Old Red Sandstone strata and then changes direction to form a north-south aligned bay across the strike of the Ardmore Carboniferous syncline (Smyth, 1939; Dawson-Grove, 1953). The direction of the coastline reverts to an east-west trend as it parallels the strike of the southern limb of the Ardmore syncline to form a cliffed coast eroded in sandstone between Ram Head and Blackball Head. The line of the coast is interrupted by Whiting Bay where the southern limb of the syncline is breached by the presence of a faulted block of Carboniferous limestone (Smyth, 1939).

1.5. Climate

1.5.1. Introduction

As climate is one of the factors which influences the type and rate of denudational/geomorphic processes such as gelifluction etc., a brief description of the climatic parameters is considered relevant at this point.

1.5.2. Temperature

The isotherms for mean daily air temperature for the month of January 1931-1960 indicate variation of temperature from 5°C in the north of the county to 6.5°C in the south (Atlas of Ireland, 1979). The mean daily air temperatures of 15-16°C for the month of July over the same period display little or no variation within the county, although, obviously, altitude would produce localised effects on temperature and other climatic variables. Annual mean daily air temperatures range around 10°C and the mean daily range also shows a north-south gradient, from 7.5°C in the north to 5.5°C in the south of the county.

1.5.3. Frost

Like mean daily range in air temperature, the probability of earlier frosts increases with distance from the coast. The mean date of first air frost ranges from November 1st in the north of the county to December 1st in the extreme south. The reverse also holds true for the mean date of the last air frost which occurs around May 1st in the north and March 1st in the south.

1.5.4. Precipitation

The variation in mean annual precipitation which occurs mostly outside the months April-June, is associated with the distribution of upland ares in the county. The greatest orographic effect is produced by the mountainous areas which receive a total of 1400 mm of rainfall p.a. The Drum Hills also produce a significant local orographic effect receiving a total annual precipitation of 1200 mm The rest of the county receives between 1000 and 800 mm p.a., with the south-eastern corner of the county being the driest area.

1.5.5. Wind

Although no wind rose is provided for County Waterford due to the absence of official wind records for the county (O'Connor, 1983), those for the neighbouring Counties, Wexford, Kilkenny and Cork, show that the predominant and prevailing winds are from the west and south-west. Some northerly and easterly winds are also experienced by these counties (Atlas of Ireland, 1979).

1.5.6. Conclusion

As may be deduced from the relatively humid temperate climatic conditions, gelifluction rates are potentially high wherever the vegetation cover has been disturbed. Deflation may also occur during the drier periods. The effect of altitude on temperatures may be sufficiently significant during the colder winters to produce small scale active periglacal features on exposed surfaces at the summit of the Comeragh Mountains (Saul, 1978).

CHAPTER TWO

THE BALLYVOYLE TILL AND BACKGROUND LITERATURE

2.1. Introduction to the 'Ballyvoyle Till'

2.1.1. Informal Status of the 'Ballyvoyle Till'

The till at Ballyvoyle, referred to by Watts (1959) as the Ballyvoyle Till, was first identified and described as "boulder-clay of the inland type" by Wright and Muff (1904) during the course of an investigation of the 'pre-glacial' raised beach. The "boulder-clay of the inland ice" was characterised by the authors as a typical till containing striated sub-angular and rounded boulders of Old Red Sandstone (predominant), with some admixture of Carboniferous and Silurian clasts randomly positioned throughout a clayey matrix. They also concluded that the till was deposited by a southward advance of ice from the Central Plain. The evidence for this was based on the northerly provenance of erratics in the till and the north/south orientation of striae on subjacent rock surfaces in the Youghal and Waterford areas. A distinction was made between the 'boulder-clay of the inland ice' at Whiting Bay and the underlying 'marly boulder-clay' associated with 'Irish Sea Ice'. A third 'boulder-clay' was distinguished as being associated with 'West Cork Ice' at Ballycottin in Co.Cork and possibly at Youghal in west Waterford. Their analysis of the stratigraphy, morphology and lithology of the glacial deposits along the south coast led to the recognition of a single glacial event during which the 'Irish Sea Ice' advance slightly predated those of the 'inland ice'. The following sequence was recorded immediately east of Ballyvoyle Bridge:

Boulder-clay	5-8 m
Coarse blocky head	1-1.5 m
Beach shingle	traces (3.5-4.4 m HWM)
Rock-platform	

The above stratigraphic sequence, although incomplete, was regarded as typical of the type of succession common to the coastal exposures on the south coast from Counties Cork to Waterford. The "terraces of drifts" which lay in the lee of the 'pre-glacial' rock cliffs were commonly seen to be capped by an "upper head" at many points along the south coast. The componenents of the sequence were interpreted as the end products of 'pre-glacial'-periglacial-glacial-periglacial climatic conditions respectively. Thus the Ballyvoyle Till was informally introduced as a stratigraphic unit into the literature.

As a term, the 'Ballyvoyle Till' was informally coined by Watts (1959) and adopted to describe "the local boulder-clay which forms the thickest drift deposit of East County

Waterford, and is well exposed on the coast at Ballyvoyle Head". Descriptions of the till echo closely the remarks of Wright and Muff (1904): "At all sites the boulder content of the clay is predominantly local, but a little limestone and chert occurs and the clay may give a calcareous reaction in places, although largely decalcified". The stratigraphic relationship between the Ballyvoyle Till and three other glacial deposits (including those laid down by 'Irish Sea ice', an earlier local till at Newtown and a later limestone-bearing till found at the surface in the Mothel area) was outlined and wider conclusions and correlations were drawn (see discussion below).

2.1.2. Formal Status of the 'Ballyvoyle Till'

The term 'Ballyvoyle Till' was widely accepted. Between 1959 and 1973 there were many references to the Ballyvoyle Till (see under heading entitled: 'Background Literature'). The term appeared informally in a general paper on the correlation of Quaternary deposits in Ireland and the British Isles (Mitchell *et al.*, 1973). The term 'Ballyvoyle Till' as applied to its outcrop at the type site, Ballyvoyle Head (X 34 94), does not fulfill the standard requirements (under three separate headings) as outlined by standard stratigraphic procedure necessary for the establishment of a formal stratigraphic unit (Hedberg, 1976). Firstly, the upper (erosional) boundary of the till unit which is defined at other sites by the unconformably overlying 'upper head' is not present at the typesite (see the description of Wright and Muff, 1904, above). Secondly, the term is not ranked and finally, it includes a genetic connotation. Because of its established nature the term 'Ballyvoyle Till' is retained in an informal capacity until or unless the present study concludes that a change in status is justified. Alternatively, if a change in the status of the term is warranted, the introduction of a new term may result in less confusion.

2.1.3. Current Status of the 'Ballyvoyle Till'

The informal status of the term is partly recognised in the most recent reference to the Ballyvoyle Till as a ranked lithostratigraphic unit (Warren, 1985). The till is regarded as a "constituent member" of the Bannow Formation (see under heading entitled: 'Background Literature') on the basis of similar petrology. Reference to both the Bannow Formation and the Ballyvoyle Till is presumably covered by the informal term "?Munsterian tills?"

2.2. Early Background Literature

2.2.1. Introduction

The first major published references to the glacial sediments of County Waterford date from the early Geological Survey of Ireland.

2.2.2. 1844-1865

This section deals with the findings of Oldham (1844), Du Noyer (1858), Jukes and Wynne (1861) and Du Noyer (1865). The Glacial Theory was in its infancy and interpretation of the origin of the superficical deposits was still partly influenced by the Diluvial Theory. As a result, mechanisms of erosion, transport and deposition were not generally specified or differentiated and stratigraphic relationships between 'drift' types were not interpreted to any great extent.

The major 'drift' types which were identified in County Waterford by the officers of the mid-19th century Geological Survey included the following:

1. A gravelly limestone 'drift' located up to 150 m O.D. in the northern foothills of the Comeragh and Knockmealdown Mountains in the northern part of the county (Oldham, 1844; Du Noyer, 1858). Erratic limestone pebbles were observed at somewhat higher altitudes of 223 m O.D. in the same areas.

2. 'Drift' with limestone pebbles and some admixture of local rocks (Silurian and Devonian) on the Rathgormuck plateau and to the east (Du Noyer, 1865). (Large erratic boulders of Devonian Old Red Sandstone lying south of Kilmacthomas and north-south oriented striae in the eastern part of the county were also noted by the same

author.)

3. Sand and gravel deposits of local origin in the Blackwater valley and 'clay and gravel drift' containing limestone erratics in the Lickey valley, in western County Waterford (Jukes and Wynne, 1861).

4. Devonian drift in the Comeragh Mountains (Du Noyer, 1865).

5. Calcareous 'marl' containing marine shells and flints at Whiting Bay in south-western County Waterford (Jukes and Wynne, 1861).

2.2.3. Diluvial/Glacial Paradigm (1866-1894)

Close (1866) and Kinahan (1866)

Close was the first to draw the connection between the erosive and depositional effects of glaciation. He also distinguished between general, district and local ice and associated deposits. On the basis of striae and distribution of limestone erratics in the 'drifts' to the south of Clonmel, he recognised that the Comeragh Mountains had experienced a local glaciation and that the lowland to the east had been glaciated by a major advance of ice from the north-west (Close, 1866). Later, Kinahan (1878) considered that the local glaciation of the Comeraghs succeeded that of the lowland as he regarded the valley moraines to be superimposed on the deposits laid down during the general glaciation. This conclusion was reiterated by Hull (1978).

Following Kinahan (1866), Close accepted that flint and Galway granite erratics in the southern part of Ireland must have been dropped by floating ice in the 'Esker Sea'. This sea was thought to have formed 'a short time previous to the close of the glacial period' when the country was submerged 90-120 m below current sea-level. The deposition of the associated stratified drift and eskers was therefore considered to have occurred after the production of the drumlins and the rock striations (Close, 1866).

Wynne (1868)

In a paper on the disturbance of the level of the land near Youghal, Wynne referred to two deposits which he attributed to former changes in the level of the land *vis à vis* that of the sea:

1. Stratified drift containing shells and flints of which the cliff at Youghal was composed were interpreted as a raised beach deposit associated with a former lowering of the land surface in the Youghal area. A similar deposit at Whiting Bay, County Waterford was referred to in a post-script.

2. The second deposit was the submerged outcrop of peat on the foreshore at Youghal. This deposit had been previously described in Smith's *History of Cork* (1750). Wynne was uncertain as to whether both deposits were related. He concluded that at the close of the 'Glacial Period' that the land became depressed by 27-30 m or more

(the approximate height of the drift cliff). Subsequently, the land was thought to have risen again but not to its former level "for a great portion of the boggy strand at the western side of Youghal Bay is never more than a few feet below low-water mark." (Wynne, 1868, p.7).

Kinahan (1878)

Kinahan recorded raised beaches of various levels although they were not accompanied by precise references, localities of outcrop or descriptions. He also alluded to the frequent reports of submerged bogs and forests off the south-west coast of Ireland. He cited an interesting example of a submerged pine forest at Clonea and one of a submerged peat at Tramore at a depth of "four to five fathoms" off the Waterford coast (Kinahan, 1878, p.265).

Ussher and Kinahan (1879)

A further reference to post-glacial submergence is provided by these authors who describe in detail a submerged crannog on the foreshore resting on marly till at Ardmore in County Waterford.

Lewis (1894)

Lewis accepted Close's observations, remarking on their unerring accuracy, particularly that of the existence of the end-moraine. He concentrated on trying to establish the southerly limit of glaciation in the country and attempted to distinguish between glaciated and unglaciated terrain. He recognised a zone or 'fringe' lying south of 'the moraine' which was characterised by redeposited glacial material and which he waveringly considered to be unglaciated. He also recognised till which had been redeposited with the admixture of frost shattered local fragments.

On the whole, Lewis regarded the west Waterford area as unglaciated but to have been substantially affected by redeposition of glacial products by running water as on the Tallow ridge and in the Blackwater valley around Cappoquin and Lismore. He viewed the till in the Drum Hills as having been redeposited with local angular fragments in places. The south side of The Gap in the Knockmealdowns was thought to be unglaciated. The area to the north of Dungarvan, particularly around Ballinamult, was considered to have been subjected to a locally derived glacier from the mountains up to a height of 250 m O.D. approximately. Similarly, the area to the east, between Dungarvan and Stradbally was viewed as having been invaded by ice from the Comeraghs. Only the northern and north-eastern part of the county were regarded as glaciated terrain. The north-eastern shoulders of the Comeraghs were reported to have been glaciated up to 300 m O.D. and 'the moraine' was traced eastward from there, north of Rathgormuck to the lowland into the abundantly striated terrain of east County Waterford.

2.3. Early 20th Century Glacial Literature

2.3.1. Wright and Muff (1904)

"Indeed, it is only in that part of Ireland which has been most neglected by glacial geologists that there existed a condition of glaciation sufficiently feeble for the ample preservation of unconsolidated deposits laid down prior to the boulder-clay.....The action of the land-ice on the coast from Clonakilty to Carnsore Point has been comparatively feeble; and where recent marine erosion has not proceeded too far, the beach is in consequence well preserved." (Wright and Muff, 1904)

Although this paper purports to be about the 'pre-glacial' raised beach of the south coast of Ireland, it also deals very largely with the unconsolidated deposits which rest upon it. The term 'pre-glacial' is used throughout the paper to signify 'prior to the deposition of the boulder-clay of the area in question'. It was recognised that most of Ireland had been covered by an ice-cap centred "in the neighbourhood of Fermanagh" during "the Glacial Period". From there the ice was thought to have moved in a south-easterly direction until it passed off the east coast north of the Wicklow Mountains. At this point the ice is described as dividing into an easterly and westerly branch. The westerly branch moved southward along the western flanks of the Wicklow Mountains into Waterford "where the striae indicate ice-motion from north to south out to sea." The easterly branch was regarded as having been deflected southward along the east coast by the presence "in the basin of the Irish Sea, of a more or less independent ice-sheet," which flowed in a southerly direction, passed over the south-east corner of Ireland and spread along the south coast "at least as far as Power Head in County Cork."

The stratigraphic relationship between the deposits associated with the two ice streams is also considered. It is suggested that the 'Irish Sea Ice' attained its maximum extent before that attained by the ice of inland origin. The fact that "the marly boulder-clay of the Irish Sea Ice is overlain" by the boulder-clay deposited by the ice of inland origin at Dungarvan is cited, among other examples, as supporting evidence. Further west, in County Cork, the boulder-clay associated with the local Kerry/Cork ice is seen to overlie, and therefore, also postdates, the marly boulder-clay of the Irish Sea Ice at Ballycroneen. The western limit of the deposits laid down by the ice of inland origin was not actually established.

The authors investigated many sites along the south coast of Ireland in Counties Cork, Waterford and Wexford. The five sites (from west to east) visited in County Waterford

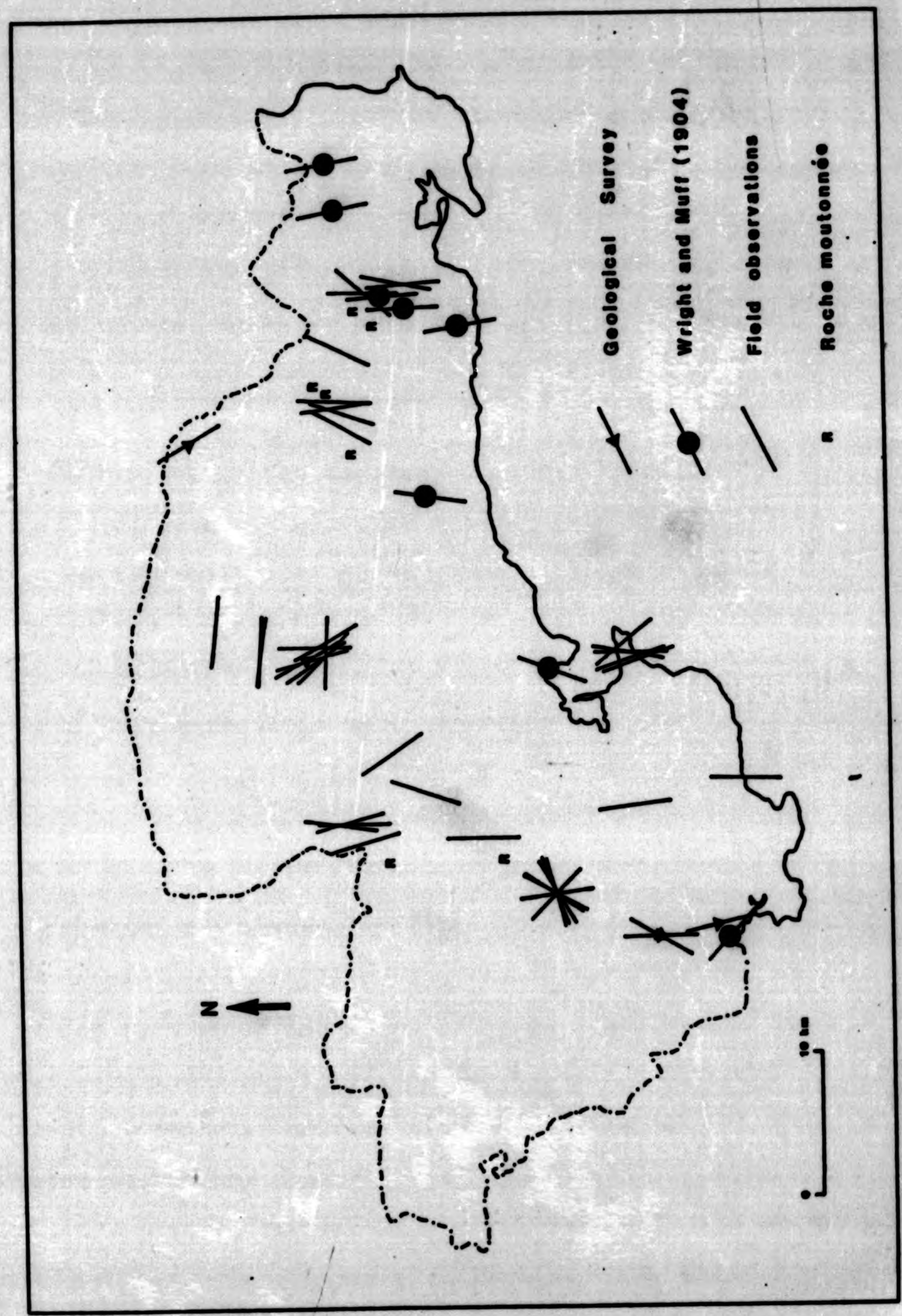


Figure 7 Striae and roches moutonnées in County Waterford.

include: Youghal, Whiting Bay, Ardmore, the south side of Dungarvan Harbour and Ballyvoyle Head. Their site observations are worth noting for their wealth of detail, precise descriptions and incisive comments (see Appendix 1).

Although no sections to the east of Ballyvoyle Head were described by the assiduous authors, a list of striae in the neighbourhood of the south coast of Ireland was compiled (for details of the Waterford striae see Appendix 2, Figure 7). The striae located in County Waterford included nine sets and a single set not referred to in the Memoirs of the Geological Survey, but included on their 1" O.S. sheet 188.

A summary of observations made by Wright and Muff (1904) and starting with the lowest identified stratigraphic unit includes the following:

1. **Raised Rock-Platform**

"The most persistent relic of the raised-beach period is the buried rock-cliff and shore platform". Obviously, the raised beach and platform were regarded as synchronous. The smooth water-worn surface of the platform was described as sloping seaward at 3^0 to 10^0. It is notched up to 1-1.2 m above its surface on the landward side where this is visible. The platform was thought to be about 3.6 m above the modern platform. Its presence was noted at

Youghal, Whiting Bay, Ardmore, Dungarvan and Ballyvoyle Head in County Waterford.

2. Raised Beach-Deposits

"These consist of stratified gravel and sand commonly cemented into a hard conglomerate or sandstone by oxides of iron". The beaches vary in thickness from a few centimetres to 3.6 m and are composed of ellipsoidal pebbles, sometimes covered by sorted sands. The raised beach was regarded as the product of coastal processes on a depressed land surface 3.6 m below that of the present. Raised beach deposits were recorded in the text at Ballyvoyle and implicitly, on the south side of Dungarvan Harbour, in County Waterford. However, in accordance with Wright and Muff's practise of associating the raised beach deposits with the rock platform, the raised beach was mapped on the accompanying sketch map at the end of the text as occurring also at Whiting Bay and Ardmore Bay. Erratics identified from the raised beach at Youghal include grey flints and volcanics. The volcanics are similar to those which outcrop to the east along the south coast of Ireland (see Appendix 3 for detailed description). The provenance of the erratics indicates transport in a south-westerly direction i.e. against the prevailing winds and tides, and for this reason a glacial origin and subsequent marine working was adduced; hence the qualified use of the term 'pre-glacial'.

3. The Lower Head

"The lower head, or rubble-drift, is found overlying the raised-beach shingle and blown sand. When the latter are not present, it rests directly on the platform. It consists of angular rock-fragments of strictly local origin identical with the rocks forming the cliff or slope against which it is banked." Its accumulation was thought to have occurred toward the end of the raised beach phase and was interpreted as the product of frost shattering under changed climatic conditions. It was considered to have formed when the land was elevated to between 3-6 m above present day levels. The lower head was recorded by Wright and Muff (1904) at the following localities in County Waterford: Whiting Bay, Ardmore, Dungarvan and Ballyvoyle Head.

4. The Marly Boulder-Clay

This deposit was described as a greenish or bluish-grey calcareous clay with contorted lamination. It was seen to contain shell fragments and infrequent rounded and striated pebbles including flint and volcanic erratics of north-easterly provenance. Localities of its outcrop, as cited by Wright and Muff (1904), include: Whiting Bay and Dungarvan where it was recorded to overlie the lower head and underlie the 'boulder-clay of inland' origin.

5. The Boulder-Clay of the Inland Ice

In County Waterford, boulder-clay associated with the advance of inland ice was seen to rest directly on a striated platform in the gorge of the Blackwater, north-east of Youghal. "In Whiting Bay it overlies the marl and contains some limestone in addition to Old Red Sandstone, which is the predominant constituent as far as Dungarvan." Further east, the contained clasts were reported to reflect the Lower Palaeozoic volcanics, shales and slates of the solid geology; until at Ballymadder, County Wexford, the boulder-clay "is composed chiefly of local rocks, but also contains large blocks of the Leinster granite." Cited outcrops of the boulder-clay associated with ice of inland origin occur at Youghal, Whiting Bay, Dungarvan and Ballyvoyle Head in County Waterford.

6. The Upper Head

"In some sections the upper head differs from the lower head only in that it contains a few pebbles derived from the (underlying) boulder-clay; in others it becomes very loamy, and the rounded pebbles rather abundant. In the latter case it is not easy to separate from the weathered top to the red boulder-clay". Very often it is found to form "small flat cones at the mouths of valleys" in other areas. No outcrops of this periglacial deposit were reported from the sections logged in County Waterford.

2.3.2. Reed (1907)

This author published five separate short papers in the *Geological Magazine* within the same year (Reed, 1907a, b, c, d, and e). Two of these notes concerned the cirques of the Comeragh Mountains (Reed, 1907b and c), while the remainder dealt with the unconsolidated glacial sediments in three coastal localities in east County Waterford (Reed, 1907a, d and e).

Comeragh Mountain Cirques

The subject under discussion in the two notes which deal with the cirques is very much restricted to the cirque characteristics Reed, 1907b and c). Following Close (1866) and Carvill Lewis (1894) in turn, Reed agreed that the cirques whose bases lie between 380 m and 457 m O.D. probably lay above the maximum altitudinal limit of the lowland glaciation, 305 m O.D. Only at Coumgorra, at the head of the Nier valley, was any possibility of mountain ice descending into the lowland envisaged. No contact between the mountain and lowland ice was considered as it was assumed, following Hull (1878), that the local ice-cap with its attendant cirques, formed subsequently to the advance of lowland ice.

Fornaght Strand

The first of the three coastal sections described is at Fornaght Strand (Reed, 1907a). The 12 m high section is located at the northern end of the strand. Here the deposits, which rest against the Devonian conglomerates of Knockavelish Head, are described as dipping away from the valley side toward the south or south-south-east at an average dip of 15^0, in which direction, they are also found to thin out rapidly. The varied sequence was described as follows:

8.	Soil with cockle shells	0.1-0.3 m
7.	Head and boulder clay	1-1.5 m
6.	Head (angular fragments)	1-1.2 m
5.	Boulder clay	0.3-6 m
4.	Stratified subangular stones	0-4.5 m
3.	Angular fine head	0-1 m
2.	Sand layer	1-1.2 m
1.	Stony, sandy layer	1.2 m

Working from the bottom up, and within the stratigraphic framework of Wright and Muff (1904), beds 1. and 2. were interpreted as the equivalent of their raised beach gravel and sand units (see above). Bed 3. was thought to correspond with the lower head. The overlying bed 4. was interpreted as "stratified early glacial gravels". Beds 5. and 6. were regarded as corresponding with the till and upper head respectively.

As in the case of Wright and Muff (1904), Kinahan (1878) and Wynne (1868), Reed also thought in terms of "Post-

Tertiary land movements" in order to explain the presence of the raised beach, wave-cut platform and the 'submerged forests'. [Reed noted the existence of a submerged forest, reported to appear some 9-12 m (horizontal distance) from the HWM on Fornaght Strand. Thirty tree stumps were counted. Wisely, no stratigraphic interpretation of the submerged forest was attempted given its relative spatial isolation from the recorded sequence as described above.]

Woodstown to Passage East

The second short paper deals with the coastal section on the west side of the Waterford Estuary (Reed, 1907d). Here, the typical sequence established by Wright and Muff (1904) of platform, beach, lower head,'boulder clay' and upper head was found to be interrupted in the townland of Newtown by a lower 'boulder clay'. This unit was reported to intervene between the beach and the lower head for a short distance (200 m) before thinning out to the north (see Appendix 4 for further details of Reed's 1907 publications). Reed's discussion of the detailed observations was minimal. The origin of the lower till at Newtown was not alluded to and no attempt was made to correlate it with any other previously identified stratigraphic unit.

Tramore Bay to Dunmore East

Reed's third short paper dealing with coastal features in County Waterford covers the coastal strip south and west of Dunmore East as far as Tramore Bay (Reed, 1907e). He observed that the sandstone cliffs were interrupted at intervals by valleys which were filled with 'Boulder-clay and other drift materials', which fact, in his view, testified to the pre-glacial excavation of the valleys.

Two sections were described in some detail: the first of these lies south of Summerville House on the east side of Tramore Bay; while the second section is located at the head of Rathmoylan Cove on the south coast between Tramore Bay and Dunmore East. The platform, lower head, 'boulder clay' and upper head sequence of the south coast was reconfirmed in these two localities.

Reed's detailed findings largely corroborated the earlier observations made by Wright and Muff (1904), although the 'marl', associated with 'Irish Sea ice' further west, was not encountered in the sections from east County Waterford.

2.3.3. Charlesworth (1928)

In this paper on the deglaciation of central and southern Ireland, Charlesworth deduced that the 'Older Drift' in the south of Ireland was separated from the 'Newer Drift' to the north by the 'Southern Irish End Moraine' [originally mapped by Lewis (1894)]. Charlesworth regarded the 'Newer Drift' as the equivalent of the "Wurm

Glaciation of the Alps". His deductions were based on the 'freshness' of the 'drifts' to the north of the 'End Moraine', the relative absence of moraines south of the 'End Moraine', and the finds of remains of 'glacial mammalian fauna' exclusively in the caves of southern Ireland.

Charlesworth regarded the independent ice-centres in the Kerry and Wicklow Hills, the Comeraghs, Galtee, Knockmealdown, and other mountain-clusters of the south as contemporaneous with the 'Irish Sea Ice', and with southward advance of the general ice in the Midlands to the 'End Moraine': "In the Comeraghs the glaciers....were chiefly confined to the eastern and northern sides, and protruded beyond the mouths of the magnificent corries to considerable distances down the mountain-slope, in places descending to altitudes as low as 600 feet (182 m) above sea level. The outermost moraines, like those of later date (as described in the Memoirs, 1865 and by Reed, 1907), are of great size, and composed chiefly of super-glacial material." (Charlesworth, 1928). Unfortunately, no accompanying map of these features is provided in the paper.

2.3.4. Charlesworth (1930)

Charlesworth's conclusion "that the only forces which affected sea-level (during the Pleistocene) were those due to the ice-sheets themselves;" represented a step forward in the Irish glacial literature from the previous position of inferred former changes in the level of the land surface. He envisaged a drop in sea level of about 90 m "during the period of maximum glaciation and of the deposition of the shelly boulder-clay of the southern coast.... The ice sheet - possibly not for the first time - shrank from the southern coast of Ireland to a position at present unknown, but situated possibly somewhere in the region of the Central Plain. Its subsequent re-advance [Early Magdalenian] carried the ice-front forward to the line of the 'Southern Irish End-Moraine'... It is certain that life entered the country during some part of this 'Aurignacean Oscillation' or amelioration of temperature". This last conclusion was based on the glacial cave fauna found to the south of the so-called 'End-Moraine', as already referred to above.

2.4. Mid-Twentieth Century Glacial Literature

2.4.1. Farrington (1939)

The 'end-moraine' was unquestioningly adopted as such by Farrington (1939) who accepted it as "the limit of the younger of the two ice-sheets" as traced by Charlesworth (1928). The 'older drift', either to the south of, or above the limits of the 'younger drift' was described: "In the mountainous areas there is found, above the younger moraines, traces of the older limestone-bearing drift, now largely destroyed by weathering and, for the most part, only recognisable by the associated erratics, since the limestone has been almost totally leached."

Farrington recognised the existence "at various places" of "an old boulder-clay, much kneaded and contorted," which was found to underlie the 'younger drift' and to crop out in areas lying "far south of the marginal belt of the younger drift". He also recognised the deposits of "a third ice-sheet" which had extended from the mountains of West Cork and Kerry. Like Wright and Muff, before him, Farrington found that the associated 'boulder-clay' contained only local rocks and was found to overlie the 'boulder-clay' "of the older northern ice-sheet." (see note below). Although the stratigraphic succession is clear, the time relationship between the two deposits is questioned: "There are certain indications which point to the conclusion that this drift was considerably older than the early mountain glaciation.

NOTE: The 'marly boulder-clay' does not appear to have been distinguished from the 'older limestone-bearing drift' on the south coast by Farrington, who seems to have ignored the earlier conclusions of Wright and Muff (1904) who found that the former predated the latter wherever they were found to crop out in the same section as at Whiting Bay and Dungarvan.

2.4.2. **Farrington (1947)**

The question of the contemporaneity of the local ice centres with the advance of lowland general ice to the 'Southern Irish End Moraine' was examined by Farrington in his work on the local and general glaciations in County Wicklow. He asserted that studies of "the Leinster Chain have shown that there were at least four glacial episodes in that area. Two general and two mountain glaciations have been recorded with certainty. These appear to alternate with one another and their deposits are superimposed in the following order, the most recent being named first:

Athdown Mountain Glaciation
Midland General Glaciation
Brittas Mountain Glaciation
Eastern General Glaciation

Two mountain glaciations have been described from the Galtee group and from the Mount Leinster group. They also occur in the Comeragh range where fresh moraines have been noted by the author lying within the valleys the mouths of which are occupied by older boulder-clay.... There is some evidence that south east of the Comeraghs this ice-cap was relatively more extensive than elsewhere, but no detailed study has been made." (Farrington, 1947). No accompanying map was published. Presumably this latter statement refers to the distribution of conglomerate erratics from the Comeraghs in the lowlands between Kilmacthomas and the sea as reported in the memoirs of the Geological Survey as referred to above (see section 2.2.2.). A still earlier mountain glaciation, termed the Enniskerry Mountain Glaciation, was thought to have preceded the Eastern General Glaciation in the Wicklow area (Farrington, 1944).

Farrington had previously correlated the older Comeragh cirque glaciation with that of the Brittas Mountain Glaciation and the younger/inner cirque moraines of the Comeragh Mountains with the Athdown Mountain Glaciation of the Wicklow Mountains (Farrington, 1939). By extension, although he did not refer to it, he must have regarded the earlier advance of the lowland limestone-bearing ice into County Waterford (south of the 'Southern Irish End Moraine'), as predating the earlier of the Comeragh Mountain glaciations.

The Eastern General Glaciation in County Waterford

Following Lewis (1894), Farrington noted the occurrence of 'northern drift' at 1,200 feet (366 m) O.D. at The Gap in the Knockmealdowns. Again, following Lewis (1894), Farrington accepted that the ice "did not extend down the southern slope", which he regarded as unglaciated. However he did envisage that ice, which succeeded in building up to such heights against the northern foothills of the Knockmealdown Mountains, must certainly have allowed "a considerable tongue of ice to pass by the Ballinamult gap at the eastern end of the ridge, and it is possible that the existence of such a tongue might help to explain some of the difficult problems of the glaciation of the country to the east of the Blackwater gorge." Farrington viewed the effects of glaciation in eastern County Cork and western County Waterford as being so slight "as to leave the topographic features virtually unaltered. Probably nowhere in Ireland can the details of subaerial topographic development be so clearly seen." (Farrington regarded the "reddish boulder-clay" at Youghal as a deposit associated with the "earlier Kerry and Cork glacial phase" and not with the Eastern General Glaciation.)

2.4.3. Mitchell (1948)

Writing in 1948, Mitchell believed himself to have investigated an interglacial deposit containing organic remains which rested in a hollow on the surface of the drifts associated with the 'Brittas Mountain Glaciation', which in turn overlay those of the 'Eastern General Glaciation' and occurred approximately 5 km to the south of the 'Southern Irish End Moraine' (as mapped by Charlesworth, 1928), at Ardcavan in County Wexford. The organic-rich sediments were overlain by what was interpreted as a soliflucted facies of the underlying drift composed of local material. This interglacial material was interpreted as being of last interglacial age and was accepted as corroborating proof of the status of the so-called end-moraine of what had by then been termed the 'New Drift'. This drift was associated with the separate and most recent general glaciation i.e. the Midland General Glaciation (Farrington, 1944).

Farrington's stratigraphic framework was fleshed out and given further weight by the findings as described in the second half of Mitchell's 1948 paper. In contrast to the deposit at Ardcavan the interglacial mud, which underlay the 'Old Drift' at Kilbeg in County Waterford, contained *Abies* pollen. The 'drift' was, however, described as "probably belonging to" the Brittas Mountain Glaciation. This latter correlation was somewhat surprising in view of the fact that the 'boulder-clay of inland origin' as recorded by Wright and Muff (1904) on the south coast of County Waterford at Youghal, Dungarvan and Ballyvoyle, had been correlated (implicitly) with the Eastern General Glaciation (Farrington, 1947 p. 91). The new correlation reverted to Farrington's (1939) view that the correlative of the Brittas Mountain Glaciation in west Waterford was separated from the preceding Eastern General Glaciation by an interglacial. The interglacial mud at Kilbeg was therefore interpreted as a penultimate interglacial deposit lying underneath the deposits associated with the Brittas Mountain Glaciation and possibly overlying those of the earlier Eastern General Glaciation.

2.4.4. 1950-1957

During the next decade several short references were made to the glaciation of County Waterford in the light of new findings made outside the confines of the county boundaries.

Farrington (1950)

In a very brief note on unglaciated areas, Farrington referred to the very thick "rockmantle" on the middle slopes (between 304 and 365 m O.D.) on the southern side of the Kockmealdown Mountains as a possible indicator of unglaciated terrain.

Mitchell (1951)

The position adopted by Mitchell (1951) and (1952) where the Eastern General Glaciation and the Brittas Mountain Glaciation were interpreted as roughly penecontemporaneous events conflicted with Mitchell's earlier interpretation that the interglacial deposit at Kilbeg divided the deposits of the two glaciations stratigraphically into separate phases of glaciation.

Wirtz (1953)

In this paper on the Pleistocene succession in Ireland and western Britain, Wirtz included descriptions of two sections in County Waterford: Ballyvoyle and 'Woodstown' on the west bank of the Waterford estuary:

1. The description of the section at Ballyvoyle hardly differed from that of Wright and Muff (1904). The site was accepted as lying south of the end-moraine of the last glaciation and the glacial sediments exposed at the coast were therefore, automatically assigned to the penultimate glaciation.

2. The section at 'Woodstown' is described as being 25 m high. The only section of that height in the locality is the one in the townland of Newtown and so it is assumed that this is in fact the section which Wirtz visited. The textual description includes the following details and closely resembles that of Reed (1907):

8. Soliflucted layer derived from underlying till.
7. Till of local origin contemporaneous with ice in Irish Sea (Eastern General Glaciation).
6. Slumped
5. Layer of course head marking renewed glaciation.
4. Phase of weathering associated with ice retreat.
3. Till of local northern origin laid down by ice which eroded the beach (equivalent to the Enniskerry Mountain Glaciation).

2. Raised beach slumped on platform (correlated with penultimate interglacial).

1. Raised rock-platform.

Farrington (1954)

Once again Farrington (see comments on Farrington 1950) seems to have been unaware of Wright and Muff's record of local drift of inland origin on the east side of the Blackwater estuary near Youghal. His discussion of the glacial succession in east County Cork referred only to the "boulder-clay of the older Kerry-Cork glaciation" which overlies "the marly boulder-clay of the Eastern General ice-sheet" as portrayed in his accompanying map.

Mitchell (1957)

In this general review of the Pleistocene Epoch in Ireland, five new developments concerning the interpretation of Quaternary events in County Waterford were fleetingly introduced (starting from the bottom of the stratigraphic column):

1. A thin layer of peat was found to lie on the rock platform at Newtown, County Waterford. It was reported to be of the same age as the interglacial deposits at Gort in County Galway and Kilbeg in County Waterford on the basis of its *Abies*, *Picea* and *Rhododendron ponticum* pollen content. The peat was described as being "covered by glacial deposits of Saale age."

2. Three glacial stages of probable Saale age were

recognised [the Enniskerry mountain glaciation, followed by the Munster general glaciation (formerly the Eastern General Glaciation) and the Brittas mountain glaciation in turn]. A stratigraphic equivalent of the Enniskerry mountain glaciation was briefly referred to as having been identified "on the coasts of Wicklow, Wexford and Waterford." No localities were cited, although it is possible to deduce that the reference probably alluded to the lower diamictons at Clogga, Nemestown and Newtown respectively.

3. For the first time since 1904, the presence and source of the 'boulder-clay of inland origin' in the coastal exposures on the south coast of County Waterford were once again recognised. The recognition was only partial in that the lines of ice-movement on the accompanying map clearly show movement of ice from the central lowlands off the coast of County Waterford. Unfortunately, no there is no supportive textual reference to this supposed ice movement.

4. The effects of periglacial activity in the form of stone polygons (which are seen in section at the roadside at Raheens, County Waterford) were noted south of the "main Weichsel ice". This periglaciation was associated with the advance of ice in the midlands to the "Tipperary moraine" (formerly the 'Southern Irish End Moraine'). It was taken as partial proof of the limit of the Midland general ice in the absence of any marine interglacial

deposits. All the weight of evidence for the existence of the last interglacial continued to rest on the interglacial deposit at Ardcavan.

5. Finally, the Athdown mountain glaciation was recorrelated with the 'main Weichsel ice' and no longer with the late Late-Glacial as heretofore (Jessen and Farrington, 1938; Farrington 1947 and Mitchell, 1951), thus implicitly reinstating the contemporaneity of the Comeragh Mountain cirque ice (which had previously been correlated with the Athdown mountain glaciation on the basis of similar height of the snowline and morphology of the cirque moraines) and the general ice in the midlands.

Stephens (1957)

In this paper the oldest and youngest elements in the Quaternary stratigraphic column were reviewed: namely the "interglacial platform" and the early post-glacial raised beach on the east coast of Ireland. Stephens' findings are potentially relevant to the Pleistocene 'history' of County Waterford as aspects of both subjects feature in the glacial literature of the county. Stephens accepted Mitchell's (1948, 1951) correlation of the Pleistocene succession in Ireland including his assignment of the raised rock platform on the south and east coast to the Great Interglacial (Mindel-Riss) to which he added: "although there is no definite proof that it may not be even older." He also concluded that as the platform appeared to display "no discernible tilt along the east coast of Ireland", possibly indicating that "Eastern Ireland had recovered isostatically its 'interglacial' level, it is raised with reference to present day level."

Regarding the early post-glacial raised platform found along the east coast, Stephens concluded that "to the south of Arklow the water plane of the raised beach period must be regarded as reaching present day high water mark or passing below it. Consequently the old beach and cliffline have been destroyed by later submergence and erosion, while further north isostatic recovery was sufficiently rapid and of such an amplitude as to preserve the raised beach.....The submerged peat beds and forests around our coasts range in age from the Mesolithic (Pollen Zone VI approximately, which pre-dates the Early Post-Glacial submergence in Scotland and Northern Ireland) to the Late-Neolithic, and perhaps even more recently."

2.4.5. Watts (1959)

In this most recent major published reference to the glacial sediments of County Waterford (see discussion above under 2.1.1.) Watts re-examined the interglacal deposit at Kilbeg which was previously investigated by Mitchell (1948). He also systematically examined for the first time, two types of interglacial deposits at Newtown, one of which has already been briefly alluded to (Mitchell, 1957).

Kilbeg

In contrast to Mitchell's earlier general conclusions which were due to the unlogged nature of the original organic material from which the samples were drawn, Watts was able to determine and chart the progression of an interglacial cycle almost from its initial stage through to the final stage. The continuity of the vegetational succession, as determined from pollen rain into a rock-bottomed lake, was punctuated by one major interruption toward the end of the cycle. The cycle was divided into five stages: the middle period was characterised by an "unusual arboreal vegetation" consisting of an almost evergreen forest with *Abies*, *Picea*, *Pinus*, *Taxus*, *Rhododendron* and *Buxus*. With the exception of *Alnus* and *Betula* the deciduous trees were absent. This tree-flora was similar to that in the Caucasus now and was mixed with a "fully Atlantic" type herb-flora resulting in a marked similarity between the interglacial flora at Kilbeg and Gort, and dissimilarity between the interglacial flora at Kilbeg and the inferred British equivalents at Hoxne and Clacton.

Newtown I

The thin layer of peat resting on the rock-platform in the townland of Newtown on the west shore of Waterford Harbour, was first noticed by Farrington and Mitchell. It was subsequently referred to by Mitchell (1957) and its stratigraphic position was described by Wirtz (1953). Watts re-examined the stratigraphy at Newtown. His descriptions closely concurred with the detailed observations of Reed (1907) to whom he did not refer. He recorded the following composite sequence which was based on descriptions of two separate points approximately 200 m apart and of the intervening exposure:

> "Boulder-clay 'Ballyvoyle Till'.
> Second 'head'.
> Boulder-clay 'Newtown Till'.
> Stratified sand and silt.
> First 'head'.
> Peat and associated silts.
> Rock platform of raised beach."
>
> Watts (1959 p.118)

The flora of the peat (which was nowhere clearly stated to crop out in section under any of the above units *in situ*), was characterised as pine forest with local willow and birch scrub and a heath-type herb flora. Watts concluded: "if it (the flora) belongs to the same period as the Kilbeg interglacial deposit, as the author believes to be indicated by the stratigraphy, it must belong to the end of the interglacial period and not the beginning. If this is so, it must represent a continental period at the end of the interglacial, and belong in the period represented by an unconformity at Kilbeg."

Newtown II

"At a point 50 m to the north of the main exposure of the lower boulder-clay" two layers of "apparently stratified" silts containing "secondary" warmth-demanding plant remains, akin to those of the Kilbeg deposit, were observed. They were therefore dismissed as being stratigraphically unimportant.

Watts understood the importance of setting the position of the organic sediments accurately "in the general sequence of Quaternary deposits in the area". He recognised the existence of the 'pre-glacial' raised beach (termed the Courtmacsherry beach by Mitchell, 1957) as the lowest element of the stratigraphic column (with which he correlated the Kilbeg interglacial deposit) but did not cite any localities of its outcrop in County Waterford. The underlying raised rock platform and the overlying 'lower head' of previous literature were not alluded to.

Watts identified as next in sequence four types of boulder-clay which were regarded as the product of a single glaciation "best understood as the results of contact and competition between an inland ice sheet and an ice sheet centred on the Irish sea which moved parallel to the coast" (Watts, 1959):/

1. Watts stated that the advance of the ice sheet from the Irish Sea (termed 'the Eastern General Glaciation') was shown by stone orientation studies to have moved along the County Waterford coast in a south-westerly direction. No data was provided to support this claim and no reference was cited although an acknowledgement to the following author (Stevens, 1959) "for some of the data on the Waterford drifts" was included among several other names at the end of the paper. The deposits associated with the 'Irish Sea ice sheet' were reported to crop out at Tramore, Kilfarrassy Strand, Ballyvoyle Head and Dungarvan. Of these outcrop localities, only Dungarvan had been previously noted (Wright and Muff, 1904). Unfortunately the sections were not described and only the general stratigraphic position was recorded: "The clay is not seen inland, and where it is seen it is the lowermost boulder-clay. Outside this area this clay overlies deposits of the Courtmacsherry Beach."

2. The single outcrop of the red stony 'Newtown Till' is then described as cropping out between two layers of head and underneath the 'Ballyvoyle Till'. It is interpreted as representing "an early stage of activity of an inland ice sheet, separated from the main period of activity of the inland ice by a retreat stage in which 'head' was formed".

3. The 'Ballyvoyle Till' (as described in Section 2.1.1) was regarded as the product of the main local glaciation.

4. The fourth, a limestone boulder-clay represented the uppermost unit in the accompanying stratigraphic table. It was termed the 'Mothel Till' and was recorded at Mothel and Halfway House on the east and west sides of the Comeragh Mountains in northern County Waterford respectively. "The 'Mothel Till' appears to overlie boulder-clay of the main local glaciation (Ballyvoyle Till) but the stratigraphical situation is obscure and no exposure is known where the two are satisfactorily seen to be in contact". More fieldwork was called for to "ascertain its distribution and stratigraphical relationships".

All three interglacial deposits occur south of the 'end-moraine'. They are located within and under glacial deposits ('the Ballyvoyle Till') which were correlated, along with the antecedent 'Newtown Till' and the subsequent 'Mothel Till', with the Saale Glaciation of Northern Europe. As a result, the interglacial deposits were automatically referred to the Riss-Saale or Great Interglacial according to Mitchell's (1957) stratigraphic framework. Watts did investigate the possibility of the Kilbeg deposit belonging to the preceding interglacial. He dismissed this possibility on the grounds of floristic differences with British Cromerian sites and the lack of a strong Tertiary element in the floristic content of the Kilbeg deposit. However, because of his uncritical acceptance of the status of the 'end-moraine' of the 'last glaciation', Watts did not fully explore the possibility of a last interglacial age for any of the three deposits examined [see Warren (1979) for a detailed and critical assessment, on palynological and stratigraphical grounds, of the age of the 'Gortian' deposits].

2.4.6. Stevens (1959)

This doctoral thesis represents the last major unpublished reference to Quaternary sediments in County Waterford. In the course of her research on the Pleistocene deposits of Counties Wexford and Waterford the author described twenty exposures in glacial sediments in County Waterford. Till fabric analyses, heavy mineral analyses and erratic content were employed to distinguish between glacial deposits of various origins and ages. The now traditional stratigraphic framework as proposed by Mitchell (1957) was adopted with few and slight amendments:

1. The 'Eastern General Till' was described as being quite similar to the calcareous facies of the 'Ballyvoyle Till' (see below) in terms of its erratic content except for the shell content of the former. Texturally, the clayeyness of the former contrasted with the sandiness of the latter. The heavy mineral content of the 'Eastern

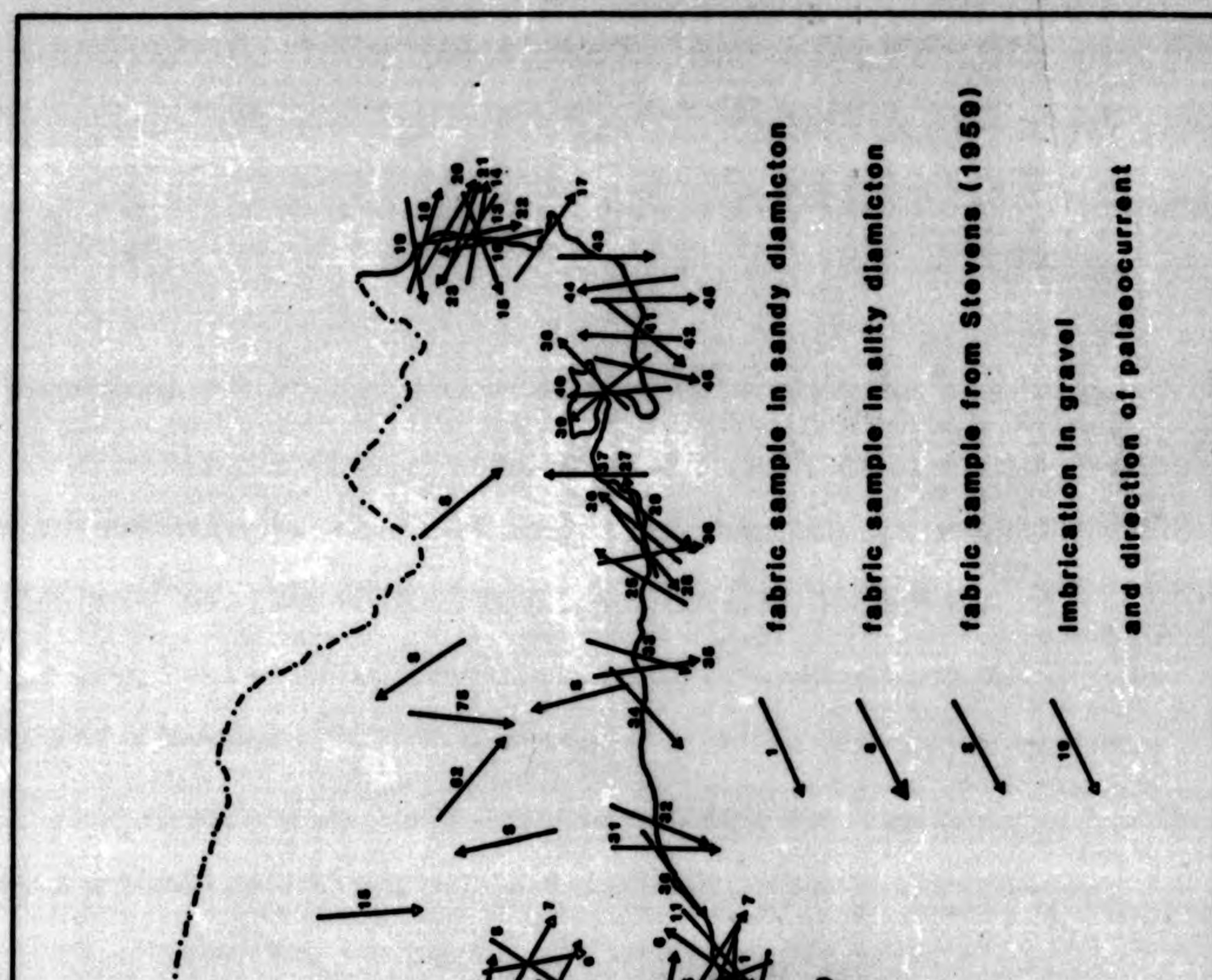


Figure 8 Directional modes from fabric and imbrication samples

General Till' was comparable with that of the 'Fethard Till' (both being derived from a northerly, granitic area). Preferred stone orientations of clasts taken from outcrops of the 'Eastern General Till' at Ballyvoyle, Kilfarrassy and Garrarus Strand (new locality) showed a north-east to south-west alignment. This observation was interpreted as being consistent with a flow of ice in a south-westerly direction across the south-east of Ireland. The previously recorded outcrop of 'Eastern General Till' at Tramore (Watts, 1959) does not appear to have been confirmed by Stevens (1959).

2. The 'Newtown Till' was thought to be an early outlier of the 'Fethard Till' of County Wexford as their characteristics coincide very closely. The heavy mineral content of the two deposits was seen to be almost identical reflecting their derivation from the Leinster granite and the associated metamorphic aureole (Appendix 5). The preferred orientation of the contained stones in the 'Newtown Till' was shown to parallel that of the clasts from the 'Fethard Till' i.e. north-north-west to south-south-east (Figure 8). The red, stony character of the lower till at Newtown was considered to be derived from the contained Old Red Sandstone clasts which, in turn, was thought to be derived from Devonian Old Red Sandstone near Waterford town to the north. It was compared to a lower facies in a similar stratigraphic position at Lumsdin's Bay on the east side of the Waterford estuary. Because of this probable correlation

between the two tills it was suggested that the 'Newtown Till' possibly succeeded the advent of the 'Eastern General Glaciation'. (The deposits associated with this latter event were found to be overlain by the 'Fethard Till' to the east of Kilmore Quay.) This tentative correlation was suggested in the absence of any point of contact between the 'Newtown Till' and that of the 'Eastern General Glaciation'.

3. It was suggested that the second (upper) layer of head at Newtown might have been "transported into a secondary position by the ice" although no reason for such an interpretation was put forward.

4. The 'Ballyvoyle Till' was divided into two facies: a lower limestone-bearing calcareous till and a non-calcareous sandy till containing occasional chert and limestone erratics. The calcareous facies is reportedly characteristic of deeper sections and was found mainly in coastal/valley exposures as at Ballyvoyle, Kilfarrassy, Garrarus and Newtown; while inland, it has been reported at Ballycashin, south of Waterford town. The non-calcareous facies was found mainly in shallow exposures, commonly on the higher land as at Kilmacthomas and Kildermody. Coastal outcrops were observed at Clonea Castle, Dunabrattin Head, Annestown and Tramore. Most of the above localities represent previously unrecorded finds of the 'local boulder-clay'. Both facies were regarded as grading into each other to produce a hybrid non-calcareous

till with a small proportion of limestone and chert as at Kilbeg. Heavy mineral analyses show the 'Ballyvoyle Till' to be particularly poor in content in contrast to the underlying glacial deposits; it is characterised by those minerals derived from the volcanic rocks of County Waterford itself, largely hornblende and chloritic matter. Preferred orientation of the contained stones is from north-west to south-east at most inland sites. While a north-east to south-west direction was preferred at most of the coastal sections. These directions were taken to be consistent with the general north to south pattern of striae as recorded by Wright and Muff (1904) in east County Waterford and with similarly oriented striae at Kilbeg. Stevens concluded that a south-easterly movement of ice was indicated over eastern County Waterford while a south-westerly trend was inferred at the coast. A long, sinuous north-trending ridge composed of 'fluvio-glacial' gravels was also recorded near Callaghane Bridge. This ridge was interpreted as being associated with the northerly retreat of the Ballyvoyle ice.

5. Finally, the 'Mothel Till' of Watts (1959) was considered redundant as the associated limestone-rich 'fluvio-glacial' gravels around Mothel and Halfway House were regarded as grading laterally into the limestone-rich facies of the 'Ballyvoyle Till'. In effect it was regarded as an inland equivalent of the lower limestone-bearing facies of the 'Ballyvoyle Till' and was found mainly in the valleys, particularly the valley of the River Nier.

Unfortunately, none of the above conclusions have been published and do not seem to have been widely appreciated as a result.

2.4.7. 1960-1976

Several brief references to the glacial sediments in County Waterford have appeared in review-type papers relating to the Quaternary succession in Ireland during these sixteen years. Apart from general references, a small number of more detailed contributions have been made (dealt with in chronological order according to date of publication). Many will be referred to again at relevant places throughout the text and in the chapter on correlations.

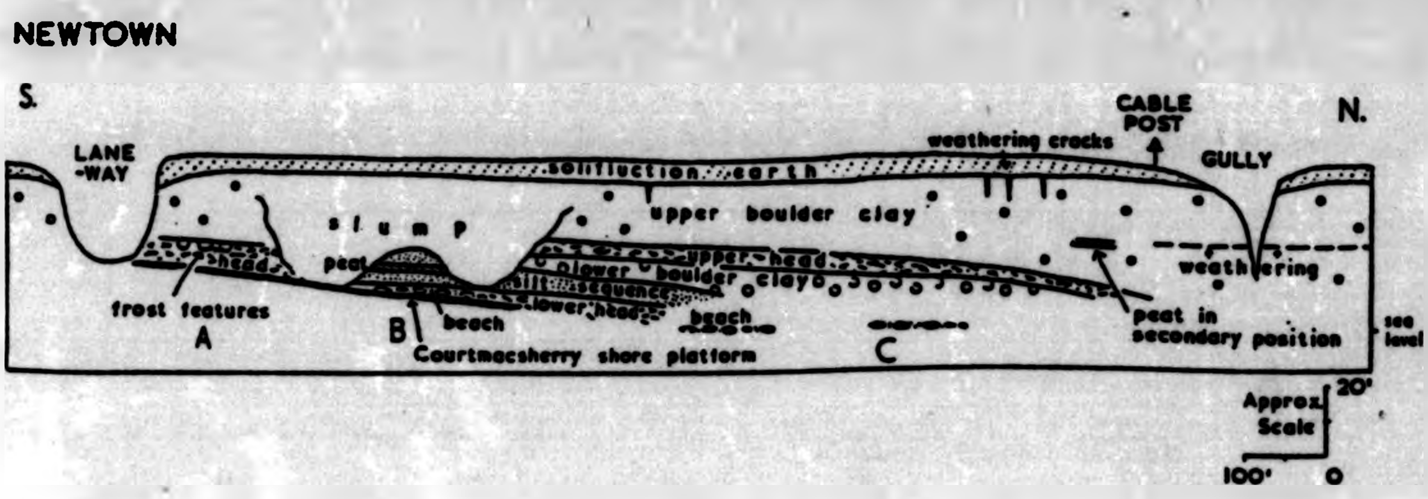
Mitchell (1960)

In this paper Mitchell reviewed the evidence for three former couplets of warm and cold periods in the Irish Sea area: the Cromer, Hoxne and Ipswich warm periods whose deposits intercalate those of the Lowestoft, Gipping and Smestow cold periods. New terms were introduced for some of the Irish deposits of the, by then, traditional succession (see Figure 14). Three deposits of particular relevance to the Pleistocene record in County Waterford were renamed: the Ballycroneen [formerly the Eastern General (Farrington, 1944), later, the Munster General or Munsterian (Mitchell, 1957)] 'boulder clay' (after the most westerly site at which the deposit was recorded), the

Garryvoe boulder clay (formerly the Greater Cork-Kerry) [after the locality of its most easterly outcrop as described by Farrington (1954): "where a boulder-clay with local rocks rests on sands and boulder clay of Ballycroneen age"] and the Tipperary moraine (formerly the Southern Irish End Moraine). The erratics contained in the Courtmacsherry beach furnished the author with sufficient evidence upon which to base the former existence of an early cold period (Lowestoft): "I attribute the transport of the erratics now found on the platform and in the beaches to an ice-sheet of Lowestoft age that came down the Irish Sea, reaching at least to Cork and to Cornwall." Mitchell (1960).

Synge (1960)

Somewhat similar views in relation to the glaciation of southern Ireland were expressed in this assessment of the Quaternary Period in Ireland, although, the creation of new terms was largely avoided. "Scottish ice in the basin of the Irish Sea" was thought to have advanced southward and to have crossed onto the present coast between Dungarvan and Power Head. Synge agreed with Mitchell (1957): "In the south, between Dungarvan and Nemestown (Co. Wexford), ice from the north-west (this advance was termed the Munster General Glaciation by G. F. Mitchell) was powerful enough to keep the Scottish ice off the coast." Thus the view, originally expressed by Carvill



(after Mitchell, 1962).

Figure 9 Sketch of section at Newtown

Lewis (1894), that western County Waterford did not experience significant glaciation by ice from the midlands continued to be held. Eastern General ice from the north-west was, however, shown diagrammatically by Synge to have reached the Youghal area on the accompanying map (p. 126). This ice was considered by Synge to have been responsible for the carriage and deposition of Galway granite erratics to Cork Harbour and south Kilkenny to the west and north of County Waterford. Corrie glaciers were considered to have existed in the Comeraghs and Knockmealdowns during the Later Midlandian Glaciation.

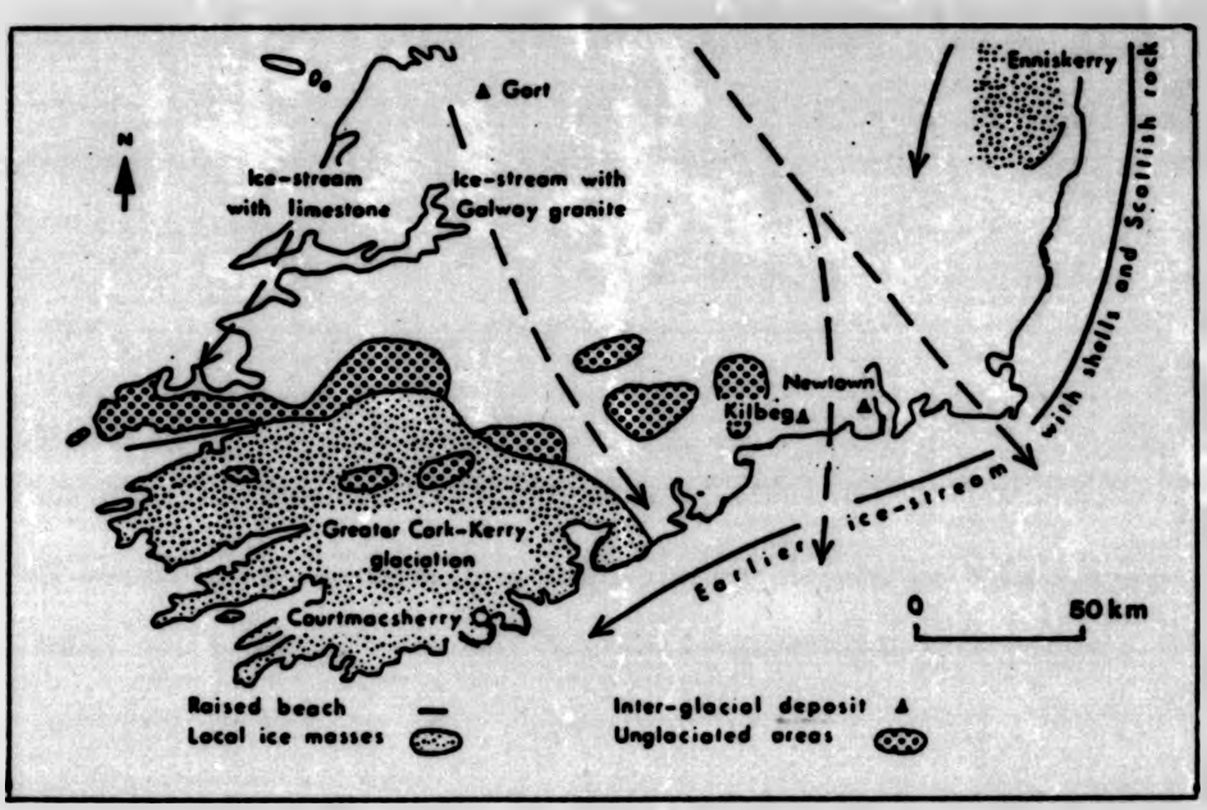
Mitchell (1962)

This report on a field meeting held in Wales and Ireland recounts visits to Newtown, Callaghane Bridge, Raheens, Kilbeg and Ballyvoyle Head in County Waterford. Two new pieces of information gleaned from the descriptions of the sites include:

1. The occurrence of shell fragments (thought to have been picked up in the Waterford estuary by southbound ice) in the 'upper boulder clay' (Ballyvoyle Till) at Newtown [see sketch and stratigraphic table (Figures 9 and 14)].
2. Both fresh and weathered limestone were recorded in the "degraded esker" at Callaghane Bridge.

Mitchell and Synge (1964)

Both authors contributed to the section on glacial geology in the soil survey of County Wexford. Two points of



(after Mitchell and Synge, 1964).

Figure 10 Glaciation of southern Ireland relevance to the glacial succession in County Waterford were noted:

1. Doubts about the interglacial status of Ardcavan were reflected in its uncommented-upon omission (for the first time) as a type-site for the last interglacial from the accompanying stratigraphic table.

2. The accompanying map seems to reflect doubts about the extent of glaciation in western County Waterford as the arrows depicting the movement of ice from the Galway area of Saalian age point to east Cork, east Waterford and Wexford only (see Figure 10).

Orme *et al.* (1964)

Similar confusion about the extent of Saalian ice from the Irish Sea in west Waterford is also reflected in this joint contribution on the physique of the south of Ireland. Outcrops of this deposit which were formerly recorded on the south coast of County Waterford at Dungarvan (Wright and Muff, 1904), Tramore, Kilfarrassy and Ballyvoyle Head (Watts, 1959) and at Garrarus by Stevens (1959) were all omitted from the map (p. 492). The coastal areas between Ardmore, western County Waterford and Kilmore Quay in County Wexford were portrayed as having been glaciated by ice of Saalian age from the midlands.

Orme (1964)

This study of Tertiary surfaces in the Drum Hills included the only direct reference to the glaciation of this particular part of west County Waterford. Orme followed his predecessors in accepting the following position: although the area was "covered by various ice streams during Pleistocene times", it was "not severely glaciated and remained ice-free during the last regional glaciation in Ireland." However, unlike his predecessors, he appears to have appreciated Wright and Muff's (1904) conclusion regarding the invasion of the area by ice of inland origin. The "various ice streams" included "at least two main ice streams... An earlier phase carried brown, calcareous till containing shell fragments, flints, east Waterford igneous rocks and Irish Sea basin materials into the Dungarvan corridor and to beyond Youghal brickworks from the east and north-east.... A later phase carried coarser red till of mainly local debris south and south-west across the Drum Hills into the Lickey valley, where large limestone erratics occur, and down the Blackwater valley." (Orme, 1964 pp 66-67). Unfortunately, Orme did not discuss the evidence upon which his conclusive statements were based and no localities are described.

Synge (1964)

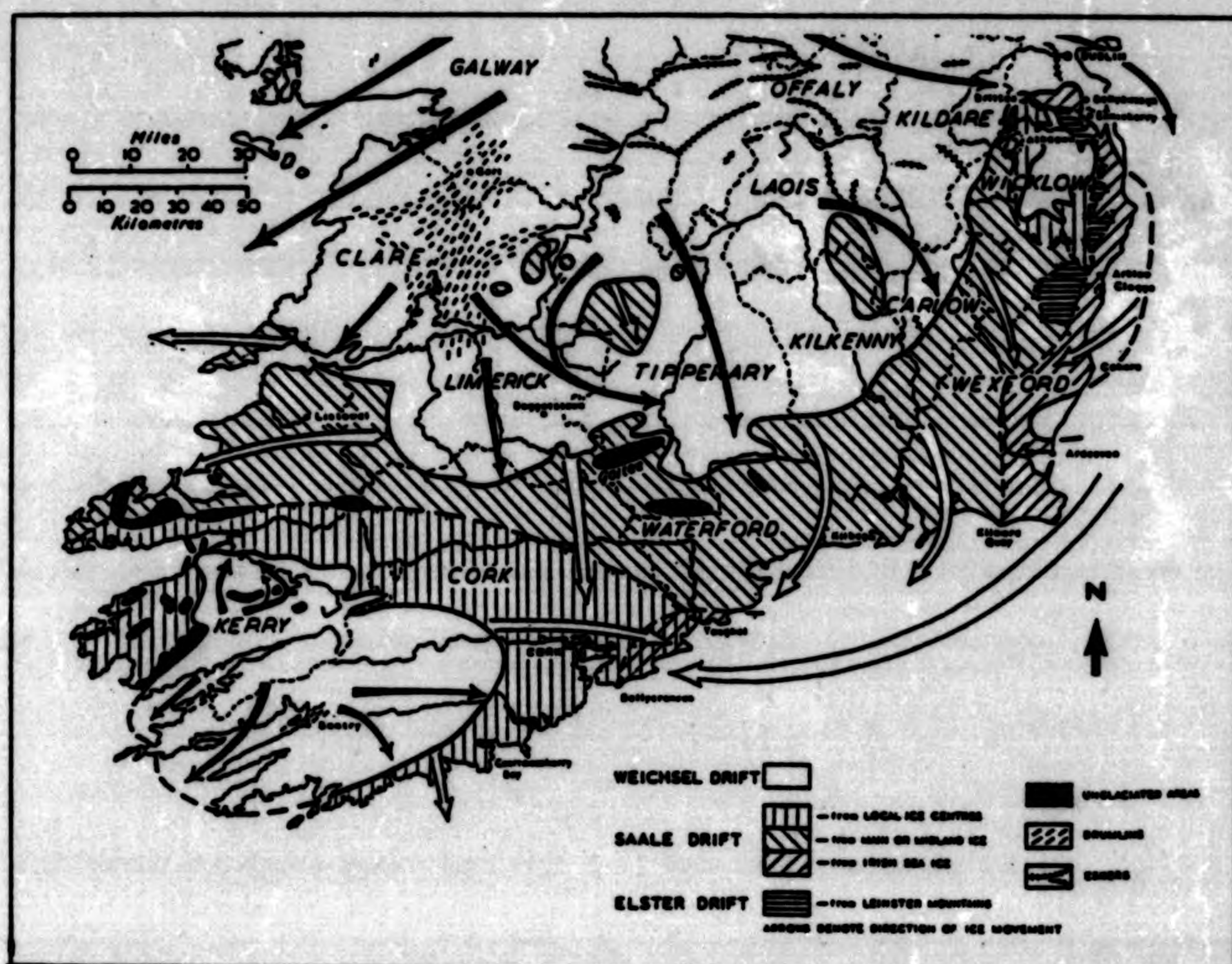
Synge discovered beach material intervening between the lowermost Clogga Till and the overlying Eastern General/Macamore Till on the east coast. The beach was tentatively correlated with the Courtmacsherry beach on the south coast. The overlying Macamore Till was thought to be overlaid by the Bannow Till (formerly the Munsterian or inland equivalent of the Eastern General and the Brittas Boulder Clay of Mitchell, 1957 and 1962) in western County Wexford (see Figure 14). This discovery had implications for future interpretations of the succession in Waterford as will be seen later.

Watts (1964)

Interglacial deposits were discovered in the course of well-digging at Baggotstown, County Limerick (inside the limits of the Tipperary moraine) in 1959. Samples were taken from the excavated material and subsequently analysed. An interglacial sequence similar to that at Gort and Kilbeg was sandwiched between two stony tills and overlain by "a small organic interglacial deposit containing a temperate flora stratified in the boulder-clay above the main interglacial deposit". The uppermost boulder-clay was less than five metres deep and was considered, rather doubtfully, by Watts to "represent several glacial episodes". The lowermost boulder-clay was interpreted as pre-Gort in age and a similar occurrence was cited at Kildromin, County Limerick.

Farrington (1965)

Farrington remarked about the precariousness of



(after Orme *et al.*, 1966).

Figure 11 Glaciation of southern Ireland

correlations in this attempt to correlate those "drifts of the south-east" which were regarded as overlying the Eastern General boulder-clay saying that the most prominent symbol in his stratigraphic table was a query.

Orme (1966)

A number of astute observations in relation to the age and distribution of the beach and platform and the overlying surficial deposits in County Waterford are made (or remade) in the course of this article:

1. The position, as outlined in Orme *et al.* (1964) (see above), was corrected in this review of Quaternary sea-level in Ireland to indicate a more extensive glaciation of the Waterford coast by 'Eastern General' ice of Scottish/Irish Sea origin (see Figure 11, a reproduction of map on p. 129).

2. It was suggested that the comparative rarity of recorded striae on the raised platform (given that it was glaciated twice since the formation of the raised beach which rests directly on its surface) was due to "contemporary wave action."

3. It was further suggested that the platform itself tended to survive "in sheltered locations protected from destruction by modern seas by either a thick cover of superficial deposits or protective rock headlands." (p. 130). Following Wright and Muff (1904), many of the bevelled cliffs on the Waterford coast were interpreted as having been eroded, along with any overlying surficial

sediments, since their deposition.

4. At other places, the raised beach and associated shore platform were traced into embayments and estuaries such as that of the Blackwater and the "limestone corridors of Waterford". This observation, also noted by Wright and Muff (1904), led to the conclusion that the formation of the platform (and therefore, that of the beach) followed a period of downcutting associated with low sea-level, (probably during the late Hoxnian or early Saalian) as exemplified by the buried rock channel of the Blackwater estuary. But, as Orme pointed out, because of the doubts cast about the status of the Ardcavan interglacial deposit and its removal by marine erosion, the "minimum age of the platform, which certainly pre-dates the main Weichselian glaciations, thus depends insecurely on the variable weathering rates of the older drifts." (Orme, 1966, pp. 135-136).

5. Finally, Orme underlined the difficulty in establishing the "precise age of the former shore-zone" according to the age of the overlying deposits. He pointed out that the floristically featureless peat which rests on the platform at Newtown (Watts, 1959) is overlain by slumped deposits and could therefore just as easily represent a post-glacial peat deposit. However, Mitchell (1970) reported a ^{14}C date of greater than 38,000 years B.P. (Birm. 89) for this peat.

Farrington (1966)

The early raised beach in County Cork was the subject of a similar (to that of the above publication), though more specific, study which appeared in 1966. Many of the observations recorded in this paper are of potential relevance to the coastal succession in Waterford which strongly resembles that to the west in County Cork.

1. The author noted the north-easterly origin of the far-travelled erratics in the beach and attributed their presence there to an older (Mindel) glacial event.
2. He also recorded periglacial shattering and striae on the platform (usually in beach-free areas) to the west of Garryvoe i.e. areas which were regarded as having been invaded by expansion of ice during the Greater Cork-Kerry glaciation.
3. The area to the east of Garryvoe was characterised by more frequent occurrences of the raised beach and the absence of striae. The lowermost boulder-clay at this locality and further east was typified by the comparatively stone-free deposits of Eastern General ice whose lack of erosive power was implicitly inferred.

In this publication Farrington continued to echo some doubt about the correlations put forward by Mitchell (1960) where the raised beach and its overlying deposits were attributed to the penultimate interglacial and subsequent glacial periods respectively. Farrington acknowledged the challenge, presented by John (1965) and

Bowen and Gregory (1965) wherein the Courtmacsherry beach and its British equivalent and the overlying glacial sediments were assigned to the last interglacial and glacial periods respectively.

Watts (1967)

Further doubts were cast on the basis of the stratigraphic correlation with the publication of this paper on an interglacial site in County Limerick.

1. Floristically, the interglacial sites at Kilbeg, Gort, Baggotstown and Kildromin display marked similarities despite the fact that only the first-named site lies outside the so-called end-moraine of the last glaciation and underneath 'older drift', while the two latter sites occur under less than five metres of till which must represent "both the Saale and Weichsel glaciations". "The placing of Kildromin in the Gortian interglacial draws attention to the strange failure of Irish Quaternary geologists to find Eemian (Last Interglacial) deposits. In principle, it should be easier to find Eemian than Gortian deposits since they have been less exposed to erosion and should not be so deeply buried. One might be tempted to think that the known Irish interglacial sites have been wrongly dated and are really of Eemian age." (p. 345).

2. The upper *Pinus*-dominated organic deposits at Newtown and at Fenit (Mitchell, 1970) were interpreted as being

"almost certainly pre-Bemian", presumably because of their occurrence underneath deposits lying outside the 'end-moraine'.

3. Watts was uncertain whether to place the upper probably unconformable herbaceous-dominated sediments at Baggotstown and Kildromin in a separate and younger interstadial or to assign them to the end of the 'Gortian' interglacial.

4. The author also stated that "while the sampling method was adequate for pollen-analysis it does not yield enough material for macrofossil work or for studying stratigraphy of the glacial deposits." (Watts, 1967, p.340).

Killeen (1968)

'Fresh' moraines with steep slopes were located within the cirques of the Comeragh Mountains. The moraines displayed a double sequence usually separated by 60 m in altitude. These moraines were attributed to the later mountain glaciation (which was regarded as the local equivalent of the Midlandian) as the Comeraghs were considered to lie beyond the limits of the last general glaciation.

Synge (1969)

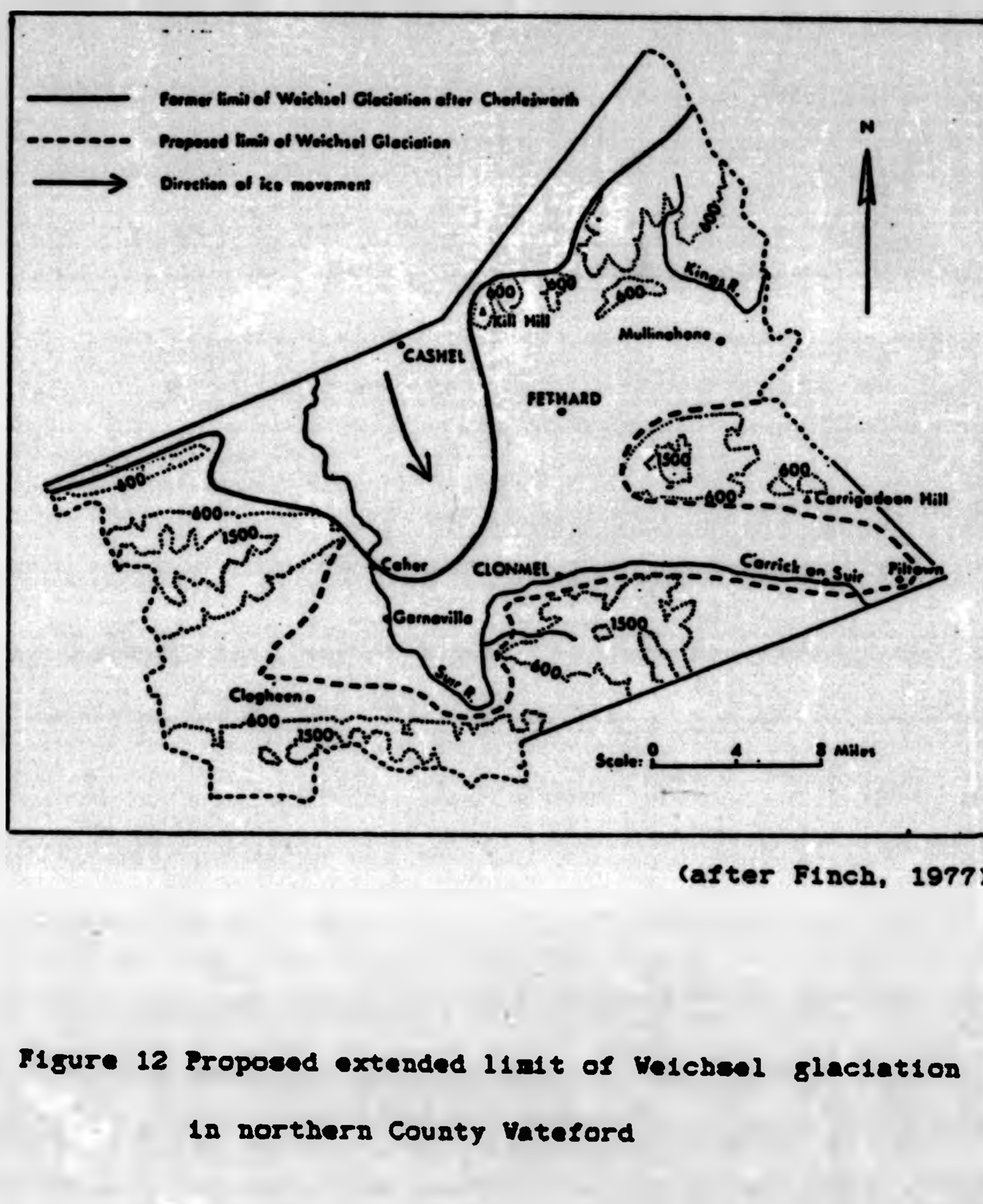
Synge concluded in this brief paper on the Wurm ice limit in the west of Ireland that the Ballylanders end moraine [formerly, the 'Southern Irish End Moraine' of Charlesworth (1928) and the Tipperary moraine of Mitchell

(1960)] of the last glaciation was formed c.23,000 B.P. although no basis for the age was cited.

Synge (1970a)

The traditional stratigraphic table was re-presented once again. According to this author, Ardcavan was reported to have been rejected by Mitchell as the type-site of the last interglacial in Wilson (1968). Mitchell no longer regarded Ardcavan as lying outside the limits of the last glaciation and consequently, the former interglacial deposits were assigned by him to the Late-Glacial. Other organic sediments of possible last interglacial age were suggested in its place: namely, the pine-containing organic horizon under a drumlin at Meenbog, County Mayo and a layer of polleniferous sands caught up between two layers of till at Shortalstown, County Wexford.

Synge saw no "evidence to support the idea that the drift south of this glacial limit, here termed the Ballylanders moraine, can be regarded as an earlier stage of the same glaciation" (p. 40). He cited the absence of constructional glacial features (with the exception of kames), the widespread impact of solifluction, periglaciation and weathering exclusively found in areas underlain by 'older drift' as evidence of the subsequent interglacial and glacial periods. He considered the Ballyvoyle till on the east Waterford coast as the lateral



(after Finch, 1977).

Figure 12 Proposed extended limit of Weichsel glaciation in northern County Wateford equivalent of the Bannow till on the Wexford coast and both units were firmly assigned with a Saalian age.

Synge (1970b)
In this brief analysis of the glacial drifts of south-east Limerick, Synge reiterated the basis for distinguishing between the 'older' and 'younger drifts': degree of weathering, 'freshness' of drift features and amount of solifluction.

Finch (1971)
This author working on the soils of the south Tipperary area, remapped the limits of the Weichsel drift deposits (formerly mapped by Charlesworth, 1928) according to the characteristics of the soils which have developed on their surfaces. He also regarded the preservation of limestone boulders on the surface of the drifts as features "exclusive to the Weichsel Age drift in Ireland".

Using the distribution of the Elton. Howard and Baggotstown soils, Finch redefined the limits of the Weichsel ice sheet in the south Tipperary area extending the original limit as defined by Charlesworth (1928) to the south and south-east. The new limit implied the incursion of Midlandian ice into the northern foothills of the Knockmealdown and Comeragh Mountains and down the Suir valley as far as Piltown (Figure 12).

Colhoun and Mitchell (1971)

Estuarine sands caught up between two tills at Shortalstown, County Wexford were found to contain relatively large amounts of tree pollen including that of *Quercus, Pinus* and *Betula*, with 7% *Ulmus*. The short pollen diagram from this site was interpreted as indicative of interglacial conditions very similar to those described for the middle of Zone *e* of the last interglacial at Ipswich (West, 1957).

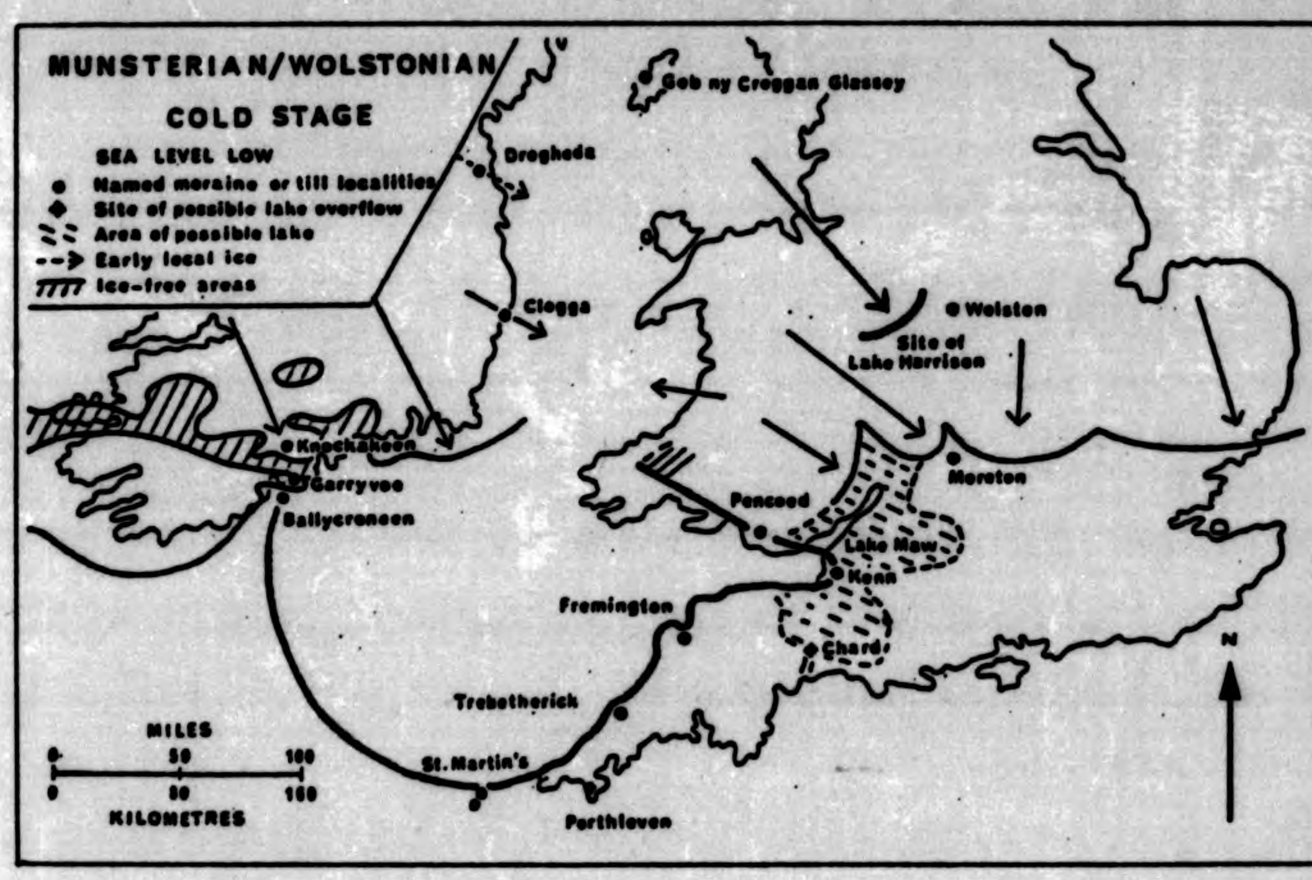
The lowest unit in the disturbed sequence consisted of a lower till which was thought to be derived from the north as it contained flint and shell fragments and other sub-local erratics "derived from parent rocks a short distance north of the site". However, the small percentage (2.67%) of Carnsore granite (whose outcrop lies well to the south) was not explained. Mechanically, the lower till was distinguished from the upper till (which was found to overlie the interglacial marine beach and pollen-bearing estuarine sands) by being slightly coarser on average. It contained higher percentages of gravel and sand and less silt and clay than the upper till. The upper till which was sheared into position, was thought to have come from the north also on the base of its erratic content and till fabric analysis. Chemically, the lower till had a slightly higher carbonate content than the upper till. Mitchell affirmed: "From their stratigraphic position and their difference in colour, carbonate content, and average grain size, it must be concluded that the Lower Till and Upper Till deposits were of different origins and age." (p. 218).

The organic deposit at Ardcavan was once again stated to be of lateglacial age as it lies within the limits of the last glaciation. Outside these newly established limits at Tomcool, County Wexford, "soliflucted Munsterian till whose surface has been disturbed by the formation of pingos (Mitchell, 1971)", was contrasted with the pock-marked surface of the Midlandian glacial deposits where lateglacial sediments dated to 9,100 B.C. were found in the basins of the kettle holes.

Mitchell (1972)

The correlation-table in this second approximation of the Pleistocene history of the Irish Sea displayed new correlations some of which appeared to disregard previous interpretations of the Irish Quaternary sediments on the east and south coast (Synge, 1970a):

1. The Cahore beach [formerly correlated with the Courtmacsherry beach of the penultimate interglacial (Mitchell, 1960)] was correlated with the Shortalstown marine sand and was therefore attributed with a last interglacial age. This correlation confirmed Mitchell's (Colhoun and Mitchell, 1972) earlier view that the bed of the Irish Sea was invaded by ice during the last and



(after Mitchell, 1972)

Figure 13 Munsterian Cold Stage in southern Ireland.

penultimate glacial periods and introduced the idea of two separate interglacial beaches associated with the last and penultimate interglacial periods respectively.

2. During the penultimate glaciation Mitchell envisaged an initial advance of ice from the Irish Sea westward to Ballycroneen, followed by "an interval, marked in some places by the development of head (*e.g.* Garrarus, Co. Waterford)", and then by an advance southward of Irish ice as far as Midleton, Co Cork (termed the Knockakeen Lobe, after the village of that name where associated gravels occur). "Farther to the east a lobe pushed between the Galtees and the Comeraghs, and then expanded southwards between Ballyvoyle Head and Waterford Harbour." (p.190). According to this description, much of west Waterford was not glaciated during this or the subsequent glacial period (Figure 13).

Finch and Gardiner (1972)

In a soil survey carried out at Ballygagin, 3 km to the west of Dungarvan, a brief reference was made to the glacial drift "of Saale age laid down by an ice sheet from the north-east or east-north-east. This drift is composed principally of Old Red Sandstone from the Knockmealdown and Monovullagh Mountains but some shales and Carboniferous are also present." Unfortunately, these observations were not elaborated, nor were any references quoted to support them.

Mitchell *et al.* (1973)

This publication on the correlation of the Quaternary deposits of Ireland and Britain marked the first attempt to link some of the changes which had taken place in the interpretation of the succession on the east coast with the traditional model as applied to the succession of Quaternary deposits on the south coast of Ireland.

In the column for the south-west (Counties Kerry, Cork and Waterford), on the general correlation chart for Ireland (Figure 14), all of the recognised Pleistocene deposits of the succession on the south coast were assigned to the penultimate (pre-Shortalstown) glacial and interglacial periods. Penney stated in the explanatory notes on the regional contributions (p.7-8) that deposits were not necessarily arranged in stratigraphical order within any one 'box' "(though where the order is known, they are; and this is made clear in the notes)." Hence the following units were listed from the Waterford succession [obviously not in order of stratigraphic succession, although it is stated in the notes that "the Ballyvoyle Till was deposited by ice that moved S from the Midlands; it passed to the E of the Comeragh Mountains, and crossed the present coast-line at Ballyvoyle. This till is probably younger than the Ballycroneen Shelly Till (Watts, 1959)]:

Ballycroneen Shelly Till

Ballycroneen Lower Head

Ballyvoyle Till and associated tills

BRITISH REGIONAL STAGES	IRISH REGIONAL STAGES	A MIDLANDS	B NORTH-WEST	C NORTH-EAST	D EAST	E SOUTH-EAST	F SOUTH-WEST	G WEST
FLANDRIAN	LITTLETONIAN	Pinstubbin Raised Beach 1 Littleton Bog 2	Drumahallan Upper Raised Beach 1 Cannon's Lough Muds and Peats 2	Cushendun Raised Beach and associated beaches 1	Sutton Raised Beach 1			
DEVENSIAN Late	MIDLANDIAN Late	Cortaleckin Upper Salix herbacea Clay 3 Cortaleckin Mud 4 Cortaleckin Lower Salix herbacea Clay 5 Tullamore Moraine 6 Mackey Inner Moraine 7 Ballylanders Moraine 8	Cannon's Lough Clay-mud 3 Cannon's Lough Mud 4 Malin Head Raised Beaches 5 Shaley End-moraine 6 Moville End-moraine 7 Golvin Till 8 Maguiresbridge Till 9	Roddansport Mud 2 Roddansport Mud 3 Roddansport Clay 4 Malone Sands 5 Rathlin Island Raised Beaches 6 Torr Head Raised Beach 7 Killough Raised Beaches 8 Templetown Raised Beaches 9 Armoy Moraine and associated deposits 10 Cran Lodge Moraine 11 Annalong Valley Moraine 12 Rathmore Moraine 13 Bush Moraine 14 Tervbrannan Till 15 Glastry Upper Till 16 Glastry Shelly Lower Till 17 Dunmore Head Moraine 18 Kilkeel Moraine 19	Ballybetagh Salix herbacea Clay 2 Ballybetagh Mud 3 Dunany Moraine 4 Port Raised Beach 5 Tagher Moraine and associated earlier moraines 6 Glenasmole granitic outwash 7 Killakee Moraine 8 Killiney Upper Shelly Till 9	Shortalstown Upper Silt 1 Shortalstown Mud 2 Shortalstown Lower Silt 3 Athdown Moraine 4 Blessington Moraine 5 Shortalstown Upper Shelly Till 6	Finglas River Gravel 1 Finglas River Mud 2 Finglas River Cryoturbated gravel 3 Whiddy Island Mud 4 Coomroanig Moraine 5 Coomnahorn Moraine 6 Killumney Moraine and associated moraines 7	Roundstone Upper Salix herbacea Clay 1 Roundstone Mud 2 Roundstone Lower Salix herbacea Clay 3 Accrymore Innermost Moraine 4 Anaffrin Inner Moraine 5 Ballycastle/Mulrany Moraine 6 Anaffrin Outer Moraine 7 Accrymore Outer Moraine 8 Newport Till 9 Screebhill Till 10
DEVENSIAN Middle	MIDLANDIAN Middle		Derryvree Mud 10 Hollymount Sand 11					Oldhead Peat 11
DEVENSIAN Early	MIDLANDIAN Early							
IPSWICHIAN	Not yet named					Shortalstown Estuarine Sand 7		
WOLSTONIAN	MUNSTERIAN	Mackey Outer Moraine 9 Athea Till 10 Ballyvergin Till 11	Derryvree Till 12 Dunaff Till 13 Spinkin Till 14 Bavereagh Shelly Till 15 Burnfoot Shelly Till 16 Malin Beg Shelly Till 17 Lackagh Till 18 [illegible] Till 19 Roofan Sand 20	Derryogue Shelly Gravels 20 Dreenaugh Shelly Till 21 Ballymartin Upper Shelly Till 22 Big River Shelly Till 23 Ballymartin Granitic Till 24 Ballymartin Lower Shelly Till 25	Killiney Lower Shelly Till 10 Tullyallen Shelly Till 11 Kell Glacio-marine Series 12 Drogheda Till 13	Shortalstown Lower Shelly Till 8 Brittas Moraine 9 Bannow Till 10 Kilmore Quay Upper Till 11 Kilmore Quay Shelly Till 12 Bunclody Granitic Till 13 Kilmore Quay Head 14	Garryvoe Till 8 Ballycroneen Shelly Till 9 Ballycroneen Lower Head and associated head deposits 10 Knocknadoon Upper Head and associated head deposits 11 Ballyvoyle Till and associated tills 12 Ooly Moraines 13 Ballinatuillage Till 14 Youghal Till 15	Belderg Shelly Till 12 Erris Till 13 Killadoon Till 14 Gort Upper Solifluction Gravel 15
HOXNIAN	GORTIAN	Baggotstown Mud 12 Kildromin Mud 13				Kilmore Quay Raised Beach 15 Ballykeerogemore Mud 16	Ballyinbegugne Peats and Silts 16 Newtown Peat 17 Courtmacsherry Raised Beach and similar raised beaches 18 Kilbeg Mud 19	Gort Mud 16
ANGLIAN	Not yet named							Gort Fine Sandy Clay 17 Gort Lower Solifluction Gravel 18

(after Mitchell *et al.*, 1973)

Figure 14 Stratigraphic correlation of Quaternary deposits in Ireland.

Newtown Peat

Courtmacsherry Raised Beach and similar beaches

Kilbeg Mud

The "associated tills" included the upper till at Newtown and the till overlying the Kilbeg interglacial deposit. Raised beaches similar to that at Courtmacsherry were recorded at Newtown and Ballyvoyle from the Waterford coast. This interpretation almost totally ignored Synge's (1970a) correlation of the Cahore and Courtmacsherry beaches. The only acknowledgement of the implications of Synge's (1970a) correlation were the positioning of the Ballyvoyle Till below the Ballycroneen Shelly Till in the correlation chart and the inclusion of the word 'probably' in the accompanying explanatory note as quoted above.

Of the sequence as listed above, only the head and the shelly till figured in the recommended Stratigraphical Table of the Irish Quaternary as formal stratigraphic units (p.69).

Synge *et al.* (1976)

Interpretations which were elaborated in the course of a field trip to west Clare, north Kerry and the Blackwater valley suggested that the deltas at 75-90 m O.D. near Lismore (including the Ballyin deltas) "were laid down in a lake from outwash derived from Midlandian ice further north. This lake was most likely impounded by Irish Sea ice at Youghal."

South of Tallow a different gravel series was identified capping the Watergrasshill watershed. These gravels were found to contain Galway granite erratics and were "interpreted as kame terraces deposited on the ridge crest as it emerged from the decaying ice sheet at the close of the Munsterian Glaciation. Frost heaving is much in evidence in the upper layers."

Lewis (1976)

This paper confirmed Farrington's (1947) observation that the Knockmealdowns remained unglaciated during the 'Eastern General Glaciation' although the unglaciated area was much more restricted than hitherto recorded. Lewis defined the upper limits of the Munsterian glaciation at around 350-365 m on the basis of the distribution of limestone erratics at the surface and in the drifts. He considered the Knockmealdowns to have been surrounded by ice during this general glaciation while cirque/valley glaciers occupied the north-facing hollows of the high ground (above 458 m O.D. in the valley which contains Lough Moylan at its head). Subsequent cirque glaciation as evidenced by "morphologically 'fresh'" cirque moraines, was thought to have extended down to 240/275 m O.D. during the advance of Midlandian ice which was regarded as terminating in the lowlands, some distance to the north of the Knockmealdowns.

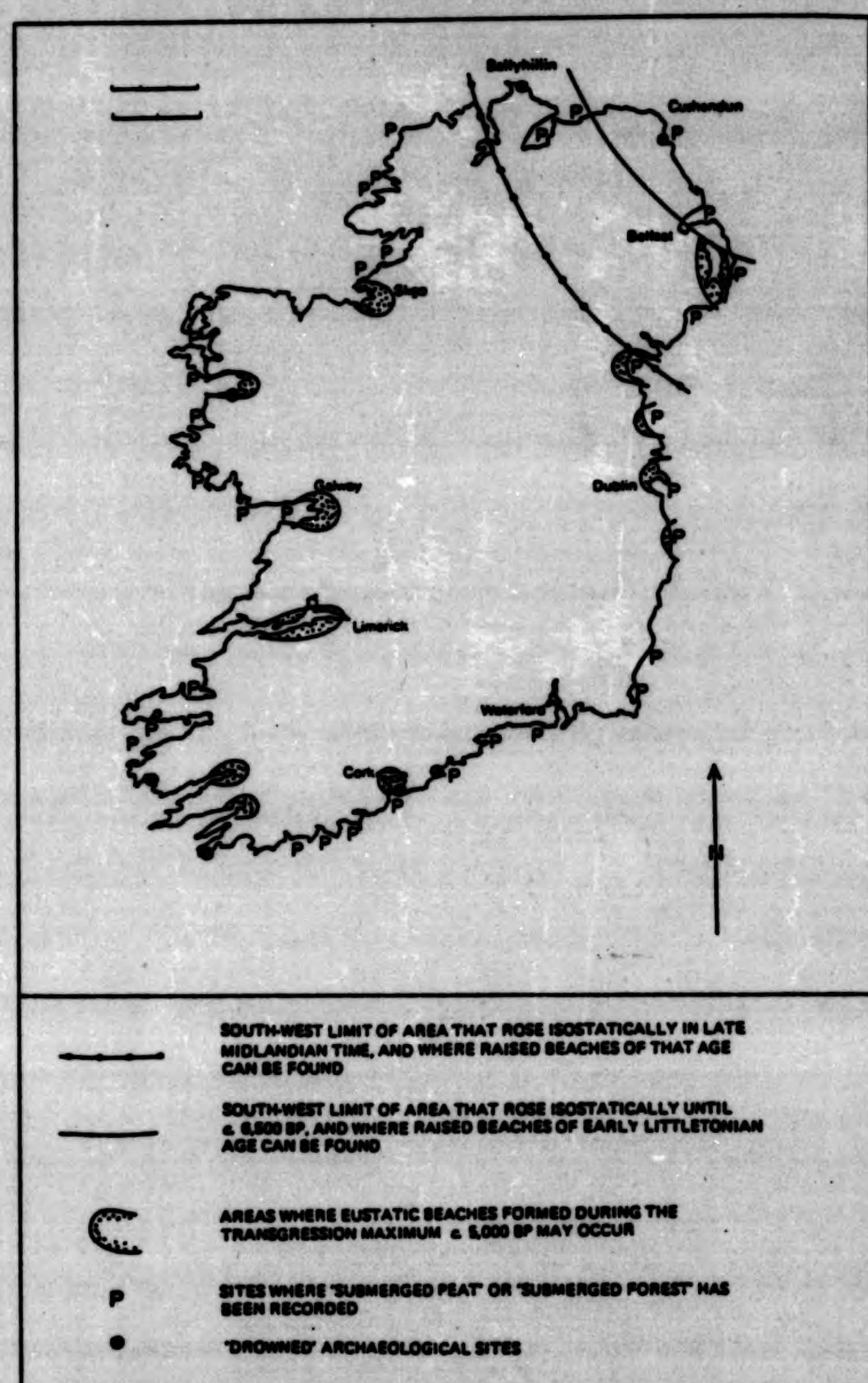
Mitchell (1976)

The table showing the stages of the later Pleistocene in Ireland and Britain (p.43) was largely based on that of Mitchell *et al.* (1973). It included two new items of interest to the Waterford succession:

1. The stratigraphic position of the Ballyvoyle Till was returned to its pre-1973 position indicating a post-Ballycroneen ice advance of inland origin, termed the Ballyvoyle Lobe. This lobe was paralleled by the Knockakeen Lobe which advanced into part of west Waterford leaving the intervening areas unglaciated and their limits undefined (Figure 2).

2. A redeposited femur from a woolly mammoth (*E. primigenius*) from a cave at Castlepook in County Cork was dated to 33,500 B.P. and was interpreted as indicating ice-free conditions in southern Ireland during the early stages of the most recent glacial phase until mid-Midlandian times.

Finally, the distribution of previously recorded, but unreferenced outcrops of submerged peats or forests (including sites at Tramore, Dungarvan and possibly Youghal in County Waterford) was plotted and interpreted as evidence of a post-glacial transgression which occurred around 5,000 years B.P. (map p.64, Figure 15).



(after Mitchell, 1976)

Figure 15 Postglacial sites in Ireland.

2.4.8. The Last Decade (1977-1987)

The last ten years have seen the publication of one or two papers which commented directly on the glacial succession in County Waterford. Apart from these fairly recent novel ideas, other publications based on work in the adjoining Counties Wexford and Kilkenny have come up with certain findings which have implications for the interpretation of the Quaternary sediments in County Waterford.

Synge (1977)

In this chapter on the coasts of Leinster, Synge's views on the glacial succession related back to a correlation of the Cahore beach with the Courtmacsherry raised beach on the south coast (Synge, 1970a). Accepting the penultimate interglacial age for the Kilbeg organic sediments, and their correlation with the Newtown peat which was regarded as resting in turn on the beach and raised rock platform, Synge was faced with the question of the age and significance of the stratigraphic position of the overlying Ballyvoyle/Bannow Till. The paradox of a till of penultimate glacial age overlying younger interglacial marine sediments at some points and older pollen-bearing deposits of penultimate interglacial age at others (as at Kilbeg and Newtown) was resolved by Synge's sophisticated, comprehensive and challenging hypotheses.

Synge presented four different (and compatible) interpretative models to explain the glacial succession on the south coast of Ireland:

1. According to Synge the normal glacial succession between Cullenstown and Wood Village on the Wexford coast was characterised by the Bannow Till of penultimate glacial age which had been redeposited during the last (Midlandian) glaciation as a soliflucted unit to overlie head and beach of last glacial and interglacial age respectively. (The western limit of this Midlandian advance of ice southward down the basin of the Irish Sea was repositioned at Kilmore Quay.) This type of succession was found to rest on an unstriated marine surface whose surface had been modified during the relatively higher sea levels of the last interglacial or subsequent interstadial and was typified in the exposures east of Ballymadder Point. The position and age of both the till and the peat at Newtown were re-interpreted and accounted for in terms of this "slumped succession" model.

2. Only at Cullenstown, was the original Bannow Till to be seen *in situ*. Here, Synge believed "that the present coast now lies behind the old one, so that fresh till *in situ* is now being exposed." (Synge believed that the formation of the 'old' raised beach post-dated that of the underlying platform and that it paralleled the modern coastline i.e. that it was not necessarily associated with the erosion of the 'pre-glacial' notch on the landward side of the platform). The *in situ* Bannow Till was seen to

rest on a striated platform. The 'old' beach in the vicinity of Cullenstown was seen to contain many erratics derived from the till and was regarded as having actively eroded the till in primary position according to this "behind the beach" model.

3. The third scenario envisaged to explain the glacial succession in County Wexford involved the Hook Head area. Striae were observed under till in primary position at the top of the low rock cliffs. The absence of any marine erosional or depositional features was noted. Synge suggested that perhaps "this limestone plateau subsided as a block after the formation of the raised beach." (p.204).

4. A fourth and final version was put forward to explain the complete absence of the raised beach on the east shore of Waterford Harbour and hence the impossibility of assessing the stratigraphic relationship between it and the tills as at Broomhill and Stonewall.

Culleton (1978)

Some questions of potential relevance to the glacial succession in Waterford arise out of this work on the limits and directions of ice movements in south County Wexford. A north/south-aligned boundary was found to separate the mutually exclusive distributions of the drifts of Irish Sea and inland origin respectively. Following Watts (1959) and Colhoun and Mitchell (1971), Culleton viewed the two ice sheets as penecontemporaneous. Three unresolved questions, impinge on the interpretation of the Waterford succession.

1. Flint-rich gravels occur at Mulmontry in south Wexford beyond the limits of the Irish Sea deposits. These were classified on the basis of erratic content and were interpreted as indicating ice-free conditions to the west of the limit. However they might also have been interpreted as having been reworked by meltwaters from a slightly later advance of ice of inland origin. This interpretation would be more in line with previous observations concerning the superposition of the till of inland origin over that of Irish Sea basin origin in areas to the west, as at Dungarvan (Wright and Muff, 1904).

2. Also enigmatic is the distribution of the Carnsore granite erratics in the extreme south-east of County Wexford. The distribution of the erratics indicates a west-north-westward carriage. Such a direction runs counter to the erosional and depositional evidence associated with the till overlying the outcrops of Carne granite and adjacent areas. Striae with a north-north-easterly orientation have been recorded on rock surfaces underlying this till (Wright and Muff, 1904). While till fabric analysis carried out on the contained stones also indicates a similar direction of ice movement (Stevens, 1959).

3. The third, and to my mind, incompletely explained phenomenon is the occurrence of minute shell fragments in the till of inland origin at Cullenstown, Blackhall,

St.Patrick's and Dollar and Booley Bays. Culleton explained the presence of these shell erratics by postulating that they were picked up by south-bound ice of local origin as it crossed the Waterford estuary and Bannow Bay.

Collins (1981)

A study of soils on Munsterian and Midlandian drifts in the Suir valley on the north bank of the river at Piltown, County Kilkenny highlighted an interesting contrast in the nature of the soils and of the drifts as parent materials for the overlying soils: "The soils developed on Munsterian-age drift are generally more acid and podzolised than those on the younger Midlandian-age drift with the exception of eroded and/or rejuvenated areas." The drifts were contrasted according to the lithology of the contained pebbles and stones. The Munsterian-age drift appeared to have been largely derived from the acid volcanic rocks of eastern and southern County Waterford; while limestone was the predominant constituent lithology of the Midlandian-age drift. The former composition is somewhat surprising in view of the directions of ice movement as indicated in previous and background literature concerning the Pleistocene sediments in County Waterford. All previous records refer to a south-easterly movement of ice in east Waterford whether of Midlandian or Munsterian age. Three hypotheses were suggested to explain the rather anomalous carriage of erratics over a distance of 30 km from south-eastern County Waterford.

1. Synge suggested reworking of fluvial deposits in a northward-flowing drainage system from the Waterford plateau (due to glacial blockage of south-flowing streams by ice from the Irish sea) (personal communication, 1980). However, as Collins pointed out, the angularity of the material militates against this hypothesis.

2. A northwestward expansion of ice from the Irish Sea as indicated by the distribution of Carnsore granite was considered as a possible explanation until Culleton established the western limit of such an expansion at Kilmore Quay to the east, in County wexford.

3. A final explanation was considered. This involved a northward movement of ice from the Comeraghs, but as Collins noted, "it would have to have moved in a large anticlockwise arc to pick up substantial amounts of acid volcanic debris in southeast Waterford." (Collins, 1981, p.107).

Synge (1981)

The non-conformist views expressed by Synge (1977) and Warren (1979) were further extended and refined in this brief paper on Quaternary glaciation and changes of sea level in the south of Ireland. Synge again questioned the penecontemporaneity of the Ballycroneen and inland ice (Synge, 1977) and suggested that there "are indications that the coastal ice arrived considerably later, after the dissolution of the inland ice." He raised a number of reasons in support of his interpretation:

1. Synge wondered whether the till which seals the interglacial deposit at Kilbeg was not in fact soliflucted, thus implying a penultimate or antipenultimate glacial age for the deposit depending on whether the younger or older age interpretation was applied to the underlying interglacial deposit.

2. Synge introduced yet another possible [fifth, see Synge (1977) above] way of interpreting the (to him) paradoxical succession: "At Newtown, also in Co. Waterford, the organic beds occur near the base of a marine cliff where much slumping occurs at the present day (Synge, 1977). Even if the overlying till is *in situ* (Mitchell, 1948) its identification with inland ice rather than with coastal ice is a matter of conjecture". He noted the (almost) complete absence of striae on the Courtmacsherry platform between Garryvoe and Kilmore Quay. He mistakenly quoted a sole set of striae recorded at Dungarvan underneath shelly till (Wright and Muff, 1904) as corroborating support for his argument. (Synge was mistaken on two counts: firstly, the striae referred to were found under till considered by these authors to be of inland origin; secondly, another set of striae was recorded under shelly till near Youghal, in County Cork.) The absence of striae was taken as evidence of glaciation prior to the formation of the Courtmacsherry beach. With regard to the younger Ballycroneen ice, Synge maintained

that the "coastal ice that laid down the marine tills on the south coast, for the most part, would appear to have been weak in erosive power, as in most places it merely truncated the head that seals the raised beach. In some localities the marine till passes upwards into a local stony till attributed to inland ice from the north (Wright and Muff, 1904). But this Ballyvoyle till (Watts, 1959) may, in part at least, represent a local facies of the coastal ice, derived from the local rock and pre-existing drift. Further investigation is required to demonstrate whether this is so, or not." (Synge, 1981, p.310).

3. At Booley Bay on the east side of the Waterford estuary in County Wexford, Synge noted that the "stony till beds interspersed with layers of shelly marine till have been pushed against the rocky coastline and deformed into a vertical position by sea ice." (p.309). This observation seems to be a little at odds with the previously noted weakness of the erosive power of the advance of ice from Irish Sea .

Thomas and Summers (1982)

Work on the east coast in the Screen Hills area led to the conclusion that the glacial sediments there were explicable in terms of an advance, retreat and marginal oscillation of a terrestrially based Irish Sea ice-sheet during the late Midlandian glacial stage.

2.5. Summary

In all, seven lithostratigraphic and two biostratigraphic units have been recognised among the Quaternary sediments in County Waterford. These include the raised beach which is overlain at Newtown by silts and interglacial peats and in most other localities, by the lower head. This head is overlain by Ballycroneen Till which is in turn overlain (at Dungarvan) by Ballyvoyle Till. The interglacial mud at Kilbeg, the lower till and overlying head at Newtown are also reported to be overlain by the Ballyvoyle Till. This till is generally found to crop out at or near the surface in eastern and northern County Waterford and is overlain by an upper head. Finally, post-glacial submerged peats and forests (not generally included in the stratigraphic column) have been recorded below HWM.

The bulk of the sequence has been traditionally assigned to the penultimate interglacial and glacial respectively (Mitchell *et al.*, 1973). Alternatively, the sequence has been attributed with a last interglacial and glacial age respectively (Warren, 1985). While Synge (1970a and 1977) envisaged a penultimate interglacial age for the biostratigraphic units, a penultimate glacial age for the Ballyvoyle Till unit, a last interglacial age for the beach, and a last glacial age for the Ballycroneen Till of Irish Sea basin provenance.

2.6. Issues for Clarification

The questions which arise out of this detailed review of the literature include the following:

1. What is the true origin, nature, and extent of the Ballyvoyle till?
2. Is the Ballyvoyle till *in situ*, slumped or a reworked facies of an older till of inland origin by a younger advance of coastal ice?
3. What is the relationship between the Ballyvoyle till and neighbouring/adjacent glacial and interglacial deposits?

CHAPTER THREE

METHODOLOGY

3.1. Introduction

Investigational procedures were selected according to their perceived, or anticipated, degree of usefulness in determining the nature and extent of the 'Ballyvoyle till' and in differentiating it from other neighbouring glacial or unconsolidated deposits. Methodology and techniques adopted to carry out this essentially stratigraphic research project may be divided into two major groups: field and laboratory procedures.

3.2. Field Work

3.2.1. Reconnaissance Survey

A reconnaissance mapping programme was carried out to identify the basic stratigraphic units in the area in 1979.

Initially, the object of the reconnaissance survey of the coastal exposures to the east and west of Ballyvoyle Head was to appreciate, establish, and extend the findings of previous workers in the field. This work entailed the logging (in field note-books) of facies changes, characteristics of individual units as identified on the basis of textural, structural/sedimentological, petrographic and erratic content (including ghosted limestone casts, where appropriate). The nature of the contact between the units distinguished was noted. Relevant information was summarily and regularly recorded (wherever exposure allowed) on quartered sections of the 1:10560 maps of the Ordnance Survey. Standard equipment included pick, spade, hammer, knife, hand lens, compass/clinometer, 30 m tape, mapping case, maps, field note-book, pencil, waterproof marker, sample bags, and 10% dilute hydrochloric acid. Well exposed sections were photographed and sampled for textural, and petrographic analyses (see descriptions below), while diamicton or gravel fabric analyses were carried out in the field.

3.2.2. Detailed Sketches and Descriptions of Exposures

Once the salient sedimentary units had been identified at a number of locations, a systematic survey of the coastal sections of County Waterford, was undertaken to establish the lateral extent of the units and their relationship to each other and neighbouring deposits. This work which involved a more detailed version of the former approach was also continued inland as described above (Section 1.2.).

All exposures of glacial deposits were noted and examined in detail. Almost every section over 2 m high was sampled for fabric or imbrication (in the case of gravels) analysis and petrographic analysis, while twenty samples were collected for particle size analysis (see below). Most exposures were created by one of the following processes: fluvial erosion, trenching for soil drainage schemes, excavations made at building sites and road widening/straightening projects and quarrying for sand and gravel or road metalling material. At critical sites (e.g. Newtown and Whiting Bay), exposures were drawn to scale on squared paper and relevant information was sketched and photographed where possible.

Morphometric mapping was employed wherever the surface expression of constructional unconsolidated features warranted attention. Glacial erosion as evidenced by the survival of striated surfaces and roches moutonnees features was recorded. Surface distribution of erratics was also noted and mapped, although, as will be seen later, some (in places, many) of these are considered to have been anthropogenically introduced to the area as manurial spreads.

3.2.3. Fabric Analysis

This technique was selected as one possible means of determining the regional direction of the most recent ice movements as reflected in the glacial sediments to the east, west and north of Ballyvoyle. Doubts about the theoretical underpinnings cast some doubt on the reliability of its general indiscriminate application as an isolated indicator of former regional ice movements (see below). However, given the selective application of this technique, the implications of the results of fabric analysis were considered valid, particularly as they were used in conjunction with complementary techniques such as distribution of erratics, striae, carry-over of pebble lithologies, grain-size analyses and consideration of glacially-derived morphology.

The technique was also selected as a means of distinguishing between glacial deposits *in situ* and those whose fabric has been post-depositionally realigned parallel to the maximum topographic slope by periglacial gelifluction.

Theoretical Background

The fact that the majority of the long axes of clasts in till display a preferred orientation has long been noted (Miller, 1850; Holmes, 1941 etc.). It was realised that many fabrics displayed both parallel and transverse maxima with respect to inferred directions of ice movements (Boulton, 1971; Dreimanis and Vagners, 1972; Lindsay, 1970 etc.). Evenson (1971) concludes that the genesis of organised fabrics in basal tills is related to shearing of particles in a flowing medium with respect to each other and the ice/till interface. Obviously stresses in the depositional and post-depositional environment are of paramount importance in determining the resultant fabric.

A review of the literature suggests that at least four broad glacial depositional environments may be associated with the production of organised fabrics:

1. Post-depositional alignment

MacClintock and Dreimanis (1964) noted that fabric subsequently overridden by ice of continental thickness can become reoriented parallel to the direction of the most recent ice movement up to depths of approximately 10 m along upward curving shear planes as displayed at the margins of many ice sheets.

Banham (1966) reported that transverse and parallel fabrics could be related to two different deformation styles in two tills at Mundesley, Norfolk: Till which had been subjected to open folding was associated with fabric maxima parallel to the direction of ice movement, and normal to the fold axis. These fabrics were attributed to laminar shearing along the limbs of the folds. Tightly-folded till, on the other hand, was associated with fabric maxima parallel to the fold axes and normal to inferred ice movement. These preferred clast orientations were explained as being due to rotational axial planar shearing in the fold noses.

2. **Viscous flow/basal shearing**

Parallel orientation of fabric by viscous flow in shearing ice is suggested by Glen, Donner and West (1957). This theory is elaborated by Evenson (1971) to suggest that flow occurs within basal ice along upward- curving shear zones in areas of low pressure due to the existence of sub-glacial pressure gradients. Resultant fabrics in basal tills display strong parallel, and weaker transverse maxima associated with protracted flow (Kauranne, 1960; Harris, 1971 etc.). Evenson also recorded an associated up-glacier plunge of the long axis of individual clasts or boulders. This up-glacier plunge is noted by Wright (1957), Boulton (1971) and others.

3. **Inherited tectonic structures from parent ice**

Harrison (1957) suggested that fabrics in englacially-derived debris result from and are inherited from original tectonic shearing of the parent ice as in a basally-derived melt-out till. The survival of this type of till intact is thought to be a relatively rare phenomenon (Boulton 1968).

4. **Oriented fabrics in surface ablation tills**

The survival of oriented fabrics associated with flow tills related to ablation and surface slope is thought to be much more common (Boulton, 1968; 1971). Fabrics from supraglacial flow/ablation tills will therefore, most probably, not reflect former directions of regional ice movements.

Summary

Of the above types of till, therefore, only those derived from subglacial depositional processes (intact englacially-derived melt-out tills being rarely preserved) and those subsequently overridden, will produce fabrics with maxima parallel to the last phase of ice movement in the area.

Distribution of sample sites

Till fabric analysis as described by Andrews (1971) was applied to eighty samples largely on a single sample per site basis (usually, at least one per 15 km^2). Where facies changes had been noted on the basis of field work, each facies was sampled. Several samples were taken from individual facies at critical sites such as Newtown. Sites where post-depositional processes may have been active were also sampled in order to ascertain whether the preferred orientation of the contained clasts was influenced post-depositionally by local rock slopes.

Method

The vertical face of each exposure was cleared. Clasts were selected from a restricted area/shelf cut into the cleaned-up face below modern or periglacial disturbance. Sites lying adjacent to large boulders visible in the face of the exposure were avoided, as were clasts which were not separated from each other by at least a thin film/skin of matrix. The orientation and plunge of the 'a' axis (axis normal to the 'b' axis, which was taken as the maximum plane of projection) were measured using a compass/clinometer. The characteristics of fifty clasts were recorded at each site. Clasts which had an a/b ratio of 2:1 and whose long axes measured between 8 mm and 120 mm were selected.

Presentation of data

Fabric data is presented in the form of rose diagrams. The percentage of clasts in 10^0 class intervals starting at 5^0 is portrayed. The resultant modality indicates former lines of ice movement. A directional sense of ice movement is reliably conveyed only when other lines of evidence such as erratic carry-over etc. are considered as plunge is not consistently up- or down-glacier (as inferred). Strength of modality is tested statistically according to vector analysis as described by Curray (1956) where vector mean and standard deviation are calculated. This data is presented in tabular form and on individual rose diagrams.

3.2.4. Gravel Fabric Analysis

This technique was applied in a manner very similar to that described for till fabric analysis (Rust, 1975). Fifteen samples were collected from twelve sites. The technique was mainly applied to imbricated para-horizontally bedded gravels of glaciofluvial origin to ascertain directions of paleocurrents (Rust, 1975 and others). The orientation and dip of the a/b plane of imbricated discoidal clasts with a:b:c ratios of 2:2:1 were recorded. Observations were confined to clasts with long axes longer than 3 cm to avoid scatter or 'noise'. Stones whose dips did not lie between 5^0 and 85^0 were omitted as their direction with respect to the paleo-current direction could not be reliably determined. Sample size averaged 25 stones. This information is presented in tabular form. Data is visually presented as points plotted on directional plunge rose diagrams. Data was also subjected to vector analysis as described above (Curray, 1956). The resultant vectors are interpreted as indicative of former paleocurrents in streams issuing from nearby ice masses.

3.2.5. Aerial Photographs

Several flights of aerial photographs at the 1:10000 scale exist for the coastal areas of County Waterford (available for consultation at the Geological Survey of Ireland). These were used in conjunction with field work to map erosional and constructional glacial and periglacial morphology.

3.2.6. Borehole Records

The borehole records in the Groundwater Section of the Geological Survey were consulted to gain some insight into the depth of unconsolidated sediments. The majority of these records consist of returns made for the drilling of wells. As such the level of classification of the unconsolidated material is rudimentary. The records for County Waterford included information relating to over 527 points which are located on a townland basis only. Depths were plotted on a 1:250,000 scale map of the county and provide a generalised impression of regional depths of surficial deposits.

In the absence of sufficient exposures, local knowledge, derived from well-digging and quarrying for sand and gravel, was used to distinguish between features composed of solid rock and constructional glacial landforms.

Logs of boreholes drilled in the course of mining exploration (lodged in open files with the Mineral Resources Division of the Geological Survey) provided additional information about 100 localities (approximately).

Further information about depths of surficial unconsolidated sediments was based on borehole records relating to major construction projects in the Dungarvan area (generously supplied by Waterford County Council).

Finally, minimum depths were indicated in the logging of the shallow 1.7 m trench dug for the laying of the Waterford gas pipeline in the north of the county (logs held in the Quaternary and Geophysical Section of the Geological Survey of Ireland).

3.3. Laboratory Work

3.3.1. Particle Size Analysis

This technique was used on a restricted basis in order to establish a quantitative basis for observations which had previously been made qualitatively i.e. the strong contrast between the tills of Irish Sea and inland origins was already widely recorded (Wright and Muff, 1904).

Theoretical Background

Given the well established variablility in granulometric characteristics within and between tills, the limitations in the application of textural parameters as an isolated distinguishing factor in till differentiation are generally acknowledged (Krumbein, 1933; Shepps, 1958; McGown, 1971; Boulton, 1971; Dreimanis, 1976 etc.). A few broad generalisations about till granulometry seem to be well established:

1. Texturally, ablation tills are more variable than basal tills of the same stratigraphic unit (Dreimanis, 1976). These tills may be depleted of fines by surface winnowing meltwater, or enriched in fines by redeposition processes (Boulton and Paul, 1976).

2. Lodgement/basal tills and tills derived relatively intact from englacial positions within the glacier system by means of melt-out display relatively straight line frequency curves due to maximum mixing of all grades and lithologies (Dreimanis and Vagners, 1972).

3. Bi-modality in the clast and matrix sections of the frequency curves is associated with mono-mineralic content i.e. predominance of one lithology (Dreimanis and Vagners, 1972). According to this premise, the proportion of fines should increase down-glacier due to comminution processes.

Summary

From a consideration of the above observations it would seem that the granulometry of a given till is explained in terms of constituent lithologies and glacier mechanics. Given the high degree of potential variablility in both factors, the use of this technique as a basis for till differentiation *per se* was considered to be very limited and hence was not applied extensively throughout the research.

Method

Sixteen samples from multifacies sequences were analysed.

The samples were processed according to Irish standard procedure (I.S. 5:1974). Non-gravel samples were first broken up by hand and dried in an electric oven at a temperature of 105^{0}C. The samples were then dry sieved and weighed down to 40 microns. Silt and clay fractions (below 40 microns or .04 mm) were determined by the pipette method (according to the I.S. 5:1974 method).

Presentation of data

Fractions were calculated as percentages of the total weight of the material remaining on the 37.5 mm sieve. They were then plotted as cumulative frequency curves on semi-logarithmic graph sheets. The finer fractions of the data (below 2 mm) are also presented on a clay-silt-sand ternary diagram as a visual aid in rapidly summarising data characteristics (Krumbein, 1933; McGown, 1971 etc.). Thus having established general grain size envelopes for the various diamictons, these are used as an aid in distinguishing between diamictic facies which display elements of both types as identified in the field. The nature of the granulometry of the various sediments identified is considered and forms part of the basis for comparison with findings of others as reported in general discussions relating to genesis of diamictic characteristics and for correlation of the sediments with others outside the area investigated.

3.3.2. Petrographic Analysis (Stone Counts)

This technique, as used in the Quaternary Section of the Geological Survey of Ireland, was selected as an aid in tracing spatial/lateral and vertical trends within the surface glacial/periglacial deposits as previously identified on a qualitative basis as a result of field observations. This analysis of the petrography of the phenoclasts provides a basis for the differentiation of the various stratigraphic units recognised within the area (Warren, in press).

Theoretical Background

Variation in the lithological content and granulometric parameters in till may be influenced by the subglacial surface, underlying solid geology, and glacial erosion, transport and deposition (Dreimanis, 1976 etc.). Progressive comminution and abrasion at the base of an temperate ice sheet results in the reduction to less than 0.1% in the frequency of occurrence of clasts of any lithology over a distance of 35 km (Goldthwait, 1971). On the other hand, material which is transported supraglacially or englacially may survive intact for hundreds of kilometres. Englacial material may also be preferentially deposited on moderately high ground (Shilts, 1976). Thus ablation till (as opposed to lodgement till) may contain proportionately more far-travelled material and may be found on higher ground or higher in the stratigraphic sequence assuming an uncomplicated phase of deglaciation. However, in zones of compressed flow where basal material is evacuated to an englacial position, the above distinction in lithological content will not be apparent (Drake, 1971). Therefore variation in pebble lithology may be partially explained by rate of survival of individual clasts, and their mode of emplacement within the glacial system, mode of transport and mode of deposition.

Method

The technique involves the washing, sieving, identification and counting of approximately 400 pebbles of the total number which have passed through the 11.2 mm mesh sieve and which have remained on the 5.6 mm mesh sieve per site sampled. Ten lithological types were recognised: limestone, silicified limestone or chert, sandstone, conglomerate, quartz, granite, acid volcanic, basic volcanic, shale, and flint for each of the 104 samples. The results are presented in tabular form (Appendix 6).

Presentation of data

It was attempted to group the data statisticallly according to cluster analysis (Orloci and Kenkel, 1983). The results of this procedure are summarised for visual appraisal in dendrogram form. The data are also presented in a simplified and generalised collapsed version on ternary diagrams to illustrate the nature of variation in pebble content of the materials sampled (single sample per site/facies basis) and the variation in carry-over of erratic lithologies.

3.3.3. Stoniness

Although not measured directly, a relative indication of the degree of stoniness is provided (referred to informally throughout the text) by the absolute numbers of stones counted per sample. Those samples where less than 400 pebbles were counted and identified for the purposes of pebble lithology analysis represent the total presence of stones in the entire sample. Occasionally, more than one 5 kg sample was required in order to generate a sufficient quantity of stones suitable for statistical analyses. Such instances are clearly indicated throughout the text and most commonly relate to the processing of samples from the relatively stone-free diamicton of Irish Sea basin provenance. The degree of stoniness is interpreted as an indication of the lithic or non-lithic origin of the glacially deposited material and thus serves to highlight the contrast between tills of different origin, although it is never used as a differentiating indicator in its own right (see discussion of background theory for particle size analysis above).

NOTE: The application of microfabric analysis was considered inappropriate owing to the general high degree of stoniness of the glacial sediments in County Waterford.

CHAPTER FOUR

GLACIATION AND DEGLACIATION - MORPHOLOGICAL EVIDENCE

4.1. Introduction

This chapter looks mainly at the morphological evidence for glaciation and deglaciation in the area mapped. Altitudinal ice limits and directions of movement or retreat are established on the basis of erratic distributions, depositional and erosional glacial and glaciofluvial features. The information resulting from this geomorphic investigation is then combined with the results of the stratigraphic approach adopted in the succeeding chapters to identify and name the various facies distinguished among the unconsolidated sediments of County Waterford.

4.2. Glacial Erosion and Deposition

4.2.1. Glacial Erosion

Striae

Striae have been recorded on at least 42 bedrock surfaces in the area mapped. The vast majority of these horizontal or parahorizontal surfaces are outcrops of Devonian sandstones. The eastern striae are etched into acidic volcanic surfaces and included quartz veins. Only one set is recorded on a diorite outcrop in the vicinity of Cullencastle.

The north/south trend in orientation of the striae is broken only by those striae which are located at relatively high altitudes (usually above 600 m O.D.) at the heads of the Mahon and Coumlara valleys in the Comeragh Mountains. A few sets of striae are recorded at intermediate heights. These striae are also located within the Comeragh valleys and are aligned parallel to the valley sides. The remainder are located on surfaces lying at or below 190 m O.D. The highest of these occur in the Ballynamult Gap and on the Drum Hills to the south. This lower group displays a fairly consistent north/south trend which in many places cuts right across the structural grain of the underlying bedrock.

Discussion

The pattern of striae, in conjunction with ice moulded surfaces is indicative of former glaciation from north to south in the area mapped. It would appear that this glaciation extended right to the coast in both eastern and western halves of the county. Apart from the striae recorded by Wright and Muff to the east of Dungarvan, only one other set of striae was recorded on the raised shore platform itself (Wright and Muff, 1904). These striae are located near the eastern boundary of Ballyeelinan townland under diamicton which has a calcareous and silty matrix and which contains shell fragments, and flint, chert and volcanic erratics. The preferred orientation of the contained clasts yields a north-west/south-east alignment (No.54) parallel to that of the valley whose mouth is infilled with the plug of diamicton. However it is impossible to infer from this basis alone whether the diamicton was deposited by ice of northern or Irish Sea basin provenance (see Chapter Six).

The striae on the raised platform at Bayview to the east of Dungarvan which were recorded by Wright and Muff underlie a diamicton very similar to that at Ballyeelinan (Wright and Muff, 1904). These authors considered the diamicton to be the local "O.R.S. boulder clay" of inland origin. Nearby outcrops of the same dimictic unit yield fabrics with east/west alignment (Nos. 4 and 70) (see Chapters Six and Seven). This alignment is quite at odds with the north/south direction of the striae. However a north/south preferred orientation of the contained clasts is displayed in a deep section in diamicton at Ballynacourty lighthouse further south (No. 1). This direction is also generally mirrored by the striae near Helvick Head on the south side of Dungarvan Bay. These data probably represent an early movement southward of ice of inland origin. A later east/west movement of ice in the area to the east of Dungarvan is probably indicated by the fabric analyses referred to above (see Chapter Seven).

The comparative absence of striae on the raised shore platform has previously been explained as being due to post-glacial marine erosion (Orme, 1966). It has also been interpreted as being due to non-glaciation of the south coast since the re-cutting of the raised shore platform according to Synge's "slumped succession" model (Synge, 1977), or, more recently, to the non-erosion of striae by later "coastal ice" (Synge, 1981).

The only exceptions to this model which could allow for the survival of striae on the raised shore platform were:

1. where the modern beach is now backed by an *in situ* till sequence of northern provenance which according to Synge actually lay out of reach of erosional marine processes during the deposition of the raised beach, as exemplified by his "behind the beach" interpretation of the Cullenstown succession (Synge, 1977).
2. or where the striated limestone block of the Hook Head area with its mantle of *in situ* till was thought to have subsided after the formation of the raised beach according to Synge's "subsidence model" . This model was partly based on the absence of marine features in the area.

However neither of these models could be applied indiscriminately to areas further west in County Waterford. The striated raised platform at Ballyeelinan, for example, is composed of Devonian sandstone and is currently subjected to marine erosion. The overlying till is regarded as *in situ* for the following reasons:

1. The diamicton has a massive matrix-supported structure which contains glacially abraded clasts including erratics.

2. Although the contained clasts are oriented north west/south east (320^{0}), almost parallel to the maximum topographic slope (315^{0}), this orientation is also similar to that of the north-westerly/south-easterly trend displayed in the exposures of silty, shelly diamicton to the west (see Chapter Six).

3. The preferred dip of the a-axes of the modal class is divided between a north-westerly (34%) and a south-easterly (56%) direction. This type of dip pattern is consistent with that of lodgement tills (Evenson *et al.*, 1977). It is not consistent with that normally associated with gelifluction processes (Watson and Watson, 1970, Warren, 1987a).

The till must therefore post-date the formation of both the underlying head and raised beach units which rest on the raised shore platform.

Thus the question as to whether the "Ballyvoyle till" on the south coast of County Waterford represents "a local facies of the coastal ice", as suggested by Synge (1981), remains unanswered for the coastal exposures of upper sandy stony diamicton between Ballyvoyle Head and Youghal.

Roches Moutonnées

Polished and plucked surfaces of rocky knolls were noted on the 6" O.S. maps and field notebooks in the course of field work. These features were largely confined to the Lower Palaeozoic acid volcanic outcrops in eastern County Waterford, particularly around the Ballyscanlan Hills, and to occasional Devonian Old Red sandstone outcrops in the western half of the county, especially to the south of the Ballynamult Gap. They are usually restricted to altitudes below 120 m O.D. in western County Waterford and 90 m O.D. in eastern County Waterford. Many of the surfaces, particularly in western County Waterford are exposed in areas where intermittent glaciofluvial gravel deposition has taken place. There is some possibility that these surfaces are remnant glacial features in a landscape which is essentially characterised by glaciofluvial deposition associated with deglaciation.

The general trend consists of clearly polished surfaces at the northern end, and plucked surfaces at the southern end of rock outcrops which appear to have been streamlined in a north to south direction (Figure 7).

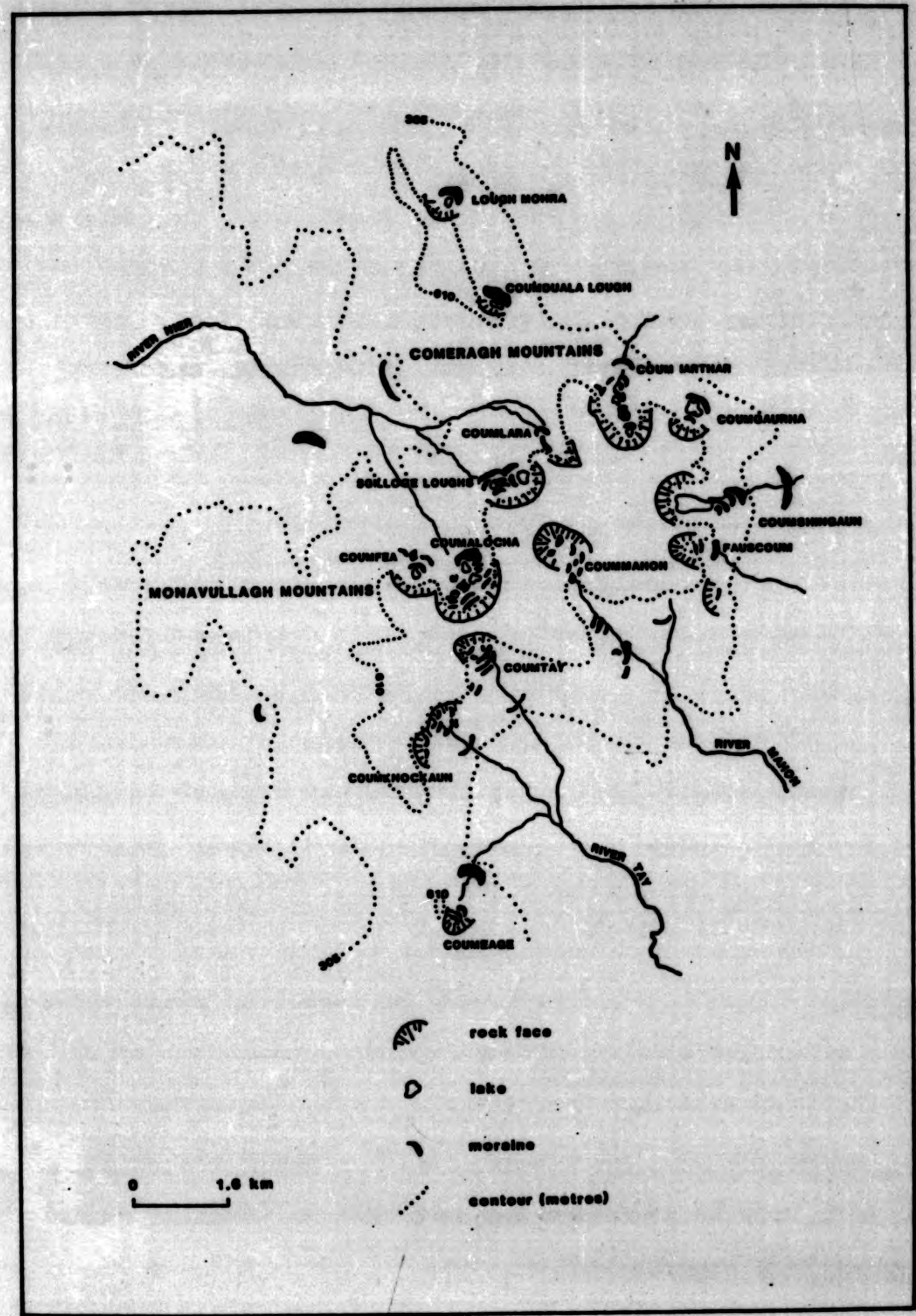


Figure 16 Cirque moraines in Comeragh and Monavullagh Mountains.

4.2.2. Glacial Deposition

The distribution of diamicton throughout the area mapped in County Waterford seems to be largely confined to valley bottoms and embayments. Shallow stony diamicton mantles the surface of the Rathgormack plateau and interfluves in the Drum Hills. These sheets of diamicton do not generally provide notable surface relief in any of these localities as they tend to drape the underlying solid rock surface which is in places deeply dissected, particularly in the eastern half of the county.

In the few isolated cases where diamicton crops out at the surface in a landscape characterised by glacial depositional features, it is seen to drape underlying features composed of glaciofluvial gravels which provide the initial surface relief. This type of morphology is particularly evident in the townland of Ballylemon Lower where a thin diamictic unit drapes glaciofluvial terraced and deltaic gravels which were deposited at the point where the Colligan River debouches onto the Carboniferous limestone plain northwest of Dungarvan.

The other exception where diamicton provides surface relief is in the arcuate valley and cirque moraines on the east and west sides of the Comeragh Mountains (Figure 16). The cirque moraines tend to form a cascading series within each valley with as few as one increment (L. Mohra) or as many as thirteen separate depositional phases (Coummahon).

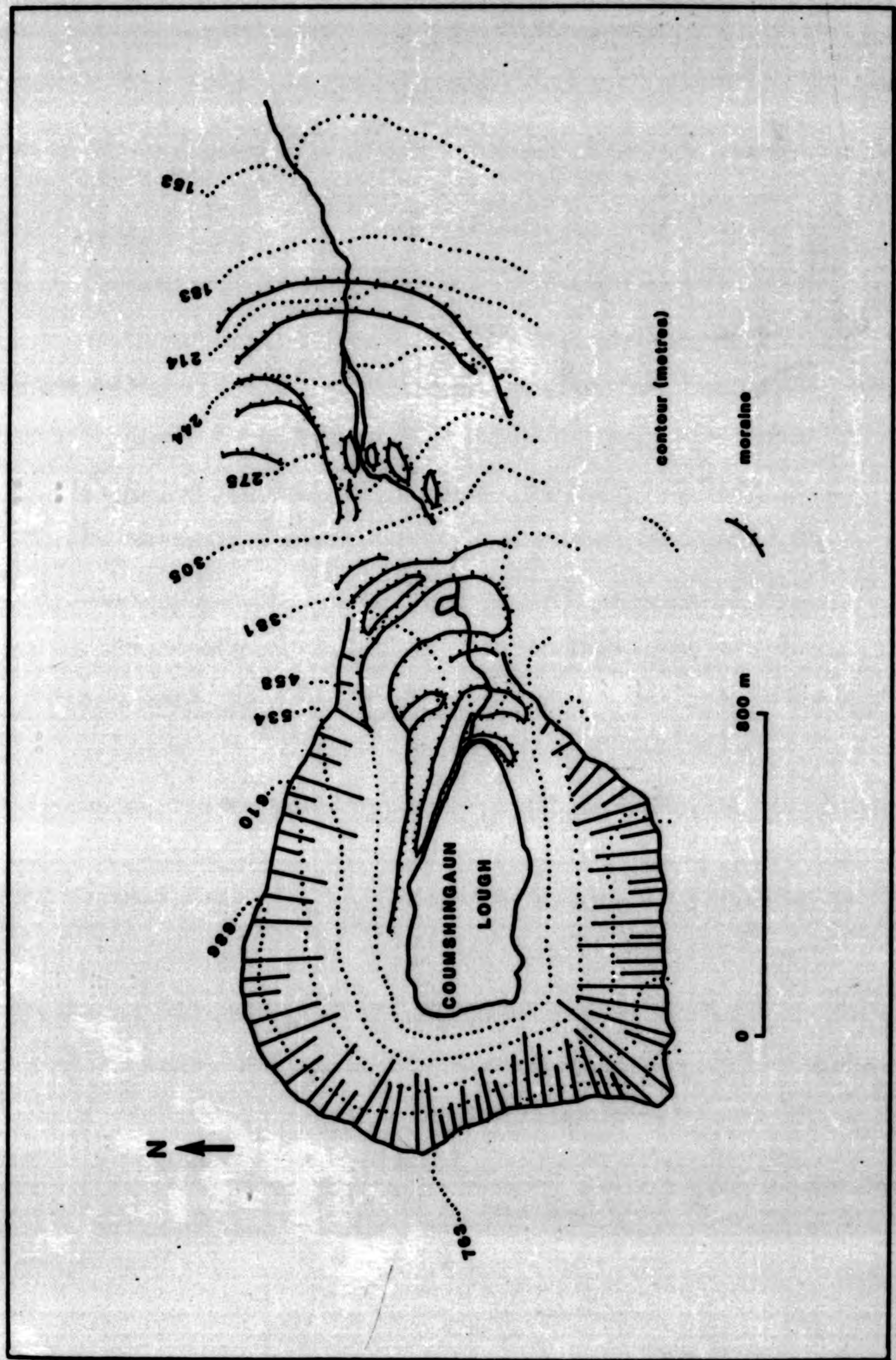


Figure 17 Cirque moraines in Coummahon.

Morphologically the outermost discernible moraines in the Nier and Mahon valleys appear to have slightly post-dated the deposition of diamicton of northern provenance (see Chapter Seven) as both of these outermost moraines contain very occasional erratics from the surrounding lowland and retain remnants of distal slopes, although these latter are quite dissected in parts by current fluvial activity (Figure 17).

The comparative absence of glacial depositional features in County Waterford has traditionally been explained by the assignation of the formation of the tills to the penultimate glacial and to their subsequent gelifluction during the last glaciation (Charlesworth, 1929; Mithchell 1973). However the comparative absence of glacial depositional morphology may in fact be related to the operation of glacial processes which differed from those which were characteristic of the Carboniferous limestone lowlands to the north of the River Suir. The hilly and mountainous topography south of the Suir valley, which is associated with underlying changes in geology, presents a complete contrast to that further north (Warren, 1987a). Given this contrast in topography and the frequency of glaciofluvial gravel deposits to the east and west of the Comeragh Mountains, it is far more likely that the glacial element in the surface relief is related to the relative importance of glaciofluvial processes associated with deglaciation of a northerly retreating ice sheet and the comparative weakness of glacial erosional (and therefore depositional) processes in upland terrain at the distal margins of a southward advancing icesheet of lowland provenance (Vincent, 1969).

Altitudinal Limits of Glaciation

Evidence for the minimum height attained by ice in the area mapped is largely based on the maximum altitudes at which various erratics were noted in the field. These erratics occurred so rarely that their presence failed to show up in the petrogaphic samples from nearby outcrops of diamicton. This approach is based on the assumption that erratic content is uniformly distributed throughout the transporting medium of the advancing ice sheet and that depositional processes also reflect such a distribution. It is widely acknowledged that neither of these assumptions resemble erratic distributions as observed in currently glaciated areas (Boulton and Paul, 1976). Therefore the results from the erratic distributions are regarded as indicative of the minimal levels attained by glacial action of lowland provenance. These results are, wherever possible, backed up by supportive evidence such as limits of erosion and/or deposition of subangular clasts and/or till.

The possibility of redistribution of erratics by a subsequent movement of ice may undermine the use of erratic distributions as an adequate basis for the investigation of altitudinal limits attained by a particular ice sheet. This factor is probably of relevance in the investigation of flint erratic distributions close to the south coast where more than a single movement of ice has already been invoked to explain variation in the petrography of the phenoclasts in the tills from this locality.

It is also recognised that limits based on this criterion alone (distribution of erratics) may be slightly underestimated because of subsequent movement downslope due to gelifluction processes. Evidence of former periglacial activity is very restricted throughout the area mapped in County Waterford. Constructional features associated with gelifluction appear to be confined to patterned ground at the summit of the Comeragh Mountains (Saul, 1974), high level gelifluction terraces above 300 m O.D. on one or two south-facing slopes, pingoid features in relatively lowlying areas associated with restricted drainage (Figure 19) and the accumulation of 'pre-glacial' (Wright and Muff, 1904) head deposits at the coast. However resulting discrepancies between present and former erratic distributions are reckoned to be of a minor order due to the aerially restricted nature of the periglacial features. The extent of underestimation is also minimised by the fact that erratics may become trapped on flat areas of slopes less than 5^{0} on stepped terrain where gravitational slope forces are practically negligible (Williams, 1961). In areas of mountainous terrain where mapped landmarks are sparse, location of erratics is approximate as are the resultant limits.

Erratic Distributions

The areas which were most closely examined for altitudinal distributions attained by various erratics were the northern and southern foothills of the Comeragh Mountains and the Drum Hills. Limestone and chert erratics were observed at the northern end of the Comeragh Mountains. Occasional flint and granite erratics were also observed in this area. The granite erratics were usually confined to gravel deposits at lower altitudes. Flint erratics were occasionally observed along the southern slopes of the southern foothills of the Comeragh Mountains, while flint, chert and volcanic erratics were fairly abundant in the Drum Hills area. Shell fragments were very occasionally found in association with the latter suite of erratics in diamicton at slightly lower altitudes in this area also. Granite erratics were fairly common in the tills along the Waterford Harbour sections. Very rounded granite cobbles with pink feldspars probably from the Galway area were confined to the gravel deposits in the Blackwater valley around Lismore.

Northern Altitudinal Limits of Glaciation

On the basis of erosional evidence (striae) the minimum upper limit reached by the ice of northern provenance in northern County Waterford was approximately 180 m O.D. south of Ballynamult on the western side of the Comeragh Mountains in the townland of Knockacaharna. However, depositional evidence based on the presence of occasional silicified limestone erratics observed at the surface in the townland of Glenpatrick on the northern slopes of the Comeragh Mountains indicates glaciation up to an altitude of 420 m. O.D.

However, careful use must be made of chert or limestone as indicator erratics in this area because there is ample historical evidence referring to the practice of collecting manurial limestone boulders and large pebbles "for the purpose of being burnt for lime" (Du Noyer, 1865). This fact was supported by field observation of rounded limestone clasts at the surface in many ploughed fields and their total absence from nearby sections. In fact two pieces of flint erratics were also found at the surface in association with surface limestone erratics on the northeastern slopes of the Comeragh Mountains in the townlands of Poulavone and Kilbrack. This latter find was associated with clearance of an old stone wall field boundary. Therefore the distribution of limestone and associated erratics was based on their presence in section rather than at the surface within the cultivated zone.

However at higher altitudes, as in the case of the silicified limestone erratics in Glenpatrick, surface occurrences were also noted.

Silicified limestone erratics are not generally encountered in section with any notable degree of frequency above 300 m O.D. in this northern area and on the Curraheenavoher ridge on the northwest side of the Comeragh Mountains. Ice of northern provenance abutted against the northern foothills of the Comeragh Mountains up to at least 300 m O.D. The central mountainous spine caused the ice stream to bifurcate. Both streams advanced southward through the lowlands on either side until they passed off the south coast.

On the east side the general level of 300 m O.D. seems to have been maintained by the southbound ice as evidenced by the presence of silicified limestone erratics in section up to 270 m O.D. on the eastern slopes of Deelish Mountain. A single flint and a volcanic erratic were found at the surface at still greater heights around the 300 m level in the same area. These erratics, normally associated with ice of Irish sea basin provenance, may have been redeposited by the ice of inland origin. This would also explain the clayeyness of the diamicton in the area. Stone-fronted gelifluction lobes occur occasionally at heights above 300 m O.D. in the same area. This same southbound ice stream seems to have crossed southwestward over Ballynacourty Point as indicated by the striae at Bayview and fabric analyses (No. 3, Figure 8). It probably continued its advance southward to erode the north/south oriented striae on Helvick Head at altitudes between 55 m and 80 m O.D.

Ice limits on the western side of the Comeragh Mountains were less easy to define on the basis of silicified limestone erratic distribution owing to its comparative absence from the sediments to the south of Ballynamult (No. 102, Figure 26). Small amounts of chert erratics were recorded in a shallow, locally derived, angular Devonian sandstone-dominated hill slope deposit near the striated rock surface at Knockacaharna at 180 m O.D. Silicified limestone erratics were recorded along with rounded Devonian material further south, at the surface, in Ballyknock Upper townland on the northern side of the Carboniferous Dungarvan syncline above the 180 m contour. They were also recorded at somewhat lower altitudes (around 134 m O.D.) in section in the townland of Kilgobnet nearby.

In the Drum Hills where the diamictic cover is so shallow or poorly exposed in most places as to render a distinction between till and soliflucted till impossible, chert or silicified limestone erratics are usually found at or near the surface in association with flint and

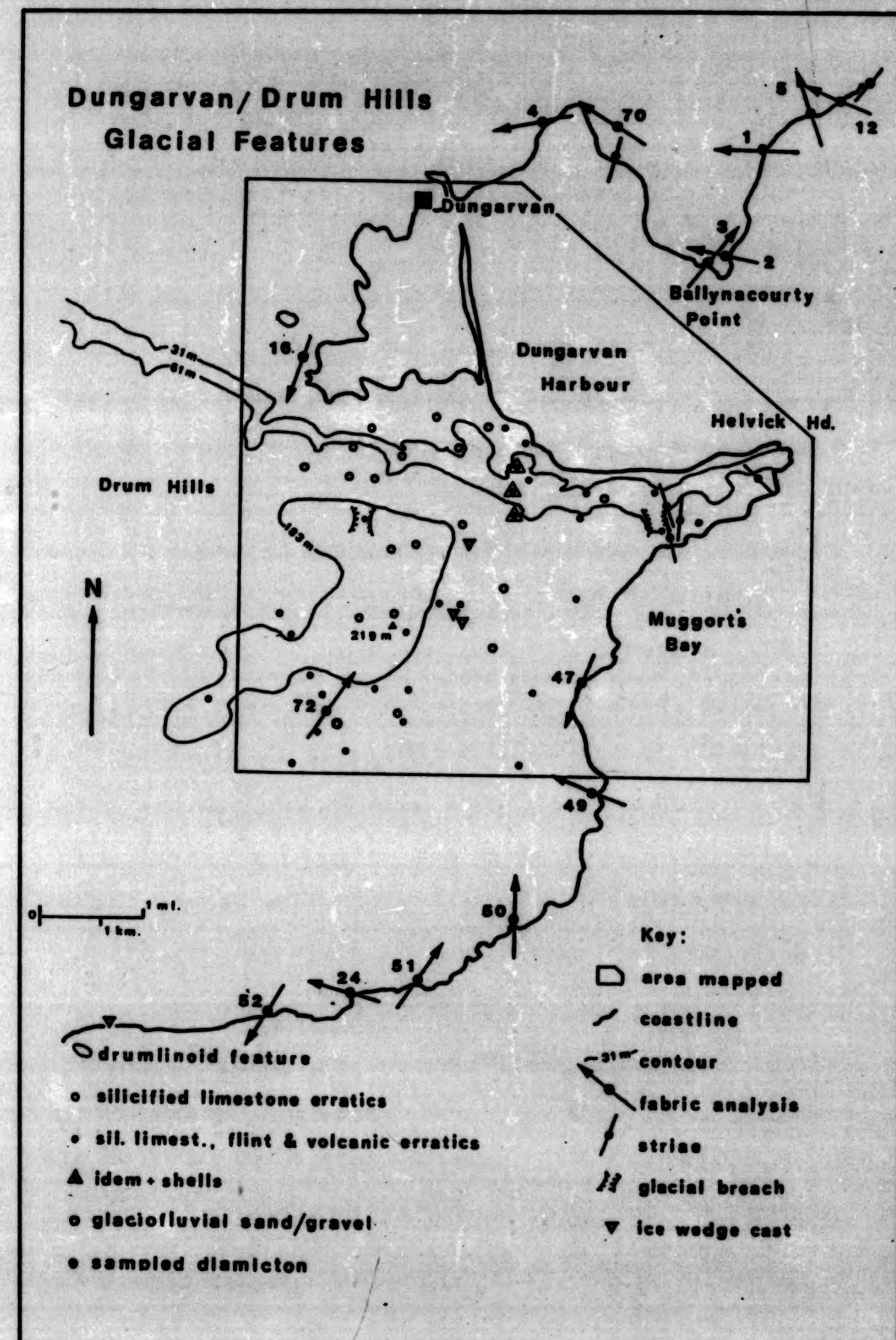


Figure 18 Glacial features in the Dungarvan/Drum Hills area.

volcanic erratics. Occasionally these erratics are embedded in a stony, silty/clayey calcareous diamicton which contains shell fragments and crops out at three places on the northern slopes of the Drum Hills overlooking the Dungarvan Carboniferous syncline. The distribution of flint erratics when plotted separately is seen to be largely coincident with the 152 m contour in this area (Quinn, 1984). When plotted with silicified limestone and volcanic erratics, two distinct distributions are found to emerge: one where silicified limestone is found as an isolated erratic and the second where it is found in conjunction with flint and volcanic erratics (Figure 18). Isolated silicified limestone erratics predominate along the northern slopes of the Drum Hills. In this area the presence of associated flint and volcanic erratics is confined to exposures in diamicton at the coast and valleys of some north flowing streams. The isolated limestone erratics are found with decreasing frequency towards the summit of the Drum Hills (219 m O.D.) and rarely on the southern slopes. The associated group of erratics, on the other hand, tends to be fairly regularly distributed along the summit of the upland area and on the slopes to the south.

This suite of erratics (silicified limestone, volcanics and flint) is distributed with diminishing frequency to the north and west of Dungarvan. However it is quite common on the summit spurs and southern slopes of the Drum Hills. Only in three cases is it found to occur in diamicton with a silty, shelly and calcareous matrix (Figure 18). All three outcrops are located in three north-facing valleys in the Drum Hills up to 90 m O.D. The same erratic suite was also observed at Barranastook near the summit of a southern spur just above the 152 m contour. The erratics were contained in a 2 m deep exposure of sandy, stony tough matrix which did not have a calcareous reaction. Apart from these isolated observations the erratic suite was either found at the surface or in shallow sections composed of frost shattered angular fragments of local origin. These sections rarely exceeded one metre in depth.

These distributions may be interpreted as resulting from an initial invasion of the Dungarvan area by ice of Irish Sea basin provenance carrying flint and volcanic erratics. It is not possible to conclude whether it was ice from this source or a later advance by ice of northern inland provenance which was responsible for the deposition of the sandy, stony diamictic facies which occasionally crops out at the surface in the Drum Hills and at the mouths of the valleys on the south coast.

That ice passed from north to south over the Drum Hills is evidenced by north/south striae near Helvick Head, Keereen and Bayview, north/south oriented glacial breaches in the

Drum Hills, north/south oriented fabrics and the southern transport of silicified limestone onto the Devonian basement of the Drum Hills from the lowlying Carboniferous Dungarvan syncline (fabric sample Nos. 63 and 72, Figures 8 and 18). The maximum altitude attained by the ice of northern provenance must have been somewhat greater than that of the Drum Hills as flint, volcanic and silicified limestone erratics were recorded around the summit (219 m O.D.). It is quite possible that ice of coastal and inland origin were confluent in the Dungarvan area at this stage. Given the unequivocal nature of the evidence indicating the presence of ice of northern origin at relatively high altitudes in the Drum Hills it is quite probable that the stony uppermost diamictic facies exposed in the coastal sections further west were deposited during the same southerly advance of ice (see Chapters Six and Seven).

4.3. Glaciofluvial Erosion and Deposition

4.3.1. Glaciofluvial Erosion

Glaciofluvial erosion may have played an important role in shaping topography. It is rarely possible to pinpoint categorically examples of this type of erosion in the field due to the lack of adequate knowledge of prior form and exposure of the eroded sediments. There is however one

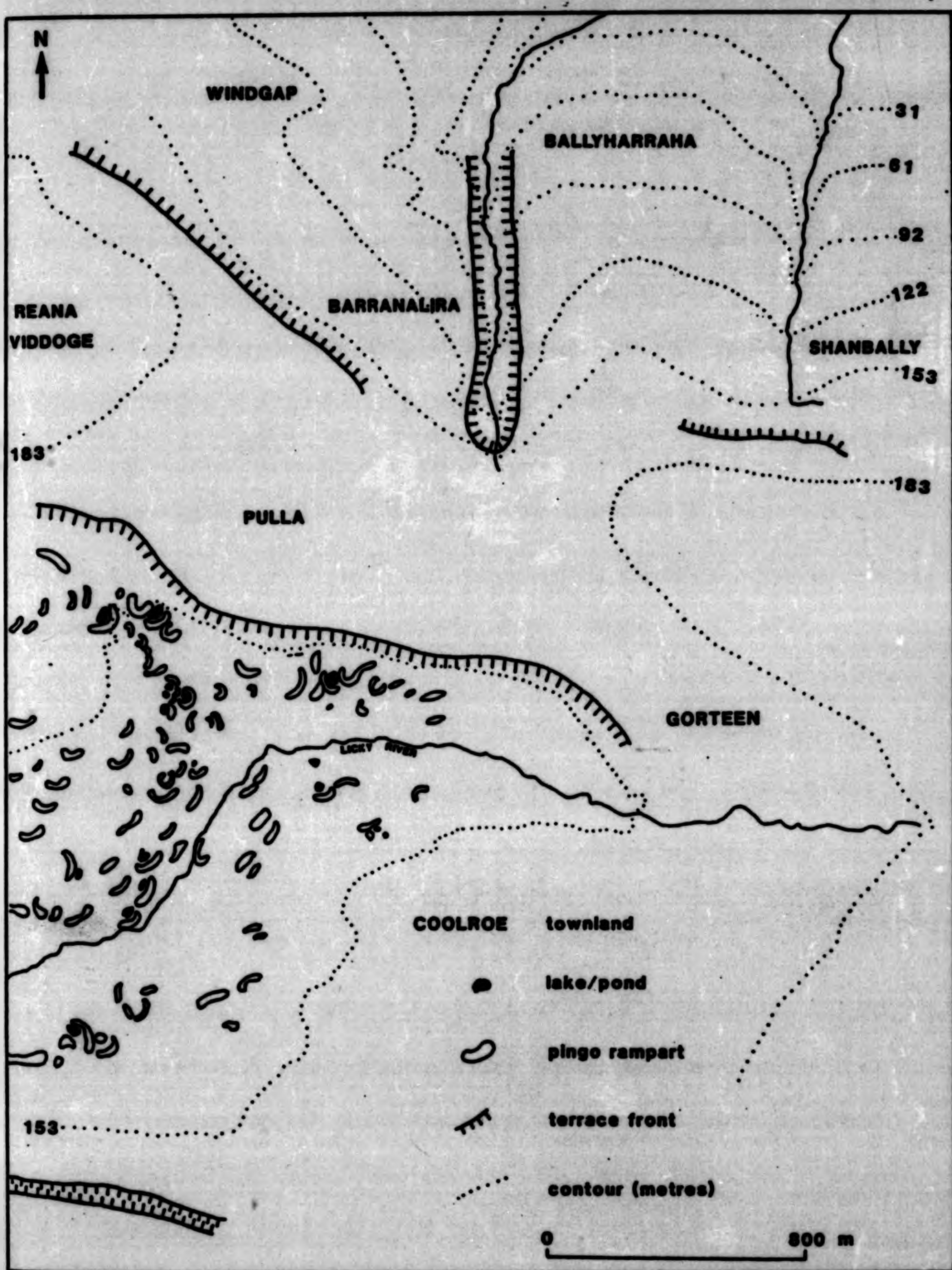


Figure 19 Terraced features and pingos at head of Licky valley.

feature which shows up in aerial photographs and which is probably attributable to this type of erosion. A washed zone is cut in the superficial slope sediments at an altitude of 167 m O.D. in the townlands of Glenmore, Windgap, Barranalira, Pulla and Reanaviddoge around the watershed at the head of the Licky River, on the northern edge of the the Drum Hills (Figure 19). This feature implies ponding of meltwater by ice masses in the Blackwater and Dungarvan valleys although no associated glaciolacustrine or glaciofluvial depositional features were observed at this relatively high altitude in either valley. Ponding of water against the northern slopes of the Drum Hills to this level would have necessitated accumulation of ice to at least this height on the northern side of the Dungarvan synclinal valley. It would also have required the blocking of both the western and eastern ends of the valley by ice of Irish Sea basin or northern origin. Ice of northern provenance was probably involved given the north/south fabric obtained from till of local origin at a similar altitude in the intervening valley of the Goish River to the northwest (No. 63, Figure 8). It has already been shown that this ice achieved an altitudinal maximum of approximately 180-190 m O.D. in areas to the north. However it is not possible to conclude whether the distribution of flint and volcanic erratics normally associated with ice from the Irish Sea basin were deposited at higher levels up to 219 m O.D. in the Drum Hills directly by ice from this source or whether the erratics were redeposited by a later southerly advance of ice of northern inland provenance.

4.3.2. Glaciofluvial Deposition

Recognition of glaciofluvially deposited features is largely based on exposures in these features usually for the purpose of sand and/or gravel extraction. Only in one case was the interpretation of such a feature based on form alone. This was in the case of a reported esker-like feature oriented north/south to the south of Waterford city in the vicinity of Callaghane Bridge (Stevens, 1959). This feature has since been almost totally removed by sand and gravel excavation and its former existence could not be confirmed in the field by the present researcher. Only disused and vegetated sand pits remain to bear witness to the former existence of virtually the only recorded outcrop of glaciofluvial sands and gravels in the area mapped in eastern County Waterford.

There are only two other morphological features composed of surficial sand and gravel in the mapped areas of eastern County Waterford. The first feature is a very localised and badly exposed outcrop of bedded sands and gravels on a spur overlooking the Clodiagh River in the townland of Ross. The second feature is located in the townland of Knockanacullin, to the north of the point where the River Tay leaves the confines of its Devonian sandstone valley. This flat-topped feature at 120 m O.D. is approximately 260 m^2 in plan. Its southern margin is characterised by steep ice-contact slopes (15^0). Devonian sandstone crops out close to the northern edge of the feature which appears to merge into the underlying rock slope. The feature is composed of bedded silt, sand and gravel in a coarsening upward sequence. The basal beds of massive (occasionally parallel-laminated) silty-sand dip toward the south at approximately 5^0. They are laterally continuous throughout exposures in the pit and are of variable thickness up to 1.5 m. They are overlain by approximately ten metres of more steeply southward-dipping (11^0) sand and gravel beds. These are in turn overlain by three metres of horizontally-bedded mostly matrix-supported gravels. Imbrication in the more gravelly parts of this unit indicates deposition in a palaeocurrent emanating from a north-westerly direction (300^0). The southwardly-dipping beds are interpreted as bottomsets, foresets and topsets in a prograding deltaic sequence respectively (Jopling and Walker, 1975). The steep outer slopes which do not appear to be related to internal bedding structures are regarded as ice-contact and the most likely depositional environment is one of subglacial origin (Boulton, 1972). The delta could have formed in ponded waters trapped beneath ice at the confluence of ice emanating from the Tay valley and joining the main south-flowing ice stream on the eastern flanks of the Comeragh Mountains.

Glaciofluvial depositional features are relatively abundant to the north, west and south of the Comeragh Mountains. In the northern part of the county high level gravels form discontinuous marginal kame terraces along the northern foothills of the Comeragh Mountains overlooking the River Suir at 90 m O.D. (No. 1, Figure 8). This type of feature also occurs at 120 m O.D. in the townland of Russellstown on the north side of the Curraheenavoher ridge in the northwestern corner of the county (No. 17, Figure 8). A small flat-topped delta-shaped feature is located at a slightly higher altitude (150 m O.D.) in the townland of Bawnfune on the southern side of this ridge overlooking the Nier valley. Limited exposure of the upper metre indicates that it is composed of coarse gravels overlain by a bed of sand 0.3 m thick which dips at 18^0 to the north west (338^0). This bed is overlain by a bed of structureless sand (0.5 m thick) which contains small pebbles and dips also to the north west at 6^0. The dip of the beds is towards the ridge. If the feature is in fact deltaic in origin then the meltwaters in which the sediment accumulated must have been draining from ice standing at this height in the Nier valley. Alternatively the feature may be a marginal kame deposit associated with ice in the Nier valley. Silicified limestone erratics on the Curraheenavoher ridge extend up to 300 m O.D. indicating former presence of ice to at least that altitude. Thus it may be inferred from the location of the delta at a lower altitude that its formation and that of the terraces at still lower altitudes must have taken place during subsequent deglaciation of the area.

To the west of the Comeragh Mountains there are many patches of superficial sands and gravels resting on Devonian bedrock. They form a shallow and discontinuous cover to the south of Ballynamult and do not really provide any significant effect in terms of relief. The deepest exposure encountered (1.7 m thick) in this area during the course of field mapping occurs in the townland of Knockgarraun on a south-facing rock spur overlooking the Finisk River just at the point where the south-flowing river changes course to flow southwestward across the Carboniferous limestone Dungarvan syncline into the River Blackwater (No. 4, Figures 8 and 26).

Features composed of glaciofluvial sediments abound in the Dungarvan area to the south of the Comeragh Mountains. The major feature is an actively worked deltaic sequence (15 m O.D.). The lowest horizon exposed in the course of extraction of the sands and gravels during the most recent visit to the pit (1984) shows input from a southerly direction. Higher up in the sequence palaeocurrent direction is from the north. This direction is maintained in the overlying terraced gravels of a coarsening upward sequence which is capped by a shallow (1.2 m) fissile loamy diamicton which thickens in a southerly direction. The upper 1.5 m of the underlying gravels is reverse-faulted (Figure 19). The fissility of the massive diamicton, together with the pro-grading deltaic sequence and faulting in the upper layers of the underlying gravels may be interpreted as the result of a minor readvance of ice of northern origin which was responsible for the deposition of a lodgement facies over gravels which had been glaciotectonised by overriding ice.

Other depositional features occur in the Dungarvan area to the south of the Comeragh Mountains. These include linear east/west trending ridges composed of horizontally bedded sands and imbricated gravels deposited in paleocurrents of northern or northeastern provenance (Nos. 3, 13, and 19, Figure 8). They are located to the south and southeast of the Ballylemon Lower deltaic complex at somewhat similar levels of approximately 15 m O.D. The internal structure of the features was poorly exposed. Exposure was sufficient for fabric sampling in two localities where the sediments were characterised by horizontally-bedded coarse gravels in a sandy matrix (Nos. 3 and 13). The dip of the ab-planes in the modal frequency indicated imbrication towards the north and north east and therefore glaciofluvial deposition from that direction (Rust, 1975). They transversely-aligned ridges probably represent the lateral equivalent of the upper coarse gravel unit at the Ballylemon Lower complex. This unit is probably a proglacial sandur-type sequence although no channel structures were observed in the two normal/dip sections. The ridge-like features may have been formed by subsequent glaciofluvial erosion by eastwardly escaping meltwater as observed internal sedimentary structures did not appear in any way to be related to outer slope forms.

Further west, in the townland of Ballyea West, near Lismore, in the Blackwater valley, terraced gravels accumulated in palaeocurrents of southwestern provenance. They are exposed in an east/west-trending ridge similar to those to the north of Dungarvan. The short ridge-like feature lies at 30 m O.D. It is probably part of a discontinuous and patchy sandur complex of gravels in the Blackwater valley as there are indications of extraction of gravels at similar altitudes in the neighbourhood (Figure 8).

Sand and gravel is currently being extracted from a deltaic complex to the north of Lismore in the townland of Ballyin at approximately 90 m O.D. The sediments in this and a lower delta were deposited in ponded water by palaeocurrents emanating from the north, probably meltwaters from ice which had entered The Gap (365 m) on the western side of Knockmealdown (Lewis, 1894; Farrington, 1947; Lewis, 1976). Ponding of water at this level in the Blackwater Valley by the presence of ice in the offshore zone both in the Dungarvan area and near Youghal at the mouth of the Blackwater, a suggestion previously put forward by Synge (1981).

A somewhat similar sequence to that of the till-capped deltaic sequence in the townland of Ballylemon Lower is seen on the south side of the Dungarvan syncline on an interfluve in the townland of Barranastook in the Drum Hills (150 m O.D.). Here a mound of fine sand and silt with faint current bedding indicating deposition from the north is surrounded by massive diamicton. This latter unit has a well-defined north easterly/south westerly fabric (No. 72, Figure 18) and contains volcanic, flint and silicified limestone erratics. The sequence is interpreted as a pro-glacial or sub-marginal glaciofluvial deposit overlain by a basal lodgement till facies deposited by ice of northerly provenance. This ice probably did have some impact on the upper parts of the stratigraphic sequence in areas further south and is almost certainly associated with the erosion of striae, glacial breaches and till deposition in adjoining eastern and western areas (see above).

4.4. Conclusions

Minimum levels attained by ice of northern provenance appear to range from 365 m in the extreme northwest around Knockmealdown (Lewis, 1976) to around 420 m in the northern foothills of the Comeragh Mountains. The level of glaciation associated with the ice of northern provenance appears to have been relatively maintained right to the coast having fallen to 300 m on the south-eastern side of the Comeragh Mountains. On the western side, the minimum level attained by ice of northern provenance, as evidenced by erratic distributions in the Drum Hills, seems to have declined to approximately 200 m O.D. The contrasting decline in minimum levels affected by ice of northern provenance on the east and west sides of the Comeragh Mountains may be apparent only in that the western side may have been subjected to different processes following initial glaciation. Certainly the northwestern part of this area seems to have had quite a marked history of deglaciation which may have been responsible for the removal of evidence of glaciation at higher levels.

In the south-western part of the county, the southerly advance of ice of northern provenance may have been somewhat weaker than that on the eastern side of the Comeragh Mountains due to the combined blocking effect of the topographic barrier presented by the Drum Hills and the contemporaneous presence of ice of Irish Sea basin provenance offshore. The presence of this ice off the Dungarvan coastline and the relative weakness of the western ice stream of northern provenance may be related. The topographic barrier presented by the Knockmealdown and Comeragh Mountains in the path of southbound ice is much higher than that presented by the relatively low and narrow Devonian rim in the eastern part of the county. Thus the relative weakness of the western stream was probably exploited by an advance of offshore ice into the Dungarvan lowland and lowlying areas to the west.

CHAPTER FIVE

LITHOLOGY OF UNCONSOLIDATED SEDIMENT UNITS IN COUNTY WATERFORD

5.1 General Stratigraphic Framework

5.1.1. Introduction

Approximately ten types of units have been recognised among the unconsolidated sediments in County Waterford (see Chapter Two). They include (in ascending stratigraphic order): raised beach deposits, organic horizons, a lower diamicton containing angular clasts, a diamicton containing subangular clasts of northern inland and Irish Sea basin provenance, glaciofluvial sands and gravels, an upper diamicton containing angular and, in places, subangular clasts, postglacial peat, colluvium, alluvium and soil development. This basic stratigraphic sequence was confirmed qualitatively by field observations of the petrography of the phenoclasts, texture, sedimentological structure, nature of contact with adjacent units and stratigraphic position of outcrop. It therefore acts as the setting for the current study which concentrates on the glacigenic sediments and their stratigraphic relationships.

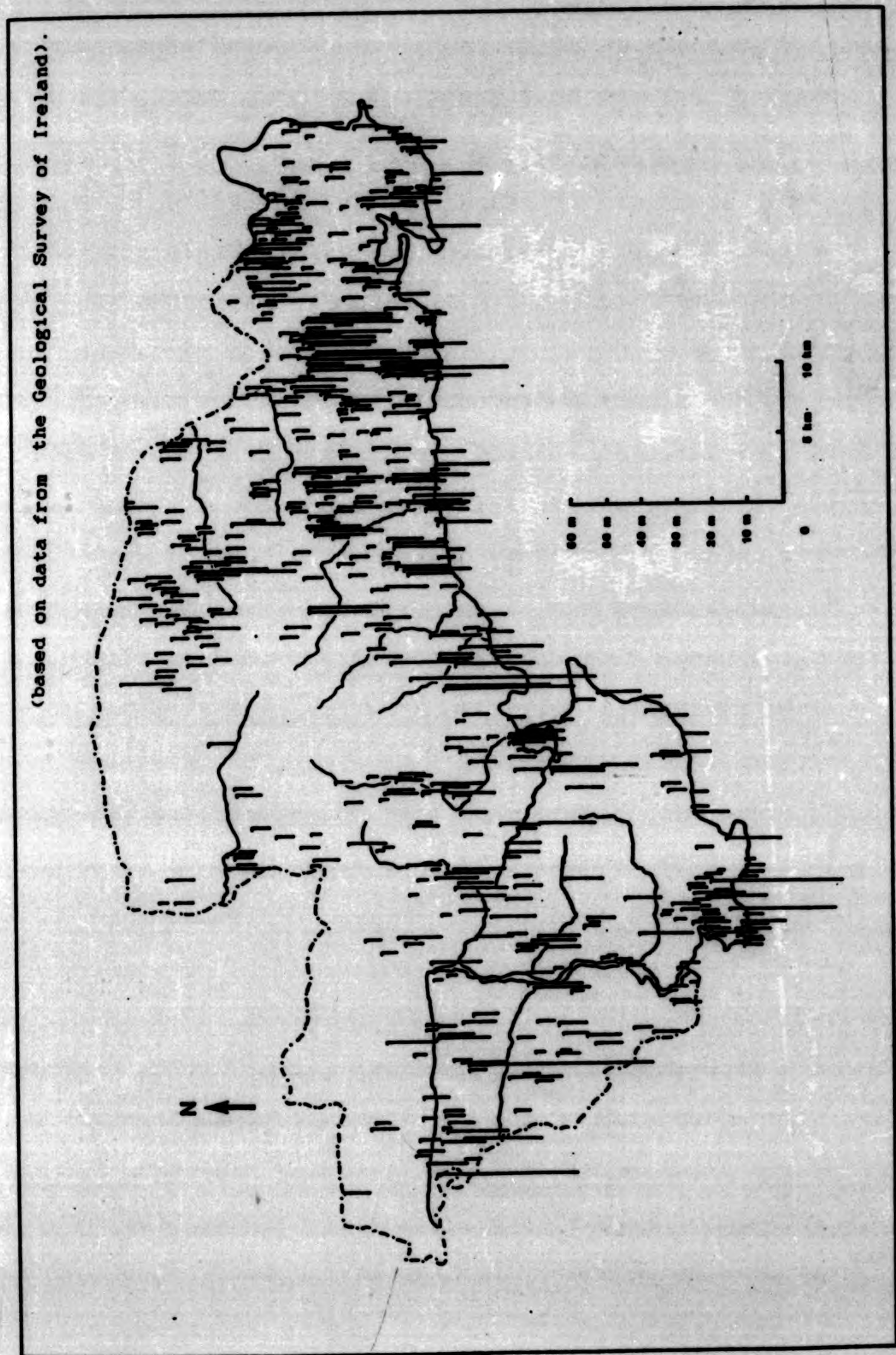


Figure 20 Thickness of unconsolidated sediments in County Waterford.

5.1.2. Location and Thickness of Unconsolidated Sediments in County Waterford

Undifferentiated surficial sediments as plotted on Figure 20 are mainly concentrated in areas of relatively low topographic relief, particularly in valleys and in the lee of the 'pre-glacial' (Wright and Muff, 1904) rock cliff along the south coast.

Although eastern County Waterford shows a greater density of deep borehole records in the Quaternary sediments three points should be borne in mind: Firstly, greater thicknesses of glacial sediments generally occur in low lying areas which are more common in the eastern half of the county. Secondly, higher frequencies of records may be related to more frequent well drilling (associated with greater density of population in eastern County Waterford) and mining activities. Thirdly, the greater apparent thicknesses of Quaternary sediments associated with the mining records may be due to inclusion of weathered bedrock as part of the unconsolidated sequence.

According to Figure 20, western County Waterford is characterised by shallow and infrequent records on the Devonian sandstone basement (generally associated with areas of high relief). Concentration of deep records is noticeably confined to the coastal limestone embayments and the Blackwater, Owbeg, Finisk, Brickey, Colligan and Nier valleys.

Unfortunately, the majority of records do not include detailed descriptions of the unconsolidated sediments (classified as overburden in the mining records). Occasional references to far-travelled erratics (granite) in the borehole logs give some indication of the presence of glacial or glaciofluvial sediments. When the records are compared to detailed field notes made in this study, it may be generally concluded that the vast bulk of the unconsolidated sediments are in fact of glacial, glaciofluvial, fluvial and gelifluctad origin.

5.2. Basis of Classification of Glacial/Glaciofluvial Sediments

5.2.1. Introduction

Unconsolidated sediment units which contained erratics and striated stones were considered to be ultimately of glacial or glaciofluvial origin. Analyses of fabric samples from diamictons and gravels, particle size distribution and the petrography of the phenoclasts (stone counts) provide a general basis for the classification of the sampled sediment units.

5.2.2. Fabric Analysis

Analyses of ninety-five fabric samples taken from diamictons and gravels, together with the results of detailed field mapping provide a general basis for the location of diamictic and gravel units in the areas mapped (Figure 8). The distribution of glaciofluvial sands and gravels tends to be concentrated in the major valley systems: the Suir, Nier, Finnisk, Blackwater, Dungarvan and Ballinamult valleys in the western half of the county; and in isolated patches on the Rathgormack plateau and in eastern County Waterford. Similarly, exposures of diamicton containing subangular clasts and deeper than 2 m seem to be generally confined within the valleys and at somewhat lower altitudes than the sands and gravels.

Only in two localities were diamicton and gravel encountered within the same stratigraphic sequence: At Clonmel, on the northern boundary of the county, two layers of diamicton composed of a clayey matrix supporting limestone clasts predominantly were separated by a horizon of limestone gravels. The second locality is situated in the townland of Ballylemon, to the north-west of Dungarvan, where a thin layer of diamicton is seen to overlie a thick sequence of gravels.

Vector analysis was carried out on the results of all of the fabric analyses. Both modal and vector directions are recorded in Appendix 7. Differences between modal and vector directions are generally minimal and within the limits of the class boundaries of the grouped data.

However some greater differences occasionally arise due to bi-, tri- and poly-modal distributions. The strength of the resultant vector in these cases is usually very weak and is generally of low statistical significance. The vector direction of non uni-modal distributions is therefore often meaningless as an indicator of the direction in which any single depositional process operated. Modal directions were selected therefore as more accurately and consistently representing former directions of ice movement. Polymodal fabrics in glacigenic diamictons may result from multigenetic or multiphasic processes (Boulton, 1972; Warren, 1987a). Interpretation of individual polymodal fabrics will be referred to throughout the text.

Fabric analyses of glacigenic diamictic sediments indicate a regional north-south pattern of glaciation in County Waterford. It is not possible to infer from fabrics alone whether ice moved from north to south or from south to north, or from both directions. However when the results from the fabric analyses are combined with those of erratic carry-over analyses, it may deduced that ice moved southward from the valley of the Suir in the north. Ice passed southward through the Ballinamult Gap on the west side of the Comeragh Mountains. Fabric evidence suggests that the ice continued to flow southward across the Dungarvan syncline and over the Drum Hills to the coast.

To the east of Dungarvan ice appears to have flowed in an east-south-easterly direction off the coast at Ballyvoyle Head. In eastern County Waterford ice moved southward and south eastward off the present coastline.

The absence of strongly diverging modal directions, particularly in the samples from the coastal areas, suggests that if there was an alternation between onshore and offshore ice movements as suggested by Wright and Muff (1904) and Watts (1959), these movements occurred in mutually opposing directions.

Only three samples diverge from regional trends. At least two of these modal directions probably reflect the movement of local ice from the Comeragh mountains to the west and east down the Nier and Mahon valleys respectively.

In contrast, gravel fabrics and isolated depositional features indicate a general northward retreat of ice and associated southward subglacial or proglacial drainage of meltwater.

As no further reliable differentiation between the sediments sampled is possible, the use of fabric analyses as part of the classificatory basis is limited to the differentiation of three groups of glacigenic sediments: glacigenic diamictons associated with general and mountain

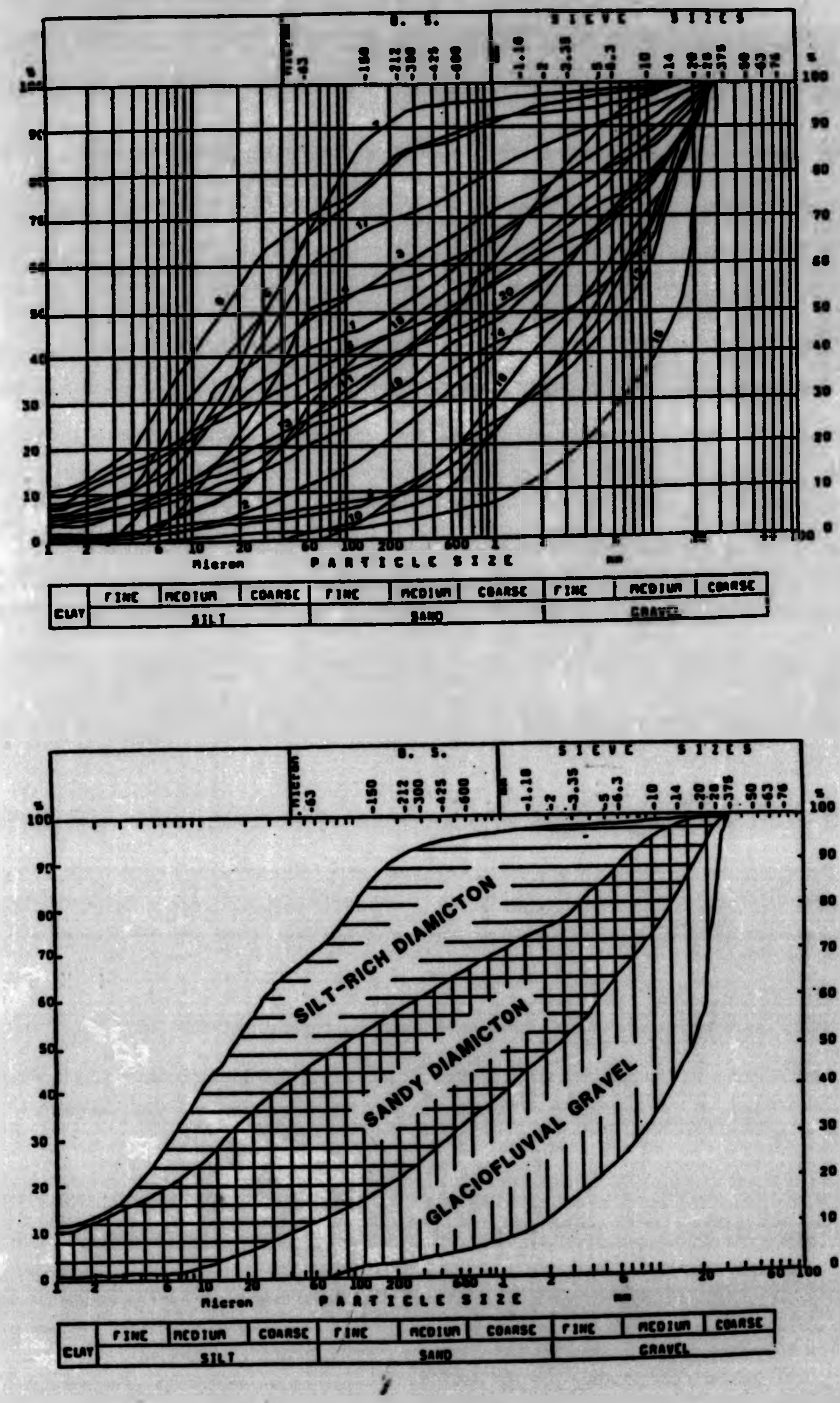


Figure 21 Grain size distribution curves and envelopes from twenty unconsolidated sediment samples in County Waterford.

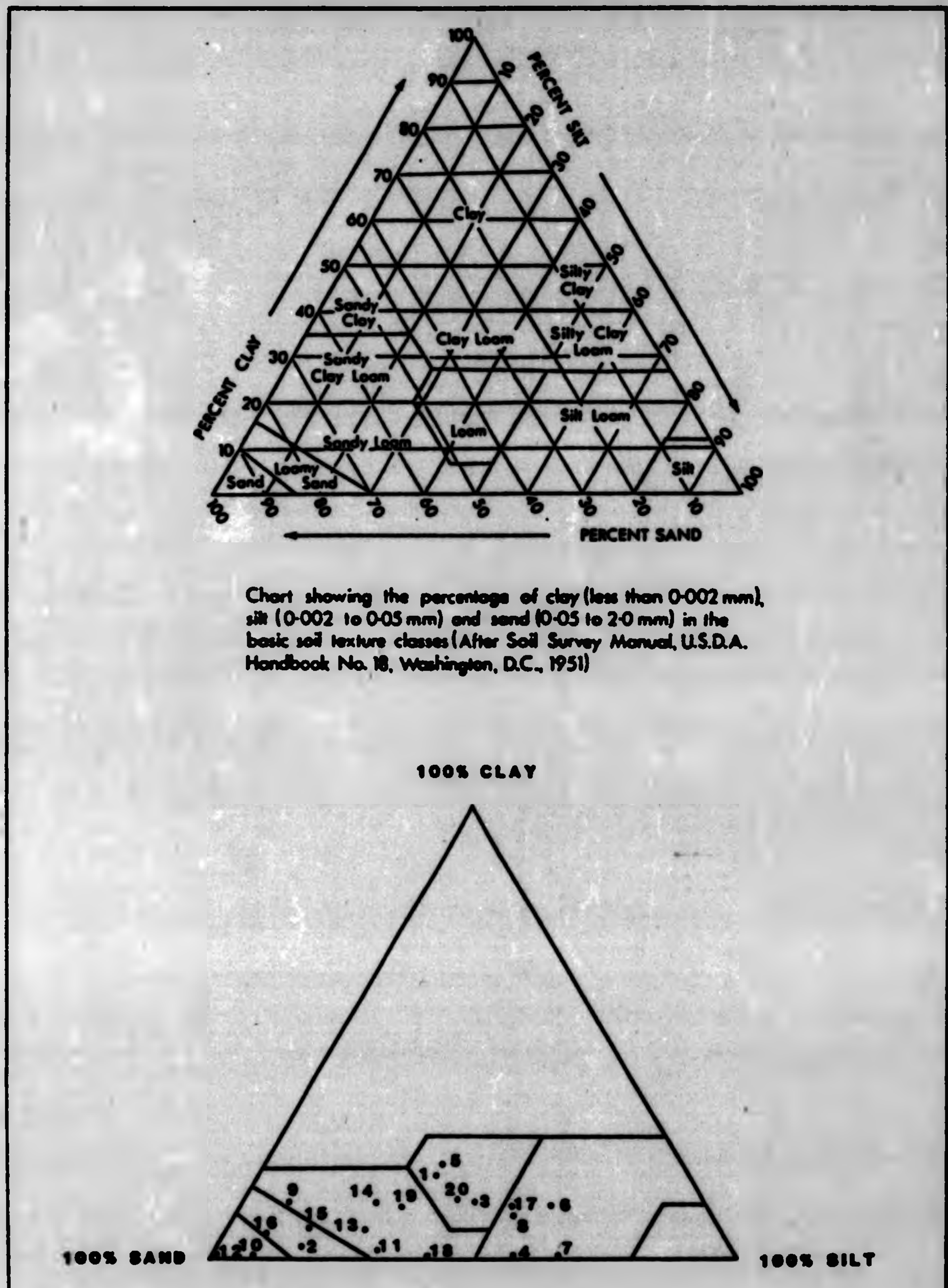


Chart showing the percentage of clay (less than 0·002 mm), silt (0·002 to 0·05 mm) and sand (0·05 to 2·0 mm) in the basic soil texture classes (After Soil Survey Manual, U.S.D.A. Handbook No. 18, Washington, D.C., 1951)

Figure 22 Ternary diagram displaying amounts of clay, silt and sand in twenty textural samples from County Waterford.

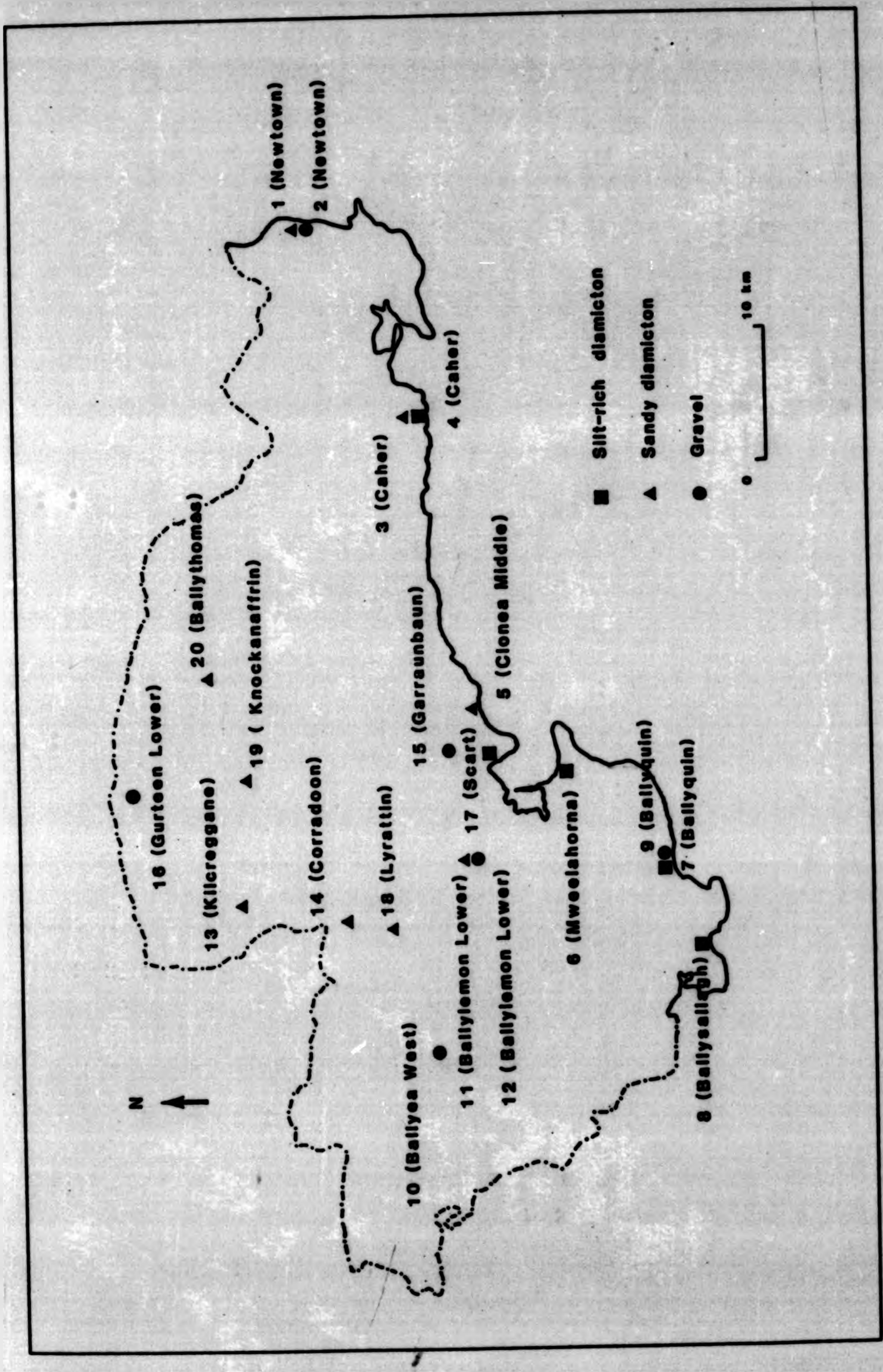
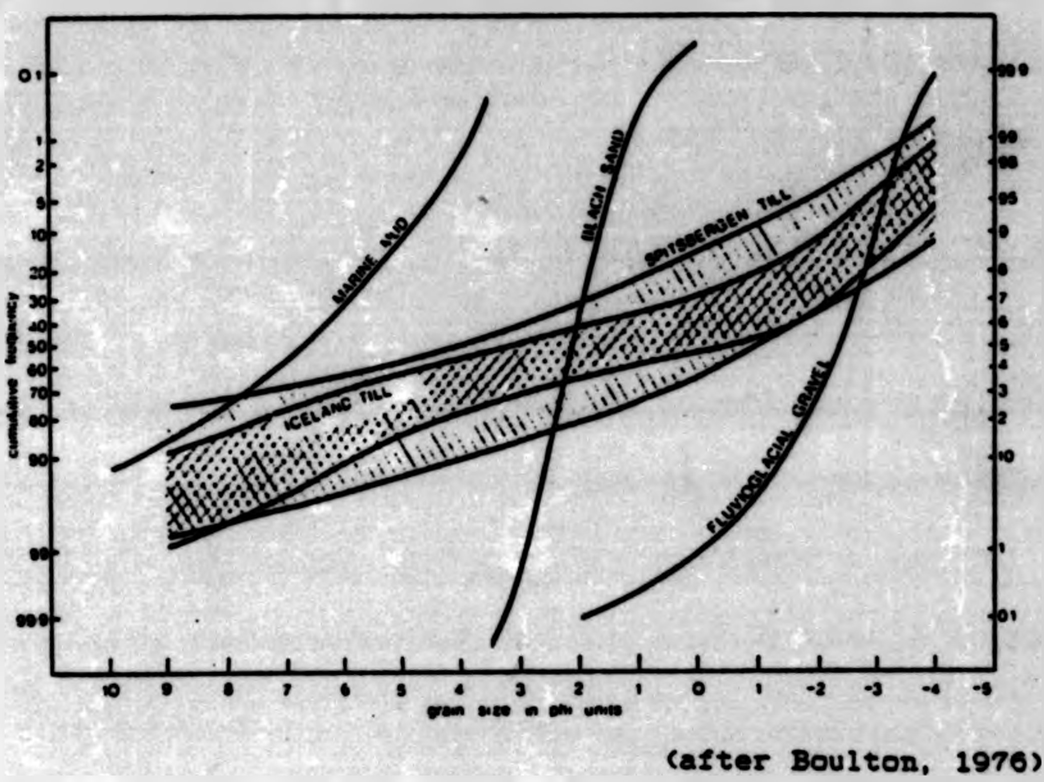


Figure 23 Location of particle size samples.



(after Boulton, 1976)

Figure 24 Marine mud cumulative frequency curve.

glaciation, and glaciofluvial deposits in County Waterford.

5.2.3. Particle Size Distribution

Cumulative percentage frequencies of grain sizes from less than 37.5 mm in diameter to clay particles are plotted on semi-logarithmic graph paper for a total of twenty samples (Figure 21 and Appendix 8). The proportions of sand, silt and clay are graphically displayed on a ternary diagram (Figure 22 and Appendix 9). Three broad categories of the relatively clay-impoverished glacial sediments may be distinguished in County Waterford on the basis of particle size distribution:

1. A positively skewed silt-rich group of glacial deposits previously identified as being of Irish Sea basin provenance (Wright and Muff, 1904). This group appears to be confined to coastal localities (Figure 23). Sample sites do not appear to be restricted to any single basement lithology. The silt enrichment is therefore probably related to extra-local provenance of the glacier system responsible for its deposition. The most likely source for such quantities of silt-rich materials is the basin of the Irish Sea as indicated by earlier workers (Wright and Muff, 1904). This observation is supported by the broad similarity between the curves from the Waterford samples and that typical of marine mud (Boulton, 1976) (Figure 24).

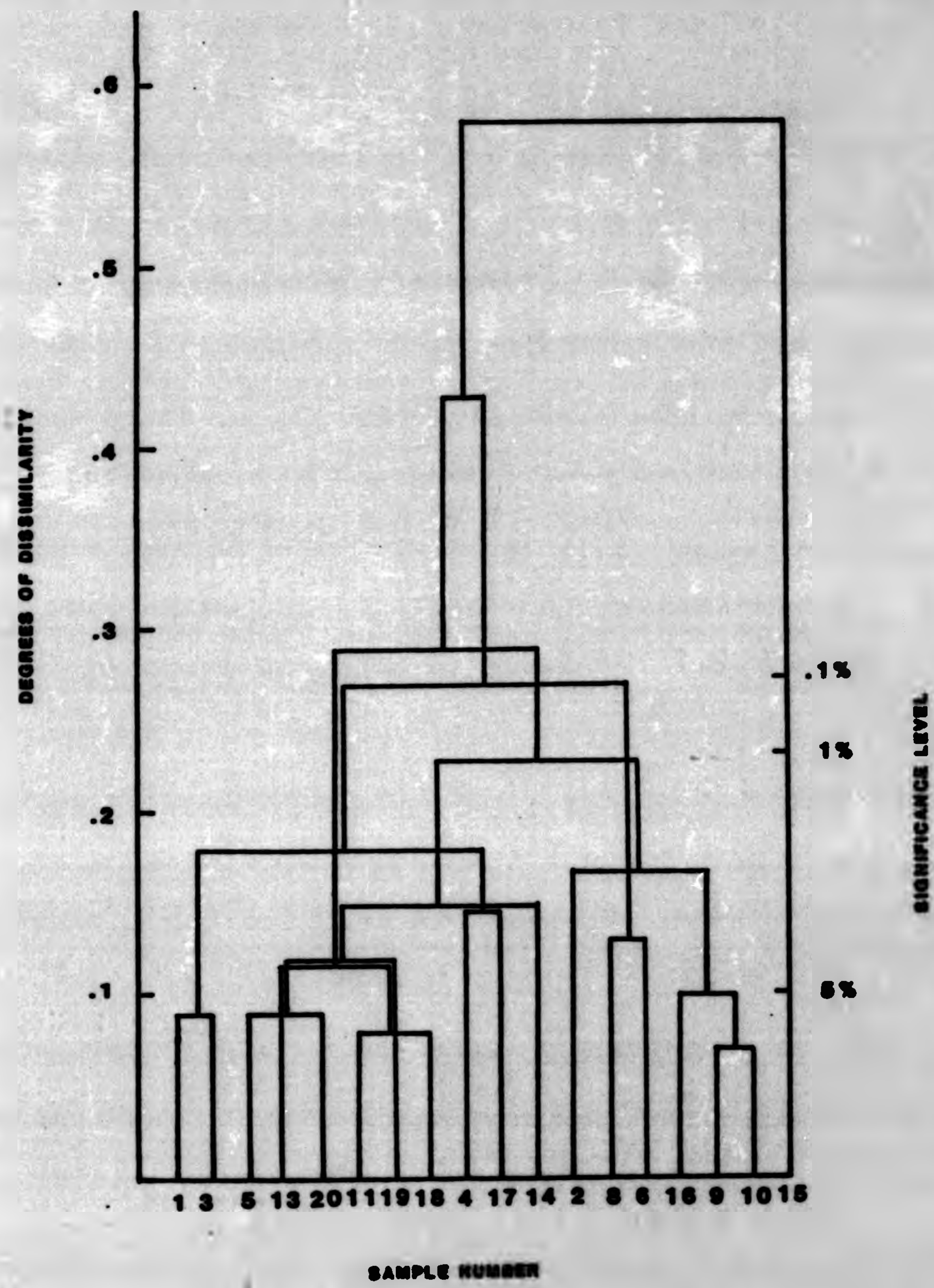


Figure 25 Dendrogram of degrees of dissimilarity between textural samples.

2. The second group contains normally distributed grain size fractions which plot out on semi-logarithmic paper as straight lines. It occupies an intermediate position between the other two groups. This group contains samples from previously identified outcrops of the Ballyvoyle Till (Watts, 1959). The samples are widely distributed throughout County Waterford and occur both to the east and west of the Comeragh Mountains. The relatively straight lines of the samples is indicative of a high degree of mixing of all fractions. Such sediments are typically deposited by basal lodgement of englacial material through melt-out processes at the base of a glacier (Dreimanis and Vagners, 1971; Boulton and Paul, 1976).

3. The third group is silt-poor. The silt-impoverished samples are characteristic of glaciofluvial gravels and allochthonous flow and ablation tills depleted in fines (Boulton, 1976; Boulton and Paul, 1976). The samples are found in proximity to those of the other two groups and are probably derived from both groups. Somewhat surprisingly this group also includes a single sample from the lower diamicton at Newtown on the west bank of the Waterford Harbour estuary, the Newtown Till of Mitchell *et al.*, (1973).

Differentiation of the groups is based on a dissimilarity matrix derived from the results of two-tailed Kolmogorov-Smirnov non-parametric significance tests (Figure 25). Individual groups are not discrete in that there is some

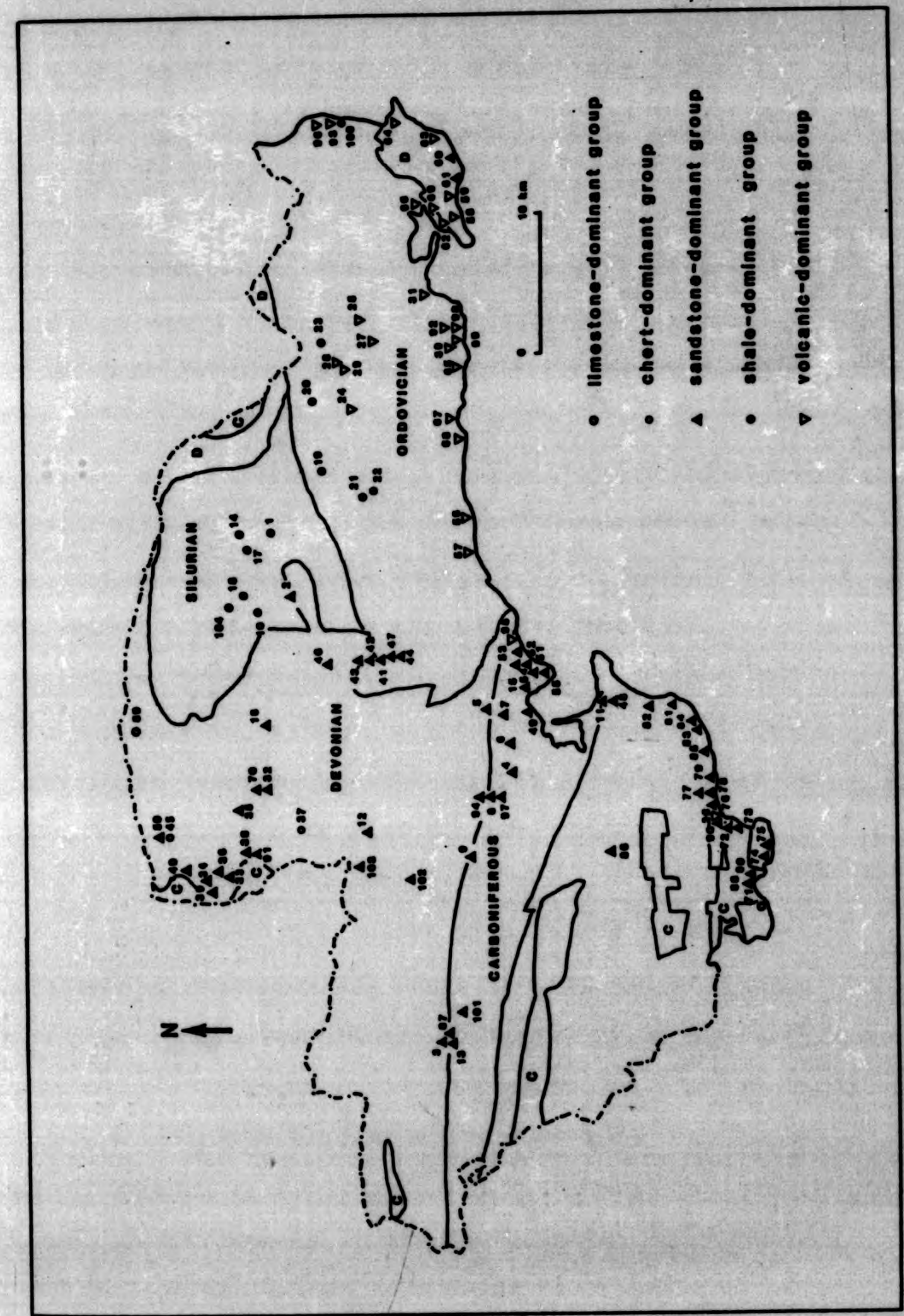


Figure 26 Location of petrographic samples.

overlap between neighbouring groups. Individual samples from any one group may not be significantly different from all other samples outside that group (Figure 26). Boundaries between groups were arbitrarily selected on the basis of the degree of dissimilarity between samples and their position on the ternary diagram. Each of the three groups identified in the grain size envelopes and on the ternary diagram is significantly different from the others at the 0.1% level of significance (Figures 21 and 25).

Particle size analysis provides a basis for distinguishing three groups within the glacial sediments investigated. Differences between the groups may be related to local variation in processes of glacial transport and deposition, to varying petrography of the phenoclasts or to a combination of both factors. The reasons for the differences between the three groups identified on the basis of particle size analyses need to be assessed in order to establish whether the results of the technique can form the basis for identifying separate mappable lithostratigraphic units. Hence the results of this analytical technique need to be augmented by those of an analysis of variation in the petrography of the phenoclasts in the glacial sediments.

5.2.4. Petrography of the Phenoclasts

Ten lithologies (solid) from which the clastic component of the sediments were derived were initially recognised. These were collapsed to five types to facilitate general comparison and contrast between samples. They include the following:

1. Limestone.
2. Silicified limestone or chert.
3. Sandstone (quartz, conglomerate and sandstone).
4. Volcanics (acid, basic and intermediate).
5. Shale and miscellaneous. The miscellaneous component never exceeds 1% of any one sample; it includes flint, shell and granite and will be specifically referred in the course of individual site descriptions.

Covariance-based cluster analysis of the data generated five major groupings related to the five lithological (solid) types submitted. Each group is distinguishable on the basis of a dominant lithological type (Figure 26). The smallest groups are limestone- and chert-dominated and are composed of two samples each. The sandstone-dominant group contains 62 samples. While the volcanic-dominant and shale-dominant groups are comprised of 26 and 12 samples respectively (Figure 26 and Appendix 6). These may be further broken down into subsets based on varying proportions of other lithologies alongside the dominant type.

Distribution of the groups is broadly related to underlying variation in basement lithology although some interesting anomalies are highlighted.

1. The two limestone-dominated samples were taken from glaciofluvial gravels and a silt-rich diamicton in the extreme north and south of the county respectively. The limestone content in both samples is erratic. The junction between the nearest outcrop of Carboniferous limestone and the Devonian sandstone which underlies the northern sample point lies approximately 1.5 km to the north. As the proportion of Carboniferous limestone clasts in the unconsolidated sediments to the south of this sample diminishes rapidly, a northern provenance is indicated for the limestone content in the northern glaciofluvial gravel sample. Carboniferous limestone crops out to the south, east and west of the southern sample point. The limestone content in the southern sample must have been transported from one of these directions as no limestone is present in the sediments between Caliso Bay and the Dungarvan Carboniferous syncline to the north.

2. The two samples in the chert-dominant group are located in diamicton which is underlain by Devonian sandstone in the north western part of the county. The chert content is erratic and is not accompanied by the presence of Carboniferous limestone. The nearest and most probable source of the chert content is the lowlying

Carboniferous limestone outcrop 2 km to the west and north west. Bedded cherts are recorded in the Croane and Kilsheelan Limestone Formations in the Suir valley to the north of the sample points (Keeley, 1983). The chert content decreases rapidly in the samples to the south and east which become dominated by Devonian sandstones. It also decreases to the north and west of the sample points where it is overtaken by the limestone content. This latter generally increases in samples from the opposite direction i.e. to the north west. This pattern would be consistent with a distance-decay function in glacial carry-over of Carboniferous limestone and chert erratics from a north western direction. Similar southward carry-over patterns of limestone and chert erratics from lowlying areas have been recorded on the Devonian foothills of the Galty Mountains (Synge, 1970b and 1979) and the Slieve Bloom Mountains (Warren, 1987b). Isolated and relatively high proportions of chert erratics (*vis a vis* those of limestone erratics) imply massive rates of leaching out of limestone as chert beds in the Carboniferous limestone generally occupy approximately less than 10% of the total recorded thickness of the Carboniferous stratigraphic sequence in the Suir syncline to the north of the sample points (Keeley, 1983). Such a situation could have arisen through selective leaching out of the calcareous component i.e. the limestone erratics in the relatively acidic hydrogeologic conditions associated with the subjacent Devonian sandstones. Inverse proportions of chert to 'fresh' limestone are characteristic of most of the glacial sediments in County Waterford. The proportion of limestone clasts exceeds that of chert clasts only in the silt-rich diamictons along the south west coast and two samples (both taken from glaciofluvial gravels) in the extreme north west of the county. All of these samples are located on Carboniferous limestone or less than 0.5 km from the junction between Carboniferous limestone and Devonian sandstone.

3. The fact that sandstone-dominated samples form the largest group is related to the widespread subcrop of Devonian strata in County Waterford. It is partly related to the preferential preservation of Devonian sandstone within the glacial system. This trend is particularly well exemplified in the glacigenic sediments of the Dungarvan Carboniferous limestone syncline where clasts derived from the subjacent rock fail to dominate any of the samples from the Dungarvan area. The predominance of Devonian sandstone clasts is also related to the direction of transport of the sandstone erratics in the glacial sediments of the county. This effect is evident in the north eastern and eastern samples where carry-over of sandstone materials from the north and north west augments the presence of sandstone as a predominant lithological type in the clastic component of the glacial sediments of County Waterford.

One major subset of this group is composed of samples with slightly lower percentages of sandstone. Naturally these samples are associated with changes in underlying solid geology and tend to be located just outside the limits of the sandstone outcrop. One exception within this subset are the samples from the south west coast which contain relatively higher proportions of limestone, chert, volcanics and shale (a single case) erratics. These erratics are not related to nearby changes in local lithologies and must therefore be interpreted as indicative of glacial transport either by ice of Irish Sea basin origin or by ice of inland, northern origin.

4. The volcanic-dominant group occupies the eastern half of the county. Although the underlying solid geology is largely composed of alternating Lower Palaeozoic shales and tuffs the samples are dominated only by the volcanic clasts indicating their superior survival ability within the glacial system. Carry-over of volcanic clasts in the glacial sediments of eastern County Waterford was mainly from the north or north east. This trend is evidenced by the location of samples dominated by volcanic erratics on Devonian sandstones in the extreme south east of the county. However two anomalous distributions of volcanic erratics are noteworthy:

a) Although localised outcrops of volcanic rocks occur within the Silurian and Devonian strata these are never large enough to significantly influence relative proportions of volcanic clasts within the samples over large areas at the present scale of investigation. Small but consistent percentages of volcanic lithologies occur within the shale-dominant samples to the north of the main volcanic outcrops on the eastern edge of the Rathgormack plateau. Their presence in these samples could be explained by an early north westerly advance of ice up the Suir valley.

b) The second anomaly associated with the distribution of volcanic erratics has already been referred to indirectly. Significant proportions of volcanic clasts occur in the samples from the south western coastal strip. Their presence in the silty diamicton supports previous conclusions about their easterly provenance associated with the westward movement of ice from the Irish Sea basin (Wright and Muff, 1904).

5. The distribution of shale-dominant samples generally does not extend beyond the limits of Silurian and Ordovician solid shale outcrops. The total proportion of shale in any one sample rarely equals those of other dominant clastic lithologies due to its comparative lack of resistance within the glacial system. Small and persistent proportions of erratic shale clasts occur in the samples on the south west coast and also in areas to the south of the main shale outcrops in eastern County

Waterford.

All of the 104 samples analysed when taken together in a similarity matrix yield a correlation coefficient of 0.4 which is just within the 0.1% level of significance according to the 'Students' t' distribution. on this basis all of the samples could be regarded as belonging to a single lithostratigraphic unit. However when the total data set is subdivided according to the last major cluster passes for each group, obviously, much higher levels of similarity within the subsets of individual lithological dominance occur (ranging from 0.9 to 0.7 at 0.1% level of significance). When taken in isolation this technique yields a basis for differentiating five groups of samples based on the five recognised dominant lithological types.

5.3. Summary

The three groups of glacial sediments which may be recognised on the basis of fabric analyses include: diamicton with fabrics oriented north-south, diamicton with east-west fabrics (associated with mountain valley locations) and gravels.

Analyses of particle size distribution also enable differentiation of the glacial sediments into three categories: silt-rich diamicton, silt-poor gravels and an intermediate group consisting of diamicton with a sandy, poorly-sorted matrix.

TABLE 1. PETROGRAPHIC COMPOSITION OF SEDIMENTS SAMPLED FOR PARTICLE SIZE ANALYSES

No.	Locality	Townland	% Limestone, chert, sandstone, volcanic and shale clasts.				
			L	C	S	V	S
1. Silt-rich Diamicton:							
4.	Garrarus	Caher	0.0	1.5	0.5	98.0	0.0
6.	Dungarvan	Mweelahorna	4.7	8.4	53.9	13.0	0.0
7.	Ardmore	Ballyquin	15.5	10.3	20.7	46.6	6.8
8.	Whiting Bay	Ballysallagh	13.1	8.1	55.6	23.2	0.0
17.	Dungarvan	Scart	0.0	7.3	81.2	8.4	2.7
		Mean:	6.7	7.1	42.4	37.8	1.9
		S.D.:	7.3	3.3	31.7	36.7	3.0
2. Sandy Diamicton:							
1.	Waterford	Newtown	1.4	0.2	36.7	58.7	3.0
3.	Garrarus	Caher	0.2	2.1	4.1	88.6	5.0
5.	Ballyvoyle	Clonea Middle	0.0	2.7	34.7	61.4	1.2
11.	Dungarvan	Ballylemon Lr.	0.0	1.0	95.2	3.8	0.0
13.	Ballymacarbry	Kilcreggane	16.3	34.7	47.6	1.2	0.2
14.	Ballynamult	Corradoon	0.0	2.2	95.6	2.2	0.0
18.	Ballynamult	Lyrattin	0.0	0.0	100.0	0.0	0.0
20.	Rathgormuck	Ballythomas	0.0	3.0	19.6	12.5	64.9
		Mean:	2.2	5.7	54.2	28.6	9.3
		S.D.:	5.7	11.8	37.7	35.3	22.0
3. Sandy Diamicton with E/W Fabric:							
19.	Nier Valley	Knockanaffrin	0.0	1.4	95.1	2.5	1.1
4. Gravels:							
2.	Waterford	Newtown	0.0	0.4	24.2	19.6	52.8
9.	Ardmore	Ballyquin	0.5	0.9	67.5	29.9	0.5
10.	Lismore	Ballyea West	4.7	30.7	62.0	2.6	0.0
12.	Dungarvan	Ballylemon Lr.	0.0	7.3	91.5	1.2	0.0
15.	Dungarvan	Garranbaun	-	-	-	-	-
16.	Clonmel	Gorteen Lower	82.5	6.1	10.7	0.0	0.2
		Mean:	17.5	9.1	51.2	10.7	10.7
		S.D.:	36.4	12.5	33.1	13.4	23.5

The results of analyses of petrography of the phenoclasts yield a five-fold subdivision of the glacial sediments according to the five dominant lithological groups (limestone, chert, sandstone, volcanics and shale).

5.4. Conclusion

The diamictons with north-south fabrics may be further subdivided into silt-rich and sandy, poorly-sorted types on the basis of textural analyses. The gravels which were sampled in the course of fabric analyses may be regarded as synonymous with those gravels sampled for textural analyses. The various groups of sediments identified on the basis of the three individual lines of evidence above may therefore be collapsed into four major mappable lithostratigraphic units. These units are differentiated on a combined petrographic (content of erratics in stone counts), textural and fabric basis (Table 1). The lithological groups do not form petrographically discrete groups as may be seen from a glance at the group means and standard deviations on the accompanying table. The four lithological units broadly correspond with those already recognised in previous literature as the till of Irish Sea basin provenance, the Ballyvoyle Till, till associated with local mountain glaciation in the Comeraghs and localised sands and gravels. Each of these units will be described individually in more detail in the following chapters.

Figure 27 Joint patterns in silt-rich diamicton.

CHAPTER SIX

SILT-RICH AND VOLCANIC ERRATIC-BEARING DIAMICTONS

6.1. Description of Characteristics

6.1.1. Introduction

The calcareous silt-rich sediments which were sampled for particle size analysis in the four localities to be described are in places laminated or show contorted lamination (see Appendix 1). The generally chocolate-brown, calcareous silts are distinctively jointed. The joints are horizontally and vertically aligned with respect to laminated or weathered surfaces and bedding planes (where present) (Figure 27). The silty diamicton contains few stones, nearly all of which are fairly rounded and striated. In most cases the predominant lithology in the contained clasts is erratic. Most of the erratic clasts are derived from adjoining outcrops of Devonian sandstones, conglomerates and quartz, Carboniferous limestones, shales and chert, Lower Palaeozoic volcanics and more far-travelled erratics. These include abundant flints and small quantities of granites of northern or north-eastern provenance (Wright and Muff, 1904). Comminuted shell fragments occur abundantly, though no shell fragments larger than one centimetre in diameter were observed in the silty diamicton. This diamicton corresponds to the "marly boulder-clay" of previous authors (Wright and Muff, 1904; Watts, 1959; Stevens, 1959). Outcrops of similar sediments occur in other coastal localities in County Waterford. Most of the outcrops of flint and shell-bearing silty diamicton were sampled for petrographic and fabric analyses (Table 1).

6.1.2. Particle Size Analysis

The five silt-rich samples which were subjected to particle size analysis were taken at or (in the case of No. 17 in the townland of Scart) near the coast (samples 6, 7, 8, 4 and 17 on Figure 23). According to the dendrogram based on degrees of dissimilarity between samples, two further samples could be added to this silt-rich group: samples 1 and 3. These two samples were also taken from coastal localities. Although they contain relatively less silt they are less dissimilar to samples 4 and 17 than 4 and 17 were to 6 and 8 in terms of total distribution of particle sizes (Figures 21 and 25). However samples 1 and 3 are not included within the silt-rich group *per se* because of other fairly significant differences between the sampled sediments which will be discussed in more detail later. Instead these samples are classified as an intermediate loamy type between the silt-rich group and the sandy loam group. Thus the silt-rich group may be subdivided on the basis of siltiness: samples

6 and 8 at one end of the scale with 73% and 68% respectively composed of fractions finer than 0.065 mm and 4 and 17 at the other end of the scale containing an equivalent 52% and 63% respectively (Appendix 8).

6.1.3. Fabric Analysis

Fabric analysis was carried out on three of the four silt-rich samples which were subjected to particle size analysis. Sample fabrics in the silt-rich strata yielded modal values of 225° in the townland of Caher on Garrarus Beach, 340° in the townland of Ballysallagh in the centre of Whiting Bay and 300° in the townland of Scart to the east of Dungarvan. As the silty sediments exposed in the cliff in the townland of Mweelahorna, just beneath Coláiste na Rinne, on the south side of Dungarvan Bay were badly slumped, it was virtually impossible to isolate an *in situ* outcrop which could be sampled for fabric analysis in that locality. The resultant modal values and closely corresponding vector directions (samples 29, 70 and 8 on Figure 8, Appendix 7) strongly resemble fabrics of neighbouring (Whiting Bay and Dungarvan areas) and overlying (Garrarus Strand) sediments. However, as already acknowledged it is not possible to categorise the glacial sediments on this basis alone and so no inferences can be made about the source and direction of former regional ice movements in County Waterford as evidenced by individual fabrics analyses.

6.1.4. Petrography of the Phenoclasts

Analysis of the petrography of the phenoclasts in the relatively stone-free silt-rich sediment group shows variation in predominant lithological type and relative proportions of other lithologies present (Table 1). The sample from Garrarus in eastern County Waterford is dominated by the presence of volcanic clasts derived from the Lower Palaeozoic rocks (98%), while the sample from the south side of Dungarvan is dominated by sandstones and related lithologies derived from the Devonian strata (81%). Although the other two samples are also both dominated by the presence of sandstone clasts (54% and 56%), there is a much wider range of lithologies present including Carboniferous limestone and chert. The absence of shale (largely derived from the Lower Palaeozoic solid outcrops in eastern County Waterford) in three out of the four samples analysed for particle size analysis is notable. Low percentages of shale clasts appearing in the sample from Scart on the east side of Dungarvan (3%) represent carriage westward of these erratic clasts. Similar transport patterns are indicated by the presence of volcanic erratics in the three samples from western County Waterford. However the presence of erratic clasts may be derived from older glacial deposits and do not necessarily indicate the most recent directions of ice movement in the county. Such inferences cannot be drawn without reference to the distribution and stratigraphic succession of the sampled sediments.

6.2. Location and Distribution

6.2.1. Location

All of the localities at which calcareous silty, flint- and shell-bearing diamictons were recorded in the course of field work are listed from west to east in the table below (Table 2). The table includes the townlands within each locality in which the diamicton was recorded. It also includes the number assigned to the sample taken from each site for the purposes of particle size, petrographic and fabric analyses.

TABLE 2. LOCATION OF SILT-RICH DIAMICTON OUTCROPS

Locality	Townland	Sample Numbers		
		Part. Size	Pet.	Fab.
Caliso Bay:	Monatray East		71	56
Whiting Bay:	Ballysallagh	8	88	8
	Cappagh		80	
	Ardoginna			57
Ardoginna:	Ardoginna		74	
	Ardoginna		75	58
Ardmore Bay:	Crushea			55
	Ballyquin (west)		73	

	Ballyquin (east)		26	10
	Ballyquin (east)	9	90	9
	Ballyeelinan		76	54
	Crobally Lower		78	
	Crobally Lower		77	
Dungarvan:	Kweelahorna	6	11	
	Kweelahorna		48	
	Scart	17	15	70
Ballyvoyle:	Knockyoolahan W.		(No longer exposed)	
Garrarus:	Islandikane East		(Recently exposed)	
	Caher	4	98	29

This list does not include previously reported outcrops of "chocolate-coloured, relatively stone-free calcareous clay often containing marine shells" at Tramore and Kilfarrasy Strand in eastern County Waterford which were not seen by the author and have presumably been subsequently buried by recent storm beach accumulation at the base of the coastal exposures (Watts, 1959).

6.2.2. Distribution

From the above list it would appear therefore that the distribution of the silty diamicton is restricted to low-lying, coastal embayments which have a pronounced easterly or southerly orientation. Such a distribution could indicate that the silty diamicton was carried onshore by ice of Irish Sea basin provenance as originally suggested by Wright and Muff (1904). Assuming that the initial distribution of the diamicton has not been substantially altered by any subsequent glacial or gelifluction processes, it also suggests that the depositional regime associated with this ice was largely controlled by the topographic relief presented by the coastline in the path of a northerly- or north westerly-advancing ice sheet. Outcrops seem to occur with greater frequency and depth of exposure and generally coincide with the Carboniferous limestone synclines in the western half of the county. The Carboniferous limestone embayments would have presented relatively less resistance to an ice mass extending onshore than the cliffed coastline associated with Devonian sandstone and Lower Palaeozoic acid volcanic basement lithologies. Outcrops of the silty diamicton also appear to be confined altitudinally to a maximum of 60 m O.D. along the coastal strip west of Dungarvan. However in eastern County Waterford the silty diamicton outcrops occur within one or two metres of the base of coastal sections and appear to be confined to embayment of valley locations. They are overlain by stony, sandy diamicton which is the predominant unit in the stratigraphic sequence in the eastern half of the county. The silty diamicton extends inland as far as the 'pre-glacial' Devonian sandstone cliff (Wright and Muff, 1904) which it does not seem to have over-topped in any locality. Again assuming no significant alteration of the original distributional pattern, the depositional process appears

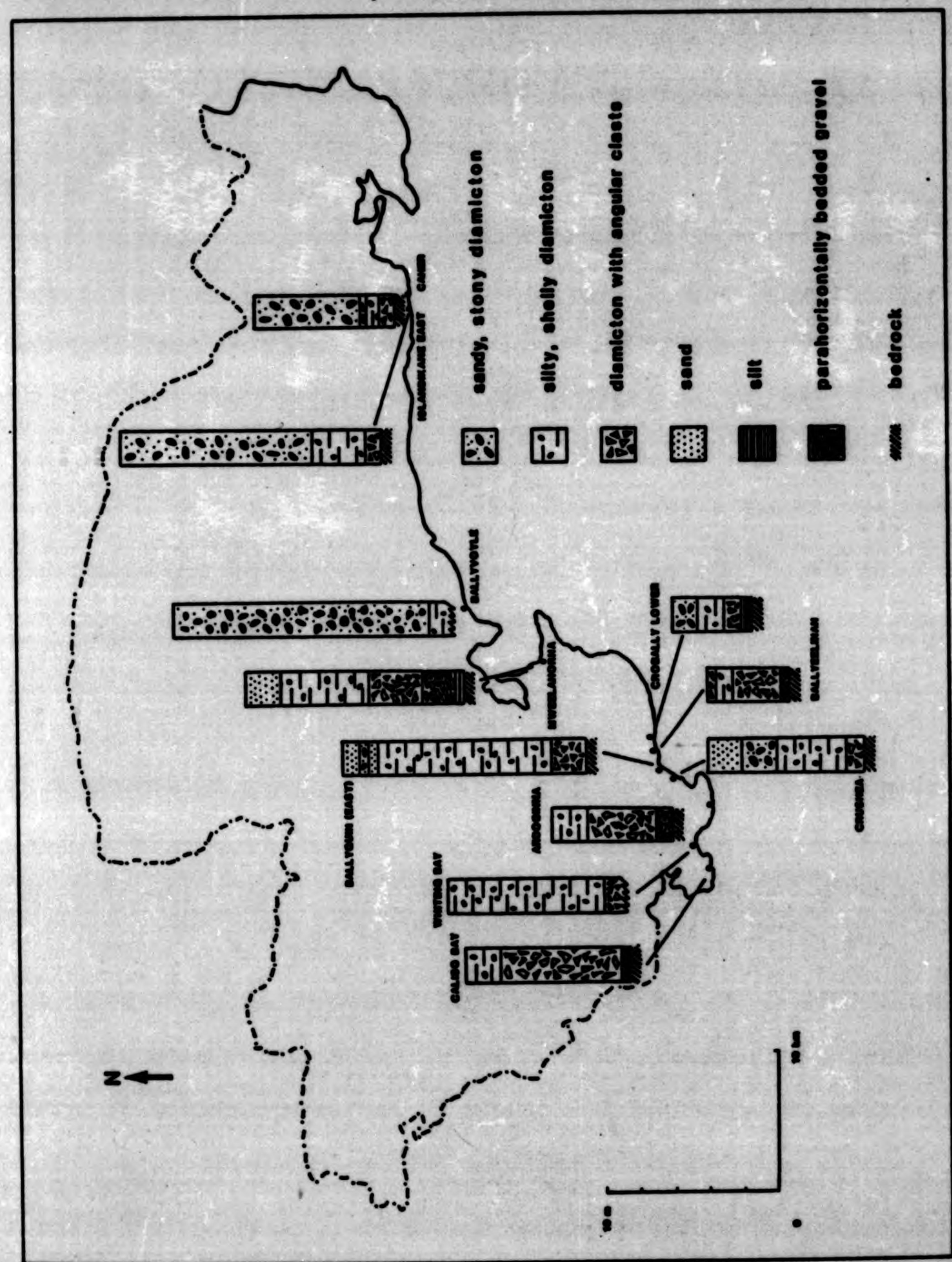


Figure 28 Logs of exposures of silt-rich diamicton.

to have been confined vertically as well as laterally.

6.3. Facies Variation and Stratigraphy

6.3.1. Caliso Bay

The following succession was recorded at the eastern end of Caliso Bay in the townland of Monatray East (Figure 28):

2 m	calcareous massive, jointed silty diamicton
7 m	sandy diamicton containing angular clasts
0.5 m	horizontally stratified rounded pebble-supported gravel with sandy matrix resting on Devonian sandstone.

Interpretation

The lowest unit is regarded as an outcrop of the raised beach deposit. This unit is commonly found in the same relative stratigraphic position *vis a vis* the underlying platform and the overlying 'head' deposit, the 'Lower Head' of Wright and Muff (1904). The relatively stoneless silty diamicton was found to wedge out against the solid sandstone outcrops at either extremity of the bay. The diamicton contains flint and shell erratics. The predominant lithology of the contained clasts are Carboniferous limestone erratics, followed by volcanic erratics probably from the Lower Palaeozoic outcrops in eastern County Waterford, Devonian sandstones, chert erratics and shales (probably derived from the Lower Palaeozoics of eastern County Waterford), in decreasing order of importance. This sample is the only one from south-western County Waterford in which sandstone is listed as the third most frequently occurring lithology. The sample from the silty diamicton is also the only sample in southern County Waterford which is dominated by limestone. It is most reasonable to assume that the limestone is derived from the present sea bed to the south or south east of the sample point as the nearest Carboniferous limestone crops out in Whiting Bay 1.5 km to the east. The survival ability of the limestone clastic component within the glacial system associated with the deposition of the silty diamicton seems to be relatively high. Many of the samples from this group contain more limestone clasts than chert (Appendix 6). This ratio of limestone to chert is considered 'normal' in the sense that it reflects the predominance of limestone over chert in the Carboniferous stratigraphic sequence from which the clasts are derived (Keeley, 1983; MacCarthy *et al.*, 1978). Thus the eastern provenance of the phenoclasts, and the silty texture of the diamicton strongly suggest westward glacial transport of the sediment from the present offshore zone. This finding is corroborated by the strong north-westerly/south-easterly alignment of the a-axes of the contained clasts which in this case dip to the south

Figure 29 Contact between silty diamicton and underlying diamictic unit at western end of Whiting Bay.

east.

6.3.2. Whiting Bay

As at Caliso Bay the silty diamicton which is exposed in the cliff at the centre of the bay thins to the east and west and is totally absent from the sections at Ardoginna Head and Cabin Point. At these points the sections are composed of head resting on raised beach and Devonian sandstone raised platform. The head unit varies in thickness from four metres on the west side to between one and three metres at the back of the western and eastern embayments respectively where it crops out beneath up to seven metres of calcareous, shell and flint-bearing silty diamicton (Figure 29). The silty diamictic unit was previously regarded as being overlain by an upper stony diamicton consisting of approximately five metres of "stony boulder-clay...probably deposited by the inland ice coming from the north" (Wright and Muff, 1904).

Stratigraphy, Structure and Sedimentology

A number of contrasts may be seen in the unconsolidated sediments between the western and eastern sides of Whiting Bay (see Chapter Eight for interpretation of the following):

1. The calcareous, shelly muds exposed in Whiting Bay rest on a bevelled platform of cryoturbated head at the western end of the bay. At the eastern end of the bay

Figure 30 Contact between silty diamicton and underlying unit at eastern end of Whiting Bay.

Figure 31 Composite drop-stone in silty diamicton exposed on the east side of Whiting Bay.

however, blocks of stratified diamicton containing angular fragments of local Devonian sandstone clasts in a sandy matrix are included in the core of folds near the base of the overlying silty diamictic unit (Figure 30).

2. The basal facies of muddy diamicton just referred to appears to contain fewer stones on the western side of the bay and seems to represent a 'purer', more marine or 'less glaciated' deposit. This facies also appears in places to contain drop stones which could be indicative of either a sub-glacial depositional environment or proximal deposition of sediments of ultimate marine origin into glacially ponded water trapped between the offshore ice mass and the rising rock slope of the 'pre-glacial' coastline or into a marine environment (Figure 31).

3. The basal diamictic facies is overlain in many places by current bedded sands and gravels indicating deposition by paleocurrents either from the east and south east. This sandy facies, together with the underlying muddy diamicton has been subsequently glacially tectonised from the south east towards which direction the sediments become noticeably more contorted. These folded and pushed sediments are particularly evident along the north/south coastal segment on the east side of the bay where the line of exposure cuts transversely across the strike of the fold axes ($24^0/204^0$). Similarly some degree of contortion is visible in the silty diamicton on the west side of the minor headland at Carrigduff where the line of exposure lies somewhat obliquely against the strike of the

Figure 32 Contorted laminations in silty diamicton exposed on the west side of Whiting Bay.

glacially tectonised sediments (Figure 32). The sandy facies may indicate an approaching of the ice margin in a prograding situation.

4. The gravelly/sandy unit is in turn overlain by a second sequence of diamictic muds which appear to have been deposited syntectonically to form one-metre thick wedge-shaped 'beds' which rest on north-westerly dipping surfaces on the northern limbs of the anticlinal structures particularly on the eastern side of the bay. In some cases this upper silty diamicton is partly interdigitated with the sand and gravel units. In other cases this facies rests on the preserved surfaces of the structural features in the underlying sands and gravels which is possibly suggestive of subsequent melt out of sediments at the grounded base of the offshore ice sheet. No dropstones were identified within the occasionally faulted upper silty diamictic unit. The upper part of this diamicton is massive in character.

5. The entire sequence is truncated by an eroded surface. East of Cappagh the succession is capped by a clayey matrix-supported stony layer 1-2 m thick in which the sandstone group forms the predominant lithology. This upper unit may represent either:

a) subsequent reworking of the lower unit by ice of inland origin with admixture of sandstone, reduction and inversion of the amounts of the limestone:chert ratio (see page 152), and dilution of the volcanic content as

Figure 33 Sand and organic beds overlying silty diamicton at Whiting Bay.

suggested by Wright and Muff (1904), or

b) deposition by ice of Irish Sea basin provenance as a relatively later local facies as suggested by Synge (1981).

To the west of Cappagh the uppermost silty diamicton is capped in places by approximately one metre of alternating blown sands and thin organic horizons (Figure 33).

Two representative sections are described. The first is selected from the townland of Ardoginna on the east side and the second from Ballysallagh on the west side of the bay respectively:

Ardoginna

0.9 m Modern soil.

1.1 m Sandy/clayey matrix-supported massive stony diamicton with Devonian Old Red Sandstone clasts predominating.

1.1 m Massive diamicton with matrix composed of mud-sized particles. The diamicton contains shell fragments and the base of the unit dips to the north-west (342^{0}) at 21^{0}. Further east these muds contain discontinuous sandy units from 1-4 cm in thickness. Towards its base the diamicton is bedded and stonier. The beds contain lag layers of stones at the base. These rest on a northwestward dipping wedge of calcareous mud beds which pinch out against the northwestern limb of an anticlinal structure in the underlying sands at this point.

0.5 m Sand interbedded with clayey units 1-2 cm thick which have been deformed along with the host sand.

0.4 m Folded beds of calcareous mud containing minute shell fragments and striated stones.

0.2 m Current bedded sands which contain a horizon of stony/clayey diamicton. The palaeocurrent direction indicates deposition from an easterly direction. Base of exposure. Immediately to the south east the sands are seen to rest on folded calcareous muds which form the core of the anticlinal structure.

Interpretation

The uppermost sandstone-dominated diamicton was thought to have been deposited by ice of inland, northern origin by Wright and Muff (1904). The compacted stony diamicton is supported by a sandy matrix. No structures were observed in this unit. It is interpreted as an *in situ* lodgement till facies because of the absence of internal bedding or stratification, its diamictic character, glacially abraded and erratic clast component and well defined fabric. This unit is described and discussed in greater detail under the fifth point of the following section. This upper massive silty diamicton is laterally continuous in all the exposures at the back of Whiting Bay. The unit is thinnest over the anticlines in the underlying folded sands and gravels. Because of its generally massive, diamictic character, siltiness, glacially-abraded clast component, erratic content of western provenance and north-westerly/south easterly oriented fabric this unit is also regarded as a lodgement facies associated with ice of Irish Sea basin origin (see following section and Chapter Eight). The stoniness of the base of the unit at this point be due to syndepositional washing or 'winnowing' of fines. However the scant matrix which is present does appear to support individual clasts. Nor does it have the appearance of having been sorted by any 'washing' process. It is merely less abundant than in the upper part of the unit. The stoniness probably represents therefore settling of clasts in a liquified sediment. This interpretation is supported by the fact that the larger clasts appear to be concentrated at the base of the unit. The surface of the underlying unit is eroded. The absence of bedding or internal stratification rules out deposition in a glacio fluvial environment. The absence of internal grading within the sandy unit may be indicative of rapid deposition in a shallow water whereby internal grading processes would be obviated (Rust and Romanelli, 1975). The sands were probably deposited in a high density turbidity or gravity current in an aqueous environment. The underlying mud unit may have been deposited as a single non-sorted sub-aqueous melt-out till unit (May, 1977; Gibbard, 1980) as further east the same sandy unit has ripples preserved on its surface at the contact between the two units. The non-erosive nature of the contact probably reflects variation in the source material released through melt-out at the base or margin of a nearby ice sheet into standing water. The current bedding in the underlying sandy unit is probably associated with meltwater activity in a pro- or sub-glacial environment. The origin and depositional environment are discussed in greater detail in Chapter Eight.

Ballysallagh

The second section to be described occurs on the western side of the bay about 2.5 km due west of the one just described:

0.5 m	Soil
1.0 m	Clayey sand
1.0 m	Stony/clayey horizon
2.0 m	Matrix-supported diamicton composed of calcareous mud containing shell fragments, flint and volcanic erratics. Many of the contained clasts are glacially abraded. The unit is horizontally laminated towards the base.

0.3 m Massive muds containing minute shell fragments.

0.5 m Bedded sands.

5.0 m Calcareous silty massive diamicton, laminated at base.

Interpretation

The massive, compacted and jointed diamictons which contain erratics and glacially abraded clasts are regarded as lodgement till facies (Dreimanis and Lundquist, 1984). The siltiness, fragmented shell content and glacially abraded erratics of eastern origin are indicative of an Irish Sea basin provenance. The laminated bases of the diamictic units is probably associated with an initial deposition of the unit in ponded water at the base of the ice sheet (Gustavson *et al.*, 1975). Bedding in the sandy unit implies multiphasic subaquatic deposition. Owing to the lack of other internal diagnostic characteristics it is not possible to determine whether deposition occurred by flow in a current or by settling out in a column of water. The stratigraphic position of the sandy unit indicates a temporary cessation of deposition associated with immediate ice-contact and the possible supercedence of glaciofluvial or glaciolacustrine/glaciomarine conditions. The sandy unit is probably the lateral equivalent of the sandy units which separate the upper and lower diamictic units described in the previous section (See Chapter Eight for further discussion).

Analyses of Samples from Whiting Bay:

Ballysallagh

The sample taken at Carrigduff in the townland of Ballysallagh from the massive, calcareous, silty diamicton which comprises all of the 8 m high coastal exposure at this point proved to be the second-most silty sample (58%) in terms of particle size distribution. The petrography of the phenoclasts shows a distribution of lithologies somewhat similar to that of the sample from neighbouring Caliso Bay to the west except that sandstone is exchanged with limestone as the dominant lithology. Fabric analysis of the unit at the same point again shows a north-westerly/south-easterly preferred orientation of the a-axes of the contained clasts which in this case dip to the north west. Thus, as in Caliso Bay, the results of the three analyses (siltiness, erratic content including shell fragments, flint and volcanic clasts of eastern provenance, and a possible down-glacier dip of the glacially abraded contained clasts whose a-axes are aligned north west/south east and are probably indicative of deposition from the south-east) combine to suggest deposition of the diamicton by ice which had moved westward and north-westward to an onshore position.

Cappagh

A sample (No. 80) taken for petrographic analysis from the stony upper facies which crops out at the surface in the eastern embayment in the townland of Cappagh bears out Wright and Muff's earlier observation that it was largely composed of Devonian-related lithologies including sandstones and grits (Wright and Muff, 1904). The sample is dominated by sandstones (80%). Volcanic clasts are fairly abundant (15%). Chert, limestone and shales each occur with frequencies of less than 2%, with chert showing an inverse ratio to the limestone content (see page 152). The reversal of the 'normal' ratio represents preferential contemporary or subsequent leaching out of the presumed original limestone content. As no cavities were noted in section there is not much evidence of post-glacial 'ghosting' of the limestone content as in areas further north. On the basis of petrographic analysis it is possible to argue that the sample may simply represent a subsequent reworking of the underlying silty diamictic facies of Irish Sea basin provenance by sandstone-bearing ice of inland origin as was suggested by Wright and Muff (Wright and Muff, 1904). However it is equally possible to argue that the upper stony, sandy diamicton was deposited as a more local facies by the same ice sheet which was responsible for the deposition of the underlying facies, namely, that of Irish Sea Basin provenance as suggested by Synge (1981). A glacio-marine origin has been attributed to a similar sequence at Killard Point in north-eastern Ireland (Mc Cabe *et al.*, 1984). Further discussion of this sequence is included in Chapter Eight.

Ardoginna

A sample (No. 57), also from the upper stony facies, was taken further to the east in the townland of Ardoginna for fabric analysis. The result yielded a strong fabric almost parallel to that of the underlying facies i.e. north-west/south-east and dipping in the same direction i.e. to the north west. Such a fabric could have been produced coincidentally by ice of inland origin. It is also possible that the upper stony, sandy facies at this point represents a local facies associated with the same icesheet advancing from the Irish Sea basin which deposited the underlying unit. The upper facies is also interpreted as a lodgement facies as no structures were observed in the compacted diamicton which contains glacially abraded erratics of eastern provenance and a preferred fabric orientation. If the diamicton was deposited by ice of inland, northern origin the erratic content of eastern provenance must have been derived from a pre-existing facies of Irish Sea basin origin by subsequent glacial reworking.

6.3.3. Ardoginna

To the south of Ardoginna Head the following succession was noted at the coast:

1-2 m Calcareous silty massive diamicton containing shell fragments, flint and volcanic erratics, crops out sporadically against the 'pre-glacial' rock cliff.

4-6 m Head composed of blocks of Devonian sandstone.

1.0 m Beach cobbles in sandy matrix resting on Devonian rock platform.

A sample (No. 74) taken from the silty diamictic unit shows the petrography of the phenoclasts to be almost identical to that in the upper massive, silty diamicton at Ballysallagh (No. 88) except for a slightly higher percentage of Devonian sandstone and lesser amounts of limestone and chert erratics (Appendix 6). The percentage of volcanic erratics is the same in both samples at 23%-24% and corresponds with the number of volcanic clasts in the sample from Monatray East (24%).

The calcareous silty diamicton is not however encountered further east as a recognisable unit in the coastal exposures until the area north of Ardmore is reached.

Flint, chert and volcanic erratics also occur in a plug of unconsolidated sediments in the valley at the eastern boundary of Ardoginna townland. Here 5 m of rounded clasts in a sandy matrix are exposed on the raised platform. The petrography of the phenoclasts of this sandy gravel (No. 75) echoes that of the upper stony facies sampled at

Cappagh (No. 80) in Whiting Bay with 22% volcanics, and a small amount of chert (1%) and flint erratics. The dip and preferred orientation of the more discoid-shaped clasts from this site (No. 58) mirror that of the upper stony facies at Ardoginna on the east side of Whiting Bay (No. 57) (Figure 8). The north-westerly dip is consistent with imbrication of the gravels in a palaeocurrent of north-westerly origin. No striations were noted on the surfaces of the contained clasts. The deposit possibly represents a torrent gravel derived from a pre-existing deposit of Irish Sea basin origin. This would explain the erratic content of the gravels. However if the gravels are in fact of glaciofluvial origin they may have been deposited by meltwaters escaping from ice located further north. Accordingly the erratic content would have to have been derived from a pre-existing deposit of Irish Sea basin provenance. Alternatively the gravels could have been deposited by meltwaters draining back (southward) under the margin of ice of Irish Sea basin sheet lying offshore.

6.3.4. Ardmore Bay

The south side of the Carboniferous limestone embayment is characterised by head composed of Devonian sandstones which in turn rests on raised beach and platform. Further north, in the vicinity of Ardmore, shallow exposures show wind blown sands overlying less than one metre of silty, shelly diamicton in some places, or head, resting on the raised platform in others. A large erratic entitled 'St. Declan's Stone' rests on the modern foreshore. It is composed of quartzose conglomerate which crops out on the foreshore some three metres to the north (Du Noyer, 1861; Smyth, 1939). As this conglomerate also crops out to the north and south of Ardmore, 'St. Declan's Stone' as an indicator erratic is not diagnostic of the direction of ice movement responsible for its entrainment and transport.

Crushea

North of the Black Rock, in the townland of Crushea, the sea cliff, which is here composed of unconsolidated sediments, gradually begins to increase in height and the following sequence is exposed:

2 m Blown sand.

2 m Rounded gravels (Devonian O.R.S. predominant) in a silty/sandy matrix.

4 m Massive, silty diamicton containing shell fragments.

1 m Head composed of Carboniferous limestone clasts.

Fabric analysis (No. 55) of the silty diamictic unit indicates a strong northwesterly/southeasterly preferred orientation of the contained clasts which dip to the south east. The direction of the preferred orientation parallels that of the two fabric samples already described from outcrops of the silty diamicton to the west at Caliso Bay and Cappagh in the centre of Whiting Bay (Nos. 56, and 8). The direction of the preferred dip contrasts with that of samples No. 8 and resembles that of sample No. 56. The silty diamicton at Ardmore is regarded as a lateral correlative of the upper silty diamicton exposed at Caliso Bay and Whiting Bay because of the resemblance of fabric, texture, erratic content and stratigraphic position between all three outcrops.

Ballyquin (west)

Petrographic analysis of two samples taken from the same unit a little further to the north east in the south western corner of Ballyquin townland contained only 65 stones between them. The result was therefore excluded from the statistical grouping exercise and is not shown on the petrographic diagram. The combined results of the two samples however indicate the predominance of volcanic clasts (42%), followed by limestone (25%), chert (19%) and sandstones (15%). This result is very similar to that obtained for another slightly more stony sample again taken from the same silty diamictic unit near the south eastern boundary of the townland (No. 26) [See following paragraph].

A third sample taken from a stony lens within the silty diamictic unit (No. 73) shows a dominance of sandstone clasts (86%), followed by chert (7%) and volcanics (5%) and less than 1% limestone and shale clasts. The composition and stratigraphic position of the stony lens is suggestive of extremely local input possibly as a sub-marginal meltwater stream.

Ballyquin (east)

The silty diamictic unit which crops out at the back of Ardmore Bay continues eastward to the eastern boundary of Ballyquin townland until it wedges out against the 'pre-glacial' rock cliff which approaches the modern coastline at this point. The succession includes:

0.6 m	Soil
0.5 m	Sand (no internal structures observed)
0.3 m	Stony massive diamicton with Devonian clasts predominant.
0.5 m	Sand (no internal structures observed)
25-30 m	Calcareous, relatively stone-free silty and massive diamicton containing shell fragments, flint, volcanic and striated limestone erratics and occasional stony lenses.
5 m	Head composed of Devonian blocks.

Easterly provenance of the silty diamicton is indicated by the results of petrographic analysis (No. 26). Volcanic erratic clasts predominate (47%); they are succeeded by sandstone (21%), limestone erratics (16%), chert (10%) and shale (7%) in decreasing order of frequency. The results of fabric analysis also follow the regional trend in that the preferred orientation of the contained clasts is aligned north west/south east (No. 10). The dip of the modal class is to the north west.

Petrographic analysis of a stony lens within the silty till unit indicates the dominance of clasts of local Devonian provenance (68%), followed by volcanic erratics (30%) and very small amounts of chert, limestone and shale (No.90). The composition suggests some reworking of the host facies in that all the elements observed in sample No. 26 are present in more dilute quantities with the exception of Devonian sandstone. Clasts composed of this local basement rock type dominate the sample. Such a petrographic composition could have been produced by a marginal surface meltwater stream finding its way to the base of the depositing ice sheet. Fabric analysis indicates that the preferred orientation of the a-axes of clasts within the stony lens (No. 9) is exactly the same as that of the host sediment (No. 10). The dip of the modal class is slightly to the west of north in both samples. If the preferred orientation and that of the dip have not been subsequently altered in either unit then it may be concluded that the northerly imbrication of the gravels in the stony lens is indicative of deposition in a palaeocurrent emanating from the same direction i.e. contrary to the south westerly provenance of the host diamicton. However it is quite possible that the dip of the clasts within the stony lens (approximately 0.5 m thick) was subsequently altered during deposition of the overlying massive lodgement till facies.

Ballyeelinan

Shallow exposures of volcanic erratic-bearing, calcareous silty diamicton were noted and sampled at the mouths of the next two valleys to the east in the townlands of Ballyeelinan and Crobally Lower. The succession on the western side of the boundary between the two townlands includes the following:

0.6 m	Head.
1.0 m	Calcareous, relatively stone-free, silty, massive diamicton which contains shell fragments, flint erratics and glacially abraded clasts.
3.0 m	Head.
	Raised platform composed of Devonian sandstone upon which rest occasional pockets up to 0.5 m thick of beach pebbles, including volcanic erratics, in a sandy matrix.

The petrography of the phenoclasts in the silty diamicton (No. 76) is fairly similar to that of the stony lens at Ballyquin (No. 73) with a predominance of Devonian sandstones (90%), 6% volcanic erratics, 3% chert and 1% limestone. The fabric analysis indicates deposition of the till either from the north west or the south east. Such directions could have been compatible with ice of either inland or offshore origin.

Crobally Lower

At the mouth the valley which divides this townland in two the following succession was noted (Figure 28):

1.5 m	Stony sandy diamicton with Devonian sandstone clasts predominating.
2 m	Calcareous relatively stone free, massive, silty diamicton containing shell fragments, flint and volcanic erratics.
1 m	Angular clasts of Devonian Old Red sandstone with occasional volcanic erratics in a sandy matrix.
4 cm	Grey stone-free, laminated silts crop out under the above unit immediately to the east. Beach cobbles resting on raised rock platform cut in Devonian sandstone.

The calcareous silty diamicton (No. 78) is dominated by

Devonian sandstone clasts (49%) with volcanics following closely in importance (44%). Small amounts of limestone (3%), chert (2%) and shale (3%) clasts are also present. The petrography of the phenoclasts is largely composed of erratics of probable eastern/south eastern provenance as in the case of similarly composed samples from the silty diamicton to the west.

The upper till facies is dominated by Devonian sandstone clasts (84%) to a much greater extent (No. 77). Volcanic clasts account for 15% of the total and this is succeeded by very small amounts of chert and shale (less than 1% each of total). Fabric analysis of the upper facies is indicative of deposition either from the north west of the south east (No. 53). This composition and fabric are characteristic of other upper stony facies to the west. The massive diamicton may have been deposited as a local lodgement facies by ice of inland, northern origin advancing over pre-existing deposits of Irish Sea basin provenance or, more simply, by ice advancing from the Irish sea basin.

6.3.5. Dungarvan

Mweelahorna

No further sections in the silty diamicton occur around the Devonian sandstone cliffed coast to the east until the limestone embayment of Dungarvan Harbour is reached. Here almost immediately to the west of the geological boundary between Devonian sandstone and Carboniferous limestone the cliffs are composed of unconsolidated sediments. They were described as "much overgrown and obscured by slipping, and are, in consequence, difficult to decipher" (Wright and Muff, 1904). Current slumping of the silty diamicton is so prevalent that it was impossible to describe any single vertical succession within the horizontal extent of their outcrop completely or to sample for fabric analysis. As with all the other outcrops of the silty diamicton already described the general sequence and lay out of the till appears to wedge out towards the Devonian 'pre-glacial' rock cliff and to overlie a thick succession of head deposits to the east of the eastern boundary of the townland. This phenomenon has already been referred to (see section 6.2.2.). (It is attributed mainly to the control which was apparently exercised over the agent of deposition, the base of the icesheet advancing west and north west from the southern part of the Irish Sea basin, by the 'pre-glacial' topographic relief.) The succession at Moat, as far as could be discerned, appears to be as follows:

1.5 m Sand (no internal structures observed)
4.0 m Head
1.2 m Raised beach

The silty diamicton becomes established as a distinct stratigraphic unit in the coastal section some 100 metres approximately to the east of Mweelahorna/Moat townland boundary. Stratigraphically it is seen to overlie the head unit and to be capped by the sand unit. Just within the eastern boundary of the townland the cliff appears to be comprised of the following succession:

2.0 m Massive sand.

5.0 m Calcareous diamicton. The matrix is composed of mud-sized particles which contain abundant shell fragments, flint and volcanic erratics. Clasts composed of Devonian Old Red Sandstone predominate. Clasts are generally rounded and striated. The silty diamicton is in places interbedded with normal and inverse graded sandy layers whose junction with the silts appears to be horizontal where visible. Lateral extent of these sandy units which are approximately up to one metre in thickness was not exposed.

3.0 m Head which contains occasional rounded clasts.

2.0 m Beach cobbles.

0.5 m White stone-free faintly-laminated silts.

There appears to be an upper and lower facies within the outcrop of silty till; the lower facies is composed of relatively stone-free "bluish marly boulder-clay" (Wright and Muff, 1904). The petrographic sample (No. 48) from the lower facies of the silty diamicton contained 62% angular Devonian Old Red sandstone clasts (probably derived from underlying head facies), 23% volcanics, 8% shale and 4% each of Carboniferous limestone and chert. The sample from the upper stonier facies (No. 11) was composed of 54% Devonian Old Red sandstone, 15% Carboniferous limestone, 13% Lower Palaeozoic volcanics and 8% chert. The lower facies contains proportionately more far-travelled material than the upper facies. This latter does not appear to be a reworked version of the lower facies as it contains much more abundant limestone and has an expected normal limestone/chert ratio (see page 152). The upper facies appears therefore to represent a more locally derived till of Irish Sea basin provenance.

The inclusion of graded sands within the silty till sequence suggests the existence of ponded water. These ponds could have been sub-glacial/marginal. They do not appear to have been of any great lateral extent. The apparently horizontal junction implies the absence of any pronounced tectonisation of the sediments during and subsequent to the depositional process.

Scart

A fairly shallow section (septic tank pit for new house) in this townland on the north side of Dungarvan Harbour revealed the following;

0.5 m Soil.

1.0 m Calcareous diamicton containing flint, shale and Devonian sandstone erratics.

1.0 m Solid Carboniferous limestone (weathered and shattered at surface).

A sample from the calcareous diamicton proved to be relatively silty (52%). The petrographic profile (No. 15) however was dominated by Devonian sandstone clasts (81%), followed by volcanics (8%), chert (7%) and shale (3%). The sample is petrographically very similar to the stony lens in the silty till exposed in Ballyquin (east), (No. 73). The total absence of limestone clasts in a calcareous matrix and resting on solid Carboniferous limestone is somewhat surprising given the presence of limestone clasts in most of the samples already described. The clastic composition of the diamicton implies syndepositional leaching of the presumed original limestone content. This process may have occurred during subsequent reworking of a formerly limestone-rich deposit. Fabric analysis from the same unit yielded a west-north westerly/ east-south easterly preferred orientation of the a-axes of contained clasts. Both lithological composition and fabric could be explained by reworking of an older till of Irish Sea basin provenance by later ice of inland origin. Alternatively, the silty diamicton could have been deposited as a localised lodgement facies directly by westward-moving ice of Irish Sea basin origin.

6.3.6. Ballyvoyle

Knockyoolahan West

During the summer of 1979 the following succession was visible in the coastal section approximately 120 metres to the east of the point where the western boundary of the townland intersects with the coastline (Figure 28):

15.0 m	Stony massive diamicton with a loamy matrix.
1.0 m	Calcareous stone-free silty diamicton containing abundant shell fragments and flint erratics. Base not exposed.

Unfortunately, during the summer of 1980 this section of the coastline was obscured by the emplacement of an embankment of Devonian sandstone blocks at the base of the exposure before it could be sampled for fabric, petrographic or particle size analyses. Stratigraphically the junction between the upper and lower diamictons was markedly horizontal and the upper surface of the lower unit appeared to have been bevelled by the operation of erosional processes during the deposition of the overlying diamicton.

6.3.7. **Garrarus**

Islandikane East

As this section was exposed subsequently to the completion of field work this outcrop of laminated silty diamicton has not been sampled. The section is located on the western side of the eastern boundary and shows the following sequence:

11.0 m Stony calcareous massive diamicton.

3.0 m Laminated silts containing abundant shell fragments.

1.0 m Head resting on Lower Palaeozoic volcanic bedrock.

Caher

A very restricted outcrop of silty diamicton occurs at the eastern margin of this townland in the following sequence (Figure 28):

6.0 m Calcareous stony massive diamicton containing striated, Devonian sandstone erratics, Carboniferous limestones and Lower Palaeozoic shales.

0.3 m Head

0.7 m Calcareous silty, stone-free, silty diamicton containing shell fragments and flint erratics.

1.0 m Head, with rounded pebbles at base resting on rock platform.

The lower silty diamictic facies was sampled for particle size, petrographic and fabric analyses. Particle size analysis confirmed the silty nature of the diamicton (58%). The petrography of the phenoclasts was dominated the volcanic content (98%) with very small amounts of chert (1.5%) and sandstone (0.5%). It is therefore an extremely locally derived deposit petrographically. Fabric analysis yielded a fabric orientation parallel to that of the upper till unit i.e. from north east to south west. The fabric structure probably denotes subsequent realignment, possibly by a shearing process, or reworking by a subsequent southward advance of ice responsible for the deposition of the upper till (*vide infra*) (MacClintock and Dreimanis, 1964; Warren, 1987a).

6.4. Conclusion

The silt-rich and volcanic erratic-bearing diamictic outcrops identified in County Waterford may be divided into two major facies: those which probably represent deposition directly by ice of Irish Sea basin provenance and those tills which have been derived from this through reworking by a later advance of ice from the north. In many cases it is not possible to establish whether the upper till facies at the western sites represent later reworking by inland ice or simply deposition contemporary with that of the lower facies as ablation till associated with westward moving ice of Irish Sea basin provenance.

CHAPTER SEVEN

SANDY/STONY DIAMICTONS AND ASSOCIATED GRAVELS

7.1 Facies Identification

7.1.1. Introduction

Sandy stony diamictic and gravel facies occur in shallow sections in many inland areas of County Waterford. They are also visible at the coast, particularly to the east of Dungarvan. These loamy- and sandy-loamy-textured diamictons contain abundant stones many of them striated. Most of the contained clasts are derived from the underlying bedrock and the majority of erratics have adjacent outcrops to the north as their source. Multi-facies exposures in diamictons occur only at the coast. Where these occur a sandy/stony diamictic facies is seen to overlie a silty, relatively stone-free facies.

7.1.2. Particle Size Analysis

Of the total number of samples which were subjected to particle size analysis, nine samples (50%) taken from diamicton were found to have a relatively sandy texture. The sediments from which these samples were taken are commonly referred to in previous literature as the Ballyvoyle Till (Watts, 1959; Stevens, 1959). These samples are composed of sand (42%-66%), silt (26%-41%) and clay (0%-21%) (Table 1). Three pairs (Nos. 11 and 18, 1 and 3, 5 and 20) from these samples showed relatively low degrees of dissimilarity in the cluster passes used in the construction of the particle size dendrogram (Figure 25). They were significantly different from each other only at the 5% significance level according to the two-tailed non-parametric Kolmogorov-Smirnov significance test. Two further samples from this group were joined at slightly higher levels of significant difference to two of the above pairs (19 + 5 and 20, 11 and 18 + 13). The ninth sample (No. 14) also joined the former group at the seventh cluster pass with a significance level of 1%. However samples 1 and 3 proved to be more similar to 4 and 17 (from the silt-rich group); while samples 5, 20, 19 and 14 were found to be closer to the silt-poor, gravel group. All three subsets of this intermediate sandy-loamy group were not joined until the penultimate and antipenultimate cluster passes. Thus this group occupies the centre ranges of the silt-rich/silt-poor continuum highlighted in the course of textural analysis. The sandy/stony diamicton occupies the textural middle ground between the silt-rich diamicton and glaciofluvial gravels.

As already observed in Chapter Five, the distributions of the grain sizes from this group plot out on semi-logarithmic paper as relatively straight lines characteristic of glacial mixing and crushing processes

processes (McGown, 1971). They are particularly characteristic of sediments deposited by lodgement of englacial material at the base of a glacier or ice sheet (Dreimanis and Vagners, 1971; Boulton and Paul, 1976).

7.1.3. Petrographic Analyses

The petrography of the phenoclasts varies widely among the nine samples. Proportions of the contained clasts range from 100% dominance of the Devonian sandstone group in a sample from Lyrattin (No. 18) in north western County Waterford, to dominance of volcanic clasts in samples from Garrarus Strand (No. 3) and Newtown (No. 1) in eastern County Waterford (86% and 59% respectively) and dominance of shale (65%) in a sample from Ballythomas (No. 20) in the north eastern part of the county (Table 1). Six of the nine samples from the sandy/stony diamicton belong to the Devonian sandstone petrographic group as recorded on the petrographic dendrogram (Nos. 19, 11, 14, 18, 13 and 5). One sample (No. 20) falls into the shale-dominant petrographic group. The remaining two samples (Nos. 1 and 3) belong to the volcanic-dominant group. The limestone- and chert-dominant petrographic groups are not represented among the particle size samples from the texturally based sandy/stony diamicton.

One point which emerges from the above observations is that there appears to be a limited relationship between textural and petrographic characteristics among the

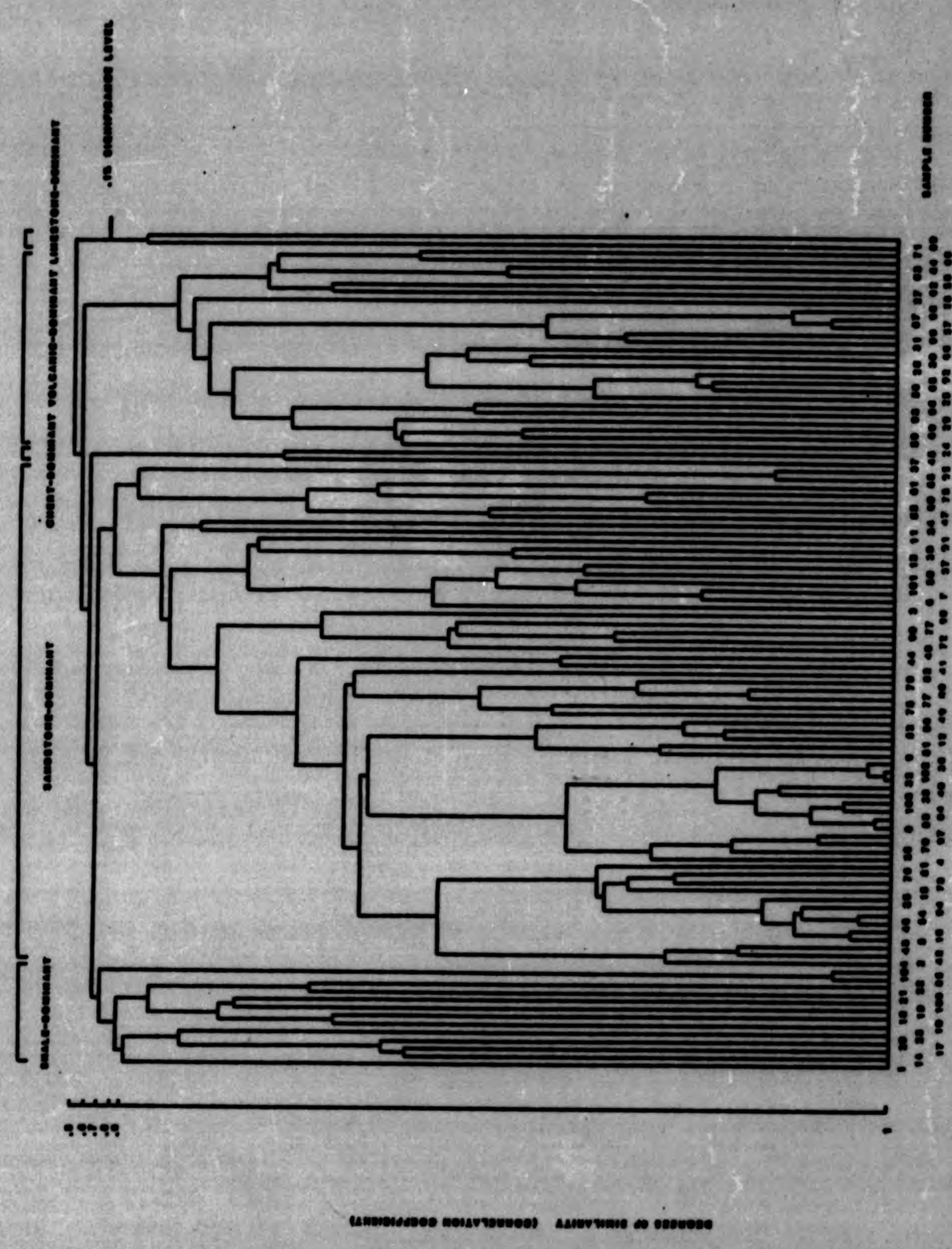


Figure 34 Dendrogram of degrees of similarity and groupings among petrographic samples.

sampled sediments. The full extent of this relationship is not established due to the very large difference between the sample sizes for each analysis. However the fact that textural samples 1 and 3 are both found within the same petrographic (volcanic-dominant) group is probably not coincidental. Both samples were taken from the sandy, stony diamicton which crops out at the surface throughout most of County Waterford. The samples therefore probably represent sediments which have been transported over similar basement lithologies and been subjected to similar conditions within the same glacial track (see Chapter Eight). Conversely, the fact that only one (No. 5) of the textural samples from the sandy/stony diamicton is found to occur within the petrographic subsets associated with the silt-rich, volcanic erratic-bearing diamicton is probably not coincidental (Figure 34). It is to be expected that samples taken from the sandy, stony diamicton will have different textural and petrographic characteristics from those associated with the shelly, silty diamicton assuming both sediments have originated in different areas, been transported over different basement lithologies and subjected to different depositional processes (Boulton, 1976). Only where transportational and depositional conditions have been similar, or where one sediment has preceded the other, will both sediments contain shared characteristics as was probably the case for that represented by sample No. 5 (Banham, 1977;

Warren, 1985).

7.1.4. Fabric Analyses

Fabric analyses of these nine samples yield a north-easterly/south-westerly preferred orientation of the contained clasts at two sites in north western County Waterford, a north-westerly/south-easterly preference at three other sites in central, eastern and southern County Waterford and a north/south preference at one locality to the west of Dungarvan (Table 1).

7.2. Location and Distribution

7.2.1. Location

The matrix (< than 2 mm in diameter) of nine samples, when analysed for particle size distribution, plotted out as a straight-line profile on semi-logarithmic paper. The samples were all taken from the sandy, stony diamicton which crops out at the surface throughout much of the county. The results of the textural, petrographic and fabric analyses of the nine samples from the sandy/stony diamicton indicate that it is widely distributed over the eastern two-thirds of the county. This textural group of samples is therefore considered to be generally representative of the sandy, stony diamicton which crops out at the surface throughout the county.

As already pointed out, only the two small limestone- and chert-dominant petrographic groups were not represented among the nine textural samples. As both of these petrographic groups are comprised of only two samples each they are therefore fairly restricted in terms of their geographical distribution. As a result their exclusion from representation among the textural samples is not surprising. If however, the third textural group (glaciofluvial sands and gravels) is considered to be largely related to the sandy/stony diamicton, then the limestone petrographic group is represented among the textural samples. Particle size analysis sample No. 1 which was taken from the limestone-dominated gravels in the townland of Gurteen in northern County Waterford falls into the silt-poor textural group. Thus only the two chert-dominated petrographic samples remain unrepresented among the eighteen textural samples. All of the remaining petrographic samples which do not appear in the list of outcrop localities of the silt-rich, volcanic erratic-bearing diamicton and associated gravels (Table 2) are therefore considered to belong to the sandy/stony diamicton or subsequently reworked facies of it. The following description of the location of the sandy/stony diamicton in parts of County Waterford is largely drawn from the subdivisions identified on the basis of petrographic analysis as described in Chapter Four.

7.2.2. **Distribution**

Apart from the samples from diamicton in south-western County Waterford which contain volcanic erratics in a silt-rich matrix already described (Chapter Six), the remaining petrographic samples taken from the Ballyvoyle and Mothel Tills (Watts, 1959) and associated sands and gravels form the following distributional pattern in County Waterford (from north to south):

a) There is a fringe of petrographic samples in the northern part of the county which, if not dominated by Carboniferous limestone erratics derived from solid outcrops in the Suir valley syncline immediately to the north of the county boundary, at least show relatively high proportions of that lithology (Nos. 1, 17, 20, 23, 34 and 41).

b) In many places this fringe is interrupted and succeeded to the south by a narrow belt of samples (Nos. 10, 12, 14, 17, 18, 37, 39, 41, 45, 50 and 104). These samples contain proportionately more chert than limestone; in a ratio which is the reverse of that in the original Carboniferous strata (ten times more limestone than chert in terms of bed thickness in the Carboniferous sequence of the Suir Valley) from which the clasts were probably derived (Keeley, 1983)

c) This is followed to the south by a zone of sandstone-dominated samples in the western half of the county, by a zone of shale-dominated samples in central

County Waterford and by a zone of volcanic-dominated samples in the eastern part of the county. Percentage frequencies of chert and limestone virtually disappear from the samples in these areas. The dominance of sandstone, shale and volcanic clasts generally reflects underlying changes in bedrock. However, in north eastern County Waterford three samples (Nos. 1, 14, and 104) contain proportions of volcanic erratics in a shale clast-dominated diamictic facies.

d) Further south, in the Dungarvan Carboniferous limestone syncline, this zone is succeeded by a belt of samples in which chert takes on increasing influence in the clastic composition of the sediments. No limestone is recorded in the samples taken from the sandy, stony diamicton at the eastern end of the synclinal valley. Only a single limestone clast out of a total of 6,400 clasts from sixteen samples was identified (petrographic sample No. 54). One sample (No. 101) taken from glaciofluvial gravels near Lismore in the Blackwater valley, 13 km to further west, contained 5% limestone.

e) In south-eastern County Waterford very small amounts of limestone and chert reappear in the deeper coastal exposures of diamicton. Sandstone clasts dominate two samples from the Dunmore area (Nos. 60 and 61) where there is a corresponding change in the underlying geology. Similarly shale clasts derived from a local outcrop of Lower Palaeozoic shales dominate a single sample from the

TABLE 3. COMPOSITION OF SHALE-DOMINANT PETROGRAPHIC GROUP

Particle size, fabric and petrographic sample numbers.			Townland	% Limestone, chert, sandstone, volcanic and shale clasts.				
Par.	Fab.	Pet.		L	C	S	V	S
-	-	1	Glenaphuca	32.0	03.6	17.5	07.0	39.7
-	-	14	Whitestown West	09.8	11.7	33.3	08.4	37.6
-	-	17	Clonea	10.5	12.3	38.8	01.2	37.1
-	-	20	Ballyduff West	11.8	07.4	38.6	09.7	32.5
-	-	23	Orchardstown	21.0	04.9	42.7	10.3	21.0
-	15	10	Ross	0.0	10.6	34.0	0.3	54.9
-	-	18	Munsburrow	0.0	14.0	23.2	02.9	59.8
-	75	19	Ballyshonock	0.0	01.2	16.1	11.5	71.0
2	14	100	Newtown	0.0	0.4	24.2	19.6	52.8
-	-	21	Whitestown	0.0	0.4	17.2	30.0	52.3
-	-	22	Georgestown	0.0	0.0	10.5	41.6	47.8
20	-	104	Ballythomas	0.0	03.0	19.6	12.5	64.9

Newtown area on the western side of the Waterford estuary (No. 100).

7.3. Descriptions of Petrographic Groups

7.3.1. Introduction

The stratigraphy of the sediments from which the petrographic samples were taken is described on a geographical basis beginning with the first group identified in the petrographic dendrogram (Figure 34).

7.3.2.1. Shale-Dominated Sediments

As already indicated these samples are largely confined to unconsolidated sediments resting on outcrops of Lower Palaeozoic shales and associated rocks in the north-eastern corner of the county. The group is composed of 12 samples (Table 3). Sample No. 85, which is dominated by sandstone lithologies, was originally included within this group on the basis of covariance and resultant coefficient of correlation. It is omitted from this group and assigned to the sandstone-dominant petrographic group for the purposes of this and following discussions.

Shale Content

All but three of the samples within this group are dominated by shale clasts. Sample Nos. 17, 20 and 23 are dominated by sandstone erratics which can only have been derived from the Devonian Old Red sandstone outcropping as a topographic high (150 m O.D.) on the south side of the Suir valley Carboniferous limestone syncline some 5 km to the north-west.

The diamicton from which Sample Nos. 21 and 22 were taken lies 0.4 and 0.9 km to the south-east of the nearest shale outcrop. Thus the dominating presence of shale erratics is indicative of southerly glacial transport of the sampled sediment. Not surprisingly these two samples are also the only ones within the shale-dominant group in which volcanic clasts rank second in frequency over sandstone clasts as the sampled sediment rests on volcanic tuffs and as they lie furthest away from the sandstone outcrop.

Volcanic Content

Volcanic erratics occur in some of the more northerly shale-dominated samples (Nos. 1, 14, 17, 18 and 104). Volcanic erratics in three of these samples may be explained by their location to the south and south-east of two minor volcanic outcrops. These occur at Clonea Castle and Mothel. Volcanic erratics in samples 14 and 17 are most probably derived from the volcanic outcrop near the village of Mothel 1.5 km to the north. The volcanic erratics in sample 1 are probably derived in large part from the outcrop at Clonea Castle 3 km to the north-west. Some of the erratics may also have been transported south-eastward from the Mothel outcrop.

Volcanic erratics in sample Nos. 18 and 104 located to the north of these two volcanic outcrops are however less easily explained. There is one small volcanic outcrop at Boola approximately 11 km to the north-west. It is just possible that this outcrop acted as the source for the volcanic erratics in the two samples located at 90 m O.D., 2.5 km to the south-east of Rathgormack (Nos. 18 and 104). Another possible explanation for the presence of the volcanic erratics in these samples would involve the prior distribution of the erratics onto the Rathgormack plateau by an incursion of ice up the Suir and Clodiagh valleys and their subsequent redistribution during a later southward movement of ice across the plateau. A third, though much less likely (given the absence of volcanic erratics in samples located to the north west) source of these volcanic erratics, could have been provided by the Carboniferous volcanic outcrop to the south of Limerick city approximately 50 km to the north-west.

Sandstone Content

In six of the remaining seven samples sandstone clasts rank second in frequency and generally decrease in relative importance among the more southerly samples with increasing distance away from the source area to the north.

Limestone Content

The seventh sample (No. 1) has Carboniferous limestone as the second most frequent lithology in the clastic component. Somewhat surprisingly this sample is not the most northerly of the group in terms of location. Generally however, the more southerly samples within this group contain no limestone clasts. Thus there is an observable southward decline in the proportion of limestone clasts within the sampled sediments with increasing distance from the Carboniferous limestone syncline to the north (Table 4).

Chert and Limestone Content

There is also a corresponding southerly decrease in the chert content of the shale-dominant samples being totally absent from the most southerly-located sample (No. 22) within this group. However the pattern is somewhat distorted by fairly low chert frequencies in three of the more northerly samples taken more than 2 m from the surface (Nos. 1, 20 and 23). Two of these samples (Nos. 20 and 23) are located closest to the Carboniferous limestone outcrop. The concomitant limestone content in the three samples is relatively high. They are the only ones from the shale-dominant petrographic group to display 'normal' limestone/chert ratios where the proportion of limestone exceeds that of chert as in the Carboniferous sequence in the Suir syncline 5 km to the north east (Keeley, 1983).

TABLE 4. LIMESTONE-CHERT CONTENT IN SHALE-DOMINANT GROUP

Sample nos. (north to south)	and height O.D.	% limestone and chert L	C	% chert+ limestone L+C	Depth from surface (m)	Distance to source (km)
104	107	0.0	3.0	3.0	1.5	6.4
14	40	9.8	11.7	21.5	1.5	6.4
18	88	0.0	14.0	14.0	1.5	7.2
17	43	10.5	12.3	22.8	1.5	7.1
10	70	0.0	10.6	10.6	2.0	8.5
1	100	32.0	3.6	35.6	1.5	5.9
20	40	11.8	7.4	19.2	1.8	6.4
23	58	21.0	4.9	25.9	2.0	5.5
19	76	0.0	1.2	1.2	2.0	8.0
100	2	0.0	0.4	0.4	9.0	13.0
21	107	0.0	0.4	0.4	1.5	13.0
22	108	0.0	0.0	0.0	2.5	14.6

Two of the samples (Nos. 1 and 23) also contain the highest combined percentages of chert and limestone. The proportion of limestone decreases to 0% within 6 km of the Carboniferous outcrop, while that of chert temporarily increases with increasing distance away from the Carboniferous source lithologies. The normal or expected ratio of limestone to chert is inverted in petrographic sample Nos. 14 and 17 (Appendix 6, Table 4). The proportion of chert then begins to decline as a function of distance/decay. It disappears entirely from the sampled stony, sandy diamicton which crops out at the surface within 11 km of the source (petrographic sample No. 22). The temporary rise in the proportion of chert may be explained in terms of relative chert-enrichment due to relative limestone-impoverishment as a result of leaching processes. This leaching out of the calcareous limestone clasts is put forward to explain a remarkably similar pattern of chert-carry over onto Devonian sandstone upland in the Slieve Bloom area by Warren (1987b).

7.3.2.2. Facies Identification and Stratigraphy

Three facies are recognised in this group on the basis of texture and stratigraphic sequence. These facies include a gravel facies and a lower and upper diamictic facies. Sample 10 was taken from a gravel facies. Sample 100 was taken from a lower diamictic facies in the townland of Newtown where there is a multi-facies sequence. The remaining samples were taken from single facies exposures in the diamicton which crops out at the surface throughout most of the county. These samples represent the third, upper diamictic, facies recognised within this group.

Gravel Facies

Imbrication analysis indicates a northerly origin for the gravel facies (Sample No. 15, Figure 8).

Lower Diamictic Facies

Fabric analysis of the lower diamicton at Newtown reveals a west/east preferred orientation of the contained clasts with a modal value of $100^0/280^0$ (Sample No. 13, Figure 8). This direction is quite consistent with the inferred direction of transport of contained Carboniferous limestone erratics from the north-west. Particle size analysis of Sample No. 1 from the lower diamicton at Newtown somewhat surprisingly falls into the silt-poor textural group characteristic of the gravels. The 'washed' character of the matrix and the angularity of many of the contained clasts suggest that the lower facies may in fact be largely composed of locally derived head material.

Upper Diamictic Facies

Fabric analysis of the surface diamictic facies in north-east Waterford corroborates the findings based on petrographic analysis with a north/south alignment of the contained clasts (Sample Nos. 62 and 65, Figure 8). Grain size analysis of the upper diamictic facies as represented by sample No. 20 falls into the sandy/stony category characteristic of the Ballyvoyle Till (Figure 21).

7.3.3. Sandstone-Dominated Sediments

Sandstone-dominated sediments are by and large confined to the western half of the county and reflect the distribution of underlying solid Devonian Old Red sandstone in that part of the county. This statistically derived petrographic group is composed of 62 samples in all. However 12 of these sandstone-dominated samples have already been assigned to the silt-rich, volcanic-bearing diamictons and associated gravels on the basis of textural analyses (see Chapters Five and Six). The remaining 50 samples include one Devonian-dominated sample (No. 85) which was unaccountably excluded from this statistically-based group. The sample was originally allocated to the shale-dominant group according to the statistical grouping procedure. Another volcanic-dominant sample (No. 95) which was originally included in this statistically-generated group is now assigned to the volcanic-dominant group in order to conform with the general basis for the grouping procedure. With the exception of the above two samples, all of the remaining 102 samples are allocated to individual groups on the basis of the dominant lithology present in the petrography of the phenoclasts of individual samples.

The sandstone-dominated petrographic group may be divided into sub-groups of various sizes and varying levels of generalisation (Figure 34). The group is divided into four sub-groups based on the sequence presented in the dendrogram. Individual groups may be further broken down into subsets according to varying petrographic profiles (Appendix 6). Individual profiles are often more similar to those in other sub-groups with only small variations in relative proportions of lithologies. However for the sake of clarity, the sequence of samples as portrayed in the dendrogram is broadly adhered to in the verbal descriptions which follow. This also allows a more detailed description of the variation among the petrographic profiles at the subregional level.

7.3.3.1.1. Sub-Group 1

This sub-group is composed of 10 samples (Nos. 2, 42, 43, 5, 16, 46, 54, 94, 35 and 81). Sandstone clasts form the predominant lithological class frequency in all of the samples within this group. Shale clasts take second place in rank frequency order in three of the samples (Nos. 2, 42 and 43). The remainder of the samples contain very small proportions of chert and volcanic erratics with the latter being slightly more numerous. The majority of samples in this group are strung out along the eastern (Nos. 2, 42, 43 and 46), western (Nos. 5, 16, 35 and 94) southern (No. 54) slopes of the Comeragh Mountains. Sample 81 is located on the south-west coast.

Sandstone Content

Devonian sandstone clasts occur with frequencies greater than 83% in these samples. There are sandstone erratics in two samples where the basement rock is Carboniferous limestone (Nos. 54 and 94). Southern transport of the sandstone erratics is indicated as this lithology decreases in frequency in samples located immediately further south. The absence of chert or limestone clasts in sediments immediately to the north of this locality also supports the idea that the most recent movement of erratic-bearing ice in the area was southward rather than northward. Samples 42 and 43 are located just within the eastern limit of basal Devonian sandstone-conglomerate outcrop at the contact with the Lower Palaeozoic shales. Thus the shale clasts in these two samples are technically erratic and imply a local southwestward carriage of shale erratics which may have been derived from an earlier and counter-moving ice advance into the Dungarvan area (see following paragraphs).

Chert and Limestone Content

Seven of the ten samples contain very small amounts of chert. In six of the samples the cherts are erratics (except No. 94). A northerly provenance of the erratics is also indicated in this case as the chert content decreases in a southerly direction. It is probably derived from the Carboniferous rocks in the Suir valley to the north. Carboniferous limestone occurs in minute quantities in one sample only (No. 54). Presumably the provenance is extremely local as the underlying solid lithology is Carboniferous limestone.

Volcanic Content

Volcanic erratics occur in nine out of the ten samples (excepting No.2), also with very low frequencies. It is possible that these volcanics could be derived from volcanic clasts in the basal Devonian conglomerates which crop out in the escarpment on the eastern side of the Comeraghs (Figure 4). Such an origin is however unlikely to explain the presence of volcanic erratics in the samples from the western side of the watershed. Volcanic outcrops in the Devonian Old Red Sandstone occur at Boola on the northern slopes of the Comeraghs, at Moanyarha on the western side and at Carrigduff and at Coolnahorna on the east side of the Comeragh Mountains (Figure 4, after Penney, 1978). Together with the volcanic outcrops on the Rathgormack plateau already referred to, these very localised outcrops of basic lavas would have been a much more likely source of volcanic erratics in the glacially derived sediments to the south of these areas (Nos. 2, 42, 43 and 46).

However the route taken by volcanic erratics in the sampled sediments in the extreme south (Nos. 5, 54, 81 and 94) and north west (Nos. 16 and 35) cannot be explained by simple southward movement of ice over these volcanic outcrops. The proportion of volcanic erratics in the sediments in the Dungarvan area decreases northward and westward with increasing distance away from the coast. This together with the very occasional presence of flint, and shale erratics in the sediments suggests that there was an incursion of ice of Irish Sea basin provenance onshore. Thus the volcanic lithologies, including acid tuffs and rhyolites, basic diorites and intermediate andesites which crop out on the southern coast to the east of Dungarvan would appear to have been the source of the same suite of volcanic erratics in the diamicton around Dungarvan and to the west (Wright and Muff, 1904).

The volcanic erratics in the glacial sediments of the Nier valley in north-western County Waterford (Sample Nos. 16 and 35) are probably derived indirectly from the Moanyarha outcrop. The outcrop is located at the head of a northern tributary of the River Nier. The erratics in the diamicton at Knockalisheen, (No. 35) which lies south of the confluence but at some height above the main valley floor, were probably glacially redistributed up valley from their original down valley river-bed location. The erratics in the diamicton exposed in the townland of Knockanaffrin (Sample No. 16) lie some distance up valley of the confluence. Assuming that Moanyarha is in fact the source of these erratics then they too must have been glacially transported up valley at least as far as Knockanaffrin. Similarly, small proportions of chert erratics (1%) in both samples would support such an interpretation as the nearest limestone outcrop lies 12.5 km to the west, at the mouth of the Nier valley.

7.3.3.1.2. Facies Identification and Stratigraphy

Two facies are recognised on the basis of textural differences: a gravel and a diamictic facies. A third facies of glacially derived sediment is recognised on the basis of fabric analysis and morphology. This localised diamictic facies is confined to valleys on the east and west side of the Comeragh Mountains. All three facies appear to be discrete in terms of geographic distribution in that they are nowhere seen together at any of the sample sites from this particular sub-group. As they all form surface deposits they are regarded, for the moment, as being stratigraphic equivalents. Petrographic sample No. 81 was taken from a shallow coastal section less than one metre high. The sample is composed of angular fragments of local origin (87%). It also contains some acid volcanic erratics (2%), basic volcanic erratics (6%) and shale erratics (5%). The shale clasts were probably derived from a very localised outcrop of Lower Palaeozoic shales in Muggort's Bay 1.5 km to the north. The shale and volcanic erratics are indicative of south-westerly transport. The orientation and dip of the clasts in the clast-supported matrix of the shallow diamictic unit lie parallel to the topographic slope of the surface and that of the underlying rock slope. The sampled sediment is regarded as a gelifluctted head deposit which has incorporated erratics. The shale and volcanic erratics could have been derived from the raised beach which is generally recorded as stratigraphically underlying the head unit on the south coast (Wright and Muff, 1904). An outcrop of raised beach resting on rock platform is exposed at the base of an overgrown section approximately ten metres to the east of the head unit. Although no erratics were recorded in this exposure of the raised beach, volcanic, flint and chert erratics were observed in an outcrop of raised beach at the eastern boundary of the townland of Crobally Lower, 6.5 km to the south west. Alternatively the erratics could have been derived from a localised outcrop of the silty diamicton which also contains the same erratic suite.

Diamictic Facies

Two of the sandy-textured samples which were subjected to particle size analysis (Nos. 11 and 19) represent the same sediments respectively as petrographic sample Nos. 94 and 16. Fabric analysis was carried out at four of the diamicton sample sites included in this petrographically-based sub-group: Fabric sample Nos. 1, 59, 64 and 71 correspond with petrographic sample Nos. 54, 46, 94 and 16 respectively (Figures 8 and 26). The alignment of the a-axes of the majority of the clasts in sample 64 reflects the very consistent north/south trend in the diamicton on the west side of the Comeragh Mountains (Figure 8). This trend together with the results of analyses of the petrography of the phenoclasts indicates movement of ice from north to south on either side of the Comeragh Mountains. This north/south trend is broken only in the area immediately to the east of Dungarvan where a north-westerly/south-easterly direction is the preferred orientation of the contained clasts. This trend is reflected in the upper layers of the diamicton at Tallacoolmore (Sample No. 1). Both fabric and petrographic analyses point to the easterly movement of ice of inland origin offshore in the area between Dungarvan and Ballyvoyle. This movement may have been preceded by movement onshore of ice of Irish Sea basin provenance as suggested by the occasional presence of shell fragments, flint and volcanic erratics and siltiness of the matrix (characteristics which have been noted in the stratigraphically underlying diamicton of Irish Sea basin provenance) in the surface diamicton at the coast.

Comeragh Valley Diamictic Facies

Modal values for the preferred orientation of the contained clasts from two of the sites are quite at variance with regional trends (Nos. 59 and 71). This is not surprising as both these samples were taken from diamicton in valleys on the east and west side of the Comeragh Mountains. In both cases the diamicton is associated with transverse arcuate moraines in which the axis of maximum thrust bisected the centre of the moraine and pointed down valley. The fabric and morphologic evidence points to the existence of a Comeragh Mountain valley glaciation. This glaciation would appear on the basis of the petrography of the phenoclasts in the associated diamictons to have succeeded movement of ice from the lowlands up valley. This provides the basis for the recognition of a Comeragh Valley diamictic facies.

Gravel Facies

Imbrication analyses carried out at petrographic site Nos. 5, 42 and 43 (Nos. 14, 6 and 7 respectively) indicate a northerly origin of palaeocurrents associated with the deposition of marginal of sub-marginal glaciofluvial (No. 14) and deltaic gravels (Nos. 6 and 7). Sample 7 was taken from the uppermost gravels in a deltaic sequence and represents a veering of the palaeocurrent direction from the north (No. 6) to the north-west possibly associated with withdrawal of ice into the shade of Comeragh Mountain at the head of the River Tay. It is recognised that fairly wide variations in the order of a 120^0 arc may be encountered within any single glaciofluvial system (Rust, 1975). Therefore the above interpretation is put forward as one possible explanation only. The accumulation of these sediments was presumably related to a general northerly retreat of ice from the south and east of the county.

7.3.3.2.1. Sub-Group 2

The next sub-group of sandstone-dominant petrographic samples is composed of 13 samples (Nos. 4, 38, 70, 97, 8, 83, 84, 103, 33, 40, 32, 102 and 36). In terms of the petrography of the phenoclasts it is very similar to that of the preceding sub-group in that sandstone clast frequencies exceed 84%. Chert clasts figure second in rank (maximum 11%). The remainder of the clasts are mainly derived from volcanic outcrops, probably from the Lower Palaeozoic outcrops in east County Waterford. The samples from this group are located in the north-western (Nos. 32, 33, 36, 38, 40, 70 102 and 103), the southern (Nos. 4, 8 and 97) and south-western (Nos. 83 and 84) corners of the county (Figure 26).

The same arguments which were used to explain the petrography of the phenoclasts of the samples from sub-group 1 are broadly applicable to the samples from sub-group 2. The sandstone content increases to the east and south in the samples from north-western County Waterford. The percentage of sandstone erratics declines from north to south in the three samples from the Dungarvan area

(Nos. 4, 8 and 97). These trends are indicative of ice movement from north to south on the western side of the Comeragh Mountains via the Ballinamult Gap. The chert content which appears second in rank frequency order is less than 11% at maximum values for this group (No. 4). As in the previous group the presence of this erratic in the north-western samples is consistent with a southerly-easterly movement of ice from the Suir valley into the Glenary, Russellstown and Nier valleys in the north-west. The chert content in the three samples from the Dungarvan area (Nos. 4, 8 and 97) shows a northward decline consistent with southward movement of ice. Very small quantities of volcanic erratics are present in all but three of the samples from this group (Nos. 32, 36 and 40). As in the previous sub-group the volcanic erratics in the north-western samples is possibly partly derived from the isolated and restricted Devonian volcanic outcrop at Moanyarha at the head of the northern tributary of the River Nier. This explanation is particularly applicable to the volcanic content in samples 38 and 70 which were taken from glacially-derived deposits some distance down-valley from the confluence. However the volcanic content in sample 103 cannot have been derived from this source. The sample lies to the south of the Suir/Nier confluence and south of intervening area where volcanic erratics are absent from sediments (No. 37, Figure 26). The volcanic content is probably related to a very local outcrop immediately to the north of the sample site. The volcanic erratic content in the southern samples (4, 8, 83, 84 and 97), as in the southern samples from sub-group 1, can only be satisfactorily explained in terms of an incursion of ice of Irish sea basin provenance into the Dungarvan area prior to the southward advance of ice of inland origin. Exotic volcanic clasts in a slope deposit in north-west County Waterford (No.36) may also be derived from deposits associated with a similar advance of ice of Irish Sea basin provenance up the Suir valley (see Chapter Four and paragraph following).

7.3.3.2.2. Facies Identification and Stratigraphy

Texturally the sediments represented by this group of samples may be divided into three facies: a gelifluoted slope deposit (No. 36), diamicton (Nos. 4, 38, 40, 70, 83, 84, 102 and 103), and gravels (Nos. 8, 32, 33 and 97).

Gelifluoted Slope Deposit

The sediment from which sample 36 was taken is composed entirely of local angular Devonian fragments in a sandy matrix at an altitude of 180 m O.D. on the northern side of the Nier valley. The composition of the sample was almost 100% locally derived although four rounded acidic and basic volcanic erratics (0.8%) were also included. At least three of these clasts could not have been derived from the Moanyarha, Boola or any of the other Devonian volcanic outcrops. These volcanic erratics must have been glacially transported to the area prior to the accumulation of the slope deposit.

Diamictic Facies

Two of the textural samples (Nos. 14 and 18) which fall into the intermediate category between the silt-rich and silt-poor samples were taken from sites whose petrographic samples belong to sub-group 2 (Nos. 103 and 102 respectively). A fabric analysis carried out on the sediment represented by petrographic sample No. 103 (No. 67, Figure 8) yielded a north-easterly/south-westerly modal value for the orientation of the a-axes of the contained clasts. The combined petrographic and fabric evidence corroborate the former movement of ice from the Suir valley southwards through the Ballynamult Gap. This regional southward movement is characterised by north/south alignment of the a-axes in the sediments from which petrographic samples (Nos. 4, 70, 83, 84) and fabric samples (Nos. 69, 76, 51, 50) were taken respectively (Figures 8 and 26). Although the modal values for the contained clasts in samples 51 and 50 lie parallel to the local maximum topographic slopes, the deposits are regarded as glacial diamicton for the following reasons:

1. The a-axes of the clasts in the modal class dip north-westward into the underlying rock slope i.e. in a direction counter to what would be expected in a geliflucted slope deposit (Watson and Watson, 1970).

2. The matrix-supported diamicton is massive in character.

3. It contains glacially abraded clasts.

4. The diamicton contains volcanic erratics of eastern provenance. The sampled sediment at petrographic site No. 83 in the townland of Ballynaharda which was sampled for fabric analysis (No. 51) is particularly erratic in character. It is composed of a calcareous matrix, has Devonian sandstone as its basement rock and contains very occasional limestone erratics. These erratic properties when combined with the evidence of volcanic content based on analyses of the petrography of the phenoclasts suggest that the diamicton is either a reworked (by ice of inland northern origin) facies of Irish Sea basin provenance or a very local facies deposited by ice advancing from the Irish Sea basin. The fabric evidence, however, seems to suggest that the former explanation seems slightly more probable on the basis that a north/south or north-east/south-west orientation of the contained clasts is more consistent with southwardly moving ice of inland origin than with the south-east/north-west movement of ice of Irish Sea basin provenance as exemplified by the alignment of clasts in the associated silt-rich volcanic-bearing diamicton further west. This interpretation is probably applicable to the neighbouring petrographic site at Monagoush (No. 84) for the same reasons. This interpretation may also have wider implications in explaining the origin of the sandy/stony facies which

overlies the silt-rich volcanic erratic-bearing diamicton to the west of Dungarvan (see preceding chapter).

Gravel Facies

It was not considered necessary to sample any of the four petrographic sites for textural analysis as sedimentological features in the sampled sediments were very obviously characteristic of glaciofluvial origin. Only one petrographic site was sampled for imbrication analysis as sedimentological features in the sampled sediments were very obviously characteristic of glaciofluvial origin. Only one petrographic site was sampled for imbrication analysis as the site was either inaccessible (No. 32) or the direction of deposition was already apparent as in the case of well exposed southward-dipping foreset beds (Nos. 33 and 97). Imbrication sample No. 2 which was taken from the same sediment from which petrographic sample No. 8 was also taken indicated a northerly origin for the palaeocurrent responsible for deposition of the coarse gravel facies exposed in the townland of Ballylemon Lower. These findings are once again consistent with a northerly retreat of ice on the western side of the Comeragh Mountains.

Stratigraphy

Nine of the thirteen samples from this lithologically-based sub-group were from single facies sites whose host sediments crop out at the surface. Samples 70 and 32 were taken from two different facies which were exposed at a single site in the townland of Shanballyanne on the south side of the Nier valley. Here a shallow facies of sandy diamicton (No. 70) is seen to overlie a gravel facies which was not well exposed. The upper diamictic facies contains chert erratics. This together with a north-west/south-east preferred orientation of the contained clasts indicates deposition from the north in line with the regional trend (No. 76). However given the existence of sandy lenses within the upper unit and the stratigraphic sequence, it is quite likely that the upper facies represents a very localised (in terms of exposed outcrop) ablation till while the lower facies was probably accumulated in a glaciofluvial depositional environment.

Samples 8 and 97 along with sample 94 from the previous sub-group all come from different facies as exposed in a sand and gravel pit in the townland of Ballylemon Lower to the north-west of Dungarvan. The uppermost facies is a shallow fissile diamictic unit whose contained clasts are aligned north/south. This unit overlies a coarse gravel which is imbricate to the north and whose upper layers appear to be somewhat tectonically disturbed. The lower gravel facies forms a series of foreset beds which dip mainly to the south. Thus the diamicton which crops out at the surface is probably the lateral equivalent of similar diamicton which crops out at the surface both at the coast and further inland. This diamictic unit is commonly referred to in previous literature as the Ballyvoyle Till (Watts, 1959). The diamicton therefore probably represents a southward advance of ice of inland origin into the Dungarvan area after the accumulation of glaciofluvial and deltaic sediments. Given the location of these deltaic sediments close to the present coastline it is most probable that drainage was temporarily impeded on the seaward side by the presence of ice offshore. The whole sequence could therefore be interpreted as a prograding sequence associated with the southward advance of ice of inland origin somewhat later than the westward advance of ice of Irish sea basin provenance.

7.3.3.3.1. Sub-Group 3

There are 11 samples in this sub-group which, in terms of the petrography of the phenoclasts, are closely related to samples from sediments which have been assigned to diamicton of Irish Sea basin provenance (see previous chapter). The samples from this group include the following: Nos. 9, 51, 12, 52, 86, 49, 79, 82, 41, 44 and 72. Five of the samples are located in the Dungarvan area (Nos. 9, 49, 51, 52 and 86), three in the south-west (Nos. 72, 79 and 82), two on the east side of the Comeraghs (Nos. 41 and 44) and one in north-west County Waterford (No. 12). The composition of these sandstone-dominated samples varies markedly in terms of second-ranking lithology of the contained clasts, from chert, to volcanics and shale, in turn. The relative proportions of these secondary frequencies remain fairly constant at about 20%.

The composition of the samples from the Dungarvan area follows trends already established in the previous sub-groups. The volcanic erratic content decreases in a northerly and westerly direction. Its presence and distance decay patterns in theses samples is indicative of transport inland by westward moving ice of Irish Sea basin provenance (see preceding and following chapters). The Drum Hills sample (No. 86) with its complement of chert and volcanic erratics was probably deposited by southward-moving ice which had passed over the Dungarvan syncline and its content of the earlier volcanic erratic-bearing diamicton. Fewer volcanic erratics are encountered in the samples from the upper stonier facies than from the lower less stony and more silty facies in the coastal exposures of this area (compare sample Nos. 51 and 55, and Nos. 54 and 52). Although none of the textural samples falls within this sub-group, that for the relatively similar silt-rich diamicton at Scart lies in close proximity.

Note: It is possible to argue that part of the siltiness of these and any of the samples from County Waterford could be associated with the underlying Carboniferous limestone bedrock basement (Dreimanis and

Vagners, 1972). However given that the same siltiness is not observable in the limestone-rich samples from the northern part of the county, it is assumed that the siltiness is erratic in character and is probably associated with the movement onshore of ice of Irish Sea basin provenance.

This pattern may be explained in terms of dilution of the erratic-bearing diamicton by a later southerly advance of ice of inland origin or by the deposition of a more local facies by ice of offshore origin. However this latter interpretation is not supported by the balance of results from fabric and imbrication analyses. The preferred orientation for the contained clasts in the sediment from which petrographic sample No. 86 (No. 63, Figure 8) was taken shows a distinct north-north-east/south-southwest alignment. Glaciofluvial gravels in the townland of Knockgarraun which were sampled for petrographic analysis (No. 9) were laid down by a north to south flowing palaeocurrent (No. 4, Figure 8). Both modal values would be more easily explained in terms of a southward moving and/or northward retreating ice sheet. However the east-west alignment of the clasts in the diamicton exposed at the coast in the townland of Skehacrine, although in line with the local trend, highlights the problems of interpretation (No. 4, Figure 8).

The interpretation which involves a more local facies associated with ice of offshore provenance fails however to explain the assymetry in the volcanic content of the glacial sediments on the north and south sides of the Dungarvan syncline. The balance of the petrographic, textural and fabric evidence from this key area is more consistent with the former interpretation involving a later southerly advance of inland ice over the relatively silt-rich, volcanic-bearing deposits laid down by an earlier incursion of offshore ice.

Two of the sites from which the south-westerly samples were taken (Nos. 82 and 79) yielded north-easterly/south-westerly modal fabric orientations (Nos. 47 and 52 respectively, Figure 8). Both orientations are at variance with local underlying rock slopes. The sediment represented by sample No. 52 is composed predominantly of angular fragments of the local Devonian sandstones in a sandy matrix although it does contain some volcanic erratics (No. 79, Figure 26). The deposit may be interpreted as a very local glacial diamictic facies largely derived from underlying head. Alternatively, it may be a head deposit derived from glacial diamicton, though this is less likely given the oblique orientation of the fabric mode in relation to the underlying rock slope as defined by the local maximum topographic slope.

Petrographic sample No. 72 was taken from the upper stony facies exposed at the coast in the townland of Ballyquin. Unfortunately because of its shallow outcrop (less than one metre) the sampled sediment was not suitable for fabric analysis due to post-glacial frost disturbance which has affected the upper metre of the unconsolidated stratigraphic column in nearly all of the Waterford sections. Petrographically, the sample with its volcanic and chert erratics compares very closely with the stony lens contained within the silt-rich, volcanic erratic-bearing diamicton exposed at the back of the beach on the eastern side of the townland. However it is not possible to deduce the provenance of the ice responsible for its deposition on the basis of the petrography of the phenoclasts alone.

The three remaining samples present no surprises or deviations from local trends. The chert and volcanic content of sample No. 12 is most probably derived from the nearest Carboniferous and Devonian volcanic outcrops to the north and north-west respectively. This together with the north/south orientation of the contained stones indicates movement of ice from a general northerly direction.

The petrography of the phenoclasts in sample Nos. 41 and 44 is very similar. Imbrication analysis of the gravelly sediment from which sample No. 41 was taken indicates accumulation in a glaciofluvial palaeocurrent from the north-east. The petrographic components of the sample, which is located just within the Devonian/Lower Palaeozoic contact zone, include Devonian sandstone, Lower Palaeozoic shales and occasional volcanic erratics and Carboniferous chert erratics. Such a composition would be quite consistent with south-eastward transport of these materials in a glacial-glaciofluvial environment.

7.3.3.3.2. **Stratigraphy and Facies Identification**

Two facies are recognised from this sub-group on the basis of texture: namely, a diamictic facies (Nos. 12, 49, 51, 52, 72, 79, 82 and 86) and a gravel facies (Nos. 9, 41 and 44). Samples which were taken from sediments within a multifacies glacially derived sequence include the following from this sub-group: Nos. 41 and 44, 51, 52, and 72.

Diamictic Facies

Of the multifacies sequences in diamicton, samples 51 and 72 represent the upper stonier facies in their respective sequences. While sample 52 was taken from the lowermost facies as exposed at the site from which the sample was selected. However all three samples were taken within three metres from the surface and may therefore be regarded as being from slightly different horizons within the same stratigraphic unit. However, in the case of sample No. 72, it is also possible that the upper diamicton, of which this sample is representative, and the lower silt-rich volcanic erratic-bearing diamictic facies, may both have been deposited by ice of Irish Sea provenance.

The remainder of the diamicton samples from this group represent single sandy stony diamictic facies which crop out at the surface and are similar to those described in the preceding sub-groups.

Gravel Facies

Two of the samples from gravels were taken from multifacies sequences (Nos. 41 and 44). Sample 41 represents the lowest gravel unit in a sand and gravel deltaic sequence on the east side of the Comeragh Mountains. The sample contains more chert, volcanic and shale erratics than samples from overlying gravel units (Nos. 42 and 43). It also appears to have accumulated in a palaeocurrent with a stronger easterly component than the more northerly and north-westerly directions in the two samples from two overlying gravel horizons. Sample 44 comes from a gravel unit which underlies a shallow sandy and gravelly diamicton (petrographic sample No. 47) in the townland of Gortnalaght on the east side of the Comeraghs. Both units may be interpreted as being part of a single episode or ablation sequence. Sample No. 9 taken from gravels to the west of the Comeragh Mountains presumably represents the western equivalent of this stratigraphic unit.

7.3.3.4.1. **Sub-Group 4**

This fourth and final sub-group is composed of sixteen samples. The group is characterised by relatively lower proportions of sandstone and higher proportions of the second-ranking lithologies, mainly chert, and volcanic clasts. The samples are distributed throughout County Waterford. Concentrations of gravels crop out in western County Waterford in the Blackwater valley (Nos. 3, 13, 87 and 101). Samples of diamicton and gravels from the Dungarvan area include Nos. 6, 7, 53 and 55. Sample Nos. 34, 39, 50 and 91 represent diamicton and gravels from north-western County Waterford. The remaining samples were taken from sections in diamicton in the east (No. 47), south-east (Nos. 60 and 61) and south-west (No. 85).

The western gravel samples which come from a series of deltas and river terraces in the Carboniferous limestone syncline between Lismore and Dungarvan contain relatively high proportions of chert clasts and occasional volcanic erratics. The nearest recorded outcrops of both acid and basic volcanic lithologies lie 35 km away in the Lower Palaeozoic sequence of eastern County Waterford. Carboniferous acid and intermediate volcanics also crop out south-east of Limerick city 50 km to the north-west. Either or both of these localities could have been a potential source of the contained acid volcanic erratics. Very occasional rounded granitic erratic cobbles containing pink feldspars (probably from the Galway area) were also recorded from these gravels. Certainly the direction of the most recent palaeocurrents responsible for the deposition of these gravels is from the north in the case of the deltaic sequence and from the west in the case of the glaciofluvial terraced gravels (Nos. 8-12, Figure 8).

The two gravel samples from the Dungarvan area (Nos. 6 and 7) were deposited in north/south oriented palaeocurrents. The composition of the samples shows an increased chert component, higher than any other in the area. The absence of any gravel deposits to the east of these localities in the Dungarvan syncline suggests that drainage had free access to the sea directly to the south into Dungarvan Harbour at the time of accumulation.

The two diamictic samples (Nos. 53 and 55) from this area show a southerly decline in the volcanic erratic content and a northerly decline in the chert content of the sampled sediments. These trends are also reflected in other samples taken from the diamicton of the area (Nos. 8, 4, 15, 95, 49, 52 and 51). Both trends indicate southerly glacial transport of erratics in the area. These directions are somewhat at variance with those indicated by the north-west/south-east alignment of the contained clasts within the sampled sediments (Nos. 5 and 2 respectively, Figure 8). The differences between inferred direction of erratic transport and that of deposition may be explained in terms of reworking of pre-existing glacigenic sediments. Assuming that the fabric of the stony, sandy diamicton represents the most recent east-west or west-east movement of ice in the area. Therefore the southward carriage of erratics must have occurred somewhat earlier. It may have occurred during a slightly earlier advance of ice of inland northern origin. However as the sediments also contain traces of shell fragments and occasional flint erratics of Irish Sea basin provenance this earlier advance must have been predated by an advance onshore of ice from the Irish Sea basin. Alternatively the earlier ice movement may have been associated with south-westerly-moving ice of Irish Sea basin origin along the coast.

The north-western samples present an interesting contrast in the amount of chert present and in the chert-limestone ratio. One gravel sample (No. 34) contains a 'normal' limestone-chert ratio whereby the proportion of limestone clasts exceeds that of chert clasts. This ratio mirrors the relative proportions of limestone to chert as recorded in the Carboniferous sequence to the north (Keeley, 1983). The ratio is inverted in a diamictic sample 5 km further south (No. 91). Here the proportion of chert exceeds that of limestone. Limestone is totally absent from a second diamictic sample which contains high sandstone and chert frequencies (No. 39) and is located 5 km to the north of sample No. 91. The combined limestone and chert content (50%) of the gravel sample referred to above (No. 34) is somewhat greater than the chert content (46%) of the neighbouring diamictic sample (No. 39) which lies somewhat closer to the Carboniferous limestone/Devonian sandstone junction and from which direction the material was presumably transported (see fabric mode No. 17, Figure 8). The higher total erratic content of the gravel sample is not surprising in itself (Boulton and Paul, 1976; Dreimanis, 1976); but the contrast in the limestone-chert content between the neighbouring samples indicates substantial contemporary 'weathering out' or leaching of the limestone content in the glacial environment given that the two sediments are related to the same glacial event. The contrast in chert content between neighbouring gravel samples is highlighted by comparison of sample Nos. 50 and 34. In the former sample there is obviously a greater input of local Devonian sandstone in the very shallow upper gravel unit from which the sample was taken and which overlies a chert-dominated diamicton. The latter sample represents a deep gravel unit where no diamicton is exposed and the material seems to be largely erratic.

The shale content in these northern samples is derived from a local shale outcrop in the upper Devonian sequence. It is not therefore an indicator erratic as is the case with the Lower Palaeozoic shales in some of the samples from the eastern and south-western parts of the county.

The petrography of the phenoclasts in two Devonian sandstone-dominated diamicton samples from south-eastern County Waterford (Nos. 60 and 61) is explicable in terms of southward transport of volcanic erratics over a Devonian sandstone basement in a glacial environment. This direction of transport is supported by fabric modes aligned north/south and north-east/south-west respectively (Nos. 44 and 41 respectively).

The sample taken from the plug of diamicton at the mouth of the stream which separates the townlands of Ballymacart Lower and Ballykilmurry (No.85) is mainly composed of rounded and subangular material of local origin. However there are fewer chert and volcanic erratics, possibly indicating deposition by ice of extraneous origin or redeposition of an earlier glacial deposit by a later ice sheet of inland origin. The east/west alignment of the fabric mode from this deposit is extremely weak and scattered (No. 24) which favours the redepostion theory.

Finally, the gravelly diamictic sample (No. 47) from the eastern side of the Comeragh Mountains which overlies a gravel unit (No. 44) contains much higher percentages of volcanic erratics (45% as opposed to 1%) than the sample from the underlying material. The petrographic content therefore implies a north-easterly origin. This is corroborated by the north-east/south-west preferred orientation of the contained stones in the upper unit (No. 73). This direction is very similar to that from the lowest gravel unit in the deltaic system to the north-east (No. 5, Figure 8) and may be associated with deglaciation and northward younging of the glacial sequence. Alternatively, it may simply be regarded as an ablation facies associated with the same glacial event responsible for the deposition of the underlying glaciofluvial unit.

7.3.3.4.2. Facies Identification and Stratigraphy

With the exception of sample Nos. 47 and 50 all the samples in this group were taken from single facies exposures. A diamictic and gravel facies were recognised on the basis of textural differences. Both gravels and diamicton generally appear to be virtually mutually exclusive in terms of distribution (Figure 8).

Diamictic Facies

The diamictic facies belongs to the sandy stony diamictic facies which crops out at the surface in most parts of the area mapped in County Waterford. A diamicton from Kilcreggane in the north-western corner of the county may be regarded as representative of this facies.

Petrographically the sample is dominated by Devonian sandstone (48%), followed by Carboniferous chert (35%) and limestone erratics (16%). The sample also contains very occasional volcanic erratics which are probably derived from the Devonian volcanic outcrop at Knoanyarha further up the Nier valley to the east (No. 91). The sediment for this sample yielded a north-easterly/south-westerly fabric orientation (No. 65) and a texture which falls into the intermediate group between the silt-rich and the silt-poor group. Both petrographic and fabric evidence point to deposition of the sediment by southward bound ice of inland origin. These characteristics are present in most of the diamicton samples from this group although individual fabric modes vary between north-western, northern and north-eastern directions as discussed above.

The gravelly diamicton from which sample No. 47 was taken probably represents a very localised and shallow outcrop of ablation till which overlies the gravel facies.

Gravel Facies

The gravel facies is probably best represented by sample No. 101 taken from terraced glaciofluvial gravels in the Blackwater valley. The gravels are dominated by Devonian sandstone erratics (62%), followed by Carboniferous chert (31%) and limestone (5%). Occasional volcanic erratics are also present. These latter may have been derived from either or both the east Waterford or Limerick outcrops as both acid and basic types were recorded from the sample. Very occasional rounded granite erratics with pink feldspars, probably from the Galway area, point to an initial south-easterly transport of erratics which may have been subsequently reworked by eastward-draining glaciofluvial meltwater in the Blackwater valley (Nos. 11 and 12, Figure 8). Texturally the gravels from which this sample was taken fall into the silt-poor group. The gravels from the north-western and Dungarvan areas are associated with a north-easterly and northerly provenance respectively (Nos. 17, 13 and 3, Figure 8).

The shallow structureless gravel unit which is 0.6 m thick (No. 50) overlies a chert-rich diamicton in the northern part of the county at 50 m O.D. It seems to be of very local origin and restricted extent as it was not recorded in any of the neighbouring sections. It may represent an ablation facies associated with retreat of the ice front northward into the Suir valley. Alternatively it may simply be a slope deposit derived from higher level gravels which are recorded in the area at 134 m O.D.

7.3.4.1. Chert-Dominated Sediments

The sediments from which the two Carboniferous chert-dominated samples (Nos. 37 and 45) were taken were not sampled for fabric or textural analysis. However they may by included within the sandy, stony diamictic facies by virtue of the petrography of the phenoclasts, qualitatively assessed texture, stratigraphic position and distribution.

Petrographically both samples represent diamicton which crops out within one km away from the source of the Carboniferous limestone. There is an almost complete absence of limestone and a very pronounced inversion of the limestone-chert ratio in these samples where the proportion of chert to limestone is the reverse of that in the source rocks of the Carboniferous strata (Keeley, 1983). The predominance of chert in these samples may be partly related to the relatively shallow exposure from which the samples were taken. (The samples were taken at 3 m and 2 m respectively from the surface.) This is in marked contrast to sample No. 91 which was taken at greater depth (approximately 5 m) beneath the surface in a more deeply exposed section. The amount of chert in these two samples implies substantial contemporary leaching out of the limestone complement within the glacial environment and also possibly some post-glacial leaching of carbonate content in the surface layers. This type of leaching is observed indirectly by the relative absence of limestone clasts in diamicton within one metre of the surface and their relative abundance at greater depths.

The content of volcanic erratics in the diamictic sample from Kilmacomma (No. 45) is particularly high relative to neighbouring samples. The source for these volcanic clasts is somewhat problematical in that there are no nearby outcrops of any such lithology. One possible suggestion is a south-eastern provenance via an early incursion of ice from offshore north-westward up the Suir valley. The nearest source of Lower Palaeozoic volcanic erratics along this route crop out in the lower Suir Valley 65 km away. Alternatively, the Limerick Carboniferous volcanic outcrop, which is 50 km distant, could have been the source of these volcanic erratics.

7.3.4.2. Stratigraphy and Facies Identification

Stratigraphically, the diamicton which crops out at the surface in the townland of Curraghteskin (petrographic sample No. 37) and beneath a shallow gravelly unit (petrographic sample No. 45) of possible slope wash origin respectively, belongs to the sandy stony diamictic facies which crops out at the surface throughout the county.

7.3.5.1. Volcanic-Dominated Sediments

The volcanic-dominated petrographic group is composed of 25 samples (see dendrogram). Two of these samples (Nos. 26 and 98) have already been allocated to the shelly, silt-rich diamictic facies of Irish Sea basin provenance (see Chapter Six), mainly on the basis of particle size analysis (No. 98) and partly on the basis of the petrography of the phenoclasts (No. 26).

TABLE 5. COMPOSITION OF VOLCANIC-DOMINANT PETROGRAPHIC GROUP

Particle size, fabric and petrographic sample numbers.			Townland	% Limestone, chert, sandstone, volcanic and shale clasts.				
Par.	Fab.	Pet.		L	C	S	V	S
5	12	95	Clonea Middle	0.0	2.7	34.7	61.4	1.2
-	-	24	Johnstown	0.4	5.2	28.9	55.4	9.9
-	42	59	Coolum	0.0	0.0	24.9	66.2	8.9
-	39	69	Summerville	0.0	1.3	20.7	64.3	13.7
-	-	29	Loughdeheen	3.9	4.5	26.2	63.4	1.9
1	13	93	Newtown (middle)	1.4	0.2	36.7	58.7	3.0
-	-	96	Newtown (upper)	0.0	4.3	40.7	55.0	0.0
-	-	25	Slieveroe	0.0	1.4	14.2	81.2	3.2
-	32	56	Ballydowane East	0.0	0.6	9.2	89.9	0.9
-	25	65	Kilfarrasy	1.1	3.4	9.9	83.8	1.7
3	27	92	Caher	3.0	3.2	6.9	86.2	0.7
-	-	28	Powersknock	0.0	1.6	14.6	71.3	12.4
-	-	30	Islandikane	0.0	0.8	9.3	78.3	11.4
-	33	66	Kilmacleague East	0.5	2.0	18.4	73.2	5.9
-	37	31	Tramore	0.0	0.0	2.4	87.9	9.6
-	30	99	Islandikane East	0.2	2.1	4.1	88.6	5.0
-	36	57	Ballyvoony	0.0	0.2	1.4	99.8	0.0
-	33	67	Benvoy	0.0	0.0	2.5	97.1	0.4
-	-	27	Reisk	0.0	3.0	19.9	42.5	34.6
-	-	62	Lisselty	0.0	0.5	10.6	49.9	35.5
-	46	58	Coolum	0.0	0.6	28.0	49.9	21.8
-	43	63	Nymphall	0.0	0.7	31.6	44.6	23.1
-	-	64	Knockavelish	0.7	5.7	18.3	52.5	22.8
-	34	68	Dunabrattin	0.0	1.9	14.1	62.8	21.3

Sample No. 95 has also been included within this group (see introduction). Thus the volcanic-dominated group as a subset of the sandy stony diamictic facies and associated gravels is composed of 24 samples (Table 5). They are for the most part confined geographically to the outcrops of the basement rock and areas to the south in eastern County Waterford (Figure 26).

Petrography of the Phenoclasts

The volcanic content in the samples rises in a southerly direction and is obviously derived from the underlying Lower Palaeozoic volcanic outcrops. The sandstone content generally decreases in the same direction with increasing distance from the nearest solid outcrop to the north of the county boundary in County Kilkenny. The chert content also decreases from north to south. This particular trend is somewhat clouded by the renewed presence of chert in small quantities in the samples from the extreme south. Three samples from the upper and lower diamictons exposed at Newtown on the west side of the Waterford estuary contain small amounts of chert. The sample from the lower diamicton (No.100) contains 0.4% chert erratics. This figure is very similar to that for the chert content of the sample from the lower layers of the upper diamicton (No. 93) which also contains limestone erratics in a normal limestone-chert ratio of 1.4:0.2 (see page 152). This ratio is inverted in the sample from the upper layers of the upper diamicton (No.96) which contains 4.3% chert and no limestone. Most of the chert erratics are presumably derived from the limestone of the Carboniferous syncline in the Suir valley and outcrops to the north and north-west. However it is also possible that chert in the southern samples may have been derived from the Carboniferous limestone outlier at Hook Head in County Wexford on the east side of the Waterford estuary. Finally, there is a third potential source of chert and limestone in the small Lower Palaeozoic outcrop of chert and limestone beds in the Tramore area although none of it appears in the diamictic sample from that area (Mitchell *et al.*, 1972). Petrographically, the volcanic-dominant samples from eastern County Waterford indicate the southward passage of erratic-bearing ice.

Fabric Analysis

Fabric analyses taken from fifteen of the sites which were sampled for petrographic analysis, in addition to seven others taken from the Newtown exposure, give a more detailed indication of the direction of ice movement in eastern county Waterford as reflected in the associated deposits (Figure 8). The general north to south direction of ice movement indicated by the results of the petrographic analyses is corroborated at most of the sample sites. However in the samples located to the west of Tramore there is evidence of a movement more from the north-east, while in the Newtown area the preferred direction appears to be generally from the north-west or west. This pattern is suggestive of a fanning out of the ice sheet as a lobate front to the south of Waterford city probably in its final stages of advance in the area. Within the group of samples from the Newtown area the results of fabric analyses indicate that the lower diamicton was deposited from the north-west (No. 14), that the lower layers of the upper diamicton were associated with southward-travelling ice (Nos. 22 and 16) and that the upper layers of the upper diamicton were once again deposited by ice moving from the north-west (Nos. 13, 15, 18, 19, 20, 21 and 23).

One other interesting point to note from the results of fabric analyses from multifacies sediments is the similarity in the modal values from the silt-rich diamictic facies and the overlying sandy stony diamictic facies in the townland of Caher at the back of Garrarus Strand (Nos. 29 and 26 respectively). This suggests that the fabric of both diamictons is representative of the most recent movement of ice within the area. The original fabric of the lower shelly, silt-rich diamicton (see Chapter Six) may have been realigned during the deposition of the overlying sandy, stony diamicton by a later advance of ice of northern origin (see Chapter Eight for further discussion).

Only in one case was the fabric of the sampled sediment undoubtedly realigned to parallel the maximum topographic slope (No. 36). Petrographically the sample (No.57) at the back of Ballyvoony cove was composed almost entirely of angular fragments of the local Lower Palaeozoic acid volcanic tuffaceous rock. Small percentages of Devonian sandstone and Carboniferous chert erratics (1.4% and 0.2% respectively) were also present in the sample. The sampled sediment probably represents therefore a gelifluctəd facies which includes erratics probably derived from a pre-existing facies of the diamicton which crops out at the surface throughout most of the area mapped.

Particle Size Analyses

Three of the sites from this group which were sampled for stone counts (Nos. 95, 93 and 92) were also sampled for textural analyses (Nos. 5, 1 and 3 respectively). All of these samples fall within the intermediate group between the silt-rich and silt-poor sediments. This group is consistently associated with sediments which have been traditionally designated as the Ballyvoyle Till (Watts, 1959; Mithchell *et al.*, 1973).

7.3.5.2. Facies Identification and Stratigraphy

Only two facies are recognised from this group: a diamictic facies and a single sampled geliflucted facies

(No. 57 described above).

Diamictic Facies

With the exception of the single sample from the gelifluctad facies all of the sample diamictons from this group may be assigned to the diamictic facies on the basis of texture, petrography of the phenoclasts and fabric. The sites sampled for pebble counts are by and large single facies exposures in glacial sediments. Multi-facies sequences were noted and sampled only at Newtown and Garrarus Strand. At both localities a lower diamicton is separated stratigraphically from an overlying diamictic facies by a head unit. In both cases the samples from the overlying diamictic facies have been statistically assigned to this volcanic-dominant group.

7.3.6.1. Limestone-Dominant Group

There is only one sample in this group (No. 89). The sample was taken from a gravel deposit overlooking the River Suir in the townland of Gurteen Upper in the extreme north of the county. Petrographically, the sample presents what might be taken as a 'normal' limestone:chert ratio of 83:6 in that the proportion of limestone exceeds that of chert in a ratio greater than 10:1 as recorded in the Carboniferous strata in the Suir syncline to the north (Keeley, 1983). The sample also contained very occasional rounded, granite erratics which contained grey feldspars. The provenance of these erratics was probably the Leinster batholith. Their presence in the gravel sample is indicative of southerly transport. Although the sampled sediment rests on Devonian sandstone the sample contains only 11% of clasts derived from the underlying bedrock. Texturally the sample falls into the gravel group (No. 16) and imbrication analysis points to deposition of the gravels in a north-flowing palaeocurrent probably associated with marginal drainage around an ice mass in the Suir valley (No. 1, Figure 8).

The gravels are a surface deposit and may therefore be regarded as the stratigraphic equivalent of a similar gravel deposit in north-western County Waterford (No. 34).

7.4. Conclusion

Three separate diamictic facies are recognised on the basis of petrography of the phenoclasts, fabric and textural analyses within the sandy stony diamictic facies. These consist of an upper diamictic facies, a lower diamictic facies and a Comeragh Valley diamictic facies. A single gravel facies is also recognised. However when relative stratigraphic position is taken into account a further diamictic and gravel facies may be added to the above list (see discussion below).

The Upper Diamictic Facies

This facies is the massive, sandy, stony diamicton which crops out at the surface throughout the county. It is composed a sandy matrix which supports clasts derived from the subjacent lithologies including Devonian sandstone, Carboniferous limestone and chert, and Lower Palaeozoic shales and volcanics. The contained clasts are commonly glacially abraded and their a-axes display a preferred orientation generally aligned north-south. Far-travelled erratics including granite probably from the Wicklow area are confined to the extreme eastern part of the county. Very occasional shell fragments, and flint erratics have been recorded from samples in the Dungarvan area. Extremely small shell fragments (<< 2 mm in diameter) have also been observed in even less quantity in the upper diamicton at Newtown on the eastern boundary of the county. This diamicton is the equivalent of the Ballyvoyle Till.

Mappable units within this facies may be recognised on the basis of the dominant lithology of the contained clasts. The diamictic facies from this group may be subdivided into shale-, sandstone-, chert- and volcanic-dominant subgroups. Individual facies are generally located on and to the south of the parent solid lithologies. The various facies merge into each other starting with the chert-dominant group in the north. This is then overtaken by a sandstone-dominant facies to the south in western County

Waterford where it reaches the coast. In eastern County Waterford the chert-dominant facies is succeeded to the south by a shale-dominant facies. This facies wedges out to the south into the volcanic-dominant facies which extends to the coast (Figure 26).

The Lower Diamictic Facies

This facies is recognised at one multi-facies section in diamicton on the coast at Newtown in eastern County Waterford. The lower diamictic facies is seen in section as a wedge-shaped body low down in a very badly exposed sequence. Its contact with the underlying units is obliterated from view by slumped material from the upper diamicton from which it appears to be separated by a thin head unit (Figure 9).

Petrographically there appears to be some contrast between the samples from the upper and lower diamictons in the Newtown sequence with the samples from the upper diamicton containing higher proportions of extra-local lithologies, namely, volcanic and sandstone erratics. Texturally, also, there is marked contrast between the upper and lower diamictons. The upper facies sample falls into the intermediate group and the sample from the lower diamicton is assigned to the silt-poor group usually associated with the gravel samples. The evidence from fabric analyses is less convincing in terms of distinguishing whether the diamictons are in fact significantly different units stratigraphically. The fabric of the upper layers of the upper diamictic facies is broadly similar to that of the lower diamicton but is in marked contrast to the lower layers of the upper diamicton. The head unit which separates the two units appears to dip northwards and pinches out in that direction. The basal layers of the overlying diamicton appear to be semi-stratified in that the long axes of the contained lie sub-parallel to each other and to the base of the upper diamicton. This is separated from the underlying frost-shattered rock platform to the north by a laterally continuous sandy parting is visible for approximately 30 m. Two silt lenses at higher levels in the sequence, approximately 4 m above the base of the unit, extend along a north/south axis for approximately 1-2 m. The upper diamicton appears to have been sheared into position over the underlying diamicton which contains much local angular material and which in turn rests on the frost shattered rock platform. This interpretation of the Newtown sequence would be consistent with basal lodgement at the warm-based front of an ice mass of inland origin (Boulton and Paul, 1976).

The Comeragh Valley Diamictic Facies

This facies is confined to the valleys on the east and west sides of the Comeragh Mountains. In terms of petrography of the phenoclasts, fabric and morphology, it appears to be related to movement of slightly younger ice down the valleys on the east and west sides of the Comeragh Mountains.

The Gravel Facies

Gravels crop out at the surface in many of the areas mapped (Figure 8) and these are regarded as belonging to a single stratigraphic unit. However in the townland of Ballylemon Lower the gravel facies is overlain by a one metre-deep layer of fissile diamicton. The question of contemporaneity and correlation of this diamicton with that which crops out at the surface in County Waterford arises. It also raises the possibility of different ages for the gravels which crop out at the surface and those at Ballylemon Lower which underlie the diamictic unit. Given that the diamictic unit at Ballylemon is of northerly provenance, then all of the diamicton and gravels which crop out at the surface to the north of this locality may be taken as belonging to the same stratigraphic position. Thus the underlying gravels at Ballylemon Lower may be assigned to a lower stratigraphic position. Gravels which crop out at the surface in the Dungarvan syncline to the south of this locality also probably post-date the Ballylemon Lower gravel unit. They may also post-date the Ballylemon Lower diamictic unit. Diamicton which crops out at the surface on the south side of the Dungarvan syncline was seen in section to overlie a gravel unit in the Drum Hills. Given that no diamicton was observed to overlie the gravels in the intervening Dungarvan syncline, then two correlations are possible: either the diamicton and gravel sequence to the south of the Dungarvan syncline is comparable in age to that at Ballylemon Lower and the gravels which crop out at the surface in the intervening Carboniferous syncline are younger than the diamicton and gravel facies to the north and south; or these gravels are correlated with the Ballylemon Lower gravel facies and both the diamictic and gravel units to the south of the syncline predate the gravels and diamicton to the north in a northwardly younging sequence (see Chapter Eight for further discussion.

CHAPTER EIGHT

CORRELATIONS AND CONCLUSIONS

8.1 Introduction

The facies variations recognised on the basis of the present research are formally named. Stratigraphic correlations are drawn between the named units within the area mapped. Then the wider stratigraphic correlations are established between the units and those which have been described in previous literature and whose area of outcrop lies outside or contiguous to the area mapped. Finally the conclusions arising out of these wider correlations are presented in a lithostratigraphic, biostratigraphic and chronostratigraphic framework for the Quaternary sediments of County Waterford.

8.2. Lithostratigraphic Units

Two major lithostratigraphic units are identified among the glacigenic and glaciofluvial sediments of County Waterford. They are derived from two separate sources: ice of inland, northern provenance, and ice from the Irish Sea basin. In neighbouring County Wexford glacial and glaciofluvial sediments from both these sources are assigned to the Bannow Formation and Blackwater Formation respectively (Synge, 1964; Culleton, 1978; Warren, 1985). In County Cork, however, till of Irish Sea basin origin is described as belonging to the Ballycroneen Formation (Wright and Muff, 1904; Mitchell *et al.*, 1973; Warren, 1985). In the same publications the Ballyvoyle Till was correlated with the Bannow Till (Mitchell *et al.*, 1973) and it was more recently accorded member status within the Bannow Formation (Warren, 1985).

A third, (minor) lithostratigraphic diamictic facies which crops out in the valleys on the east and west sides of the Comeragh Mountains is also recognised. It is proposed to name this unit the Knockanaffrin Member (S 270 130) after the townland on the western side of the mountainous ridge of the same name, where the unit is best exposed.

To maintain continuity with previous usage and to avoid unnecessary creation of new terms the glacial and glaciofluvial sediments of Irish Sea basin provenance in County Waterford are designated as the Whiting Bay Member and assigned to the Ballycroneen Formation. The latter term is selected in preference to the 'Blackwater Formation' because of the prior establishment of the geographic component in the term 'Ballycroneen Formation' (Wright and Muff, 1904). Closer similarities between the described characteristics of the stratotypes constitute a second reason for this preferred selection (see discussion below).

The formal naming of the glacial and glaciofluvial sediments of inland northern origin, commonly referred to as the Ballyvoyle Till in previous literature (Watts, 1959), is somewhat problematical. The term "Ballyvoyle Member", is the obvious choice since the term "Ballyvoyle Till" was readily adopted and had been established in literature relating to the Quaternary sediments of Ireland since 1959. Unfortunately the formal term has been subsequently used to describe sandstone units in the area (MacCarthy *et al.*, 1978). In order to maintain continuity of practice, the term "Ballyvoyle Member" is here proposed to describe the sandy, stony diamicton which crops out at the surface at its stratotype to the west of Ballyvoyle Head in line with normal procedure established for the naming of stratigraphic units (Hedberg, 1976). The Ballyvoyle Member is here regarded as a constituent member of the Bannow Formation as proposed by Warren (1985).

8.3. The Whiting Bay Member

8.3.1. Introduction

The type section for this member is located in the townland of Ballysallagh at the back of Whiting Bay (X 143 775). The succession at this point is composed of the following:

7 m silty diamicton containing striated stones, shell fragments (1-5 mm in diameter), flint erratics, and sandstone, volcanic (erratic), limestone and chert clasts in descending order of frequency.

1 m angular Devonian sandstone clasts in a sandy matrix. Base not seen.

Characteristics

The base of the silty diamictic unit is taken at the erosional contact between the upper unit and the underlying unit. (This unit is composed of frost shattered angular fragments of local Devonian sandstone. Individual clasts have their long axes oriented downslope and the interstices filled with a sandy matrix. This geliflucted unit is referred to as 'head' in previous literature (Wright and Muff, 1904; Warren, 1981). The calcareous matrix of the silty diamicton is largely composed of particles finer than 0.065 mm (68%). It has previously been described as clayey (McCabe, 1985). However the clay content is 13%. The diamicton is therefore predominantly composed of silt-sized particles. The stone content is low (less than 10% of bulk weight). Up to 80% of the phenoclasts are erratics. The predominant source of the erratics which include flints, acid and basic volcanics and Ailsa Craig micorgranite is from the east and north

(Wright and Muff, 1904). The majority of the contained clasts (which commonly fall into 2-5 cm diameter size range) are subangular or rounded and many are striated. Shell fragments (1-5 mm in diameter) of Arctic species are common throughout the matrix. Fragments rarely exceed 5 mm in diameter and no shells were observed in growth positions. On the western side of the bay contorted laminations and bedding occur towards the base of the unit (see paragraphs following). These together with the striated clasts are interpreted as the products of basal or submarginal melt-out of till of Irish Sea Basin provenance into ponded water. On the western and eastern sides of Whiting Bay the diamictic unit is divisible into an upper massive facies and a lower bedded facies. The upper part of the lower facies is composed of diamictic beds approximately 30 cms thick and separated from each other by thin sandy partings. These beds are tectonised as evidenced by folding of beds within the lower facies. The folding is particularly noticeable on the western sides of buttresses of silty diamicton which protrude seaward from the regular curve of the cliffline at the back of the bay. The modal orientation values of the a-axes of the contained clasts in the relatively undisturbed sections are aligned north west/south east and they dip to the north west. Tectonic structures in the folded beds indicate a source of pressure from the south east (see next section).

8.3.2. Facies Differentiation and Facies Associations: Two major facies are recognised within the Whiting Bay Member based on colouration differences, stratigraphic position, sedimentation style, facies associations and tectonisation: a basal facies crops out low down in the coastal section at the western end of Whiting Bay, in the core of anticlinal folds on the eastern side of Whiting Bay and at Colaiste na Rinne in the townland of Mweelahorna on the southern side of Dungarvan Harbour (see Chapter Six).

Lower Facies

The laminated blue-green calcareous silts of the lower facies at Whiting Bay contain minute shell fragments and are relatively stone-free. In places lamination in the silts is highly contorted often into a vertical position. Where the lamination is relatively undisturbed the some of the larger stones (up to 3 cm) which are present appear to be concentrated at the bases of individual beds which vary in thickness from 5-35 cm The beds are separated from each other by thin sand partings less than 5 mm in thickness. The silts from the top of the lower facies at Mweelahorna contain occasional clasts. The majority of the contained clasts have a diameter of 2.5 cm. A large proportion of these are rounded erratics of eastern or northern provenance (30% in sample No. 48). About 90 m to the east of the slipway at the western end of the Bay the basal

Figure 35 Anticlinal folds in silty diamicton at eastern end of Whiting Bay.

Figure 36 Wedge-shaped beds in silty diamicton exposed at the back of Whiting Bay.

beds appear to wedge out and be interbedded with sediments of slightly different coloration. These overlying beds, still within the lower facies, are of uniform thickness (1-15 cm) and appear to be laterally more continuous.

In the townland of Cappagh on the eastern side of Whiting Bay towards the top of the lower facies there is a sequence of sands and gravels which displays both coarsening and fining upward gradations. The sand and gravel beds together with the underlying contorted silts are folded and faulted. About 20 m to the east of the anticlinal structure the graded sand unit appears to be interbedded with current bedded gravels and sand. Palaeocurrent direction was from the east at 96^0. The uppermost beds of the lower facies in this locality progressively onlap the underlying tectonic structures in wedge-shaped beds up to one metre in thickness. The wedges thicken to the north west on the northern western limbs of a double anticlinal structure (Figures 35 and 36). Occasionally, the larger clasts, whose diameters exceed 0.5 m, are underlain by locally deflected bedding which is highlighted by thin intra-bed sand partings (0.5 mm) (Figure 31). These structures are characteristic of drop-stones of the type where the underlying bedding is disturbed and the overlying beds drape or progressively onlap the upper parts of the 'over-sized' clasts (Thomas and Summers, 1982).

Upper Facies

At the western end of Whiting Bay the junction between the lower and upper facies appears to be erosive in that the upper surface of the underlying facies is bevelled (Figure 29). At this point the base of the upper facies is marked by a line of boulders which rest on the bevelled surface of the underlying unit. This characteristic probably implies interformational settling out of the larger clasts in the upper unit through a soft sediment. The contact between the two facies is marked by a change in coloration from blue-green in the lower facies to brown in the upper facies. The change may be associated with increased sand or coarse silt content in the upper facies. It is almost certainly marked by increased stoniness in the upper facies. The size of the contained clasts is somewhat larger (> 2.5 cm). The distribution of the contained clasts is random. There is a marked vertical joint pattern in the compacted muddy matrix of the upper facies. In contrast to the lower facies, the upper facies of the diamicton does not display lamination, internal stratification or the presence of drop stones. However gravel clusters or lenses are fairly common in the exposures of the upper facies at the eastern end of the outcrop of this upper facies in the locality of Ballyquin townland. The base of the upper facies invariably occupies a stratigraphic position above the upper limit of tectonisation in the underlying unconsolidated sediments.

This facies association is reminiscent of that proposed in models of sub-glacial meltout of debris into ponded water near the margins of an ice sheet by Gibbard (1980), Dreimanis, (1979), Dreimanis (1982) and Dreimanis and Lundquist (1984).

The upper limit of the calcareous silty diamictic unit is marked by an erosional boundary. The hiatus in the succession is overlain by a sandy, stony diamicton on the east side of Whiting Bay. This stony diamicton appears to be of much more local origin, the phenoclasts being dominated petrographically by Devonian sandstone clasts. However on the west side of the bay the upper limit of the silty, volcanic erratic-bearing diamicton is overlain by horizontal beds (15-35 cm in thickness) of structureless sands alternating with thin units (2-5 cm in thickness) of organic-rich sandy beds.

8.3.3. Origin of the Silty Diamicton

The presence of partially-laminated beds of calcareous silty muds in the lower facies may be interpreted as the result of sub-aqueous deposition by settling out of individual silt particles from suspension in a column of water too shallow for particle-size differentiation to take place (May, 1977). Alternatively the partial lamination and apparent lack of vertical sorting may be due to subaqueous flow by gravity or turbidity currents. The blue-green coloration is probably related to the relative absence of oxygen characteristic of such a depositional environment. The predominance of calcareous silts in the diamicton and the occurrence of shell fragments are suggestive of an initial 'preglacial' marine origin, probably the floor of the Irish Sea basin. Shell fragments have been identified as belonging to northern and Arctic marine habitats (Wright and Muff, 1904). Fragmentation of the shells is consistent throughout the upper and lower facies of the member. No shells or shell fragments were noted in the interbedded sands and gravels. The presence of the above characteristics together with the relatively few and small clasts (many of them erratic and striated), except for occasional 'over-sized' drop-stones and allied structures, although not diagnostic *per se*, imply a possible glacial origin for the silty matrix and the contained clasts within the diamicton (Dreimanis and Lundquist, 1984). Striated clasts within this type of partially-laminated sediment are probably associated with 'rain out' or melt out from the base of an immediately adjacent or suprajacent ice sheet. Very occasional gravel clusters and attendant deformation structures in the underlying bedding are also attributable to rain out of composite gravel clasts on to bottom sediment. The association of this facies with an overlying glaciofluvial sand and gravel facies (also folded and reverse-faulted), a second bedded-silt-with-drop-stones sequence which shows lee-side syndepositional thickening and a massive silty diamictic facies is probably indicative of grounded sub-glacier marginal and direct deposition of debris entrained in or on an advancing glacier (see paragraph following).

8.3.4. Depositional Environment

The subaqueous nature of the sedimentation style of the lower facies (lamination and stratification), the occasional presence of drop-stone structures and gravel clusters, and the presence of striated erratics are characteristic of sub-marginal or sub-glacial deposition in standing or ponded meltwater. A similar association of sedimentary characteristics is interpreted by May (1977), Dreimanis (1979) and Gibbard (1980) as the result of sedimentation by bottom melt beneath a floating ice-shelf near its grounding line (May, 1977), or as subaquatic flow till at the margins of a grounded ice sheet (Evenson *et al.*, 1977). The upper facies is characterised by its south-eastern/north-western alignment of the a-axes of the contained clasts which dip down-glacier in the sample from Whiting Bay. The fabric is broadly consistent with palaeocurrent directions indicating deposition from the east and south-east of the glaciofluvial current bedded sands from the underlying facies. It is also consistent with the direction of tectonisation in the underlying facies indicating pushing by ice advancing from the south-east. As stated in the previous paragraph, this upper facies of the overconsolidated silty, volcanic erratic-bearing diamicton at Whiting Bay is in all probability a lodgement facies deposited by grounded ice of Irish Sea basin origin advancing from the south-east.

However neither of the two models proposed by May (1977) exactly fits the assemblage of sedimentary characteristics in the lower facies of the Whiting Bay Member. The lacustrotill model is applied to "till-like sediments deposited in a lacustrine environment primarily by flow mechanisms." (May, 1977). These sediments contain glacially abraded clasts, deformation structures resulting probably from penecontemporaneous slumping and liquefaction, and flow structures formed during deposition which often contain clasts composed of silt and clay. Of this suite of diagnostic features, only the glacially abraded clasts are common to the lower facies of the Whiting Bay Member. May's second "waterlaid" model represents a sequence where essentially massive diamictons are found to overlie basal tills as a slightly reworked unit under lacustrine conditions. The model incorporates sedimentary characteristics which resemble more closely those observed in the lower facies of the Whiting Bay Member: massive sedimentation with occasional "crude stratification", lower stone content than in associated lodgement tills, stones usually occurring in groups and showing evidence of glacial abrasion. All of the above are present in the lower facies which crops out at Whiting

Bay. Three possible origins for this type of diamicton are suggested:

1. deposition of glacial debris in standing water at the snout of a glacier grounded on the bottom of a lake;
2. till deposited by annual minor readvances and subsequently slightly reworked by lacustrine process; and
3. sediments deposited beneath a glacier which is floating in a lake, but where the depth of water does not allow any major amount of size separation during settling. Both facies are regarded as being related to each other and to other lacustrine deposits such as varved clays. However the stratigraphic framework of May's glacial-lacustrine regressive sequence whereby lodgement till is overlain by a waterlaid till facies and a lacustrotill facies in turn, is reversed in the unconsolidated sedimentary sequence at Whiting Bay. Here the basal unit is formed of partially laminated silts which are overlain by massive diamictic beds and terrestrial lodgement till in turn (see discussion following). Furthermore there is no association in this locality with the most distal facies of May's modelled glaciolacustrine sequence, varved sediments.

The Waite Farm Laminated Clay member exposed on the north shore of Lake Erie and described by Gibbard (1980) is similar to the basal facies in the sequence at Whiting Bay in terms of its partial lamination and inclusion of drop-stones. The stratigraphic sequence at Catfish Creek is in effect the reverse of that described by May (1977) in that the lowest glaciolacustrine facies is overlain by deltaic sands and gravels, stratified till and lodgement till in turn. Gibbard's model involves submarginal deposition in a marginal subglacial depression by basal melt out from ice advancing over glaciolacustrine sediments as the base of the ice gradually becomes grounded (Gibbard, 1980).

The lower facies at Whiting Bay could therefore be described as a waterlain till according to May's criteria listed above (May, 1977). Alternatively, it could be classified as a glaciolacustrine facies according to Gibbard's criteria (Gibbard, 1980). Lamination in the lower silty facies at Whiting Bay is highly contorted towards the top of the facies. This was not traceable over any significant distance laterally due to poor exposure. Other deformation structures were noted included folding and faulting. These and the contortions in the lamination of the lower facies were probably produced by tectonisation of the sediments at the margin of an advancing ice sheet (see above).

8.3.5. The Whiting Bay Member in Other Localities

Ardoginna Head

A silt-rich diamicton, which contains volcanic erratics and is similar to the upper facies at Whiting Bay, crops out to the east of the bay in the coastal section at Ardoginna Head. In contrast to Whiting Bay, the unconsolidated sediments do not extend far inland from the coast as solid rock outcrops associated with the 'preglacial' cliff eroded into the Devonian sandstone frequently crop out along the exposed surface of the section. Here, the silty diamicton is stonier and less silty. It also contains more phenoclasts of local origin (petrographic sample No. 75). The fabric indicates deposition from the north-west or south-east and the dip of the modal class towards the north-west is also similar to that at Whiting Bay (sample No. 58). The diamicton at this point probably represents a slightly more marginal facies than that at Whiting Bay.

Ardmore Bay

The same type of diamicton which crops out in the embayment at Ardoginna continues eastward around Ardmore Bay for a distance of approximately 3 km. At the eastern end of the exposure the facies becomes interbedded with stony lenses in the townland of Ballyquin. The lenses probably represent former marginal glaciofluvial activity.

Dungarvan Harbour

Both facies of the Whiting Bay Member are observable in the same stratigraphic relationship as at Whiting Bay in the coastal exposure on the south side of Dungarvan Harbour (Figure 28).

There is some doubt as to whether the lowlying diamictic sediments on the north side of Dungarvan Harbour represent a marginal coastal facies associated with ice of Irish Sea basin origin or a later facies associated with ice of inland, northern provenance (see Chapters Four and Seven). The diamictons displayed at the coast around Ballynacourty Point contain more stones, fewer of which are erratics, (petrographic sample Nos. 49-55) than the silty diamicton exposed on the southern side of the bay. The southern carry over of Devonian sandstone across the junction with Carboniferous limestone is more consistent with glaciation by ice of inland northern origin. The fabrics are not diagnostic in that the modal class of the a-axes of the contained clasts in the coastal and inland sections are oriented east-west and consistently dip towards the west. The direction of dip may be indicative of upshearing at the margin of eastbound ice of northern origin. However no structures were observed in the sediments which would support this interpretation. The fabrics could equally represent deposition of a marginal facies by westbound ice of Irish Sea basin provenance. The same type of argument applies to the fabrics from the upper parts of the coastal exposures on the western side of Ballyvoyle Head (sample Nos. 6 and 11). The north-easterly/south-westerly modal orientation of the a-axes of the contained clasts could equally be interpreted as having been produced by inland ice of northern origin moving southwestward off the present coast or by ice of Irish Sea basin origin moving southwestwardly along the present coast. The petrography of the phenoclasts in the upper parts of the diamicton from this area could theoretically have been derived from either ice sheet although it resembles that of other more northerly samples in terms of dominance by local Devonian sandstone clasts associated with deposition by ice of inland origin.

Ballyvoyle Head

Less than one metre of shelly, calcareous, silty diamicton was visible at the base of the section on the west side of Ballyvoyle Head during the summer of 1979. The diamicton contained few stones, many of which were striated It also contained flint and volcanic erratics. The diamicton was sampled for fabric analysis by Stevens (1959). The resultant fabric as indicated by the direction of the a-axes from the modal class was oriented north-east/south-west and dipped to the south-west. This orientation is very similar to that obtained from the upper parts of the overlying unit nearby, though at right angles to that obtained from the lowest portion. The silty diamicton was separated from the upper unit by a what appeared to be a horizontal sand parting approximately 5 mm thick. Owing to the present inaccessibility of the unit it is impossible to be ascertain whether the fabric was affected by subsequent events at the site during the deposition of the overlying diamicton (see under heading 6.3.6.).

Kilfarrasy and Garrarus Strands

Similar orientations and dips were obtained by Stevens (1959) for "Eastern General Till" at two other coastal localities further east. The sampled points were located in similar (basal) stratigraphic position at Kilfarrasy (not observed in the course of present research), and Garrarus (confirmed by present research). These orientations were interpreted by Stevens (1959) as confirming the earlier observation of Wright and Muff, (1904) (based on erratic provenance) that ice of Irish sea basin provenance moved southwest and west across the the south coast of Ireland.

The outcrop of shelly, calcareous silty diamicton containing flint erratics and (in this case) local volcanic clasts at Garrarus Strand is less than a metre in vertical exposure. The upper surface of the unit appears to dip northward when traced inland. The entire unit seems to wedge out in the same direction. It is overlain and underlain by thin diamictic units composed of sharp angular local clasts in a sandy matrix and commonly interpreted as head in previous literature (Mitchell *et al.*, 1973). The orientation of the fabric as defined by that of the a-axes in the modal class and the local character of the petrography of the phenoclasts within the silty diamicton are similar to that of the basal facies of the unit which overlies the overlying head unit. Both aspects could be interpreted as being derived by glaciodiagenesis during subsequent glaciation by ice of northern origin (Warren, 1987a). The siltiness of the textural composition, its calcareous reaction, and the presence of shell fragments and flint erratics are indicative of an original Irish Sea basin origin. The fact that ice from this source had invaded eastern County Waterford prior to the southerly advance of ice of inland origin is also suggested by two other probable remnants of associated inliers: the presence of acid volcanic erratics and associated silts in the subsoil horizon at Piltown in the Suir valley (Collins and Verling, 1976; Collins, 1981) and the outcrop of shelly, calcareous and stone-free contortedly-laminated silts at the base of the coastal section exposed at the western end of Garrarus Strand in the townland of Islandikane East. A third possible pointer to the former presence of ice of Irish Sea origin in this area is the very rare inclusion of minute shell fragments in the middle parts of the section exposed along the west shore of the Waterford Harbour estuary.

Localised outcrops of the silty diamicton and volcanic erratics of southern provenance in eastern County Waterford are consistently confined to relatively lowlying areas (less than 30 m O.D. at Piltown in the Suir valley) and the basal two metres of the coastal sections in which they were observed or reported (Stevens, 1959; Watts, 1959; Mitchell *et al.*, 1973; Collins and Verling, 1976).

The distribution of these outcrops is probably a function of protection afforded by lee situatations in the path of the subsequent southerly movement of ice of northern inland origin across the county. The remanié deposits indicate movement of ice onshore from the basin of the Irish Sea basin. It is not possible to conclude on the basis of fabric data from eastern County Waterford, whether ice moved across the southeastern corner of Ireland as envisaged by Stevens (1959) and Mithchell (1976), or whether the movement took place as a later northward expansion of weakly erosive shelf or coastal ice as envisaged by Synge (1981).

8.3.6. **Lithostratigraphic Correlation**

All of the above outcrops are correlated with each other on the basis of similar lithological characteristics (Figure 28). In western County Waterford the thick exposures of silty diamictons are overlain unconformably by a stony/sandy facies of much more local origin. East of Dungarvan Harbour only thin exposures of the silty diamicton are encountered in the coastal sections. In all cases the stratigraphic position is at the base of the coastal sections. It is overlain in all but one case directly by diamicton of inland origin except at Garrarus where a 5 cm head unit intervenes between the two diamictic units. Given the *in situ* character of the overlying diamictic unit of northern inland origin (see below), the stratigraphic relationship implies that ice from the Irish Sea basin invaded eastern County Waterford before ice of inland origin advanced southward into the area.

The Dungarvan/Drum Hills Area

The stratigraphic relationship between the glacigenic sediments of Irish Sea origin and those of inland, northern origin is not so clear cut in western County Waterford. In contrast to the eastern half of the county there is not a shallow continuous diamictic cover extending inland from the coastal exposures. The diamictic unit is generally absent, or very shallow (less than one metre) on the slopes and summit of the Drum Hills. Where present, the diamictic unit was observed in rare vertical exposures of more than two metres, either at the summit as in the townland of Barranastook or in valley bottoms (near the heads of the Goish and Licky Rivers). Fabrics (based on the orientation of the modal class of the a-axes of the contained clasts from sample Nos. 63 and 72) are aligned slightly east of north or west of south ($10^0/190^0$) and north east/south west respectively (see following paragraph). The petrography of the phenoclasts in the compacted sandy, stony diamicton on the south bank of the Goish River is dominated by Devonian sandstone (based on identification of the clasts remaining on the 5.6 mm mesh sieve in sample No. 86). The diamicton also contains relatively high proportions of chert (derived from

Carboniferous strata) by comparison with samples located to the north and south of the Drum Hills. As the valley lies immediately to the south of the Dungarvan Carboniferous syncline southward transport of the contained clasts is indicated. The presence of volcanic erratics (10%) is not particularly diagnostic of direction of glacial transport in itself. However given the probability that the diamicton was deposited by ice of northern origin, the presence of the volcanic erratics would be best explained in terms of reworking of older sediments derived from an onshore movement of ice from the basin of the Irish Sea as in eastern County Waterford.

A very short-lived section in diamicton was exposed on the summit of a southern spur of the Drum Hills by the excavation of a temporary drainage ditch approximately two metres deep in the townland of Barranastook. Here a kame-like mound composed of silty sand which contained current-bedding structures indicating deposition from the north east, was surrounded and partially overlain on its southern side by a silty, sandy and stony diamicton with a tough matrix. The diamicton was dominated by sandstone clasts and contained some chert, volcanic and flint erratics. Orientation of the a-axes in the modal class was aligned north east/south west and the predominant dip was to the north-east. The diamicton was most probably deposited by southward moving ice. It is not possible to conclude on this basis alone whether the ice which deposited the diamicton was of inland or Irish Sea basin origin. The south westerly direction of movement is similar to that indicated by the pattern of striae (see Chapter Four) in the area and also with fabric orientations based on the direction of a-axes in the lower facies of surface diamictons exposed on the northern side of Dungarvan Harbour. These diamictons are regarded as being derived from ice of inland, northern origin (see Chapter Seven). The simplest interpretation would be that the sandy, stony diamicton exposed at the surface in the Dungarvan/Drum Hills area was deposited by ice of northern origin which overrode sediments of Irish Sea basin origin. There is no positive evidence to suggest that these diamictons were deposited by a later northward movement of ice from the Irish Sea basin which overrode deposits previously laid down by ice of inland northern origin as suggested by Synge (1981). The evidence points to the opposite conclusion i.e. that the most recent movement of ice in the Drum Hills was from north to south. There is no northward carry-over of limestone or chert across the junction of Carboniferous limestone, shales and conglomerates with Devonian sandstone along the northern limb of the Dungarvan syncline. However there is a marked southerly carry-over of chert across the southern Carboniferous/Devonian junction onto the north-facing slopes of the Drum Hills. The southerly movement of ice across the Drum Hills as evidenced by the southerly transport of chert erratics from the Dungarvan syncline was most probably associated with ice of northern inland origin as the direction of movement was very much in keeping with that on the northern side of the Dungarvan syncline. The inclusion of occasional flint and volcanic erratics in the diamictic sediments in the Drum Hills area suggests that these were also transported southward along with the chert erratics and were derived from older sediments of Irish Sea basin provenance located in the Dungarvan synclinal valley to the north.

In every case the diamictons associated with deposition by ice of Irish Sea basin origin are overlain by a sandy stony diamictic facies except on the western side of Whiting Bay. It is quite possible that the sandy stony facies represents, in places, a later locally-derived marginal facies of Irish Sea basin origin, particularly in coastal exposures west of Ballymacart Cove (see Chapters Six and Seven). Thus there is no evidence to suggest that the ice of northern inland origin pre-dated the advance of ice from the basin of the Irish Sea into western County Waterford as proposed by Synge (1981).

That the sediments associated with ice of Irish Sea origin pre-dated those associated with the the ice of inland origin in County Waterford is demonstrated by its consistently lower stratigraphic position in relation to the overlying diamictic unit associated with ice of northern origin. The complement of siltiness, volcanic and flint erratics and occasional shell fragments in the basal layers of the overlying diamictic unit is probably best interpreted as reworking of the older sediments which are associated with the onshore advance of ice from the Irish Sea basin. Fabric, phenoclast petrography, texture and sedimentary structures (where present) in the upper diamicton are more consistent with the recorded properties of diamicton of northern origin. Thus the upper boundary of the diamicton associated with ice of Irish Sea origin is erosive and overlain in most places by a sandy, stony facies.

The lower boundary of the diamicton of Irish Sea origin is visible at Whiting Bay, Ardmore Bay and Dungarvan Harbour. In all cases the silty diamicton overlies a diamicton composed of sharp angular fragments in a sandy matrix of local material whose long axes dip downslope. The junction between the two units is erosive as the upper surface of the underlying unit is bevelled across crude bedding structures. On the eastern side of Whiting Bay, the junction between the silty diamicton and the underlying head unit is not marked by the normal bevelled surface of the compacted underlying head unit. The direction of the section at this point lies approximately parallel to or slightly obliquely to the orientation of deposition and the direction of push as indicated by fabric studies and tectonic structures in the silty diamictic unit. Elongated clasts composed of head are included in the cores of folds which are overturned to the north west at the base of the overlying diamictic unit. This process may not be restricted to eastern Whiting Bay. The bevelled nature of the underlying head unit may be only apparent at the other sites as the sections at these points probably represent dip exposures normal to the direction of deposition of the overlying unit. The erosive character of the junction between the silty diamicton and the underlying head unit is consistent wherever the base of the former unit is visible (see Chapter Five). The head unit is observed to rest on a horizontally bedded and stratified gravel composed of rounded cobbles in a sandy matrix. This unit is regarded as a raised beach deposited during high sea level conditions associated with probable interglacial conditions, the Courtmacsherry Beach of Wright and Muff (1904), Mitchell *et al.* (1973), and the Courtmacsherry Formation of Warren (1985). The formation of the raised beach is traditionally correlated with the Gortian interglacial (Watts, 1959; Mitchell *et al.*, 1973; Warren, 1985). The biostratigraphic correlation of organic interglacial deposits in southern Ireland includes the interglacial organic muds underlying diamicton of northern origin at Kilbeg (Watts, 1959), the interstadial organic silts at the foot of the diamicton of inland northern origin and within it at Newtown. The Gortian interglacial deposits are variously attributed with a penultimate interglacial age (Watts, 1985; Mitchell, 1976) and a last interglacial age (Warren, 1979).

8.3.7. Biostratigraphic Correlation

On the basis of the present research there is no reason to assign the interglacial and interstadial deposits in County Waterford to the penultimate interglacial. No other interglacial organic horizons were observed within or towards the top of any exposure in diamicton or gravel above those already reported in the literature and below the modern post-glacial soil development (Watts, 1985). Therefore the simplest interpretation is to assign the glacigenic lithostratigraphic units overlying the previously reported interglacial and interstadial organic deposits to the most recent glacial stage, the Fenitian of Warren (1985). Neither is there any basis for assigning these lithostratigraphic units to either the Fermanagh or Maguiresbridge Substage (Warren, 1985). The units must predate the deposition of the so-called Southern Ireland End-Moraine (Lewis, 1894; Charlesworth, 1928) which was also deposited by ice of northern origin, as this latter feature is located to the north of County Waterford (Charlesworth, 1928). The traditionally accepted maximum southern limit attained by ice during the last cold stage had already been extended beyond the moraine itself (Finch, 1971; Warren, 1987a). Whether this advance occurred during the early or middle part of the last cold

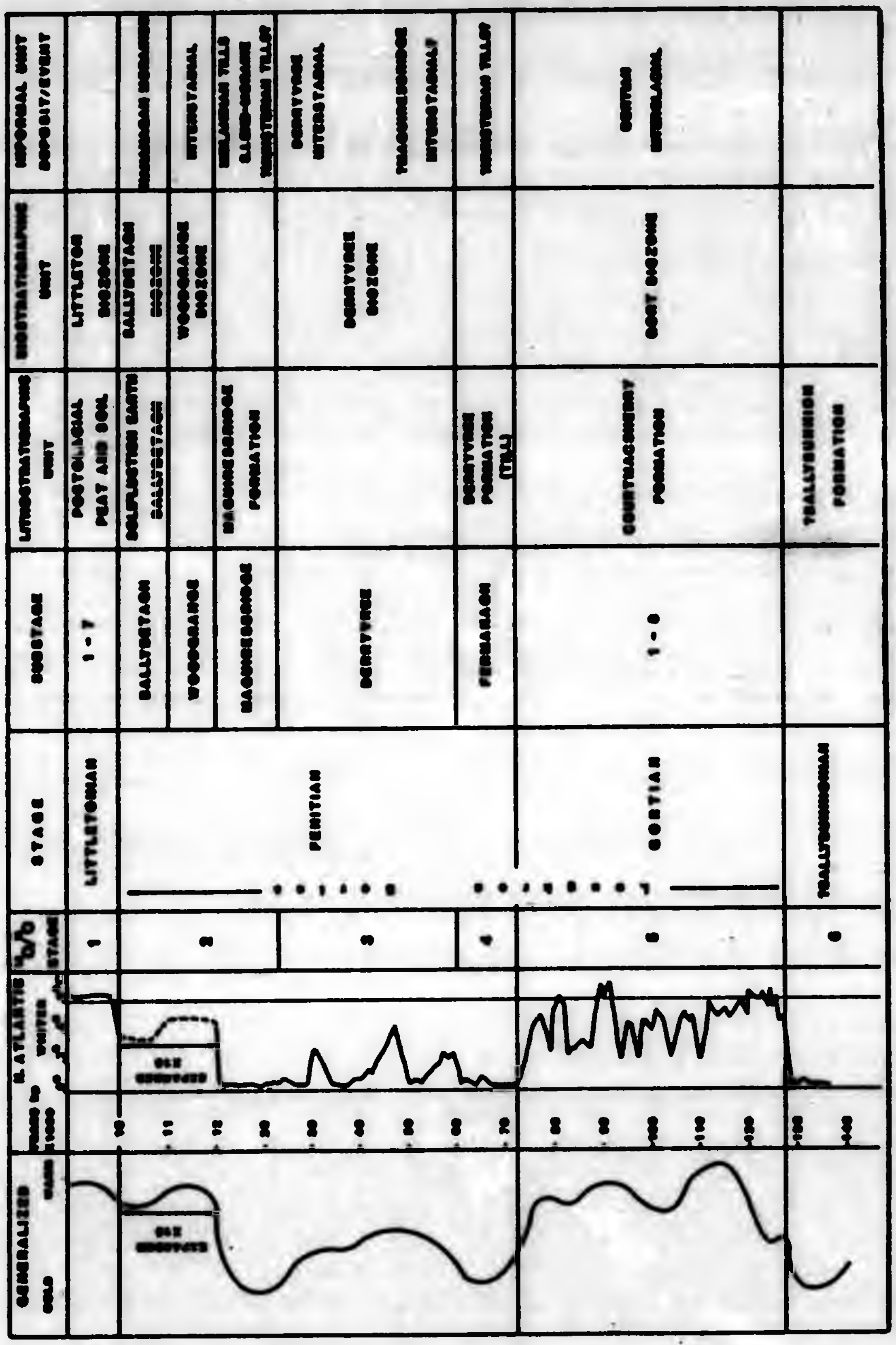


Figure 37 Chronostratigraphy of Quaternary sediments in Ireland (after Warren, 1985).

stage is not possible to determine as no dateable interglacial deposits have been found to overlie the lithostratigraphic deposits which lie to the south of it; nor have any dateable deposits been recorded to underlie any of the deposits in the immediate vicinity of the so-called end moraine or the more recently extended so-called southern limit of glaciation. Therefore as no interglacial stratigraphic marker horizon has been found to intervene between the deposits traditionally associated with the last glacial phase and those beyond their southern limit (Watts, 1985), all of the glacial lithostratigraphic units in County Waterford are regarded as being of last glaciation age by Warren (1985) (Figure 37).

8.4. The Ballyvoyle Member

8.4.1. Introduction

This member is composed of two facies: a diamictic facies and a gravel facies. Stratigraphically the diamictic facies may be further subdivided into an upper and lower subfacies. The stratotype for the main (upper) diamictic facies is located to the west of Ballyvoyle Head in the townland of Knockyoolahan (X 334 950). Here five metres of a sandy, stony diamicton were observed in the summer of 1979 to overlie one metre of calcareous, silty diamicton which contained shell fragments and occasional flint and volcanic erratics. The base of the section was not seen (see description in Chapter Seven). The base of the upper unit is marked by a sandy parting less than 5 mm thick which separates the upper and lower diamictons. The lower diamicton is interpreted as a till of Irish Sea basin provenance (see this chapter and Chapter Six). A modern soil horizon which extends approximately 0.5 m below the surface overlies the main facies of the sandy, stony diamicton. The junction between the two units marks the upper boundary of the sandy, stony diamicton. The Ballyvoyle Member includes all of the diamicton which crops out at the surface in eastern County Waterford.

The main diamictic facies encountered at the surface in the eastern half of the county seems to be replaced by a gravel facies in the western half of the county. This facies crops out in the townland of Ballylemon (X 956 220) as a prograding deltaic sequence of sand and gravel sequence overlain by a sandy stony diamictic unit (one metre thick) of northern provenance. The beds immediately underlying the diamictic unit are reverse faulted to a depth of approximately one metre. The strike faults are oriented approximately east/west and dip to the north at 40^0. The diamictic facies may represent a minor southward readvance of ice in the Ballylemon area. Outcrops of sandy, stony diamicton and glaciofluvial sands and gravels to the north of this locality on both sides of the Comeragh Mountains may be stratigraphically correlated with the diamictic unit at Ballylemon on the basis of their surface outcrop and northern provenance. To the west of the Comeragh Mountains and south of Ballynamult sand and gravel sediments predominate. Further north the sandy, stony diamicton is confined to the valley floors while gravels are located at higher altitudes on the valley sides.

A lower facies of the sandy, stony diamicton crops out as a lower diamictic unit in the coastal section in the townland of Newtown on the west bank of the Waterford Harbour estuary (S 698 074). This lower facies is not recorded at any other site in County Waterford. It is separated from an upper sandy, stony diamicton by a thin diamictic unit composed of sandy matrix-supported angular clast of local origin. The upper sandy, stony diamicton is correlated with the main (middle) facies of the Ballyvoyle Member on the basis of similar surficial stratigraphic position and lithological characteristics. The upper and lower diamictic units are distinguished from each other on the basis of fabrics, petrography of the phenoclasts and stratigraphic position (see Chapter Seven).

8.4.2. Characteristics

With the exception of the lower facies at Newtown, the sandy, stony diamicton crops out for the most part at the surface throughout County Waterford. The diamicton is composed of clasts (approximately 50% or more by weight of bulk samples) supported in a consolidated matrix. The diamicton is associated laterally and stratigraphically with sand and gravel sequences to the east and west of the Comeragh Mountains.

The petrography of the phenoclasts in the sandy, stony diamicton varies according to the single most common clast type: from chert in the extreme north, to sandstone in western County Waterford, shale in the north eastern corner and volcanic in the south eastern part of the county. No diamicton contains limestone as the single most common clast type, although higher frequencies of limestone clasts (up to 36% of the total number of clasts remaining on the 5.6 mm mesh sieve) are found in the northern part of the county which lies immediately south of the main Carboniferous limestone outcrop of the midlands. Variation in the petrography of the phenoclasts in the diamicton is largely controlled by the underlying geology. Carry-over rates vary according to rock type, being least for Carboniferous limestone and greatest for Devonian sandstone. Many of the clasts are glacially faceted and striated. Striations are more easily observed on fine-grained lithologies (e.g. limestone and shale clasts). Faceting is more commonly observed on Devonian sandstone, Lower Palaeozoic acid volcanics and diorites, and Carboniferous limestone clasts.

The composition of the matrix ranges between 40%-70% sand, 30%-50% silt and 0%-25% clay. The least sandy samples tend to contain more clay and, to a lesser extent, more silt. The two samples from the Ballyvoyle Member which contain most clay (samples taken from the upper diamicton at Newtown and the stratotype for the Ballyvoyle Member in the townland of Knockyoolahan) have a higher proportion of their matrix composed of clay sized particles than any of the four samples from the Whiting Bay Member. This provides further support for the conclusion that the provenance of the upper diamicton to the west of Ballyvoyle is quite separate from that of the lower diamicton. As the upper diamicton contains more clay and less silt than any of the samples from the Whiting Bay Member it cannot represent a more 'washed' facies of the underlying diamicton.

Sedimentary and tectonic structures in the diamictic and sand and gravel facies of the Ballyvoyle Member are observed only at a few localities (see Chapter Seven). The vast proportion of the exposures in the diamictic unit reveal a massive, structureless matrix-supported or matrix-to-clast-supported sandy, stony diamicton with a well defined fabric usually aligned north/south. This diamicton is interpreted as lodgement till produced by a southward advance of ice from the midlands.

Structures are apparent towards the base of the upper

Figure 38 Increased stoniness towards base of upper diamictic facies at Newtown.

diamictic unit at Newtown (see Chapter Seven). Occasional thin silty lenses up to 2 m wide and five centimetres thick are seen to be interbedded in a massive structureless diamicton approximately five metres above the base of the unit. Fabric samples taken from approximately the same height above the base of the unit yield modal values of the a-axes aligned north/south and dipping to the south. The lower five metres of the unit appear to contain greater numbers of larger clasts whose bases lie in subparallel planes which dip to the north and whose long axes tend to be aligned north/south (Figure 38).

The thin silty lenses containing secondary organic matter in the diamicton have been interpreted as tectonic in origin: the product of drawing out of silty clasts derived from underlying silts by shearing associated with the movement of ice from north to south (Mitchell, 1976). The silty lenses have also been interpreted as *in situ* sediments formed by washing out of silts on to temporary surfaces in the diamicton associated with post-glacial slumping and resedimentation by solifluction processes of older glacigenic deposits off the 'pre-glacial' rock cliff (Synge, 1977). Synge later concluded that the "(?northwards) carriage of streaks of organic matter" together with the upper diamictic unit in which they were observed were due to deposition by "an early Weichselian ice lobe that moved north into Waterford Harbour under pressure from shelf ice filling the Celtic Sea" (Synge, 1981).

Some elements of these three observations were confirmed. The silty lenses do appear to be aligned north/south as observed by Mitchell (Mitchell, 1976). Parallel laminations within the lenses are not significantly disturbed. The lateral and vertical junctions between the lenses and the surrounding diamicton appear to be gradational.

These characteristics are quite consistent with those of similar features described by Evenson (Evenson *et al.*, 1976). The silty lenses in the stratified diamictic tills from the Catfish Creek Formation exposed on the north shore of Lake Erie, Ontario, were interpreted as syndepositional "flow phenomena". The silt lenses at Newtown were probably formed as syndepositional flow features in pools of water at the base of the ice sheet. The fact that individual lenses and the contained lamination appear to dip slightly (less than five degrees) in a northerly direction may be explained by syndepositional localised shearing possibly along shear planes at a former ice front. This explanation would also accord with that put forward to explain the presence of more steeply northward-dipping lag layers of large clasts at the base of the unit. These winnowed layers are probably associated with washing by meltwater present at the individual interfaces of adjacent and subparallel northward-dipping shear planes within the former ice front. The lower layers of of the upper diamictic unit at Newtown may therefore be interpreted as a basal meltout till of northern origin which grades vertically into a structureless, massive diamicton characteristic of lodgement till of northern and north western origin (Dreimanis and Lundquist, 1984).

The diamicton, which contains locally-derived angular clasts and which separates the upper and lower diamictic units at Newtown, may be regarded as a glacially reworked unit through basal entrainment from a position upglacier and subsequent redeposition downglacier. This thin intervening head unit probably represents a plane of décollement as the fabric in the underlying unit appears to have retained a strong east/west orientation quite at odds with that of the north/south trend in the lower layers of the upper diamictic unit. The entire sequence above the lower head and cryoturbated platform at Newtown is therefore referrable to a single glacial event. The base of the sequence is obscured by slumped material from Raheen Stream to the Cable Post. North of this point the base of the upper diamictic unit is seen to rest on head derived from the frost-shattered surface of the underlying raised shore platform. Unfortunately the entire sequence exposed at Newtown is nowhere observed to overlie directly the raised beach which is in places cemented to the raised shore platform. The probability is that the entire sequence does post-date the formation of the raised beach. The head derived from the cryoturbated and frost-shattered surface of the underlying platform contains rounded erratics in notches at the base of the weathered material similar in size and type (basic volcanic and conglomerate erratics approximately 3 cm in diameter) to those found in the raised beach which is cemented to the platform.

The "crucial" nature of the sequence at Newtown to the "Quaternary stratigraphy of S.E. Ireland" (Synge, 1977) is questionable as the base of the sequence is obscured by slumping (Mitchell, 1962). In this, the only detailed description of the site, no direct contact was observed between the interstadial/late interglacial silty peat horizon and "apparently stratigraphically" underlying raised beach at Newtown (Mitchell, 1962). Silts which were visible at the base of the section further north were correlated with the silty peat horizon and these were recorded as directly underlying the lower diamictic unit. Therefore the entire sequence is regarded as post-dating the formation of the raised beach by inference only. If the lower head is substituted as a local stratigraphic marker horizon throughout County Waterford, then the entire sequence may be correlated with other sites within County Waterford and neighbouring Counties Cork and Wexford.

At the eastern end of Garrarus Strand in the townland of Caher the sequence exposed in the cliff shows a thick sandy, stony upper diamictic unit separated from a lower diamicton by a thin diamictic unit which contains locally-derived angular clasts in a sandy matrix. This unit is probably derived from the stratigraphically underlying head unit, a gelifluced deposit (Warren, 1987a). It is the equivalent of the lower head unit which is recorded as stratigraphically underlying both the diamictic facies of inland and that of Irish sea basin origin [Wright and Muff (1904) and present research]. The fabric in the upper (sandy,stony) and lower (silty, shelly) diamictons is very similar (aligned north east/south west). The section is continued inland as a road cutting at right angles to the coastal exposure. This affords a rare three-dimensional view of the structures apparent at the coast. The intervening head and lower diamicton dip northward below the base of the exposure over a distance of five metres. The exposure is then composed entirely of the upper diamicton. There seems to be a concentration of larger clasts in a slightly winnowed matrix towards the base of the unit. Many of the bases of the clasts seem to lie in planes which appear to dip to the north. The structures are reminiscent of those at the base of the upper diamicton at Newtown. These were interpreted as the product of meltout of till at the interfaces of successively overlying northward-dipping shear planes at the margin or front of an ice sheet of northern, inland origin (Boulton and Paul, 1976). A similar explanation is proposed to explain the structures in the unconsolidated units overlying the lower head unit at Garrarus. The sequence is therefore regarded as the product of a single glacial event in contrast to the multi-phasic interpretation put forward for the succession at the site by Mitchell *et al.* (1973).

8.5. The Knockanaffrin Member

The stratotype at Knockanaffrin (S 270 130) shows 2.5 m massive, sandy and stony diamicton. The petrography of the phenoclasts is dominated by Devonian Old Red Sandstone (95%) with very occasional silicified (1.4%) and volcanic erratics (2.5%). Many of the contained clasts are glacially faceted and striated. The north west/south east alignment of the a-axes of the contained clasts lies parallel to that of the valley. The texture of the matrix falls into the sandy loam group: 56% sand, 32% silt and 12% clay. This non-sorted masive diamicton is interpreted as a lodgement facies deposited by a valley glacier emanating from the striated plateau at the summit of the ridge (see under 7.3.3.1.2. and 7.4.1.). A section in a similar arcuate morainic feature associated with deposition by a valley glacier is exposed in the Coummahon valley on the south-eastern side of the ridge. The erratic content and the arcuate morainic morphology which is located at altitudes (240 m O.D. and 300 m O.D.) below the minimum attained by the ice of northern origin, indicate that the extension of ice from the plateau surface of the Comeragh Mountains down the major valleys probably occurred some time after the advance of ice from the midlands. The Knockanaffrin Member is also regarded as constituent member of the Bannow Formation because of its similar petrogaphy and texture (see next section).

8.6. Broader Correlations

The Ballyvoyle Till is regarded as a constituent member of the Bannow Formation (Synge, 1964; Culleton, 1978) by Warren (1985). The characteristics of the Bannow Till as described by Synge (1964) include:

1. "Heavy texture of the fabric" derived from till of Irish Sea basin provenance deposited by ice flowing south west and till of inland provenance deposited by penecontemporaneous ice flowing south east.
2. Surface of till much affected by frost action.
3. Granite and striated limestone erratics.

The Bannow Formation as defined by Culleton (1978) includes the following characteristics:

1. Deposition by ice from the north west.

2. Members are characterised by stoniness. Stoniness in tills ranges from 14%-63% and is commonly around 40%.

3. Erratics include Leinster granite, volcanics. limestone and sandstone (origin not specified).

4. Frost cracks, vertical stones and involutions are common within the deposits.

5. The petrography of the phenoclasts is dominated by Lower Palaeozoic shales and schists although variation is largely a function of underlying lithologies.

6. The composition of the till matrix falls mostly within the loam category.

The characteristics of the Ballyvoyle Member differ slightly from those of the Bannow Formation. The major difference between the diamictons from the two areas lies in the petrography of the phenoclasts. Clasts composed of Devonian sandstone predominate in the diamictons of western County Waterford and clasts composed of Lower Palaeozoic volcanics predominate in south eastern County Waterford in contrast to the predominance of Lower Palaeozoic shales and slates in the diamictons of County Wexford (Figure 26).

A second difference lies in the marginally lower clay content in the matrix of the diamictic samples from County Waterford (0%-22% as opposed to 9%-34%, commonly around 25% in the diamictic samples from County Wexford). There is a concomitantly higher percentage of sand in the diamictic samples from County Waterford (20%-63%, commonly around 33% in diamictic samples from County Wexford as opposed to 42%-66% in the diamictic samples from County Waterford (Figure 22).

The similarities between the deposits allocated to the Bannow Formation and those allocated to the Ballyvoyle Member are close enough to warrant the inclusion of the Ballyvoyle Member as a constituent member of the Bannow Formation. The contrasts in the properties of the diamictons from the two areas are sufficient to warrant a separate member status for the glacial deposits associated with ice of inland northern origin in County Waterford. Thus the Ballyvoyle Member and the Knockanaffrin Member may be correlated on a lithological basis with the Bannow Formation.

Stratigraphically, the Bannow Formation in County Wexford is regarded as having been deposited contemporaneously with till of Irish Sea basin provenance (Synge, 1964; Culleton, 1978). The Ballyvoyle Member clearly overlies and post-dates the shelly diamicton of Irish Sea basin provenance at Garrarus Strand and west of Ballyvoyle Head in eastern County Waterford. In western County Waterford the deposition of the shelly till by ice from the Irish Sea basin at Whiting Bay, Ardmore and the south side of

Dungarvan Harbour was regarded by Wright and Muff (1904) to have pre-dated that of the overlying rubble of local northern, inland origin. The stony diamicton was considered to have been deposited as a till by the southerly advance of ice from the midlands Wright and Muff, 1904). The stratigraphic relationship between the two deposits in western County Waterford is not as clear cut as in coastal areas to the east. However the weight of evidence tends to support the earlier conclusion by Wright and Muff that the local ice of northern, inland origin did in fact post-date the advance of ice onshore from the basin of the Irish Sea. There is some doubt as to whether the Devonian-dominated rubbly diamicton overlying the shelly diamicton at the coast in western County Waterford is not in fact a marginal coastal facies deposited by ice of Irish Sea basin provenance as suggested by Synge (1981). However there is no evidence to support the observation that this upper facies pre-dated the underlying facies, also suggested by Synge in the same paper (Synge, 1981).

The Ballyvoyle Member post-dates the deposition of the shelly diamicton assigned to the Whiting Bay Member in County Waterford. Therefore the Bannow Formation may be younger along its western margin; alternatively, the underlying shelly diamicton may young to the west of County Waterford. The diachronous nature of the Ballycroneen Formation has already been noted (Synge, 1970; Warren, 1985).

The Ballyvoyle Member may be only broadly correlated with the diamicton of the Garryvoe Formation which crops out in County Cork and whose eastern limit of outcrop has not yet been definitively reported. Both deposits are seen to overlie the Ballycroneen Formation. However given the absence of any reported direct contact between deposits associated with the ice of inland origin and the fact that the Ballycroneen Formation has been demonstrated to be diachronous (Synge, 1977; Warren, 1985) the correlation must remain uncertain.

Correlation of the Ballyvoyle Member with the deposits associated with the Knockakeen Lobe (Mitchell, 1976) must also remain somewhat tentative owing to the relatively undefined nature of the latter deposits. They are briefly characterised as gravels containing volcanic erratics from the Limerick area and granite erratics from the Galway area and which extend to the south as far as Midleton. The glaciofluvial gravel facies which crops out in the Blackwater valley around Lismore contains volcanic erratics (up to 11%) and very occasional rounded granite erratics with pink feldspar phenocrysts (presumably from the Connemara outcrop to the west of Galway). This facies may be associated with meltwater escaping from ice to the north and west. The Blackwater gravel facies may be correlated with the gravels associated with the Knockakeen Lobe on the basis of apparently similar composition and stratigraphic position as surface deposits. As the Blackwater gravel facies is in turn only tentatively assigned to the Ballyvoyle Member, the correlation is extremely tentative.

The shelly, silt-rich, volcanic erratic-bearing diamictons exposed on the south coast of County Waterford have been assigned to the Whiting Bay Member as a constituent member of the Ballycroneen Formation on the basis of similar lithological characteristics and stratigraphic position *vis à vis* the underlying lower head and raised beach units. The calcareous silty diamicton is normally described as clay-rich (Wright and Muff, 1904; Warren, 1985). Particle size analyses of samples from the matrix (less than 2 mm in diameter) of this deposit on the south coast of County Waterford consistently display remarkably low amounts of clay (less than 15%) and relatively high amounts of silt (over 50%). The type of shell fragments and erratics remain similar throughout the exposures in this formation on the south coast (Wright and Muff, 1904). These workers also distinguished between the greenish facies with contorted laminated whose outcrop in Whiting Bay was noted, and the brownish clayey facies with blue-faced joints which crops out in Ballycotton Bay, although they did not comment on relative stratigraphic positions between the two facies. On the evidence from the coastal sections in County Waterford, particularly in Whiting Bay, there is a suggestion that initial deposition of the silty unconsolidated sediments took place as a stratified and laminated deposited in ponded water. The outcrop of the stratified and laminated silty diamictic facies is neither laterally-, nor vertically-continuous, throughout the sequences exposed on the south coast. This phase of deposition was succeeded by direct deposition of lodgement till as indicated by the jointing structure and defined fabric from the south east of the otherwise massive diamicton which overlies the folded, and in places, faulted and stratified diamicton on the eastern side of Whiting Bay. This massive diamictic facies dominates the stratigraphic sequence in terms of bed thickness and lateral continuity in the sections on the south coast of County Waterford. The sequence of sedimentation styles is probably best interpreted as the result of fairly proximal marginal deposition in a sub-to-marginal relatively shallow glaciolacustrine environment (Gustavson *et al.*, 1975), followed by direct subglacial deposition at the base of a grounded icesheet advancing onshore from the south east over the former sediments consistent with the subglacial/proglacial sediment association model proposed by Boulton and Paul (1976).

A geliflucted diamictic unit (head) intervenes stratigraphically between the raised beach unit and the basal laminated silty diamictic unit at the western end of Whiting Bay. This, together with the eroded surface of the geliflucted unit, rule out a straightforward "on-lap facies" associated with a tide water glacier depositional environment as suggested for the glacigenic sediments on the south coast by McCabe (1987). The entrainment of head as compound clasts in folds at the base of the immediately overlying silty diamicton at the eastern side of Whiting Bay is not consistent with "submergence" or deposition by tide water glaciers "in shallow, glaciomarine environments" associated with the glacioisostatic disequilibrium model as proposed by McCabe (1987).

Neither the folding of the underlying bedded facies of the silty diamicton, nor the superior deposition rates implied by the massive silty diamictic facies exposed at Whiting Bay are consistent with the action of expanding shelf ice as suggested by Synge (1981). Synge (1981) proposed expanding shelf ice as as the source of pressure responsible for what he considered to be the result of shearing from south to north in the older glacigenic deposits exposed along the western and eastern shores of the Waterford Harbour estuary. Certainly on the western side of the estuary in the vicinity of the townland of Newtown, the deposits exposed in the cliff towards the base of the upper diamicton have been sheared from the opposite direction i.e. from north to south. A faulted stratified glaciofluvial unit is found to overlie lodgement till on the south side of the up-sheared zone.

A similar sedimentation style, which also included a supraglacial facies association, was described by Thomas and Summers (1982) in deposits associated with ice of Irish Sea basin provenance on the east coast of County Wexford. The sub-glacial and adjacent pro-glacial sequences were interpreted by these authors as the product of a temperate-based ice sheet which had initially advanced south westward from the Irish Sea basin to deposit lodgement till. The ice front subsequently retreated slightly to produce proglacial deposits overlying the lodgement facies. Finally a phase of minor readvance caused the partial overriding of the glaciofluvial sequence and the shearing into position of a wedge of lodgement till. In the Screen Hills area this phase was followed by a transition to cold-based bed conditions and the release of a supraglacial facies. A succession of these lithofacies and structural relationships was interpreted by Thomas and Summers (1982) as being consistent with minor readvance or oscillation at the front of a cold-based ice-margin following a period of sustained advance of a temperate-based ice sheet during which deposition of massive till predominated.

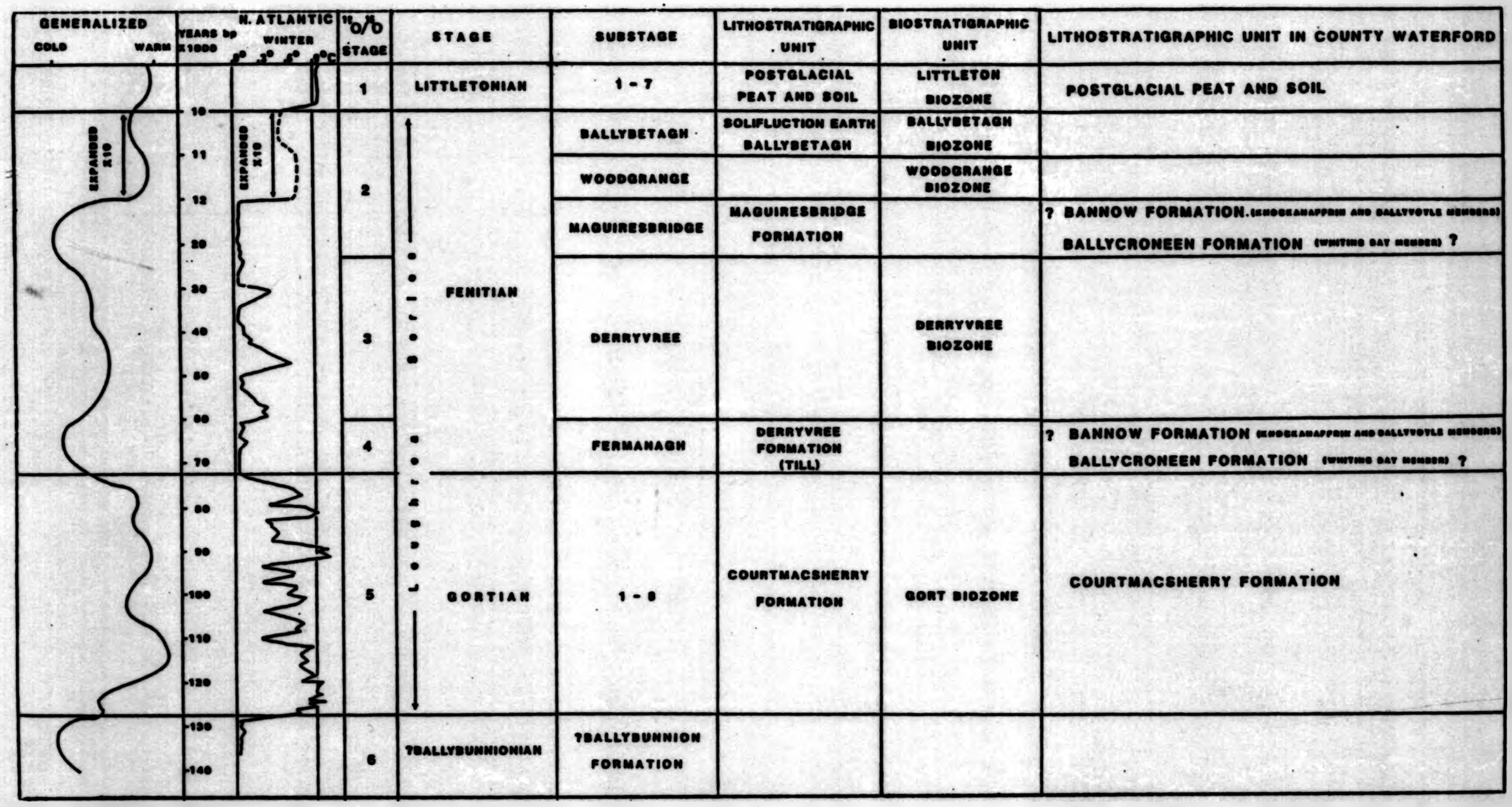


Figure 39 Chronostratigraphic correlation of Quaternary sediments in County Waterford with those of the rest of Ireland.

8.7. Chronostratigraphic Interpretation

This is based on the lithostratigrahic and biostratigraphic correlations already discussed (Figure 39). The units identified within the county are correlated with similar units from neighbouring counties. As no unit within County Waterford may be regarded as stratigraphically underlying the Courtmacsherry Formation all of the overlying sequence has been assigned to the last interglacial (Gortian), glacial/cold (Fenitian) and post-glacial (Littletonian) stages as outlined by Warren (1985) respectively. The stages representing the interglacial and following cold period could therefore be correlated with the Loughrea Series as proposed by Warren (1985) for correlation at the international level. This is in turn correlated with stages 2-5 of the palaeotemperature curves based on oxygen isotope ratios (Emiliani, 1966) and deep sea records of planktonic foraminifera in the North Atlantic some 750 km to the west of Ireland (Sancetta *et al.*, 1973).

8.8. Conclusions

The Gortian Stage

The 3-5 m O.D. raised beach is regarded as a lateral lithostratigraphic correlative of the interglacial Courtmacsherry Formation which is, in turn assigned to the

Gortian Stage (Warren, 1979). The beach gravels do not appear to include any bioclastic element. Their accumulation cannot therefore be assigned to either Arctic or temperate conditions on this basis. The erratics in the beach are not diagnostic of the depositional environment in that they could have been derived from an earlier glacial event. The interpretation that the raised beach was accumulated under interglacial conditions is based on the stratigraphic relationship between the beach and the overlying gelifluected unit. The high sea levels associated with the accumulation of the beach must have stabilised or receded sufficiently for the cessation of beach deposition and the initiation of head accumulation. This transition from marine to terrestrial periglacial conditions is consistent with the onset of glaciation. The accumulation of the beach is therefore considered to have occurred under interglacial conditions prior to the onset of cold conditions. Synge's (1981) suggestion that the raised beach was accumulated under high early glacial sea level conditions is not supported by the stratigraphic superposition of the terrestrially-accumulated gelifluected unit. Given this sequence, McCabe's view (1987) that the beach was accumulated as the initial phase of a continuous on-lap glaciomarine sequence under full glacial conditions is untenable.

It seems reasonable to assume that the most recent evidence of interglacial conditions in the coastal exposures should be correlated with that inland i.e. the Kilbeg interglacial muds (Watts, 1959), as proposed by Warren (1979). As this interglacial deposit has not been dated, and as no younger interglacial deposit has been recorded in County Waterford, the simplest interpretation is to assign it to the last interglacial (Hedburg, 1976). The traditional interpretation as proposed by Mitchell *et al.*, (1973) (see Chapter Two) can only be justified if accepted stratigraphic procedures are ignored.

The Fenitian Stage

The raised beach unit is overlain by a geliflucted facies of local origin, the 'lower head' of Wright and Muff (1904). This unit is assigned to the last cold stage, the Fenitian Stage, by Warren (1985). In County Waterford the terrestrially accumulated unit is separated from the underlying raised beach by a horizontal plane of unconformity. The unconformity is largely caused by the eroded surface of the underlying unit. It is also probably related to marine regression associated with lowering sea levels brought about by the build up of ice sheets and lowering temperatures at the beginning of the most recent cold stage in Ireland. This geliflucted facies and the overlying glacigenic sediments are regarded as having accumulated during the last glacial stage as no biostratigraphic or lithostratigraphic evidence has been found to separate these glacigenic deposits from those

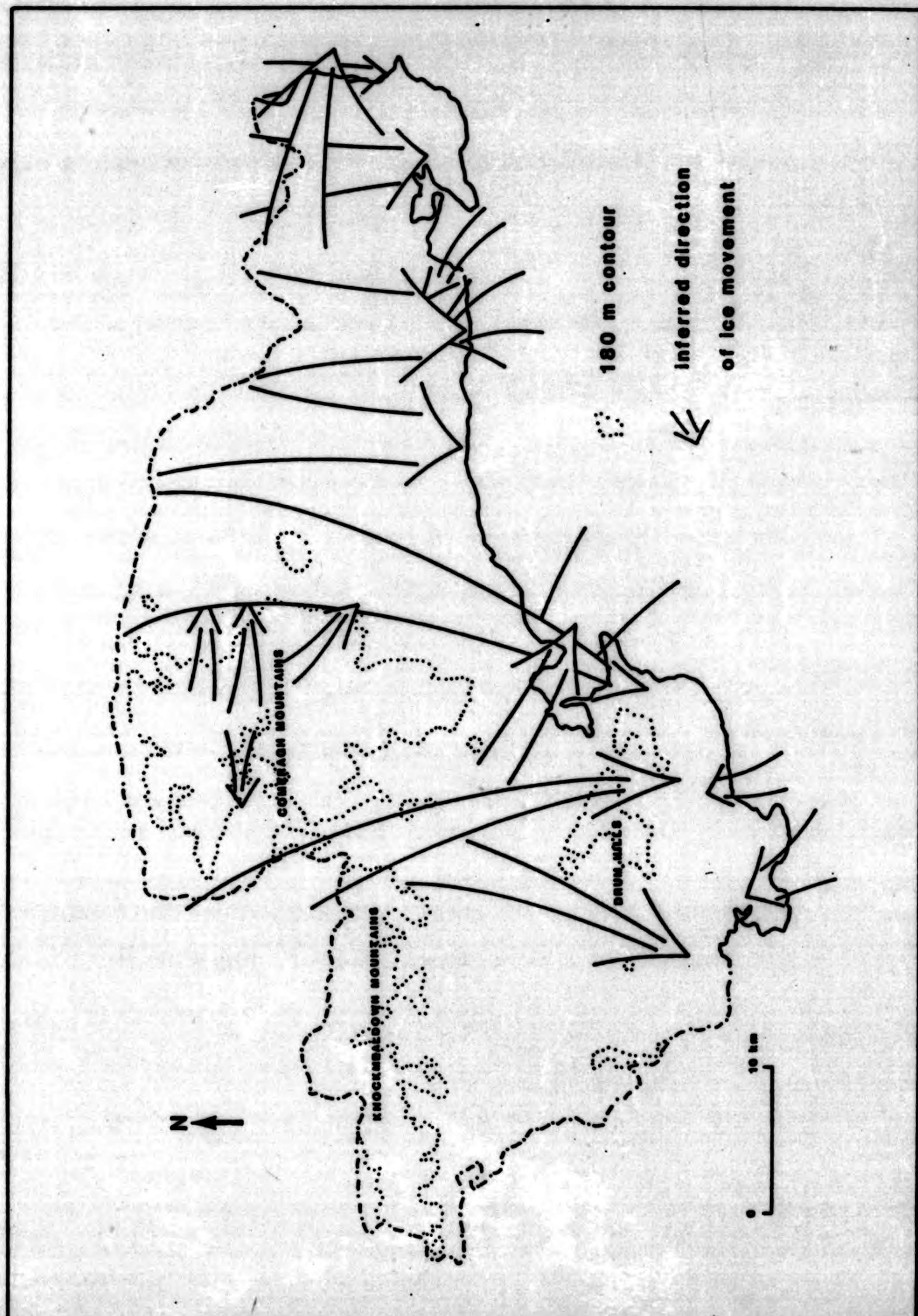


Figure 40 Direction and sequence of ice movements in County Waterford.

further north. The gelifluction facies and the overlying glacigenic sediments are therefore assigned to the Fenitian Stage following the terminology of Warren (1985) and contrary to the the traditional view as proposed by Mitchell *et al.*, (1973).

Sediments of Irish Sea Basin Origin

Ice of Irish Sea basin origin reached the southern coast before the ice of northern origin as witnessed by the stratigraphic position of the silty diamicton which immediately overlies the head unit and underlies the sandy, stony till associated with deposition by the ice of inland origin (Figure 40). The silty, shelly diamicton has been formally named as the Whiting Bay Member and is regarded as a constituent member of the Ballycroneen Formation. This formation has been assigned to the Fenitian Stage by Warren (1985). The fabrics from the silty diamicton in eastern County Waterford, as recorded by Stevens (1959), indicate deposition from a north-easterly direction. This direction was interpreted as being consistent with movement of the ice south-westward across the south-eastern corner of Ireland (Stevens, 1959). However, the fabrics in these basal outcrops may have been reoriented during the superposition of the sandy, stony diamicton which dominates the stratigraphic sequences to the east of Dungarvan. Fabrics and tectonic features in the exposures of silty diamicton, which dominate the stratigraphic sequences exposed at the coast from Dungarvan westward, indicate a north-westward advance of ice from the Irish Sea basin. An advance from this direction is more consistent with expansion of an ice sheet already present off the south coast, rather than a westward advance of the icesheet across the south-eastern corner of Ireland. The laminated and bedded nature of the basal outcrops of the silty diamicton to the west of Dungarvan are indicative of submarginal melt-out till deposited in shallow water conditions. These features were probably associated with an initially cold-based ice sheet which contained englacial material throughout the ice column (Boulton and Paul, 1976).

The overlying bedded sand and gravel unit may be associated with outwash at a retreating ice front or with a change in the nature of englacial source material.

This event was succeeded by an advance of the ice front over the underlying facies and the deposition of a massive lodgement facies of the silty diamicton which dominates the vertical and lateral coastal exposures to the west of Dungarvan. The sedimentation style associated with this facies indicates a change to temperate conditions at the base of a terrestrial-based ice sheet according to the model proposed by Boulton and Paul (1976). The expansion of ice of Irish Sea basin origin seems to have been diachronous as previously suggested by Synge (1981) and

Warren (1985). The western outcrops may represent a younger facies than those further east. The areas of outcrop of sediments associated with ice of Irish Sea basin appear to be controlled by penecontemporaneous southward advance of northern inland origin and by topographic barriers. The two ice sheets appear to have been mutually exclusive (Watts, 1959) in that where sediments associated with ice of Irish Sea basin origin predominate in the stratigraphic sequence, those associated with ice of northern origin occupy a minor part (if present at all) of the exposed sequence in western County Waterford. The reverse is true for eastern County Waterford where glacigenic sediments of northern origin dominate the sections on the south coast. This apparent sensitivity of the ice from the Irish Sea basin to the presence of penecontemporaneous ice of northern origin is consistent with the observation that the areas of outcrop of associated sediments in western County Waterford are also confined to embayment locations.

The overlying rubbly diamicton which crops out at the coast to the west of Dungarvan is largely composed of subangular clasts of local origin. This massive unit may be interpreted as a lodgement till facies deposited by ice of Irish Sea basin origin. Alternatively, it may have been deposited by a later advance of ice of northern origin. This question has not been finally resolved for the

Dungarvan/Drum Hills area (see under sections 8.2. and 8.3.). The problem is akin to that on the east coast in County Dublin where the uppermost stony facies diamictic facies is variously interpreted as being of inland provenance (Synge, 1977) and of Irish Sea basin provenance (Hoare, 1977; McCabe and Hoare, 1978).

Sediments of Northern, Inland Provenance

To the north and east of the Dungarvan area, the sediments associated with ice of northern inland origin, although much more extensive laterally, have merited less attention in the preceding discussions due to the absence of internal sedimentary structures. The diamictons, which are associated with ice of northern origin [including the Mothel Till (Watts, 1959)], are interpreted as a lodgement till facies assigned to the Ballyvoyle Member. This member is regarded as a constituent member of the Bannow Formation which is assigned to the Fenitian Stage (Warren, 1985). These diamictons are almost entirely devoid of internal sedimentary structures. The absence of these features may be partly explained by the sandy nature of the matrix where joint patterns are not readily visible except in occasional circumstances as at Ballylemon. The two other areas where internal sedimentary structures in the sandy, stony diamictic facies were observed are at Newtown and Garrarus Strand (see 8.4.). The sedimentation style at Newtown is indicative of initial deposition by lodgement at the base of a temperate-based ice sheet of north-western provenance. This initial phase is not observed at Garrarus Strand. There is some suggestion that silts of Irish Sea basin origin may have been accumulating at the same time in this locality (see 6.3.). This phase was followed by a restricted (in terms of vertical exposure) basal melt-out sequence and shearing, characteristic of cold-based ice sheets (Boulton and Paul, 1976). Then followed the major depositional phase characterised by a structureless lodgement facies which dominates the diamictic sediments exposed at the surface throughout the county. This sedimentation style is characteristic of a return to temperate conditions at the base of the icesheet of northern origin. It was also accompanied by probable submarginal prograding sand and gravel sequences on both sides of the Comeragh Mountains and by an isolated esker system at Callaghane Bridge in eastern County Waterford.

Evidence of deglaciation appears to be largely restricted to isolated marginal terraced kame deposits of gravels to the west and north of the Comeragh Mountains. The withdrawal of ice from eastern County Waterford is not marked by any depositional supraglacial or proglacial facies. Neither is the withdrawal of ice of Irish sea basin origin recorded in any sedimentary sequence. The absence of these facies is probably associated with the absence of source materials on the surface of the respective ice sheets in these areas. Instead, material falling onto the surface of the icesheets seems to have been directed into marginal and submarginal sand and gravel accumulations. This process is witnessed by the prograding sand and gravel sequences exposed at Knockanacullin and Ballylemon (associated with ice of northern origin) and the stony lenses recorded in the silty diamicton (associated with ice of Irish Sea basin origin) at Ballyquin on the south coast.

Sediments in the Comeragh Valleys

The diamictons, which have been assigned to the Knockanacullin Member as a constituent member of the Bannow Formation, have been interpreted as lodgement till facies deposited by valley glaciers in the Nier and Coummahon Valleys. These valley glaciers were, in turn, associated with an ice cap which had accumulated on the Comeragh Mountains and which appears to have expanded to its maximum extent some time after the maximum expansion of ice from the midlands (see sections 7.2. and 7.4.).

It would appear that a similar transition from cold to temperate basal conditions operated at the fronts of the two major mutually opposing ice sheets which affected County Waterford although in each case only a single oscillation is recorded. The similarity of the structural and lithofacies relationships at Newtown and Whiting Bay may be a function of similar climatic conditions and broad penecontemporaneity between the ice of inland northern origin and that of Irish Sea basin provenance.

8.9. Summary of Conclusions

Five lithostratigraphic units are recognised in County Waterford. The sequence includes in ascending order:

1) A parahorizontally-bedded clast-supported gravel unit which normally rests on the raised shore platform and is sometimes overlain by blown sands.
2) A clast-to-matrix supported diamicton which contains angular rock fragments in a sandy matrix.
3) Massive and bedded diamictic units which contain glacially-abraded clasts and far-travelled erratics of northern and eastern provenance.
4) Bedded glaciofluvial sands and gravels. This and the preceding unit are cryoturbated to a depth of 1.5 m in places.
5) A shallow postglacial soil horizon.

These units are interpreted as an interglacial raised beach deposit, overlain by a gelifluctеd deposit associated with onset of cold conditions, followed by a glacigenic sequence which was subsequently subjected to periglacial conditions only in the upper 1.5 m , and a return to warm conditions.

Two major lithostratigraphic units are recognised within the glacigenic sequence. The first unit is composed of a laminated facies overlain by a massive facies of silty diamicton (Whiting Bay Member, Ballycroneen Formation). The balance of evidence suggests that these two facies are a meltout and lodgement till facies of Irish Sea basin provenance (see section 8.3.). The second major lithostratigraphic unit overlies massive silty diamicton in eastern County Waterford. This unit is a sandy, stony massive diamicton (Ballyvoyle Member, Bannow Formation), best interpreted as a lodgement till facies associated with southerly movement of ice from the Midlands (see section 8.4.).

These interpretations lead to the conclusion that an onshore movement of ice was followed by one from the north, and that both of these ice movements succeeded the accumulation of the raised beach on the south coast. While this conclusion is in agreement with the findings of Wright and Muff (1904) it disagrees with those of Synge (1977 and 1981) and McCabe (1987).

The *in situ* nature of the glacigenic sequence which overlies the raised beach in County Waterford invalidates Synge's (1977) hypothesis that the glacigenic sequence predated the deposition of the raised beach and was subsequently soliflucted downslope.

In addition, the inland provenance of the Ballyvoyle Member (see 8.4.) invalidates Synge's (1981) suggestion that this member represented a coastal facies of Irish Sea basin origin.

The presence of the hiatus between the marine conditions associated with the deposition of the raised beach and the terrestrial conditions associated with the accumulation of the overlying gelifluced unit (see 8.8.) refutes McCabe's (1987) suggestion that an on-lapping glaciomarine sequence rests on the raised shore platform on the south coast.

Furthermore, no evidence of marine conditions was observed within the glacigenic sequence which overlies the raised beach on the south coast. The absence of these marine conditions refutes McCabe's (1987) interpretation of the glacigenic depositional sequence on the south coast

A radiating ice cap extended down the valleys of the Comeragh Mountains as evidenced by the existence of a sandy, stony diamicton in the valleys. This constitutes a third and minor glacigenic lithostratigraphic unit (Knockanaffrin Member, Bannow Formation) in County Waterford. The maximum extension of this advance appears to have postdated that of the lowland ice sheet (see

8.8.).

As no biostratigraphic interglacial deposits younger than those which underlie the glacigenic sequence at Kilbeg have been recognised in County Waterford (Watts, 1985), the entire interglacial and overlying *in situ* glacigenic sequence is assigned to the most recent interglacial and glacial respectively.

8.10. Assessment of Methodology

Limitations arise out of the stratigraphic approach adopted throughout the thesis due to the possibility of homotaxis between sediments which have accumulated or which have been transported over similar tracks at different times. This is especially true of the interglacial organic horizon at Kilbeg (see Warren, 1979). The problem of correlation is aggravated by the absence of an isochronous marker horizon in areas away from the coast, by the diachronous nature of the Ballycroneen Formation, and by the lack of dated and datable organic horizons (Warren, 1985). Because of these methodological limitations it is not possible to establish whether, or not, the massive diamictic facies of the Whiting Bay Member youngs to the west. The silty diamicton at the base of the coastal expsoures in eastern County Waterford undoubtedly predates the overlying Ballyvoyle Member;

whereas in western County Waterford the two major lithostratigraphic glacigenic units may have been deposited penecontemporaneously.

8.11. Pointers for Future Research

Ways in which the present research could be extended include:

1. The status of the only stratigraphically significant interglacial organic material which underlies a diamictic facies of the Ballyvoyle Member at Kilbeg needs to be conclusively established. The dating of shell fragments in the silty diamicton of the Whiting Bay Member and the use of amino acid techniques can only yield a maximum age for the deposition of the host deposits as the shell fragments are not in primary growth positions.
2. A detailed sedimentological study of the Ballycroneen Formation in neighbouring County Cork may throw further light on facies changes within the unit, the variability of associated depositional environments, the tectonic history and the direction and degree of younging throughout the unit.
3. Further mapping is required in the extreme western end of the county to establish the precise origin of the glaciofluvial gravels in the Blackwater valley and to examine the stratigraphic relationship between these and

the eastern limits of the Garryvoe Formation in eastern County Cork.

4. A petrological study of the volcanic erratics in the unconsolidated sediments of County Waterford could lead to a more precise identification of the provenance of these erratics particularly in the Suir valley (Collins, 1981) and in the glaciofluvial gravels in the Balckwater valley. This could, in turn, throw some light on the degree to which ice of Irish sea origin advanced inland. The approach might also be aided by a very detailed sampling of the unconsolidated sediments for heavy mineral analysis.

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APPENDIX 1. SITE OBSERVATIONS IN COUNTY WATERFORD (WRIGHT AND MUFF, 1904)

Youghal

On the Waterford side of Youghal, (on the east bank of the Blackwater) near Ardsallagh House, 0.8 km N.N.E. of Youghal Bridge, "the local stony boulder-clay rests on rock, which is striated from N. 50^0 W. to S. 50^0 E." (Wright and Muff, 1904, p.293).

Whiting Bay

A marked contrast was noted in the compositon of the cliffs between the western and eastern ends of the bay: The succession at the western end showed:

Angular red sandstone head	Up to 12 m thick resting either on:
Coarse bedded gravel	Up to 1 m thick (derived from fines in head and resting in hollows of the)
	or:
Water-worn rock platform	

"At one place a little blown sand was seen below the head." (The first indication of the possible presence of the raised beach). "A short distance west of the road down to the shore, marly boulder-clay overlies the head, which gradually thins out eastwards until the marl comes to rest on the beach-gravel. Finally, the base of the marl passes below the level of the modern beach-shingle." At the eastern end of the bay, the following section is reported:

Stony boulder-clay	4.6 m (thick)
Marly boulder-clay	6.1 m (thick)

"The stony boulder-clay is slightly reddish in colour, and contains sub-angular boulders of yellow grit, red sandstone, and vein-quartz. Its junction-line with the marl is an uneven one, and the upper clay was probably deposited by the inland ice coming from the north." The marly boulder-clay is described as being "of the usual type". Wright and Muff's own words, at once succinct and comprehensive are quoted at length:

> "The marly boulder-clay is a greenish or bluish-grey clay, which effervesces freely with acid. Some parts, particularly those of a greenish tinge, exhibit on a surface exposed to the weather, a fine lamination which is frequently contorted. This is well seen in Whiting Bay, east of Youghal. Other parts are compact and sometimes well-jointed... The marl weathers at the top to a brownish clay, with blue-faced joints. It contains fragments and numerous smaller particles of the shell of marine mollusca, including several

northern and Arctic species... The marl also contains subangular and rounded stones, some of which are striated. They are scattered sparingly throughout it, but are occasionally seen to be more abundant in its upper portion. In this connection it may be noted that a striated surface has not yet been found beneath the marl along the south coast. The stones are of various sizes; and in addition to local rocks, include a number of distant origin, amongst which chalk-flints are the most abundant. A series of fine-grained porphyritic rocks, which seem to include quartz-porphyry, felsite, andesite, porphyrite, and dolerite, form the largest class of igneous rock. Some are identical with - and others closely approach - specimens of the igneous rocks associated with the Silurian sediments of Waterford, Wexford and Wicklow. Some gneisses and altered basic igneous rocks (epidiorites) are similar to rocks cropping out on the shore between Greenore Point and Carnsore, County Wexford. A white granite, with dark quartzes and drusy cavities, is exactly like the Mourne Mountain granite; and one or two basic rocks correspond with some occurring on Slieve Foy, County Louth." (Wright and Muff, 1904; pp 266-267).

The following were listed as erratic "boulders from the marly boulder-clay" at Whiting Bay:

Flint	Probably from Antrim or the bed of Irish Sea.
Bored limestone	Bed of the sea.
Felsite(?)	Similar to 'felsites' from County Waterford.

Ardmore

Immediately east of the village, head was observed resting on the rock platform.

Dungarvan

"On the southern side of Dungarvan Harbour, the raised-beach platform can be seen emerging from beneath thick drift deposits, consisting largely of marl and sand." Then, as now, the cliffs were alluded to as being "much overgrown and obscured by slipping, and are, in consequence, difficult to decipher." Two sections are described, the first of which occurs 228 m west of Ringville Stream:

Gravel	2.4 m
Marly boulder-clay	1.2 m
Head	3.7 m
Rock-platform	

The second section lies 274 m further west:

Reddish boulder-clay (with much O.R.S.)	3-4.5 m
Fine silt	0.9-1.2 m
Fine loamy sand	1.5-3 m
Bluish marly boulder-clay	3 m
Head	3.6-4.5+ m
Rock platform probably near.	

The "reddish boulder-clay" was seen to have a relatively clayey matrix and to contain an erratic pebble of porphyry, perhaps suggesting that the upper boulder-clay had inherited some characteristics from the lower "marly boulder-clay". A flint erratic was also obtained from the top of the underlying silts. The springs which emerge from the underlying sands and give rise to much of the slumping were remarked upon. The bottom 1.2 m of the head was reported to have a white clay matrix, to occur in patches throughout the head and to be visible beneath the shingle of the modern beach.

A little to the east an exposure of "the stratified series, showing alternating silts and sands very free from stones" and some 4.5-6 m thick was noted. The bedding was seen to be contorted and current bedding in the sands was "obvious".

A ledge of limestone, "a few feet above high-water mark", was observed on the north side of Dungarvan Harbour and was regarded as a possible remnant of the 'pre-glacial' shore-platform, although no accompanying beach or head deposits were present.

Ballyvoyle Head

The description of the two sections at this locality has already been alluded to in section 2.1.1. The raised beach was not found to the east of Ballyvoyle Head on the Waterford coast due to imputed coastal erosion since the 'Glacial Period' of the rocks of Silurian age which outcrop to the east of Ballyvoyle Head.

APPENDIX 2. STRIAE IN COUNTY WATERFORD

1	37/4	Tinnabinna	310	W+M	90	under local till
2	37/2	Tiknock	345	GSI	60	
3	34/4	Coolbagh	0 and 30	GSI	15	
4	31/4	Scartore	20	W+M	6	under local till
5	24/2	Carrigcastle	8	W+M	75	rock outrop
6	26/3	Islandikane West	345, 350	W+M	60	ice-moulded ORS
7	26/1	Ballyscanlan	358	W+M	90	*idem.*
8	26/1	Carrickavantry South	355	W+M	90	*idem.*
9	17/2	Carrigavoe	348	W+M	50	on vein quartz
10	9/4	Grange Upper	350	W+M	60	
11	6/4	Curraghduff	330	GVD	600	
12	4/4	Mountbolton	330	GVD	30	on ORS
13	38/4	Ballyeelinan	N/S	IMQ	6	under diamicton
14	22/3	Knockgarraun	N/S	IMQ	30	ice-moulded ORS
15	22/2	Bohadoon	325	IMQ	90	*idem.*
16	22/2	Knockacaharna	10 and 17	IMQ	180	*idem.*
17	13/2	Caherbrack	345	IMQ	120	*idem.*
18	13/2	Caherbrack	4 and 7	IMQ	120	*idem.*
19	13/3	Doon	345	IMQ	160	*idem.*
20	13/4	Caherbrack	360	IMQ	120	*idem.*
21	16/1	Ardeenloun East	30	IMQ	75	moulded tuffs
22	16/1	Ardeenloun East	20	IMQ	100	*idem.*
23	16/1	Ballygarraun	353	IMQ	100	*idem.*
24	16/1	Ballygarraun	3	IMQ	95	*idem.*
25	16/2	Carrickadustara	26	IMQ	75	vein quartz
26	26/1	Ballynaclogh South	355	IMQ	75	on tuffs
27	17/3	Sporthouse	0 and 41	IMQ	90	*idem.*
28	26/1	Cullencastle	7	IMQ	50	Diorite
29	14/2	Comeraghmountain	165	IMQ	600	on ORS
30	14/2	Comeraghmountain	145	IMQ	640	*idem.*
31	14/2	Comeraghmountain	135	IMQ	620	*idem.*
32	14/2	Comeraghmountain	92	IMQ	600	*idem.*
33	14/2	Coummahon	180	IMQ	500	*idem.*
34	14/2	Coummahon	150	IMQ	420	*idem.*
35	36/2	Ballynagaul More	160	IMQ	60	*idem.*
36	36/2	Ballynagaul More	180, 190	IMQ	80	*idem.*
37	36/2	Helvick	140	IMQ	65	*idem.*
38	36/4	Killinoorin	160	IMQ	55	*idem.*
39	30/3	Keereen Lower	33, 68, 172	IMQ	60	*idem.*
			135, 74, 28 and 58			
40	6/2	Graigavalla	93 and 96	IMQ	180	*idem.*
41	35/4	Toor North	352	IMQ	300	*idem.*
42	2/4	Kilbrack	275	IMQ	190	

/1 = NW, /2 = NE, /3 = SW, /4 = SE;
W+M = Wright and Muff (1904); GSI = Geological Survey 1" maps; GVD = Du Noyer (1865); IMQ = author.

APPENDIX 3. ERRATICS FROM RAISED BEACH AT YOUGHAL (WRIGHT AND MUFF, 1904)

Youghal Bay	
Grey flint	
Felsite	Probably from Silurian area of County Waterford and County Wexford.
Quartz Porphyry	A rock very like this occurs on road east of Ballyvoyle Bridge and in the Boat Harbour Cove, Stradbally, County Waterford.
Andesite	Or basalt, with small porphyritic felspars (similar to that which is seen at the extreme south-east of Ballydowane Bay, County Waterford.
Epidiorite	Two specimens (probably from schists of County Wexford) and gneiss (similar to foliated granite, south of St. Helen's, County Wexford).

APPENDIX 4. SITE OBSERVATIONS IN EASTERN COUNTY WATERFORD (REED, 1907 - FURTHER DETAILS).

Reed (1907)

This author had five separate short papers published during 1907 in the Geological Magazine. Two of these notes concerned the cirques of the Comeragh Mountains while the remainder dealt with the unconsolidated glacial sediments in three coastal areas in east County Waterford.

Comeragh Mountain Cirques

The subject under discussion in the two notes which deal with the cirques is very much restricted to the actual cirque characteristics. Following Close (1866) and Carvill Lewis (1894) in turn, Reed agreed that the cirques whose bases lie between 380 m and 457 m O.D. probably lay above the maximum altitudinal limit of the lowland glaciation, 305 m O.D. Only at Coumgorra, at the head of the Nier valley, was any possibility of mountain ice descending into the lowland envisaged. No contact between the mountain and lowland ice was considered as it was assumed, following Hull (1878), that the local ice-cap with its attendant cirques, formed subsequently to the advance of lowland ice.

Fornaght Strand

The first of the three coastal sections described is at Fornaght Strand. This embayment lies between Knockavelish Head and Creadan Head and is underlain by a Lower Palaeozoic inlier with faulted boundaries against the relatively resistant Devonian rocks of the enclosing headlands. It is backed by the 'pre-glacial' cliff and platform which lie 3-4.5 m above the modern shore platform and some 180 m from the present shoreline. The 12 m high section is located at the northern end of the strand. Here the deposits, which rest against the Devonian conglomerates of Knockavelish Head, are described as dipping away from the valley side toward the south or south-south -east at an average dip of 15^0, in which direction, they are also found to thin out rapidly. The varied sequence is described as follows:

8.	Soil with cockle shells	0.1-0.3 m thick
7.	Head and boulder clay	1-1.5 m thick
6.	Head (angular fragments)	1-1.2 m thick
5.	Boulder clay	0.3-6 m thick
4.	Stratified subangular stones	0-4.5 m thick
3.	Angular fine head	0-1 m thick
2.	Sand layer	1-1.2 m thick
1.	Stony, sandy layer	1.2 m thick

Working from the bottom up, and within the stratigraphic framework of Wright and Muff (1904), beds 1. and 2. were interpreted as the equivalent of their raised beach gravel and sand units (see above). Bed 3. was thought to correspond with the lower head, though this and the overlying bed 4. were considered to show more water-sorting than would be consistent with a periglacial climate. An alternative glacial origin was suggested; they were therefore tentatively assigned as "stratified early glacial gravels, although the thickening of these beds towards the valley-side and the development of 'ferricrete' at their base, together with the inclusion of large, tumbled masses from the old cliff at the base, are points in common with the 'Lower Head'. Beds 5. and 6. were regarded as corresponding with the till and upper head respectively.

As in the case of Wright and Muff (1904), Reed also thought in terms of "Post-Tertiary land movements" in order to explain the presence of the raised beach, wave-cut platform and the 'submerged forests'. With reference to this latter feature Reed's own words are worth quoting:

> "A late downward movement of the coastline is indicated by the submerged forest of Fornaght Strand, which does not appear to have been previously noted, though Hardman (1873) referred to the one near Tramore as a 'partially submerged or silt-covered bog' and Kinahan mentioned various submerged bogs (including the latter one) on the south-east coast of

Ireland." (Reed, 1907).

The edge of the peaty soil associated with the Fornaght submerged forest was reported to appear some 9-12 m (horizontal distance) from the HWM and thirty tree stumps were counted. Wisely, no stratigraphic interpretation of the submerged forest was attempted given its relative spatial isolation from the recorded sequence as described above.

Woodstown to Passage East

The first section described in any detail in this short paper is located at Newtown Head (composed of relatively resistant 'greenstone') and is 6-7.6 m high. The accompanying sketch and description illustrate the following sequence:

Surface soil	
Rubble	0.4-1.2 m thick
Boulder clay	3.6 m thick
Sand	5-30 cm thick
Head	1.8 m thick
Rock platform	

The subsoil "frequently contains a layer of cockle-shells". The underlying rubble layer is composed of angular fragments of local origin in a scanty sandy and clayey matrix and contains occasional lenses of pure sand. It is interpreted as the representative of the upper head somewhat "washed and redeposited by running water". Below this comes the boulder clay which "wedges out rapidly against the upward sloping surface of the underlying beds. There seems to be a greater number of included boulders in its upper part [though none are of large size], as if the clayey matrix had been to some extent washed out and carried away." The boulder clay rests on a layer of sand which dips "seaward at an angle of 20^0, roughly parallel to the eroded surface of the solid rock on which the whole series of drift deposits rests.... It must be regarded as marking a local episode of a sandy shore before the deposition of the Boulder-clay.... The true Lower Head of Newtown Head occurs immediately beneath this layer of sand" and rests on the rock platform.

Newtown Head to Raheen Stream

Heading northward from Newtown Head to Raheen stream a composite summary of the descriptions of the sections observed by Reed (1907) shows the following sequence:

Sandy clay or marl	0.3-0.5 m thick
Boulder-clay	Up to 6 m thick
Bedded sand/shingle	0.6 m (in places)
(contains rolled beach pebbles)	
Small angular fragments (local)	0.3-0.5
Rock-platform	1 m above HWM

The absence of the 'true Lower Head' is noted and attributed to the possibility that distance of the present locality from the pre-glacial cliff would have precluded sufficient lateral extension seaward of the head.

Raheen Stream to Passage East

From Raheen stream to Passage East, further north, the succession, as described by Reed (1907), becomes somewhat more complicated. Unfortunately, no accompanying sketch is included for this long coastal section and the textual notes appear, at one point, confused and self-contradictory. A series of varying successions is reported (working from south to north). The first section occurs approximately 200 m north of the point where Raheen stream reaches the shore:

3.	Boulder-clay ('usual type')	(thickness unspecified)
2.	Lower Head (local, coarse, angular)	0.6-1 m thick
1.	Slate rock-platform	

From the succeeding quotation the next section, somewhat confusingly described, would appear to occur another 200 m (approximately) to the north:

"About half-way between the gap at Raheen Bridge and the gully of Carey's Stream we find a true beach deposit on the platform in the shape of well-rounded pebbles cemented together in a little coarse sand. The Boulder-clay reposing directly on these deposits is of a reddish colour and marly character, and contains few stones; it averages 2-3 feet (0.6-1 m) in thickness, but generally it passes up into the normal type of Boulder-clay except from the spot where this beach deposit occurs. At this point the reddish clay is succeeded by a sharply marked off band of greyish clay 1 1/2-2 feet (0.4-0.6 m) thick, characterised by containing numerous angular fragments of black or greenish slate, mostly small, but scarcely any fragments of Old Red Sandstone. Northwards this slaty deposit assumes a definitely bedded character with a sandy or marly matrix, at the same time increasing in thickness till about half-way between Raheen and the Cable Station it is quite 5 feet (1.5 m) thick,..." (Reed, 1907).

The source of the confusion arises at this point. As the Cable Station is located at "the gully of Carey's Stream" and as 'Raheen' is taken to be synonymous with "the gap at Raheen Bridge", the half-way point between these two sets of points must be the same. Yet, it is obvious that the author intended to indicate a second and different locality, some distance northward of the half-way point between the original coordinates cited. As is illustrated in the text, my own observations would suggest that the author may have intended to refer to the point half-way between the *original half-way point between Raheen and Carey's stream* and *Carey's stream*, which would be located some 200 m to the north of the original half-way point.

Assuming that the situation is as suggested above, the third section described is located approximately 600 m north of Raheen stream and shows the following sequence:

Boulder-clay	(thickness unspecified)
Bedded angular fragments	1.5 m thick
Boulder-clay	0.3-0.6 m thick
Discontinuous 'ferricrete'	5-7.5 cm thick
Platform	

The bedded slaty deposit is reported to thin out before reaching the Cable Station, 200 m further north, and "the Boulder-clay forms the whole cliff" which is 9-12 m in height. "Thin bands of reddish or ochreous clay 2-4 inches (5-10 cm) thick can here and there be distinguished near the base of the cliffs in the Boulder-clay, but only persist a few yards. The rubble-drift on top of the cliffs is usually thin, but rests on a somewhat irregular surface of Boulder-clay." The cliff decreases in height to 1.8-2.4 m in a northerly direction "owing to the reduction in thickness of the Boulder-clay", which appears to rest directly on the platform. Approximately 90 m to the north of Crooke, the cliffs begin to rise in height again. The "Boulder-clay, capped by about 2 feet (0.6 m) of rubble drift and subsoil, is remarkable for the large number of huge boulders imbedded in it. Many of these are non-local rocks (granites, quartzites, etc.), and these are more or less rounded and reach a size of as much as 2 1/2-4 feet (0.7-1.2 m) in length. The masses of Old Red Sandstone breccia are angular and even larger in size... examples of the Ordovician rocks, igneous and sedimentary, of Co. Waterford itself (i.e. the country to the west) are remarkably rare... The derivation of this varied assortment of non-local rocks from the area to the north (Wexford, Kilkenny, Wicklow, etc.) cannot be doubted, and the Boulder-clay which contains them must be regarded as the deposit of the inland ice and not from the west or the Irish Sea." (Reed, 1907).

About 450 m south of Passage East, a bedded deposit composed of angular fragments of the shale platform is recorded as appearing and thickening northward underneath the boulder-clay. The fifth and final section from this area is described:

Subsoil and soil	0.3-0.5 m thick
False-bedded gravel	1.6-1.8 m thick
Boulder-clay	1.8 m thick
Shale rubble	3.6-4.5 m thick

Coarse angular head	1.2-1.5 m thick
Platform in places	below HWM

The 'Lower Head' deposit becomes increasingly coarse and dominated by the presence of Old Red breccia as the hill (of which it is composed) to the south of Passage East is approached.

In summary, this short paper presents the first, and infrequently-referred to, detailed description of what was to become a much-visited and key section in the stratigraphic interpretation of the glacial sediments of southern Ireland. Unfortunately, Reed's discussion of the detailed observations was minimal. Interpretation of the sequences was heavily influenced by Wright and Muff's earlier publication (Wright and Muff, 1904). The origin of the lower till at Newtown was not alluded to and no attempt was made to correlate it with any of the other previously identified stratigraphic units.

Tramore Bay to Dunmore East

Reed's third short paper dealing with coastal features in County Waterford covers the coastal strip south and west of Dunmore East as far as Tramore Bay (Reed, 1907). He observed that the sandstone cliffs were interupted at intervals by valleys which were filled with 'Boulder-clay and other drift materials', which fact, in his view, testified to the pre-glacial excavation of the valleys.

Summerville House

Two sections were described in some detail; the first of these occurs in the cliffs immediately below and to the south of Summerville House on the east side of Tramore Bay:

Thin soil	
Wind-blown sand	0.3-0.6 m thick
Whitish marl	10-20 cm thick
Usual boulder-clay	1.8 m thick

When traced in a southerly direction, the cliff increases in height to 6 m where the lower portion of the cliff is composed of wind-blown, false-bedded sand; this is reported to be overlain by 0.6-1 m of yellow boulder-clay and 0.3 m 'drift sand' in turn. Further south, the lower sands disappear from the sequence and are replaced by 'a dark greyish clay', 1.2-2.4 m thick. It was seen to be composed of small angular fragments of black slate and to rest directly (in some places) on the Old Red Sandstone platform at between 1-3 m above HWM. In other places it was described as resting on a coarse local head which in turn rested on the raised rock-platform.

When traced in a northerly direction, the the pre-glacial cliff was found to curve westward and to survive only at intervals. The 'Lower Head' was recorded as being occasionally well-exposed in association with underlying raised beach deposits of local origin.

Rathmoylan Cove

The second section referred to above is located at the head of the cove on the south coast between Tramore Bay and Dunmore East. This section was regarded as interesting because of "the clear development and the nature of the Upper Head at the mouth of a small pre-Glacial valley. This valley runs down to Rathmoylan Cove, and is more or less filled with drift deposits. Rock bed is below the modern beach." (Reed, 1907):

Soil and subsoil	
Sandy shingle	0.4-0.6 m thick
Upper Head	0.3 m thick
Boulder-clay	1.8 m thick
Lower Head	1-1.2 m thick

Reed's findings, although quite detailed, for the most part merely acted to corroborate the earlier conclusions drawn by Wright and Muff (1904). Apart from the observations themselves, Reed's work failed to offer any new, significant insight into the understanding of the glacial stratigraphy of County Waterford.

APPENDIX 5. RESULTS OF HEAVY MINERAL ANALYSES (STEVENS, 1959)

	Fethard till	Newtown till	Ballyvoyle till	Eastern General till	Nemestown bed
No. samples:	(9)	(1)	(6)	(4)	(1)
Garnet	M	M		M	
Tourmaline	C	C		C	M
Zircon	S	S		M	
Andalusite	C	M		M	M
Staurolite	M	S		M	
Hornblende	M	M	M	M	M
Chloritic matter	C	C	C	C	C

S = only one grain present

M = several grains present

C = relatively common mineral

APPENDIX 6. COMPOSITION OF PETROGRAPHIC SAMPLES

Petrographic sample number, 6" O.S. map and grid reference.			Townland	% Limestone, chert, sandstone, volcanic and shale clasts.				
				L	C	S	V	S
1	7/4	S410125	Glenaphuca	32.0	3.6	17.5	7.0	39.7
2	7/3	S362101	Knockaturnory	0.0	1.4	89.2	0.0	9.3
3	21/3	X040997	Ballyin Lower	0.0	24.2	63.3	11.4	1.1
4	31/1	X241946	Ballinamuck Mid.	0.0	10.9	83.5	4.1	1.5
5	31/2	X283966	Monarud	0.0	1.6	94.1	2.3	2.0
6	31/1	X259946	Ringaphuca	0.0	30.1	66.2	3.4	0.3
7	31/1	X277955	Knocknasalla	0.0	29.5	64.3	6.2	0.0
8	30/2	X216955	Ballylemon Lr. (L)	0.0	3.5	95.3	1.2	0.0
9	30/1	X178976	Knockgarraun	0.0	15.2	81.0	2.2	1.4
10	7/1	S352136	Ross	0.0	10.6	34.0	0.3	54.9
11	36/1	X288887	Mweelahorna (U)	24.7	8.4	53.9	13.0	0.0
12	22/2	S198088	Tinalira	0.0	15.4	75.1	7.1	2.4
13	21/3	X039992	Ballyin Lower	0.0	40.3	52.1	6.3	1.3
14	7/2	S408150	Whitestown West	9.8	11.7	33.3	8.4	37.6
15	31/4	X290940	Scart	0.0	7.3	81.2	8.4	2.7
16	6/3	S270130	Knockanaffrin	0.0	1.4	95.1	2.5	1.1
17	7/2	S395145	Clonea	10.5	12.3	38.8	1.2	37.1
18	7/1	S365139	Munsburrow	0.0	14.0	23.2	2.9	59.8
19	16/1	S453085	Ballyshonock	0.0	1.2	16.1	11.5	71.0
20	16/2	S496099	Ballyduff West	11.8	7.4	38.6	9.7	32.5
21	16/3	S432057	Whitestown	0.0	0.4	17.2	30.0	52.3
22	16/3	S437053	Georgestown	0.0	0.0	10.5	41.6	47.8
23	17/1	S547084	Orchardstown	21.0	4.9	42.7	10.3	21.0
24	16/4	S490067	Johnstown	0.4	5.2	28.9	55.4	9.9
25	17/3	S553057	Slieveroe	0.0	1.4	14.2	81.2	3.2
26	38/4	X212804	Ballyquin	15.5	10.3	20.7	46.6	6.8
27	17/3	S542049	Reisk	0.0	3.0	19.9	42.5	34.6
28	16/2	S526076	Powersknock	0.0	1.6	14.6	71.3	12.4
29	16/2	S523072	Loughdeheen	3.9	4.5	26.2	63.4	1.9
30	26/1	X537988	Islandikane	0.0	0.8	9.3	78.3	11.4
31	26/2	S580010	Tramore	0.0	0.0	2.4	87.9	9.6
32	5/4	S228133	Shanballyanne (L)	0.0	0.0	100.0	0.0	0.0
33	5/1	S158165	Bawnfune	0.2	4.3	93.2	1.1	1.1
34	1/3	S155145	Russellstown	29.2	21.0	43.6	0.0	6.1
35	5/2	S210150	Knockalisheen	0.0	1.2	98.5	0.5	0.0
36	5/1	S161166	Bawnfune	0.0	0.0	99.2	0.8	0.0
37	5/4	S196106	Curraghteskin	0.0	68.7	31.0	0.0	0.2
38	5/1	S180146	Clonanav	0.0	10.1	88.3	0.4	1.2
39	1/3	S152173	Russellstown	0.0	45.8	53.5	0.7	0.0
40	1/3	S167192	Russellstown	0.0	5.5	94.4	0.0	0.0
41	14/4	S317047	Knockanacullin (L)	0.0	3.0	75.9	3.5	17.5
42	14/4	S317047	Knockanacullin (M)	0.0	1.9	83.0	1.2	14.0
43	14/4	S317047	Knockanacullin (U)	0.0	1.4	84.9	2.0	11.8
44	23/2	S319037	Gortnalaght (L)	0.0	3.2	72.9	1.1	22.8

45	1/2	S187202	Kilmacomma (L)	1.8	48.2	33.9	8.9	7.1
46	14/2	S317083	Coummahon	0.0	0.0	97.1	2.7	0.2
47	23/2	S319037	Gortnalaght (U)	0.0	0.7	41.1	44.9	13.3
48	36/1	X288887	Mweelahorna (L)	3.8	3.8	61.5	23.0	7.7
49	31/3	X277936	Skehacrine	0.0	6.5	73.4	17.9	2.1
50	1/2	S187202	Kilmacomma (U)	0.6	26.8	68.5	0.6	3.5
51	31/4	X309924	Ballynacourty (U)	0.0	18.5	77.0	1.5	3.0
52	31/4	X313937	Tallacoolmore (L)	0.0	13.5	78.3	7.3	1.0
53	31/4	X320943	Clonea Lower	0.0	0.3	45.8	40.2	13.7
54	31/4	X313937	Tallacoolmore (U)	0.2	0.0	97.6	1.9	0.2
55	31/4	X309924	Ballynacourty (L)	0.0	9.7	81.9	8.1	0.3
56	24/4	X406980	Ballydowane East	0.0	0.6	9.2	89.9	0.9
57	32/2	X384975	Ballyvoony	0.0	0.2	1.4	99.8	0.0
58	27/3	X628984	Coolum	0.0	0.6	28.0	49.9	21.8
59	27/3	X645987	Coolum	0.0	0.0	24.9	66.2	8.9
60	27/4	X674990	Portally	0.0	0.2	52.2	47.1	0.4
61	27/3	X655988	Ballymacaw	0.0	0.2	60.7	39.1	0.0
62	26/4	X623996	Lisselty	0.0	0.0	10.6	49.9	35.5
63	27/4	S692008	Nymphall	0.0	0.7	31.6	44.6	23.1
64	27/2	S703038	Knockavelish	0.7	5.7	18.3	52.5	22.8
65	25/4	X523980	Kilfarrasy	1.1	3.4	9.9	83.8	1.7
66	27/1	S634012	Kimacleague East	0.5	2.0	18.4	73.2	5.9
67	25/4	X482990	Benvoy	0.0	0.0	2.5	97.1	0.4
68	25/3	X477984	Dunabrattin	0.0	1.9	14.1	62.8	21.3
69	27/3	S627005	Summerville	0.0	1.3	20.7	64.3	13.7
70	5/4	S228133	Shanballyanne (U)	0.0	8.1	90.7	0.5	0.7
71	40/3	X136766	Monatray East	47.6	9.5	15.8	23.8	3.1
72	38/4	X194788	Ballyquin (U)	0.0	4.3	69.2	26.2	0.2
73	38/4	X194788	Ballyquin (L)	0.9	6.8	86.3	5.2	0.7
74	40/1	X170765	Ardoginna	8.2	2.4	65.9	23.5	0.0
75	40/1	X186764	Ardoginna	0.0	1.4	73.5	21.5	3.7
76	38/4	X224805	Ballyeelinan	1.2	3.1	89.5	6.2	0.0
77	38/4	X235805	Crobally Lower (U)	0.0	0.6	84.1	15.1	0.2
78	38/4	X235805	Crobally Lower (M)	2.6	1.8	49.1	43.9	2.6
79	39/3	X240808	Crobally Lower	0.0	1.7	87.2	11.1	0.0
80	40/1	X163774	Cappagh (U)	1.5	1.8	80.1	15.4	1.2
81	39/2	X288834	Ballynamona Lower	0.0	0.0	87.2	7.9	4.9
82	36/4	X287855	Rathmeneenagh	0.0	1.4	70.7	14.4	13.5
83	39/3	X263810	Ballynaharda	0.0	2.9	95.5	1.5	0.0
84	39/1	X277828	Monagoush	0.0	1.5	96.8	1.5	0.3
85	39/3	X254808	Ballykilmurry	0.0	2.3	94.0	3.8	0.0
86	35/1	X182886	Toor North	0.0	15.2	74.0	10.0	0.9
87	21/3	X045992	Ballyin Lower	0.0	23.9	73.4	2.7	0.0
88	40/1	X147777	Ballysallagh	13.1	8.1	55.6	23.2	0.0
89	2/1	S267222	Gurteen Upper	82.5	6.1	10.7	0.0	0.2
90	38/4	X212804	Ballyquin (lens)	0.5	0.9	67.5	29.9	0.5
91	5/1	S180138	Kilcreggane	16.3	34.7	47.6	1.2	0.2
92	26/3	X547984	Caher (U)	3.0	3.2	6.9	86.2	0.7
93	18/2	S703081	Newtown (M)	1.4	0.2	36.7	58.7	3.0
94	30/2	X216955	Ballylemon Lr. (T)	0.0	1.0	95.2	3.8	0.0
95	31/2	X326946	Clonea Middle (M)	0.0	2.7	34.7	61.4	1.2
96	18/2	S703081	Newtown (U)	0.0	4.3	40.7	55.0	0.0
97	30/2	X216955	Ballylemon Lr. (U)	0.0	7.3	91.5	1.2	0.0
98	26/3	X547984	Caher (L)	0.0	1.5	0.5	98.0	0.0
99	26/3	X544985	Islandikane E. (U)	0.2	2.1	4.1	88.6	5.0

100	18/2	S702077	Newtown (B)	0.0	0.4	24.2	19.6	52.8
101	21/3	X062988	Ballyea West	4.7	30.7	62.0	2.6	0.0
102	22/1	S158024	Lyrattin	0.0	0.0	100.0	0.0	0.0
103	13/3	S169063	Corradoon	0.0	2.2	95.6	2.2	0.0
104	7/1	S354160	Ballythomas	0.0	3.0	19.6	12.5	64.9

U = Upper part of exposed facies or uppermost facies present.
M = Middle part of exposed facies of middle facies.
L = Lower part of facies or lowest facies present.
T = Uppermost facies where more than one facies is sampled.
B = Basal facies where more than one facies is present.

APPENDIX 7. FABRIC AND IMBRICATION SAMPLES

Fabric sample number, 6" O.S. map and grid reference.			Townland	Orientation of modal class degrees	Vector direction and strength degrees	%
1	31/4	X312939	Tallacoolmore (U)	270	277	33
2	31/4	X308923	Ballynacourty (L)	280	292	8
3	31/4	X301922	Ballynacourty (L)	40	29	9
4	31/3	X277936	Skehacrine	260	261	67
5	31/4	X319945	Clonea Lower	340	337	11
6	31/2	X332950	Knockyoolahan W. (U)	30	19	31
7	31/2	X331950	Knockyoolahan W. (L)	120	128	59
8	40/1	X147775	Ballysallagh	340	351	36
9	38/4	X210803	Ballyquin (L)	350	346	42
10	38/4	X210803	Ballyquin (U)	350	323	9
11	31/2	X333950	Knockyoolahan W. (M)	230	204	18
12	31/3	X326950	Clonea Middle	280	270	22
13	18/2	S701080	Newtown (M)	300	327	21
14	18/2	S700078	Newtown (B)	100	111	18
15	18/4	S700070	Raheen	270	247	2
16	18/4	S700060	Dromina	335	332	18
17	27/2	S702039	Knockavelish	140	137	49
18	18/2	S705091	Crooke (L)	105	81	34
19	18/2	S705091	Crooke (U)	260	260	45
20	18/2	S706085	Crooke (U)	120	121	51
21	18/2	S705084	Crooke (L)	140	121	40
22	18/2	S704080	Crooke (L)	170	158	6
23	18/2	S702080	Crooke (M)	110	123	46
24	39/3	X253810	Ballykilmurry	295	333	7
25	25/4	X526981	Kilfarrasy	30	17	41
26	26/3	X545985	Caher (L)	30	35	18
27	26/3	X546985	Caher (U)	270	270	61
28	26/3	X545985	Caher (M)	230	228	42
29	26/3	X547985	Caher (B)	220	230	50
30	26/3	X541985	Islandikane East	170	150	29
31	24/4	X397977	Killelton	180	182	40
32	24/4	X410979	Ballydowane	210	202	15
33	25/4	X459988	Benvoy	195	192	52
34	25/3	X474984	Dunabrattin	230	242	33
35	25/4	X481988	Benvoy	170	172	38
36	24/4	X332975	Ballyvoony	205	197	29
37	26/2	S530009	Tramore West	180	172	59
38	27/1	S632081	Kilmacleague East	45	33	39
39	27/3	S629006	Summerville	310	320	48
40	26/4	X622995	Brownstown	355	337	10
41	27/3	X656988	Ballymacaw	210	200	24
42	27/3	X646990	Coolum	360	12	62
43	27/4	S693009	Nymphall	180	159	9
44	27/4	X673989	Portally	350	330	41

45	27/3	X668984	Rathmoylan	180	176	68
46	27/3	X629984	Coolum	190	192	45
47	36/4	X285857	Rathnameenagh	200	187	34
48	83/1	S195227	Raheen	175	178	51
49	39/2	X290838	Ballycurreen South	290	298	47
50	39/1	X278819	Monagoush	10	357	54
51	39/3	X262809	Ballynaharda	30	25	26
52	39/3	X238805	Crobally Lower	210	223	31
53	38/4	X234804	Crobally Lower (U)	180	166	24
54	38/4	X224803	Ballyeelinan	320	314	44
55	38/4	X193785	Crushea	140	161	6
56	40/3	X137766	Monatray East	140	134	31
57	40/1	X160795	Ardoginna	330	345	31
58	40/1	X185764	Ardoginna	340	326	19
59	14/2	S317083	Coummahon	200	184	7
60	83/1	S198225	Clonmel	190	177	54
61	83/1	S198225	Clonmel	10	8	43
62	15/2	S412098	Newtown	310	298	9
63	35/1	X182886	Toor North	190	195	31
64	30/2	X216955	Ballylemon Lr. (T)	0	3	72
65	5/1	S103138	Kilcreggane	210	187	40
66	22/2	S198088	Tinnalira	200	208	36
67	13/3	S169063	Corradoon	40	10	18
68	31/2	X298972	Garranbaun	280	283	25
69	31/1	X241946	Ballynamuck Middle	160	156	23
70	31/4	X290940	Scart	300	313	18
71	6/3	S270130	Knockanaffrin	110	103	53
72	36/3	X248848	Barranastook	35	30	29
73	23/2	S319097	Gortnalaght	230	211	26
74	23/2	S301026	Boolatin	280	289	11
75	16/1	S453085	Ballyshonock	20	5	48
76	5/4	S228133	Shanballyanne (U)	170	157	3

Imbrication
sample no.

1	2/2	S267222	Gurteen Upper	140	134	82
2	30/2	X216955	Ballylemon Lr. (U)	325	344	38
3	31/1	X277955	Knocknasalla	360	355	64
4	30/1	X178976	Knockgarraun	5	6	55
5	14/4	S317047	Knockanacullin (L)	30	37	81
6	14/4	S317047	Knockanacullin (M)	170	169	68
7	14/4	S317047	Knockanacullin (U)	300	305	52
8	21/3	X038992	Ballyin Lower	60	56	69
9	21/3	X042990	Ballyin Lower	250	244	34
10	21/3	X043995	Ballyin Lower	350	355	69
11	21/3	X062985	Ballyea West	245	254	30
12	21/3	X062985	Ballyea West	190	204	17
13	31/1	X259946	Ringaphuca	340	350	62
14	31/2	X283966	Monarud	50	65	16
15	7/1	S352136	Ross	355	358	86
16	36/1	X244904	Bawncarrigaun	20	355	40
17	1/3	S155177	Russellstown	60	58	29
18	83/1	S198225	Clonmel	40	19	19
19	30/3	X180935	Canty	160	180	74

APPENDIX 8. RESULTS OF PARTICLE SIZE ANALYSES

Sample number	% of particles (diameters mm) less than: .002	.0045	.009	.017	.035	.065	.15	.3	.6	1.18	2	5.5	14	20	37.5
1	11	19	24	28	35	42	47	53	59	66	72	79	87	97	100
2	2	4	6	7	9	13	18	25	33	42	53	68	81	87	100
3	8	12	23	36	42	49	55	62	67	72	77	85	91	97	100
4	0	0	9	19	34	52	55	58	62	66	72	80	86	92	100
5	10	17	22	27	31	37	43	47	52	56	62	68	77	88	100
6	11	21	39	54	66	73	78	86	88	93	95	96	97	100	100
7	0	7	18	30	53	70	87	94	96	97	98	99	99	100	100
8	8	13	31	42	53	68	77	85	88	92	96	98	99	100	100
9	3	4	5	6	7	8	9	10	16	24	34	52	68	86	100
10	0	0	0	0	0	3	5	7	13	24	35	48	67	83	100
11	2	4	7	9	17	28	36	44	51	68	74	83	87	96	100
12	0	0	0	0	0	0	5	12	20	25	32	45	64	83	100
13	5	9	13	16	22	28	33	41	50	63	76	89	98	100	100
14	5	8	10	14	17	22	27	33	38	44	48	55	64	84	100
15	1	2	2	3	3	4	5	6	7	8	13	23	37	54	100
16	2	3	4	5	6	7	8	13	19	31	43	58	71	81	100
17	8	13	19	29	44	63	67	72	75	81	86	90	95	97	100
18	0	4	7	9	17	31	42	49	55	60	67	76	87	95	100
19	6	8	13	16	19	26	29	36	43	48	57	67	79	88	100
20	8	9	13	18	26	34	38	43	47	52	56	66	77	88	100

APPENDIX 9. PERCENTAGE OF CLAY, SILT AND SAND IN PARTICLE SIZE SAMPLES

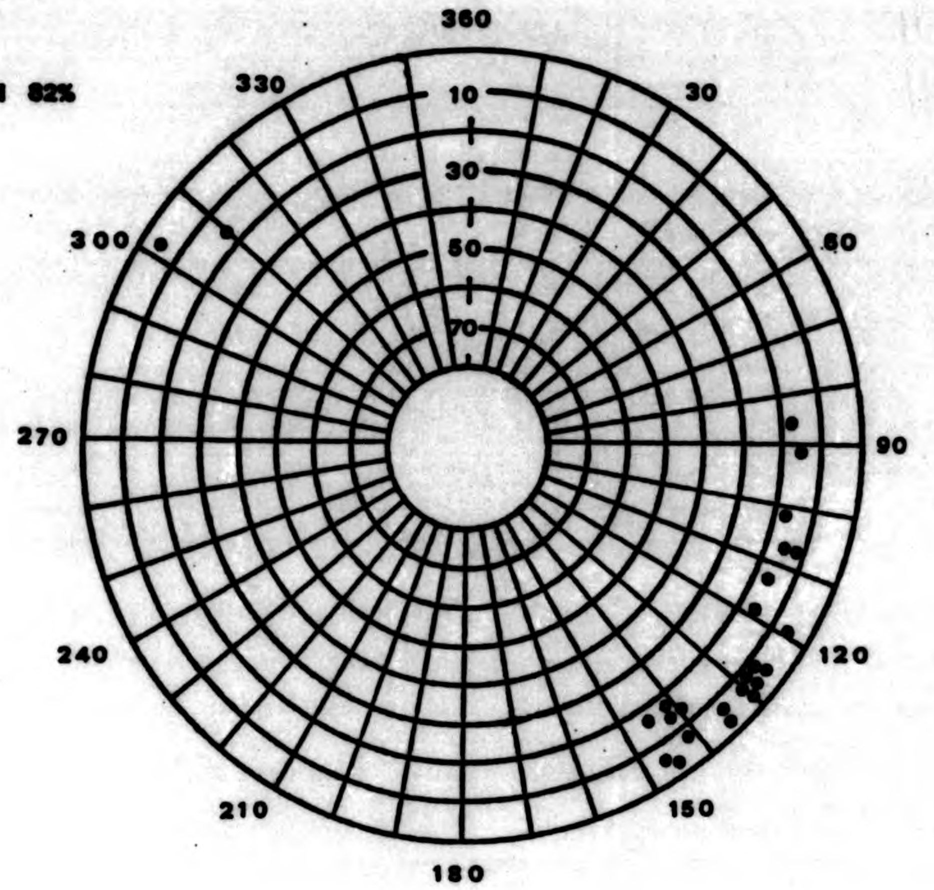
Sample number, grid reference and 6" O.S. map			Townland	% Clay	% Silt	% Sand
1	S703081	18/2	Newtown	19	33	47
2	S703081	18/2	Newtown (B)	4	16	80
3	X547984	26/3	Caher	13	45	42
4	X547984	26/3	Caher (B)	0	58	42
5	X326946	31/2	Clonea Middle	21	34	45
6	X288887	39/1	Mweelahorna	12	60	18
7	X212804	38/4	Ballyquin	0	64	36
8	X147777	40/1	Ballysallagh	10	53	37
9	X212804	38/4	Ballyquin (lens)	13	9	78
10	X062985	21/3	Ballyea West	0	9	91
11	X216955	30/2	Ballylemon Lower (T)	3	31	66
12	X216955	30/2	Ballylemon Lower (U)	0	0	100
13	S140138	5/1	Kilcreggane	8	26	66
14	S169063	13/3	Corradoon	13	26	61
15	X298972	31/2	Garranbaun	8	16	75
16	S267222	2/2	Gurteen Upper	8	8	85
17	X290940	31/4	Scart	11	52	38
18	S158024	22/1	Lyrattin	0	41	59
19	S270130	6/3	Knockanaffrin	12	31	57
20	S354160	7/1	Ballythomas	14	41	45

APPENDIX 10. POLAR AND ROSE DIAGRAMS BASED ON DATA FROM IMBRICATION ANALYSES

IMBRICATION SAMPLE NUMBER 1

VECTOR DIRECTION 134

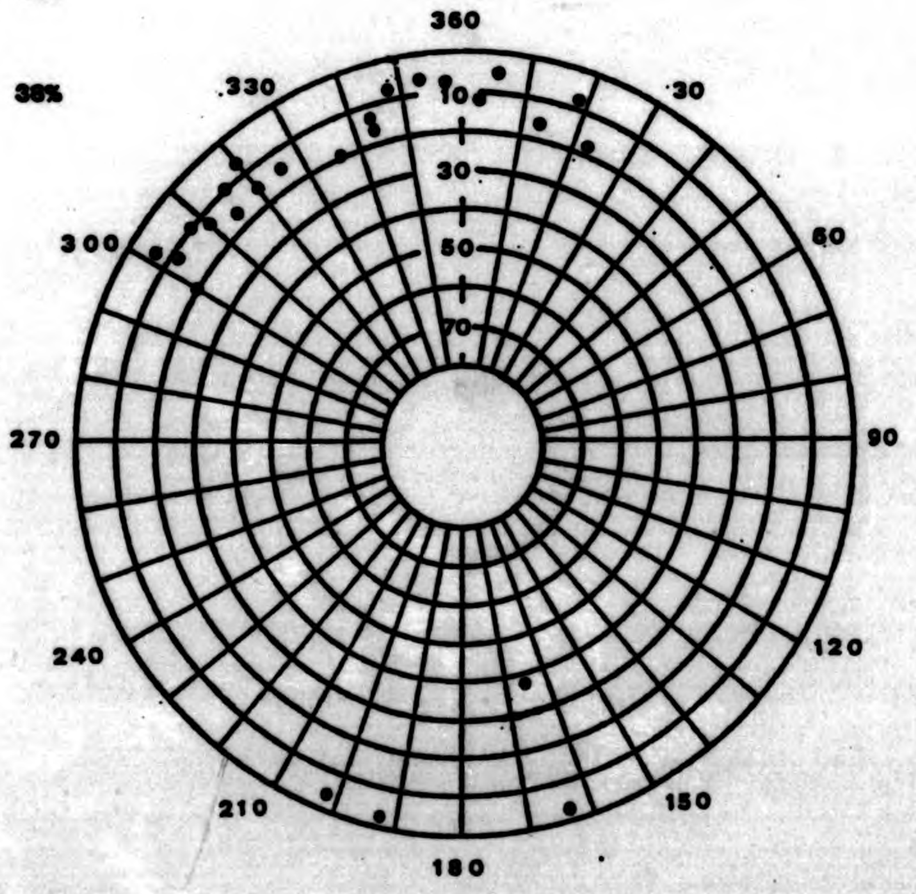
VECTOR STRENGTH 82%



2

344

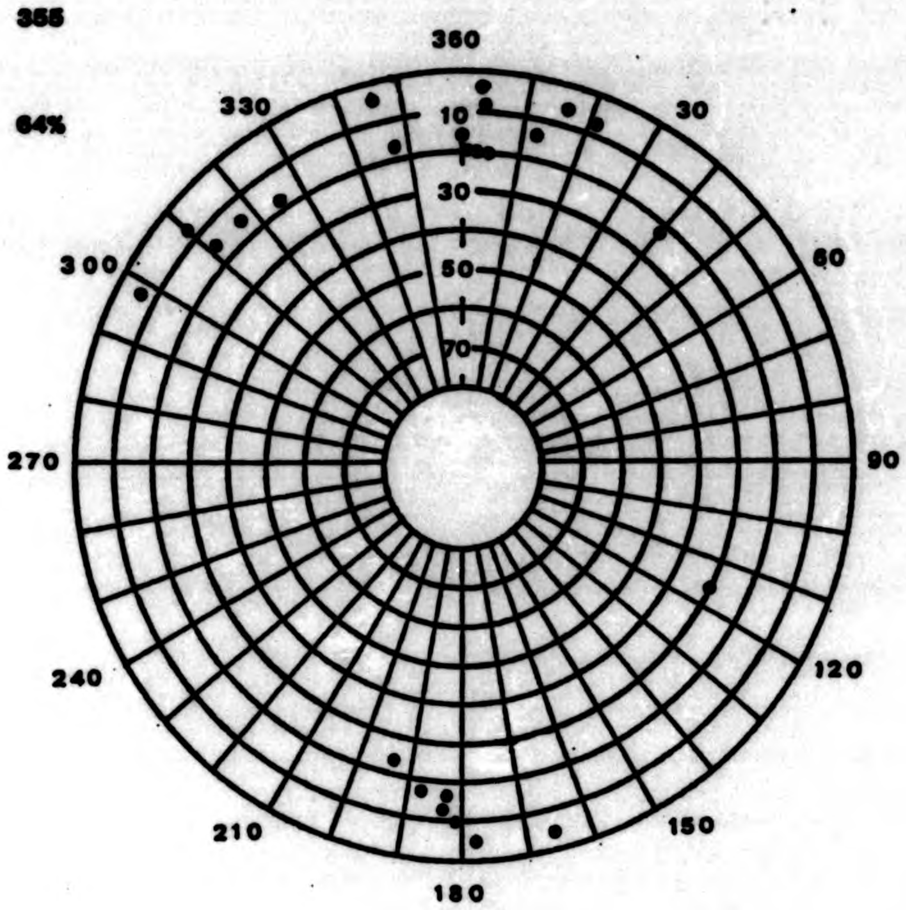
38%



3

355

64%



360
330
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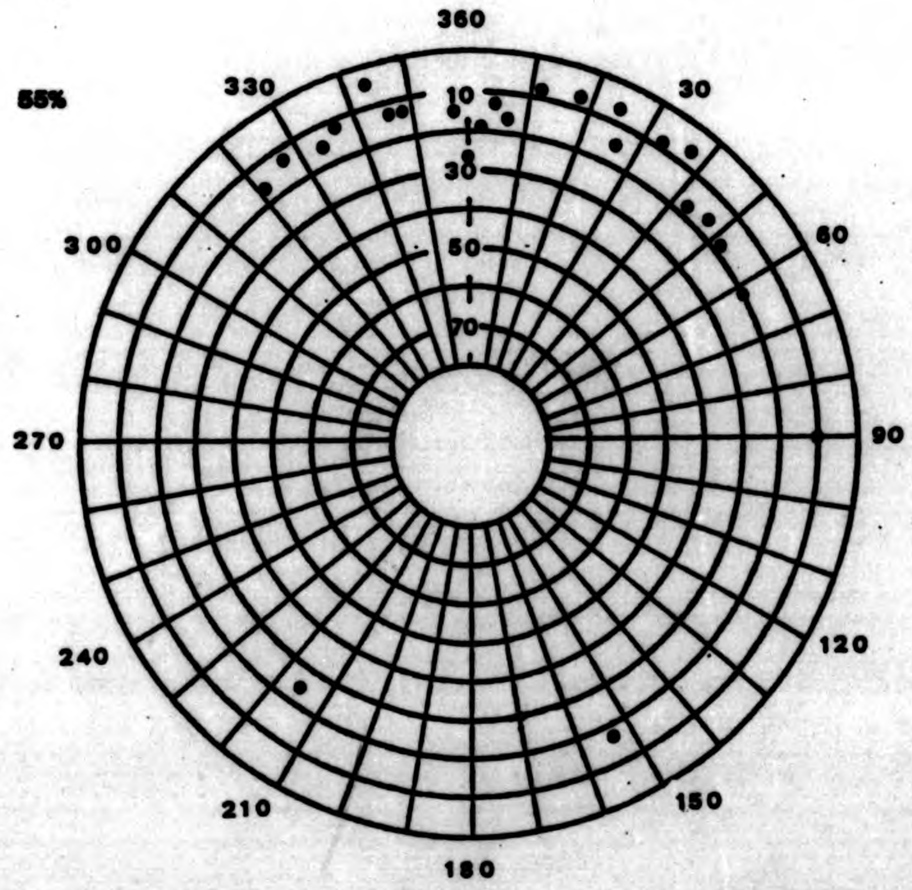
60
270
90
240
120
210
150
180

4

6

55%



360
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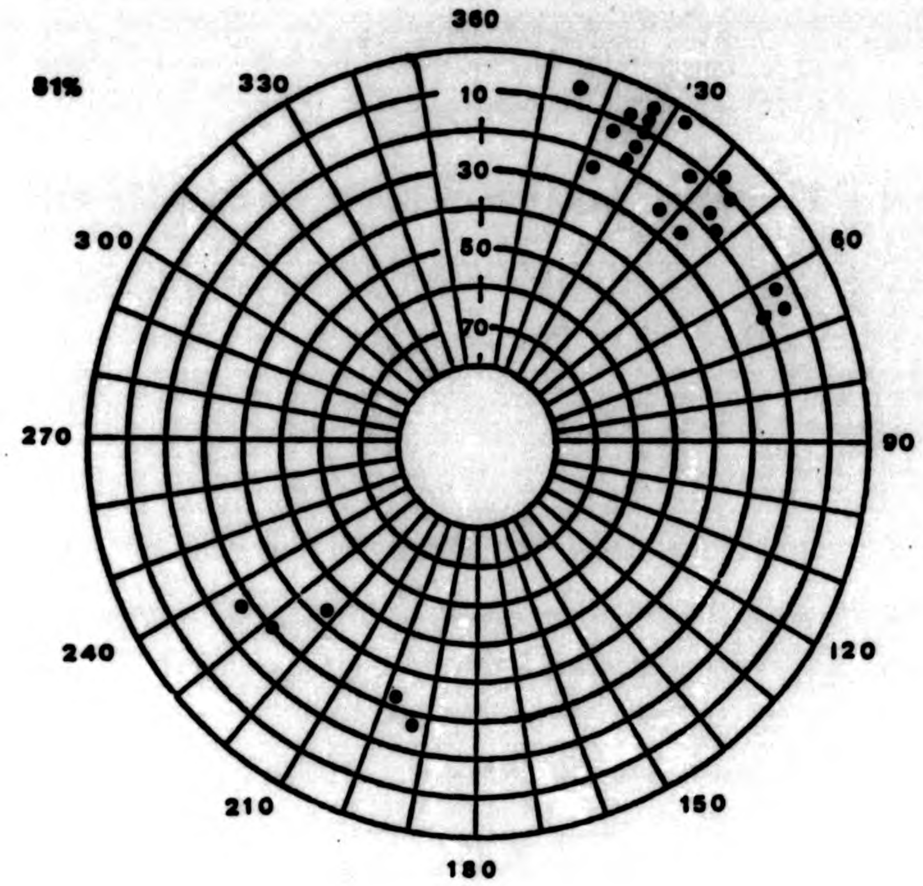
270
90
240
120
210
150
180

5

37

81%



6

169

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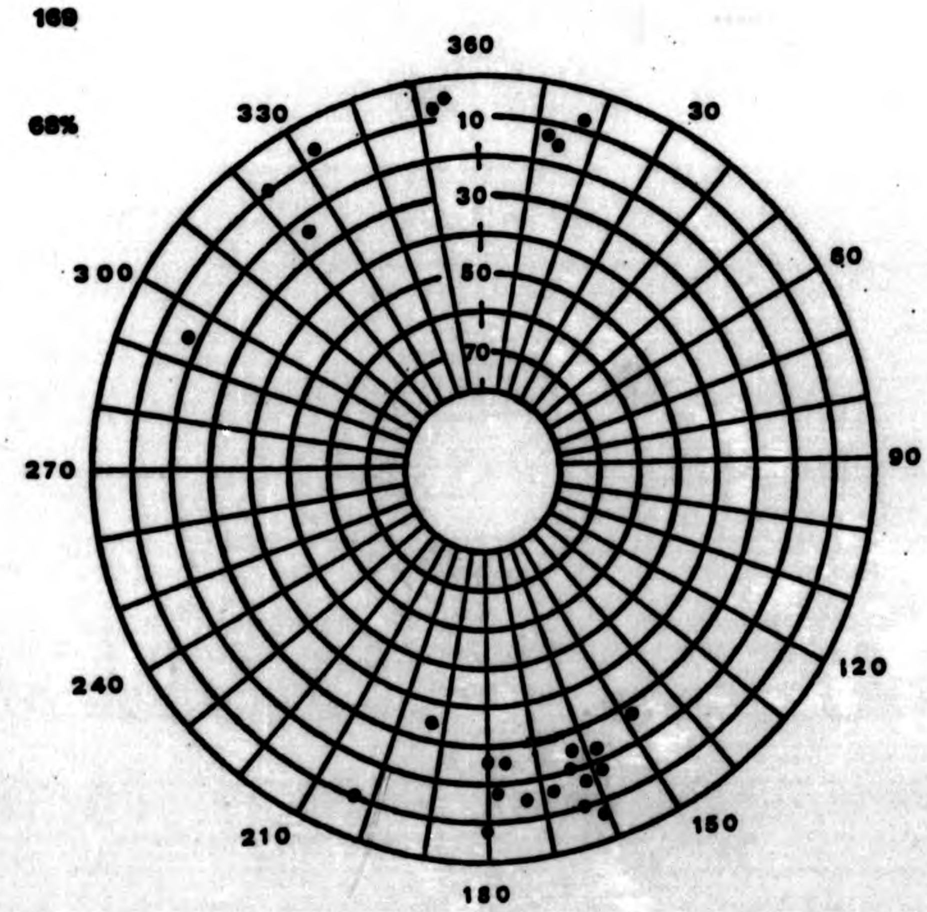

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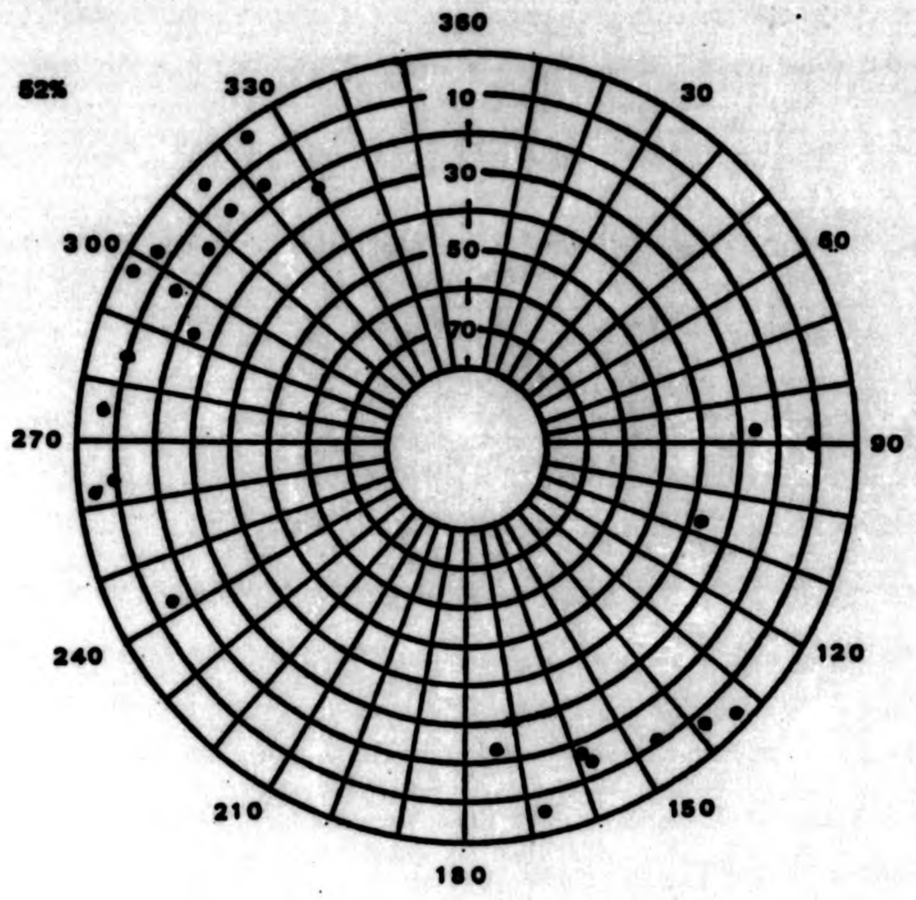
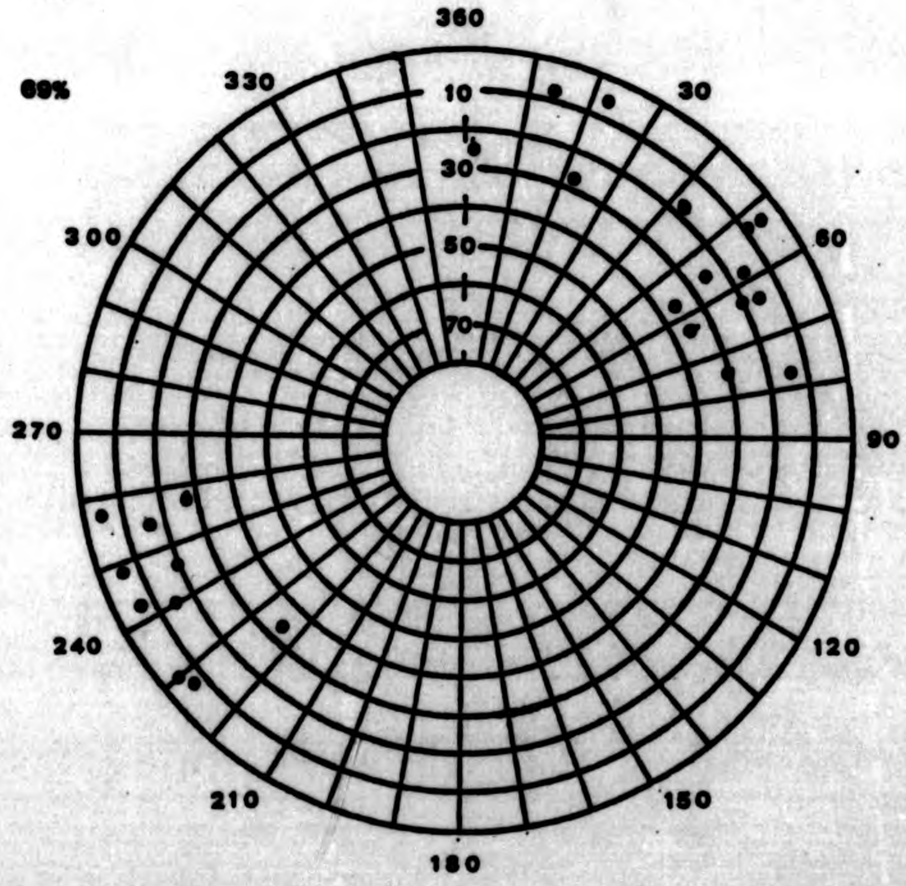
52%



8

56

69%



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244

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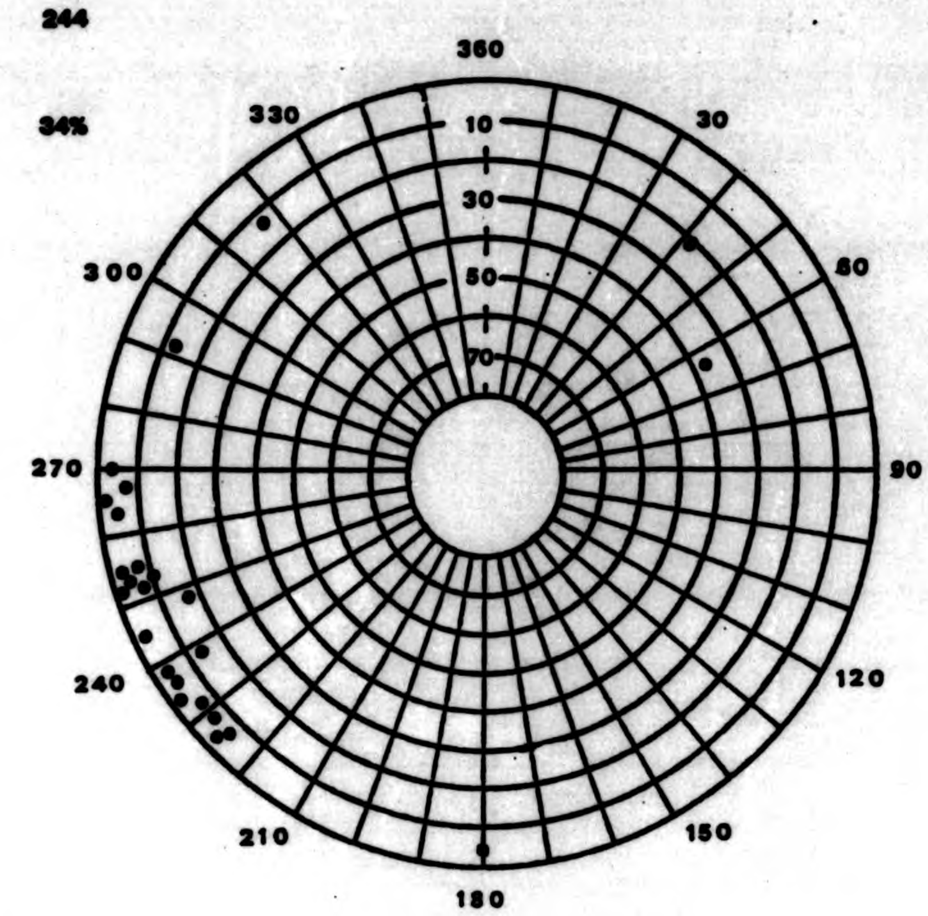

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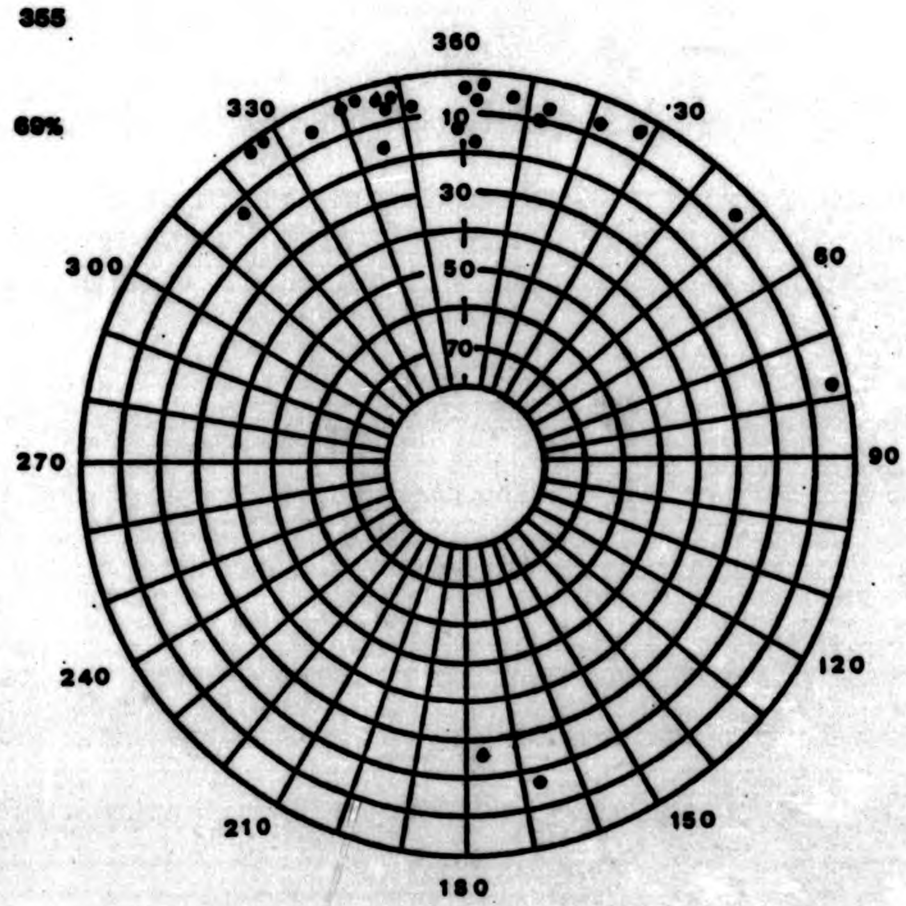
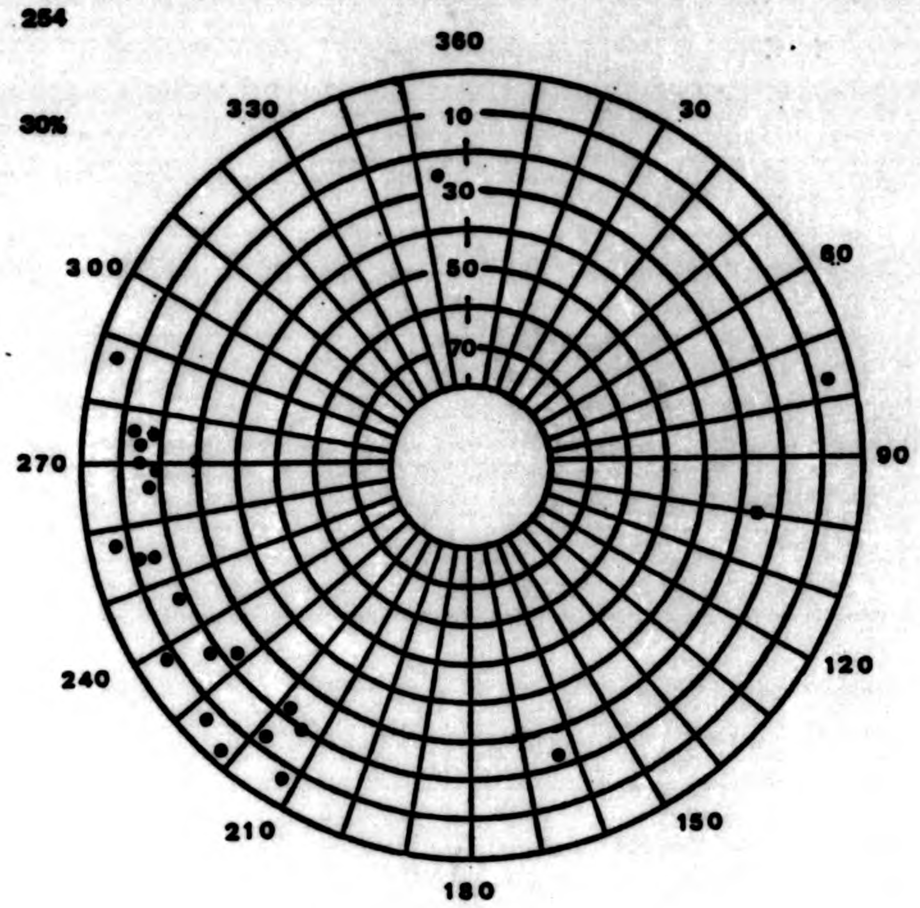
69%



11

254

30%



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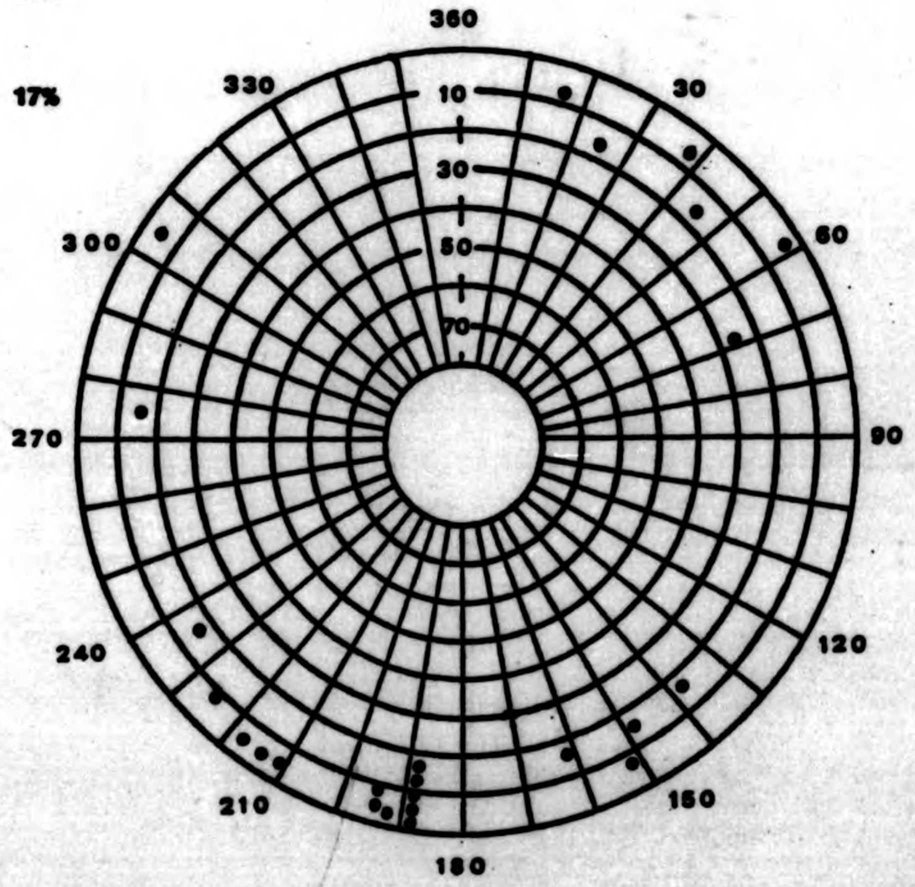
204

17%



13

350

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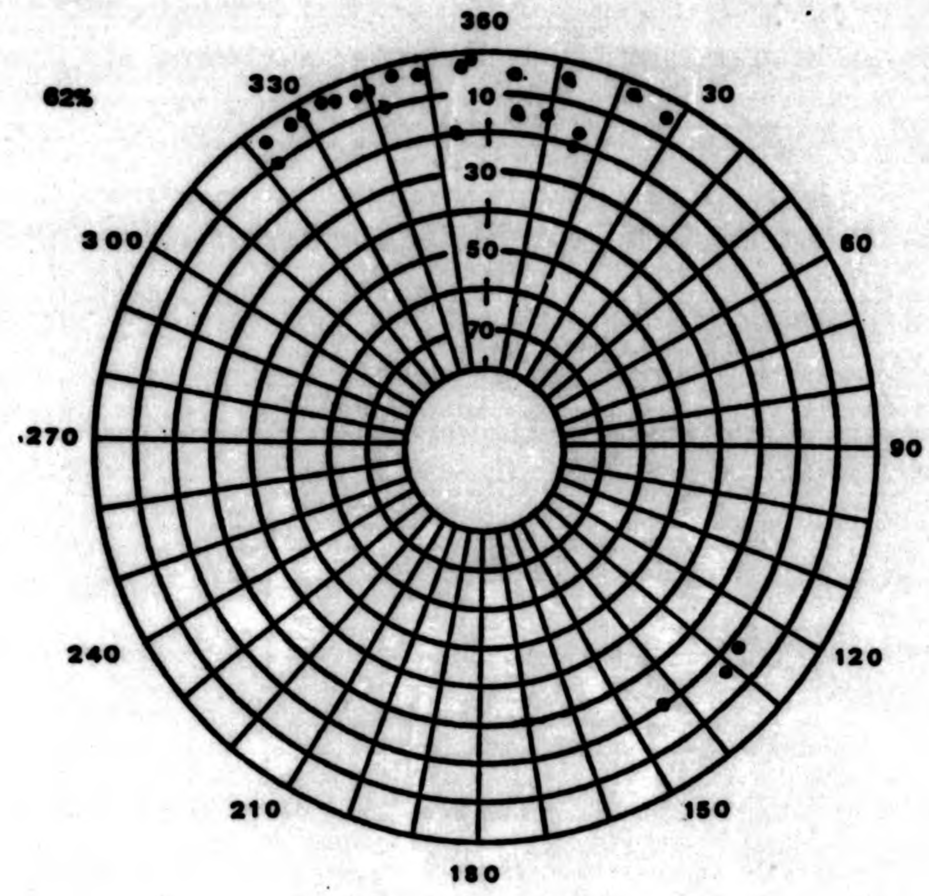

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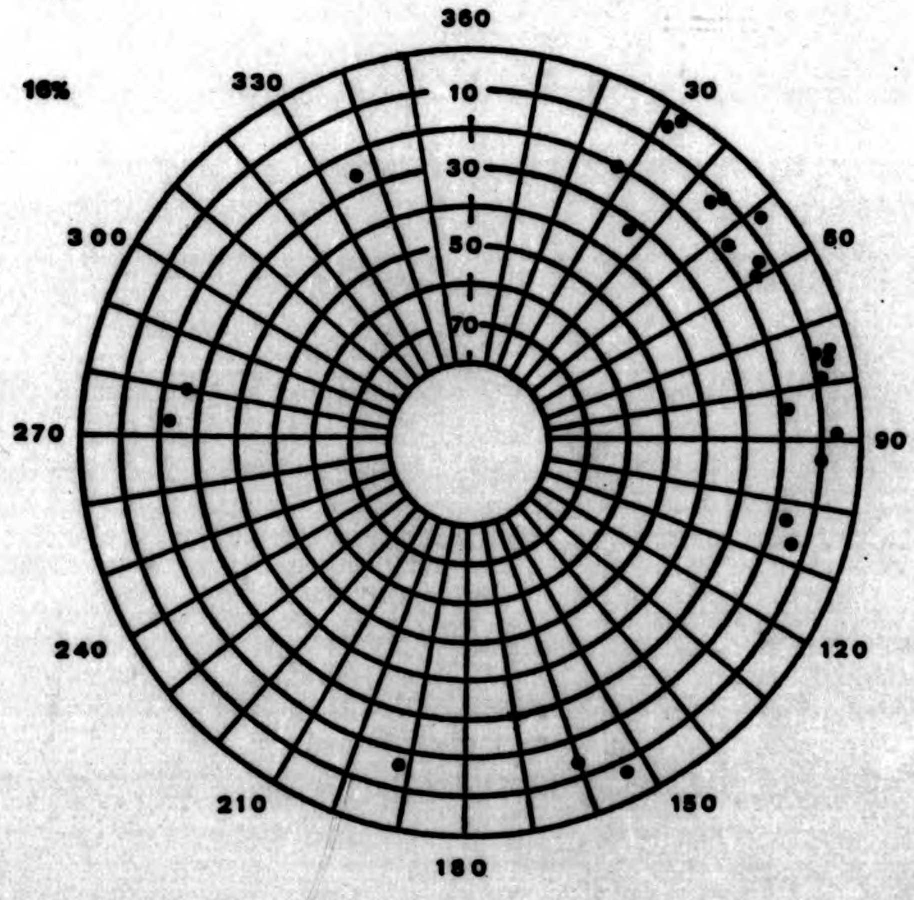
16%



15

358

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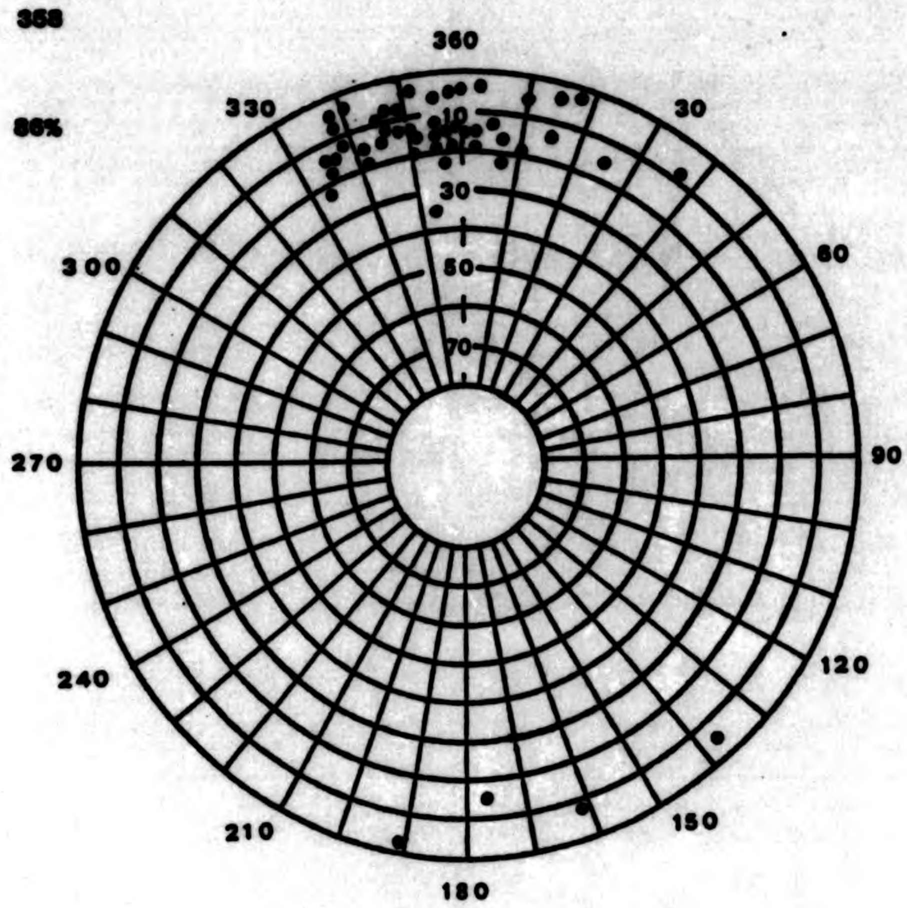

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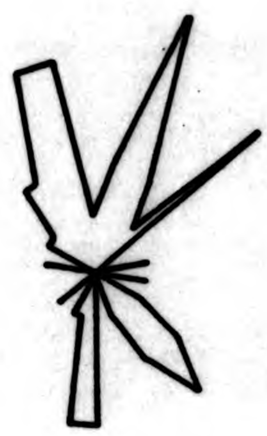

17

58

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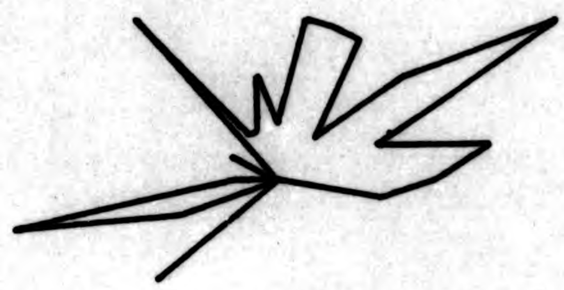

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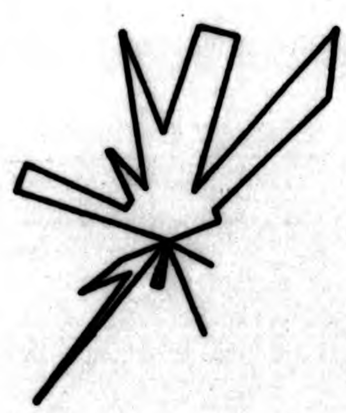

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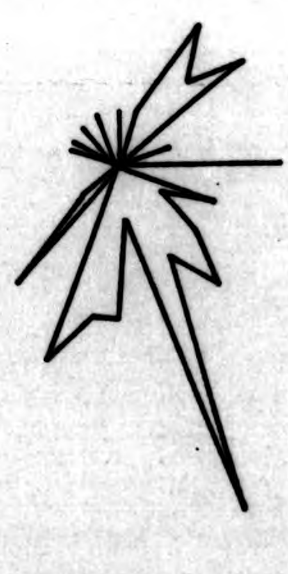
180

74%



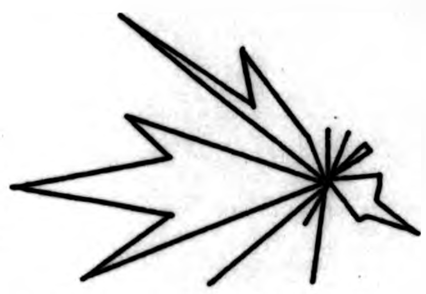
APPENDIX 11. ROSE DIAGRAMS BASED ON FABRIC DATA

FABRIC SAMPLE NUMBER: 1

VECTOR DIRECTION : 277

VECTOR STRENGTH : 33%

N



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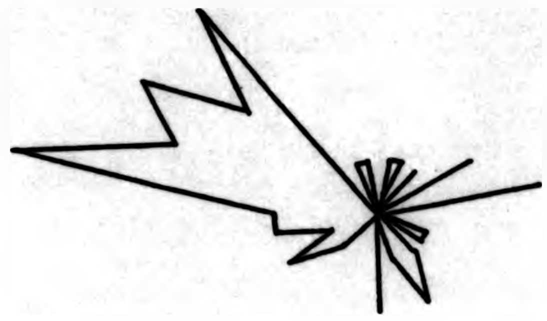


(compass readings uncorrected for magnetic variation of twelve degrees to the west)

CLASS INTERVAL: 10 DEGREES

⎵ = 2%

3

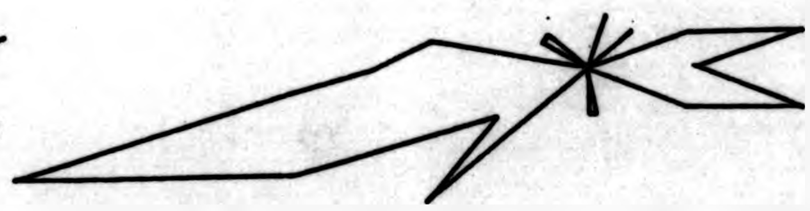
29

9%

4

261

67%



5

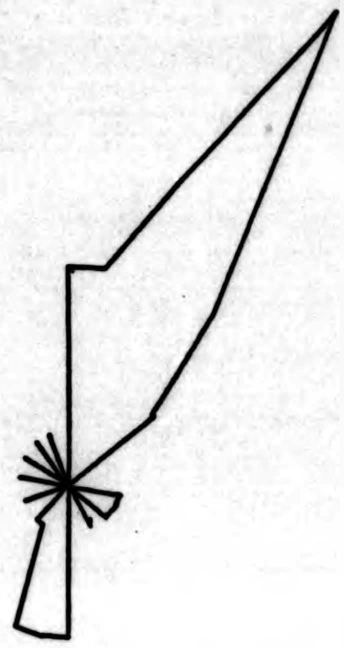
337

11%

6

19

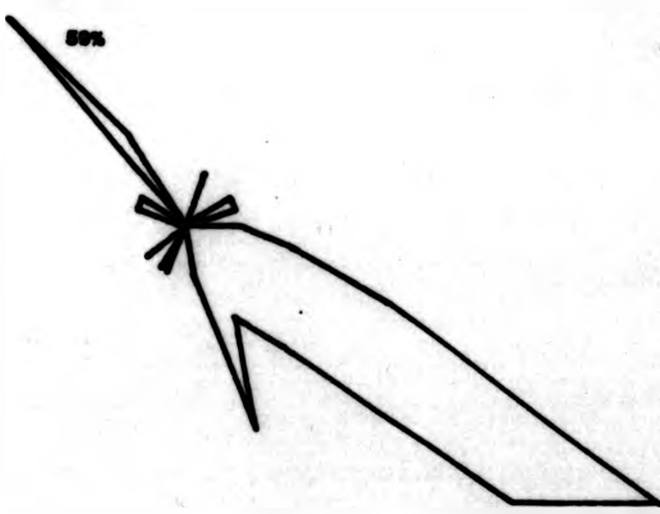
31 %



7

128

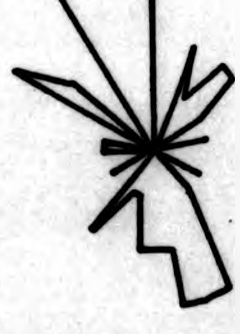
59%



8

351

36%



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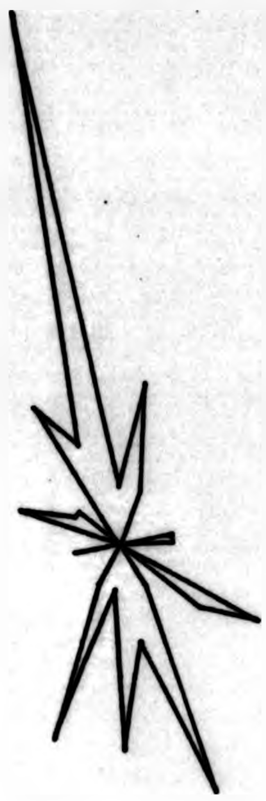

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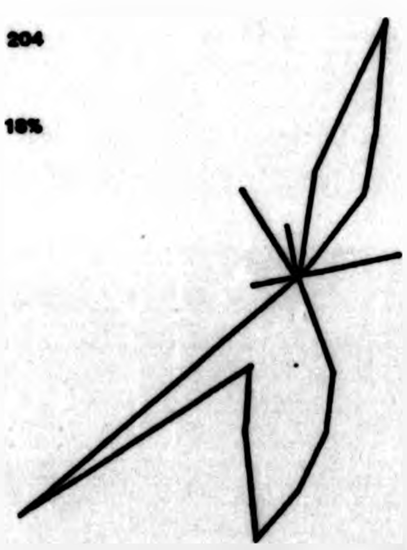

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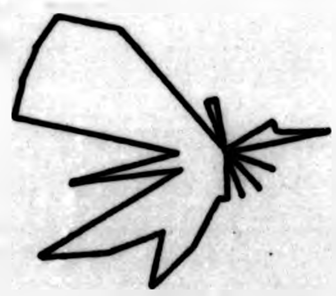

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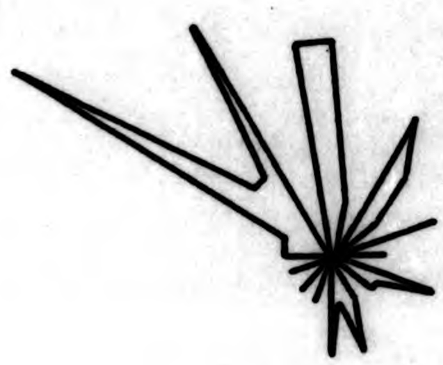

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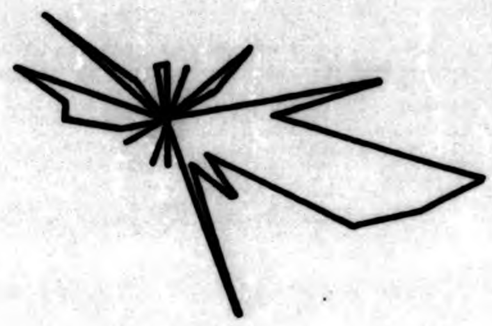

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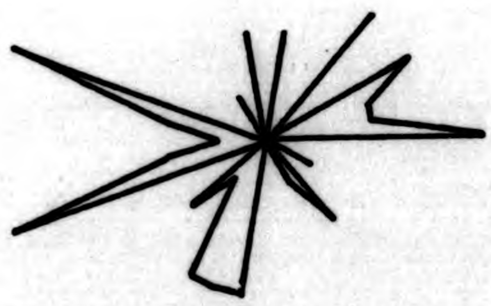

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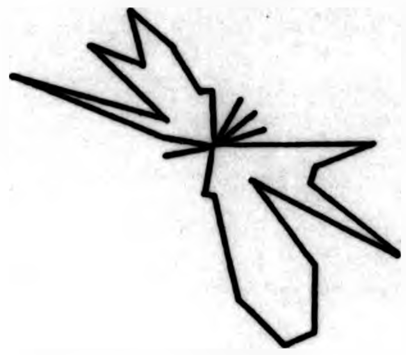

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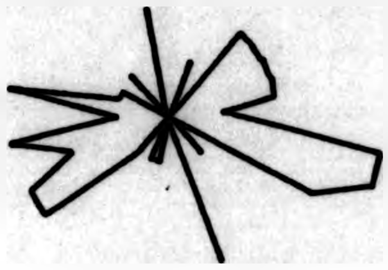

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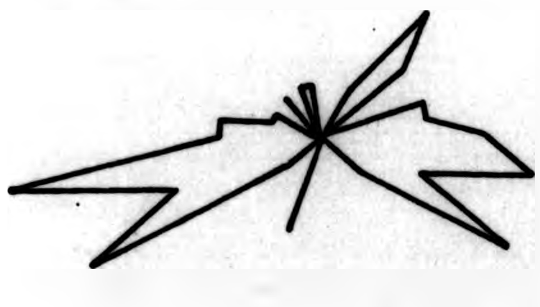
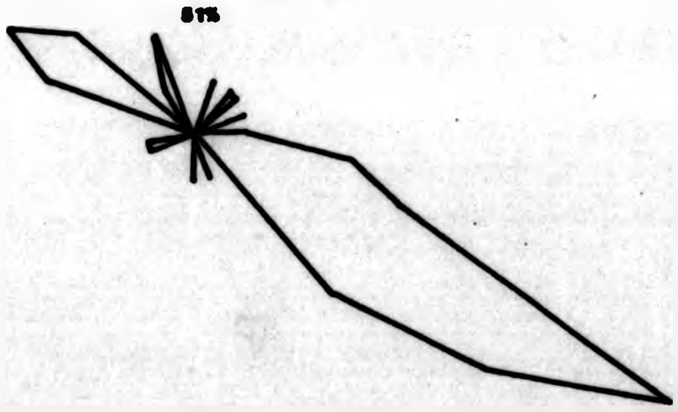


20

121

51%



21

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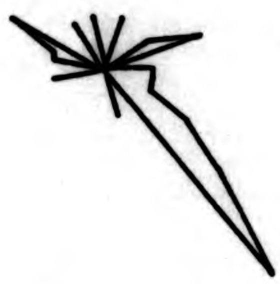

This sample is based on 25 clasts.

22

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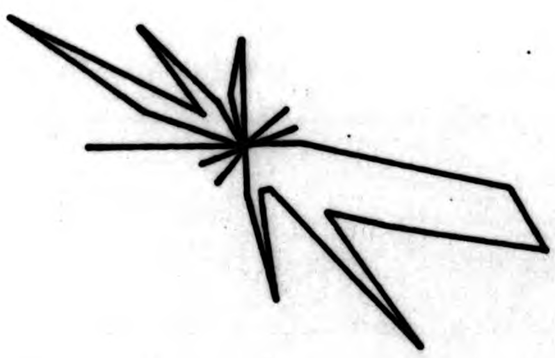

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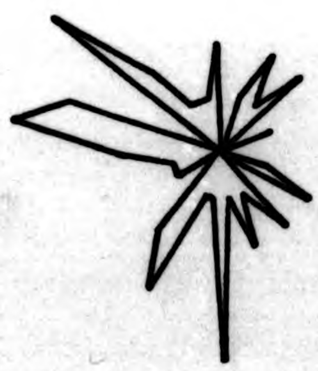

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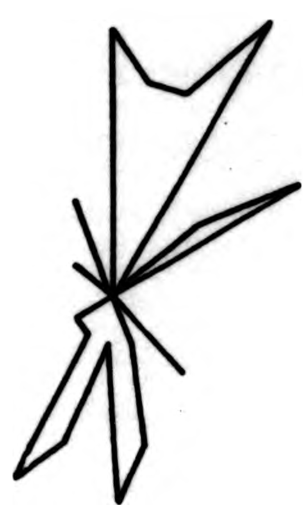

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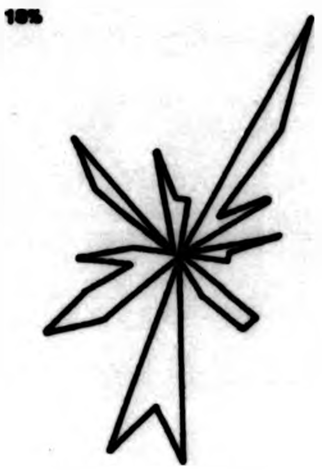

27

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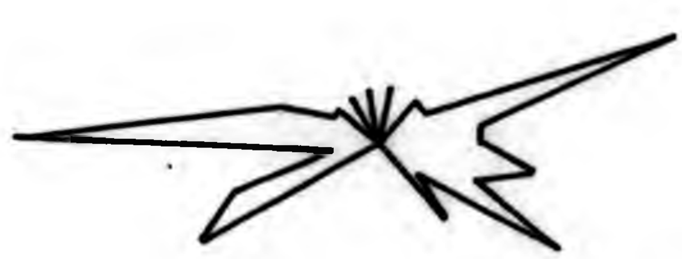
61%



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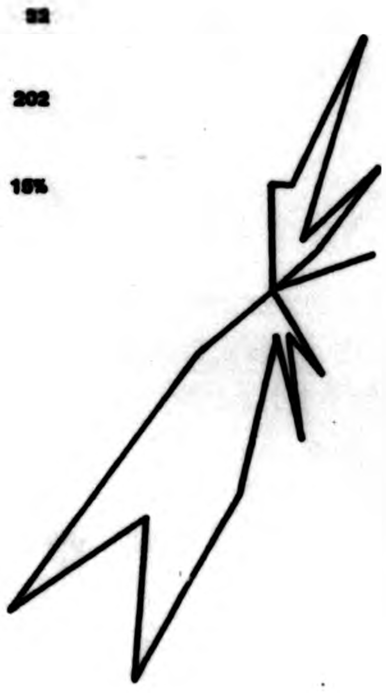

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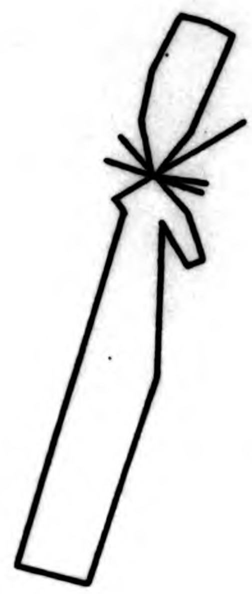

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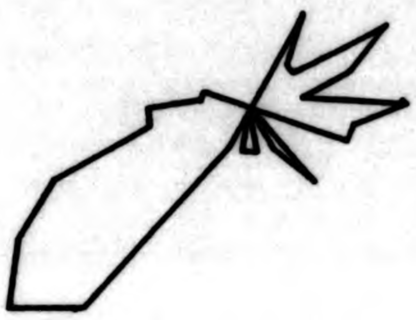

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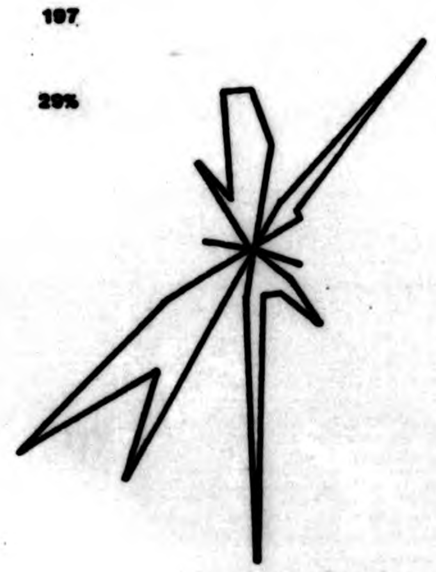

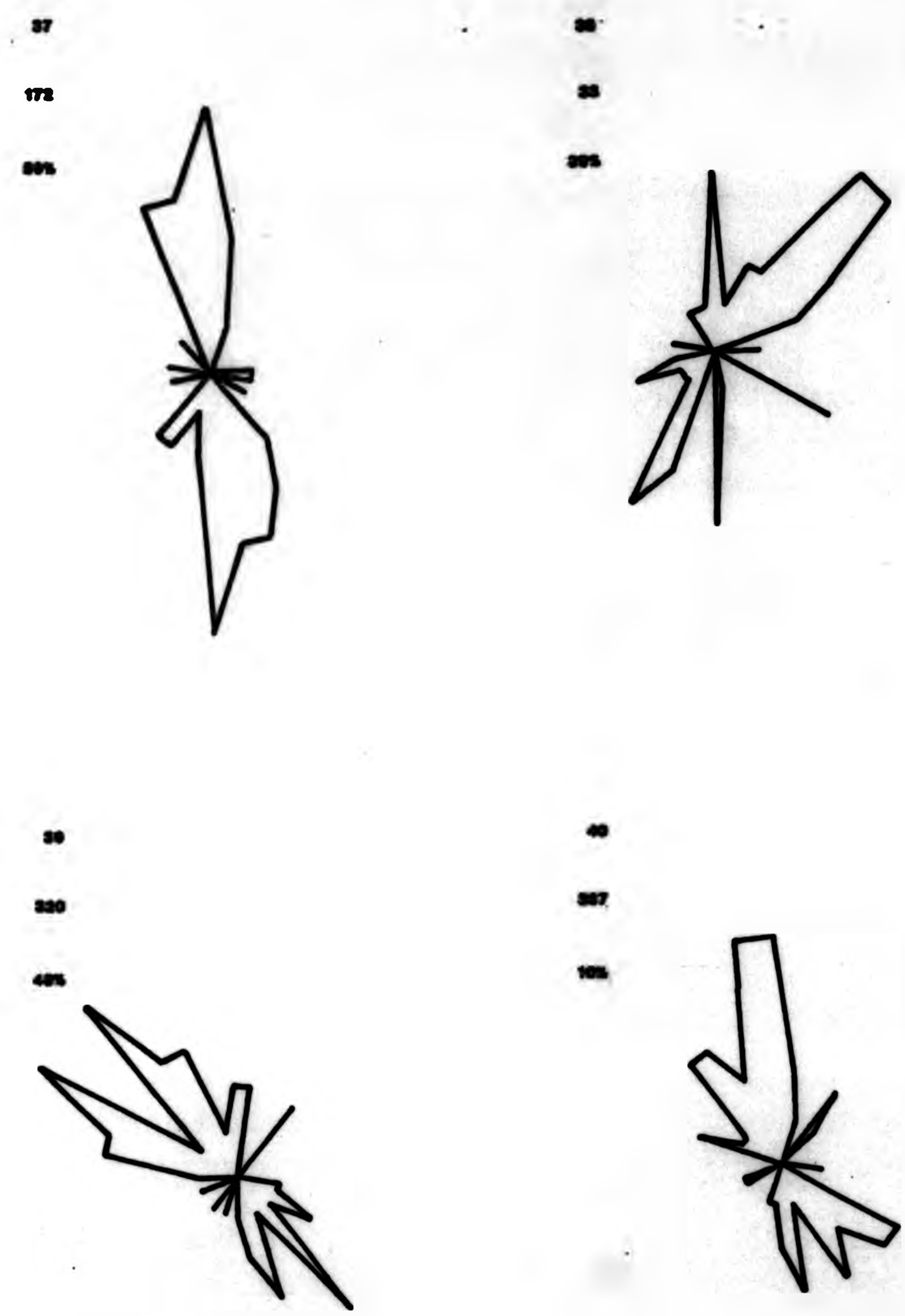

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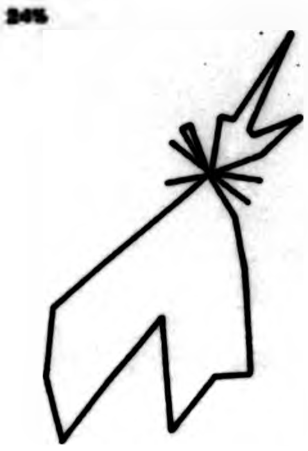

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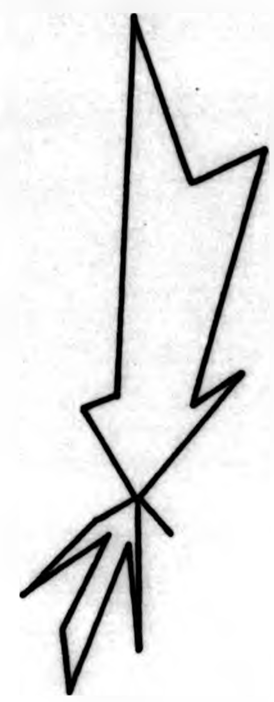

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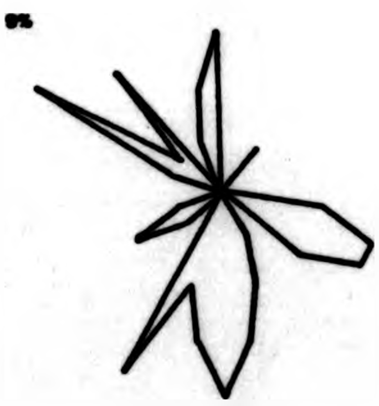

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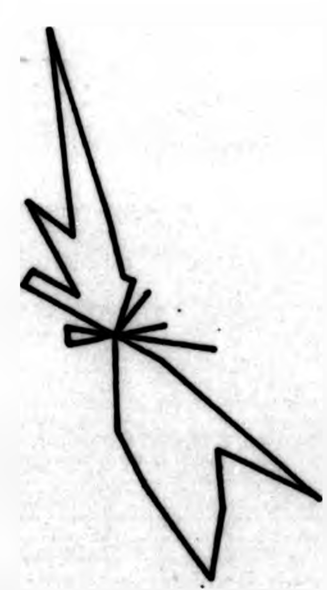

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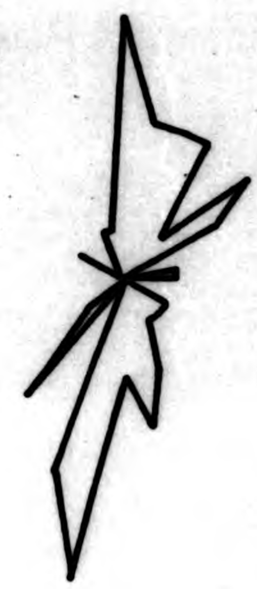

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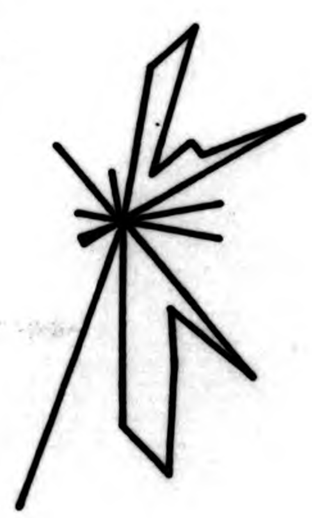

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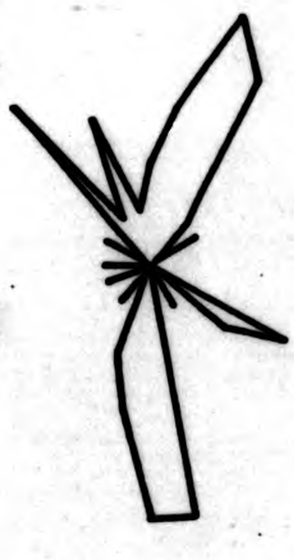

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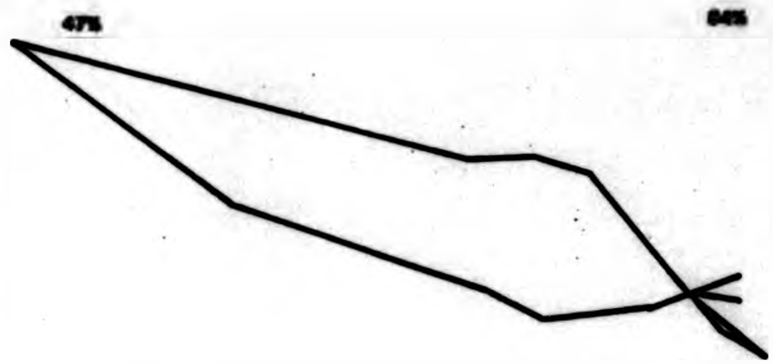

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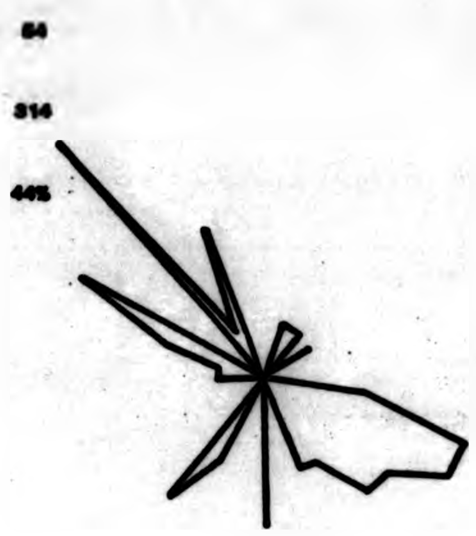
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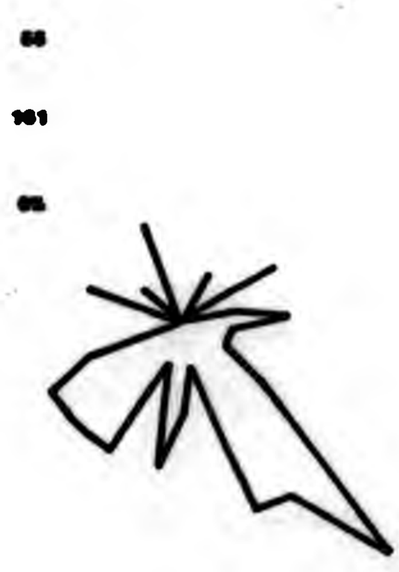
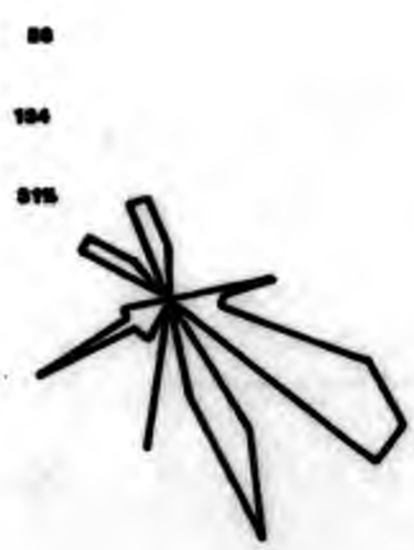
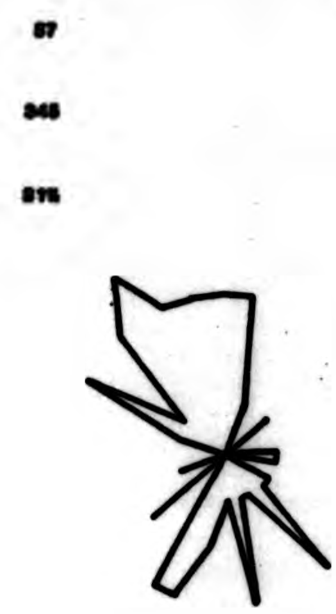
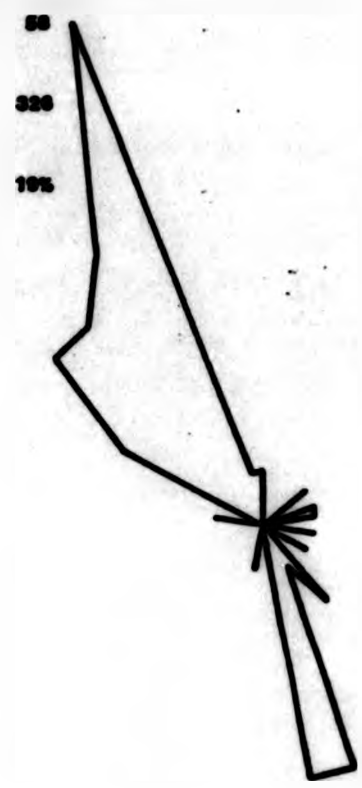
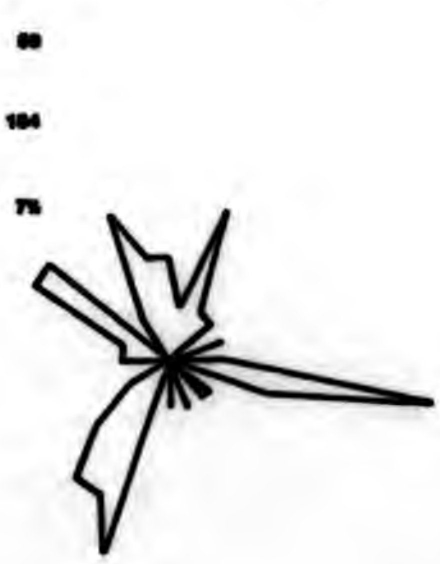





57
345
31%


58
326
19%


69
164
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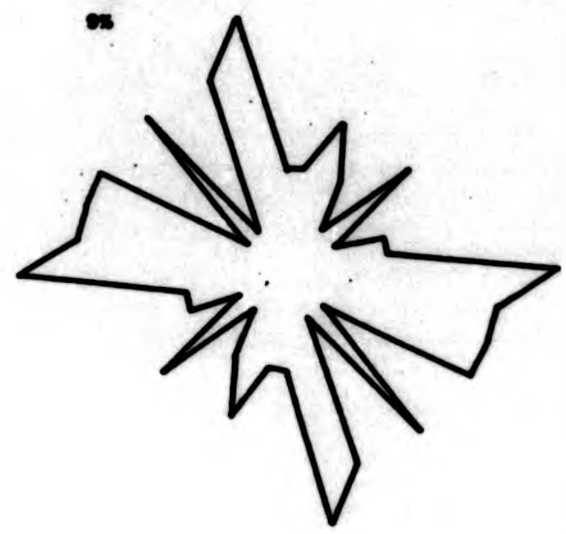


Dips of a-axes are not recorded and

—— = 1% in this sample.

63

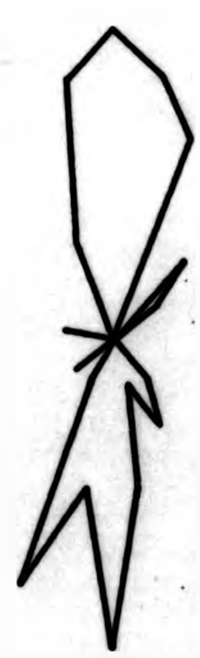
196

31%

64

3

72%



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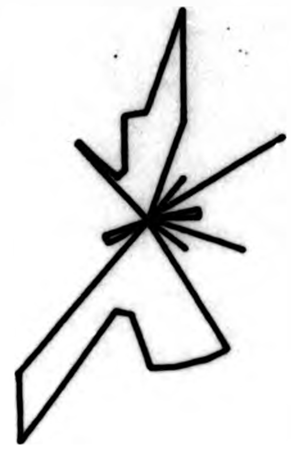

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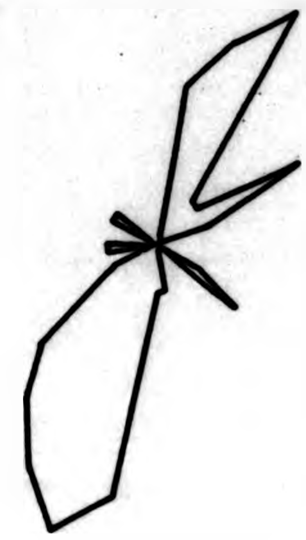
30%



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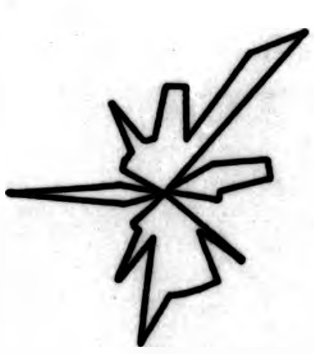

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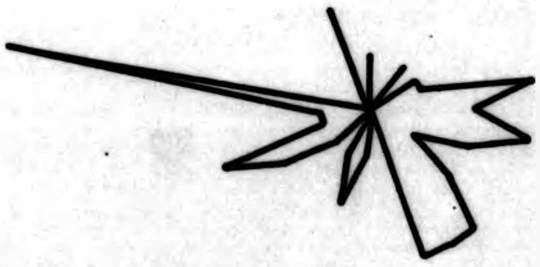

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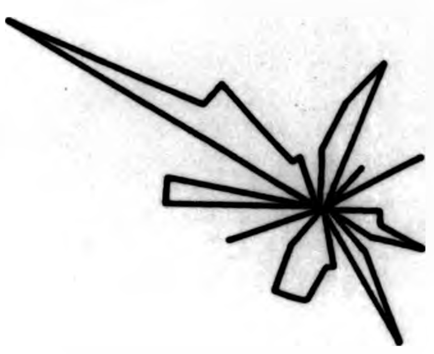

71

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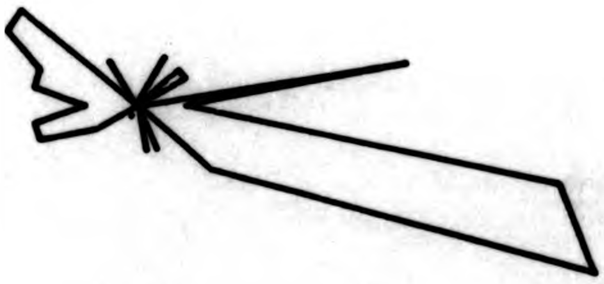
58%



72

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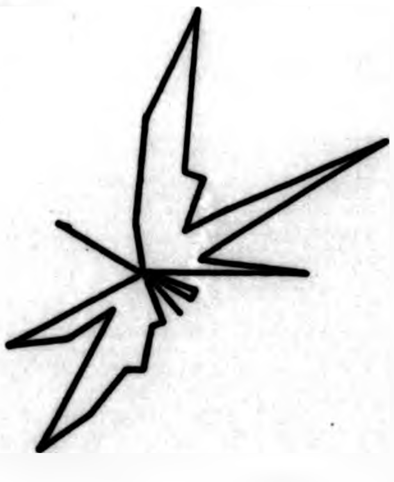
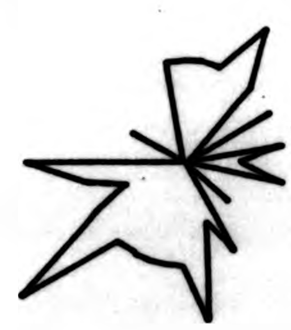
20%



73

211

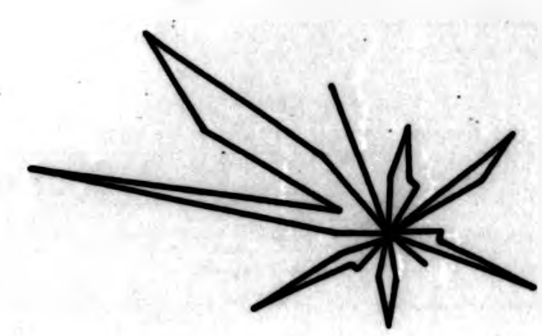
26%



74

289

11%



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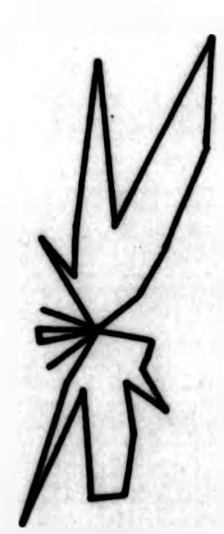

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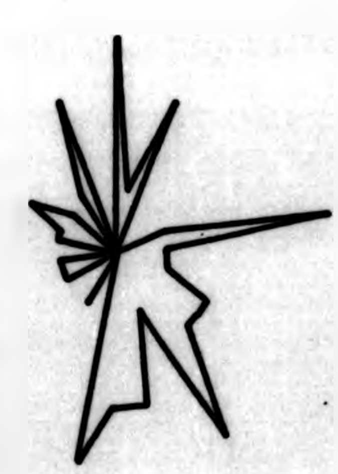
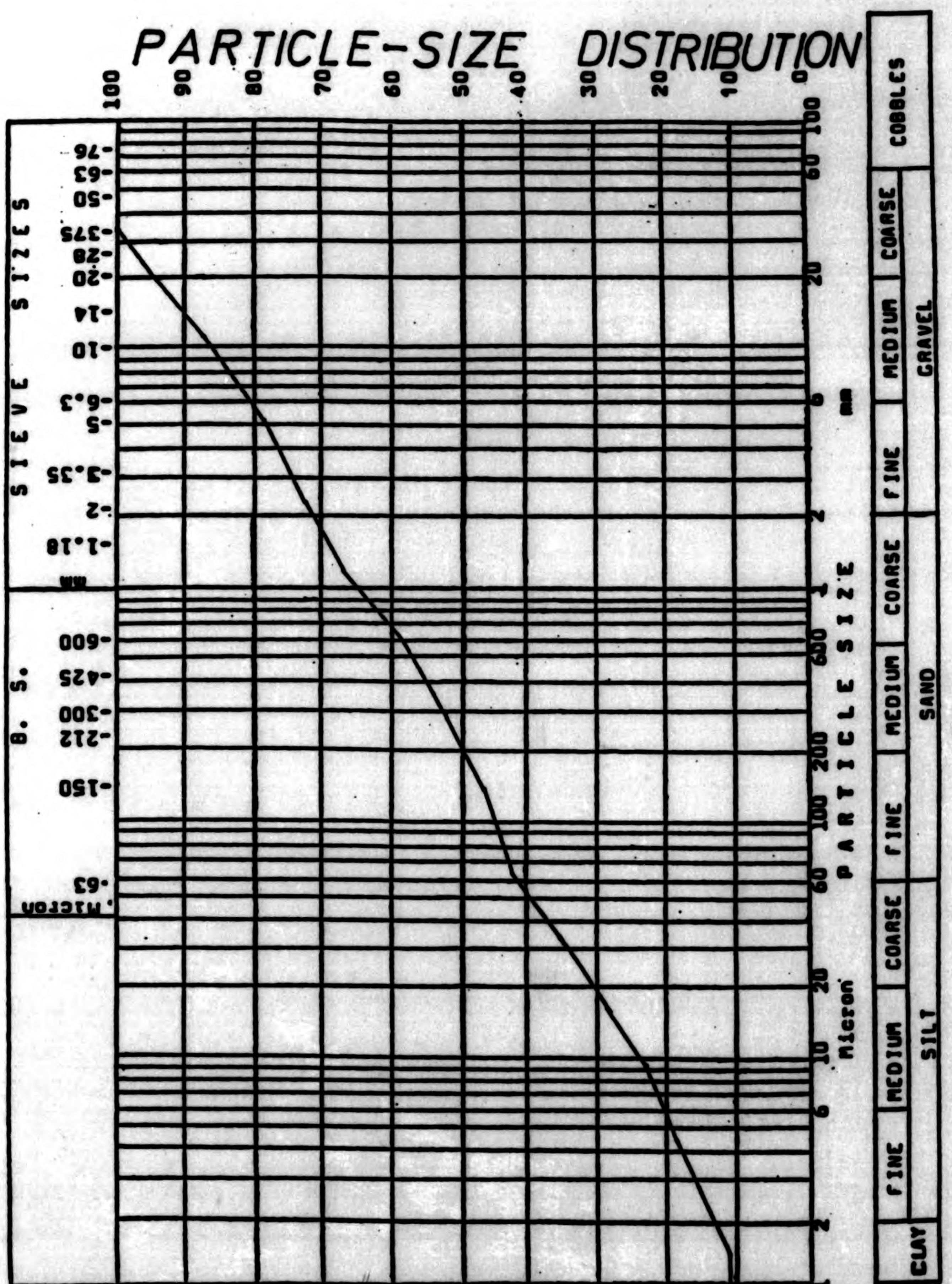
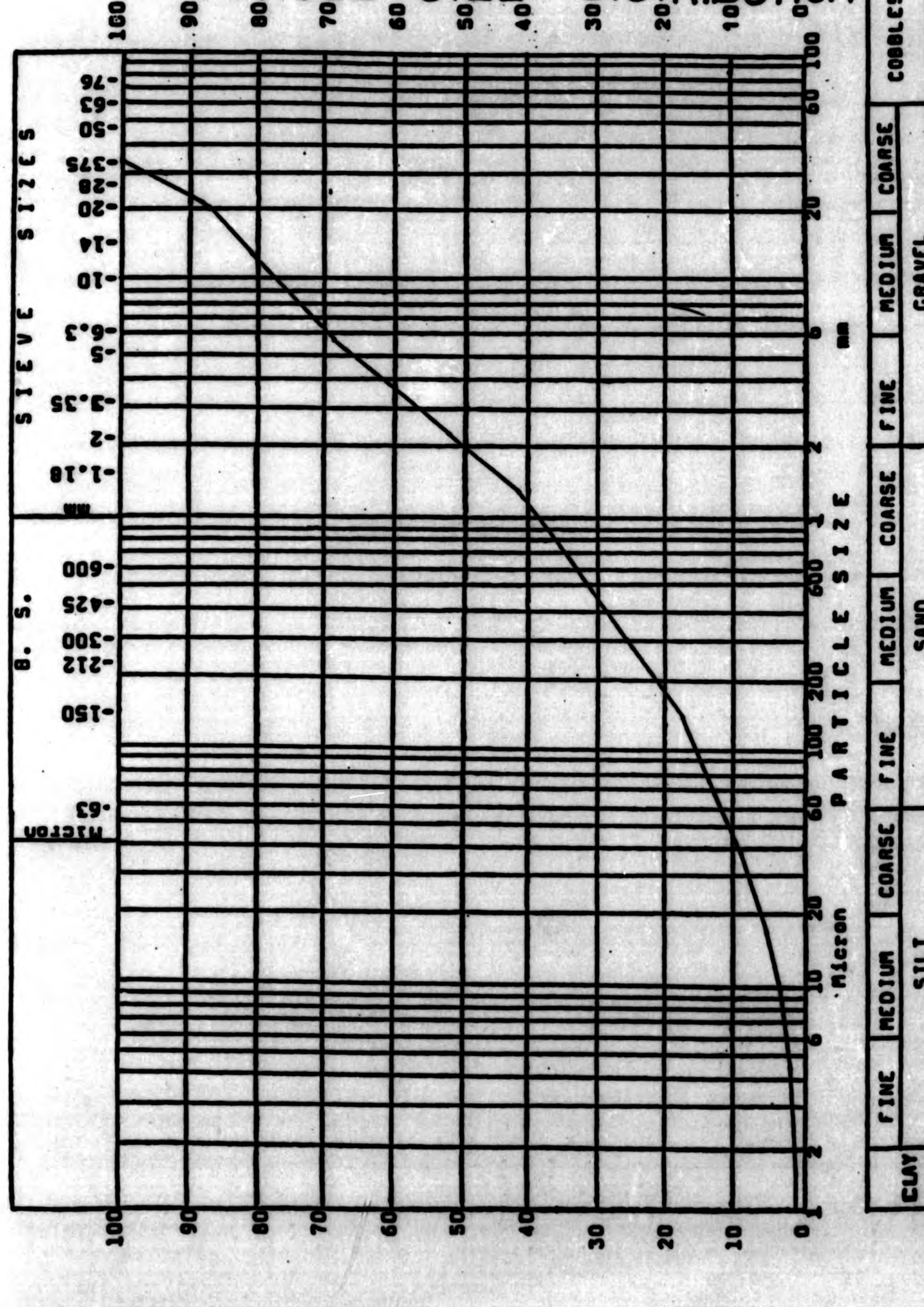


APPENDIX 12. CUMULATIVE FREQUENCY CURVES OF INDIVIDUAL PARTICLE SIZE SAMPLES

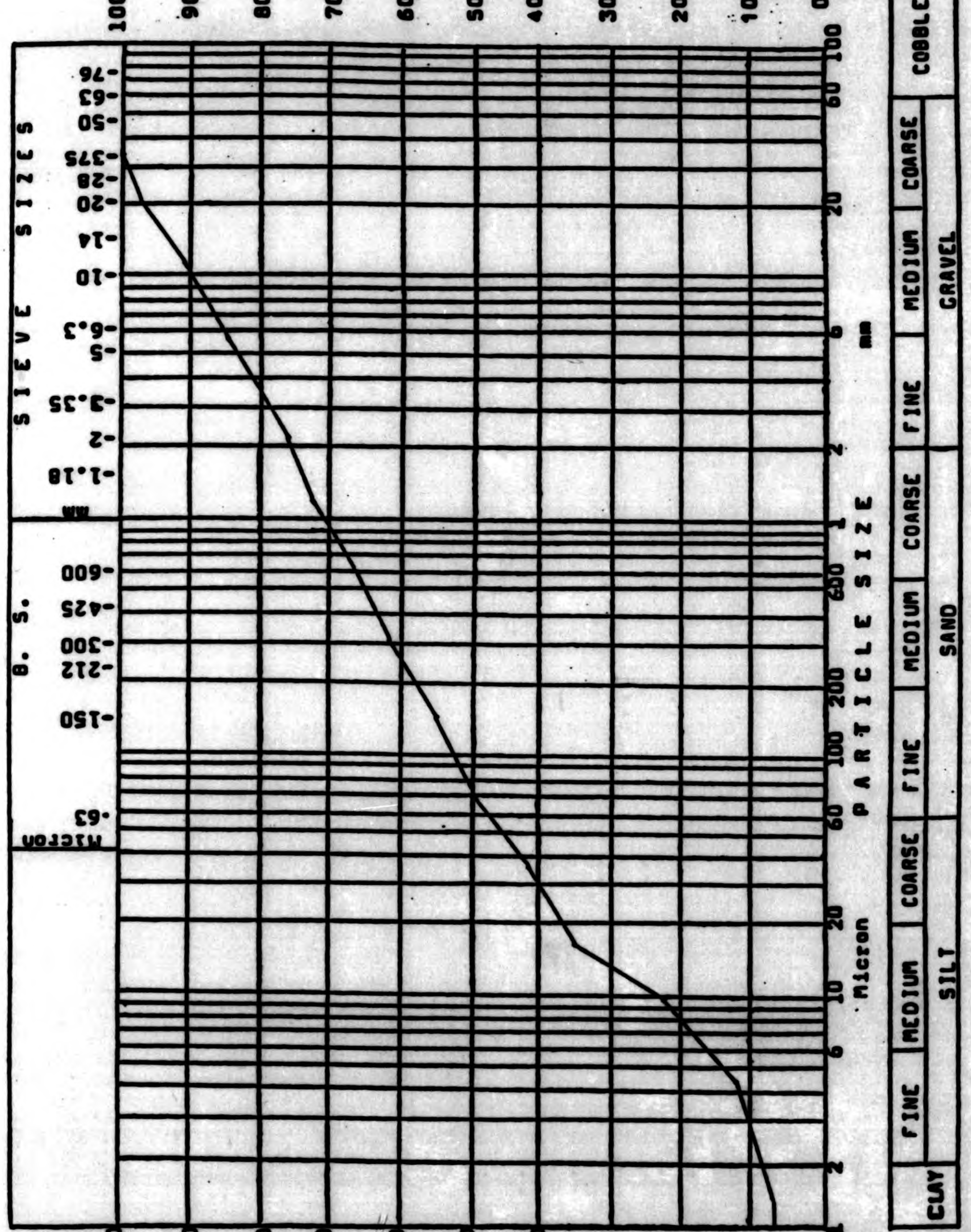
SAMPLE NUMBER 1



PARTICLE-SIZE DISTRIBUTION



PARTICLE-SIZE DISTRIBUTION



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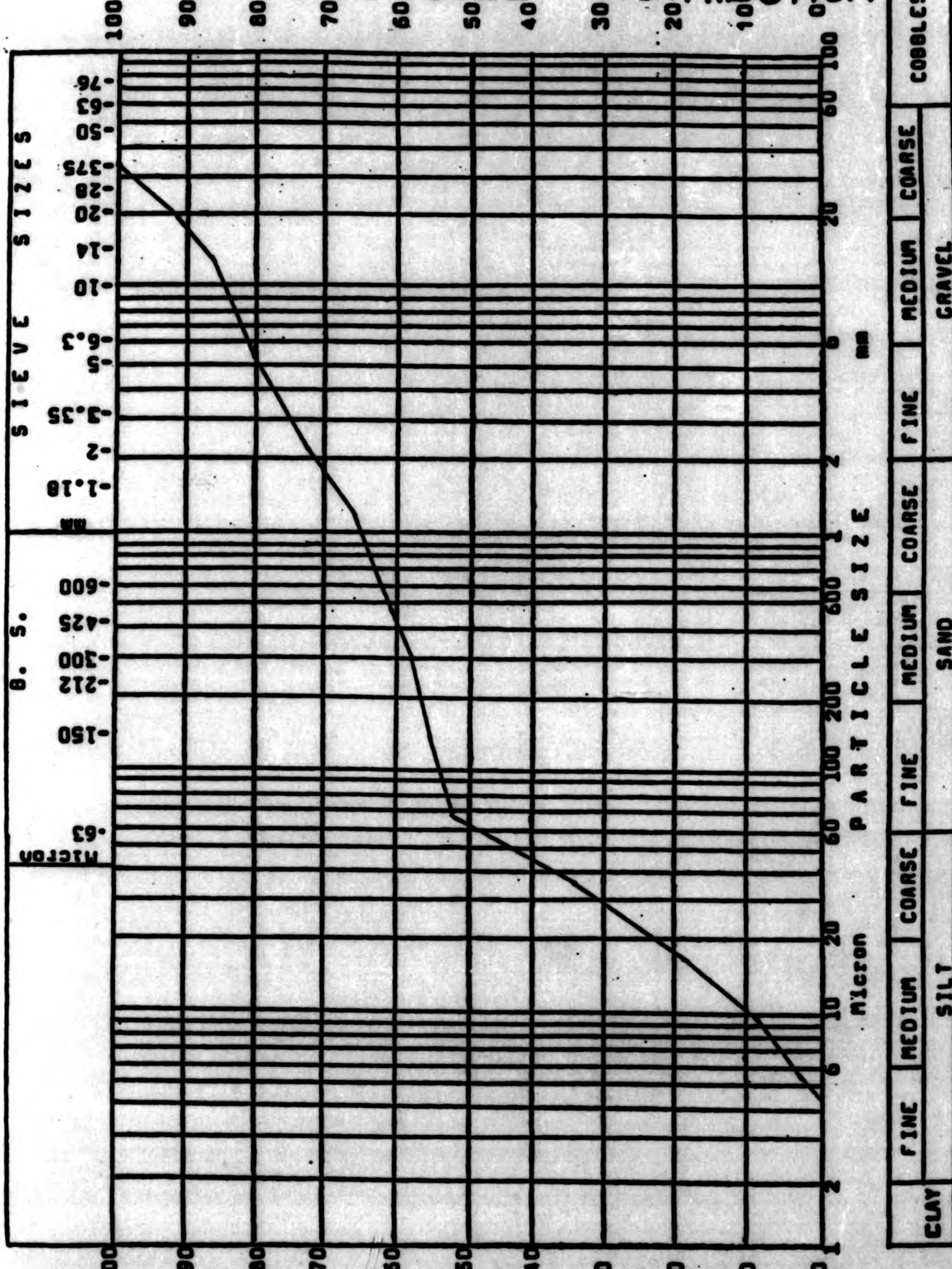

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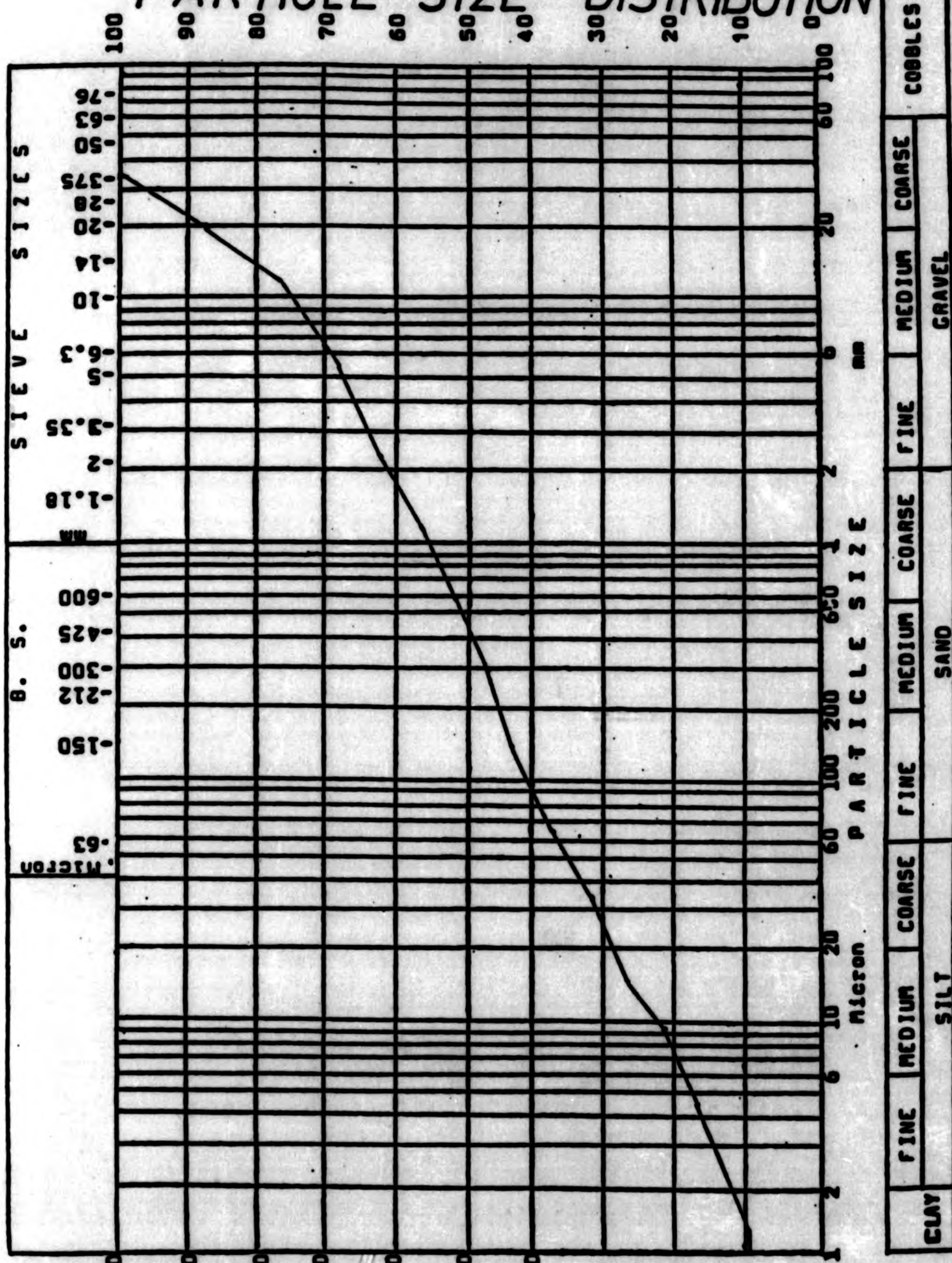

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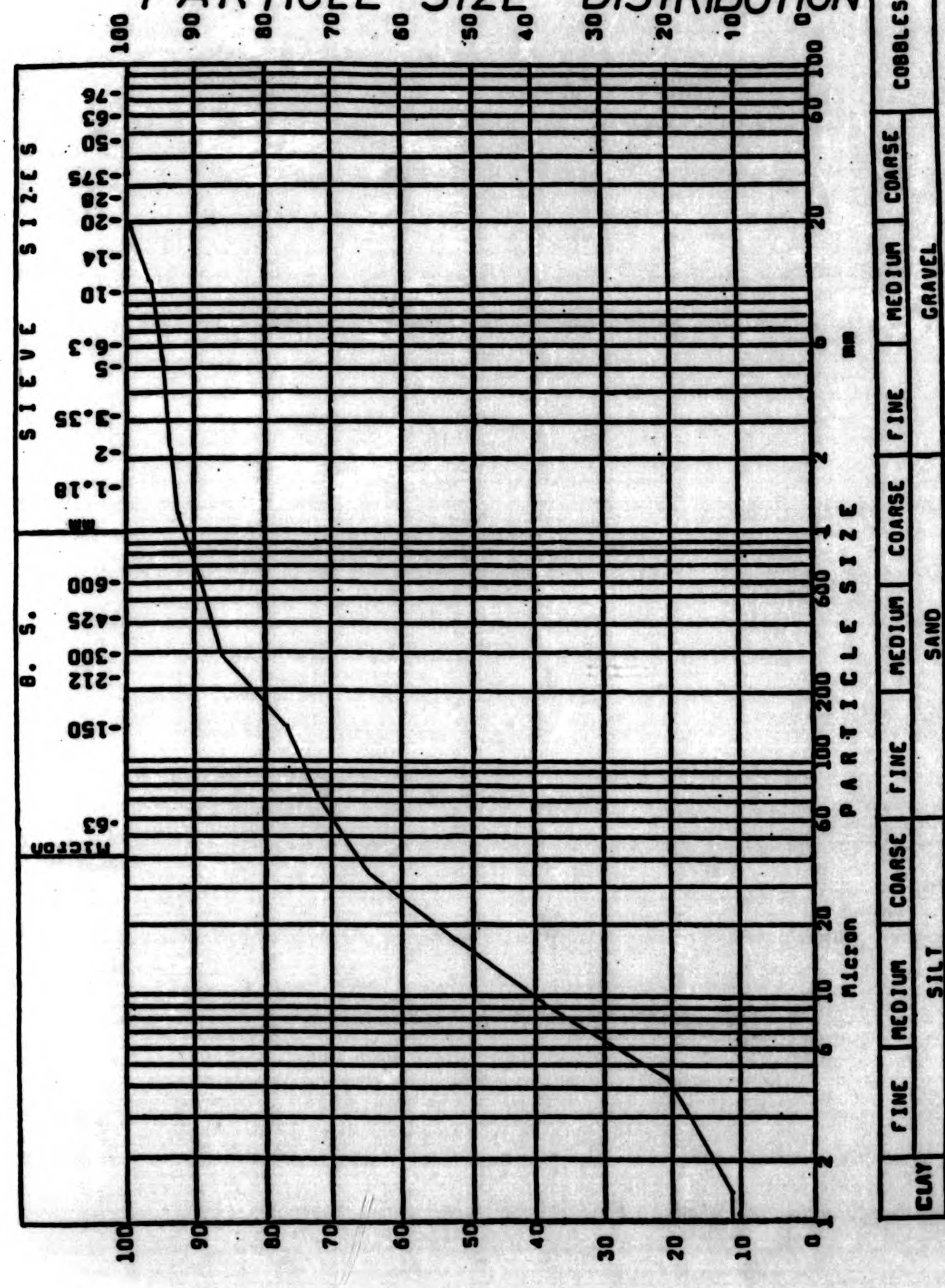
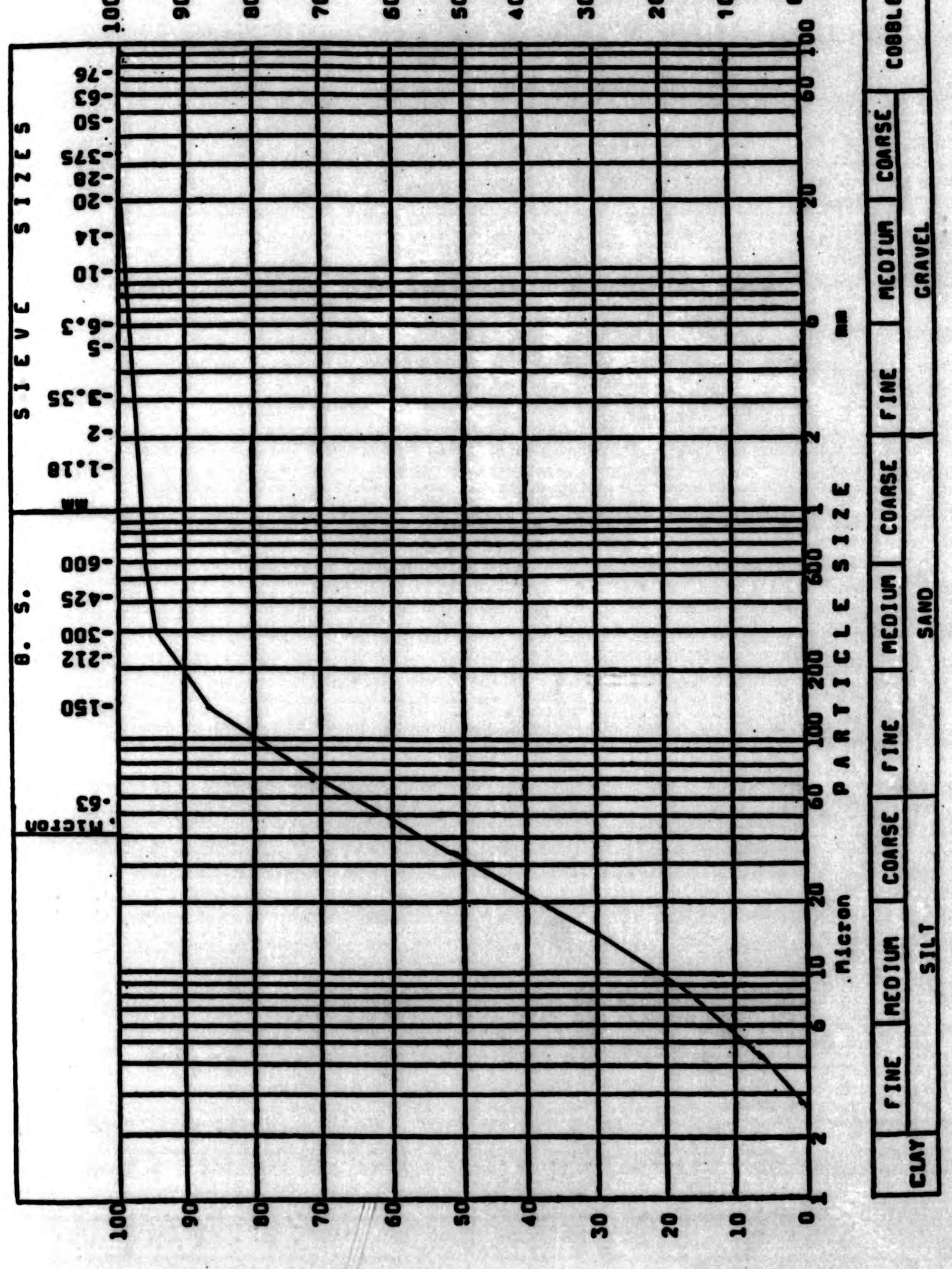


PARTICLE-SIZE DISTRIBUTION



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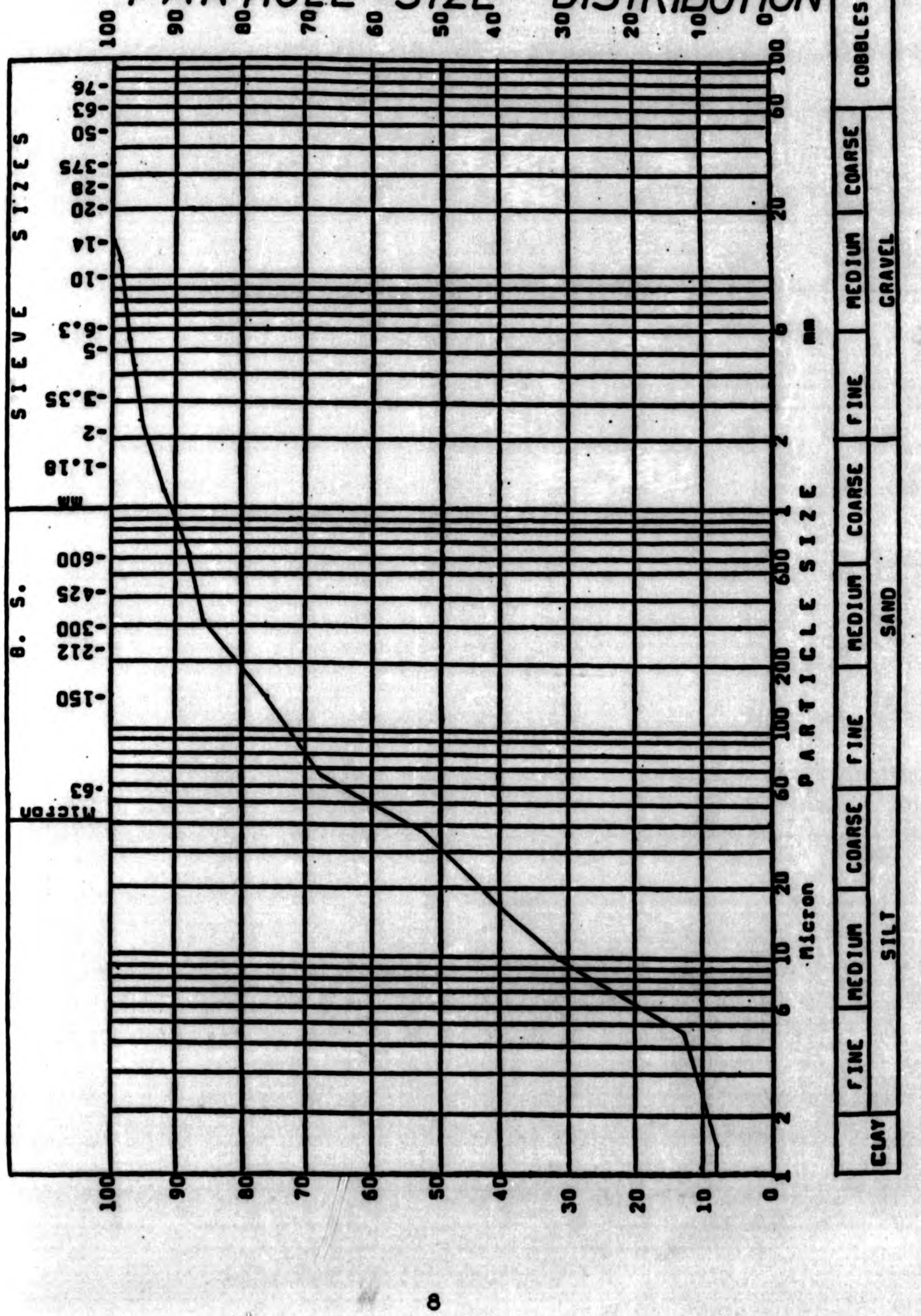
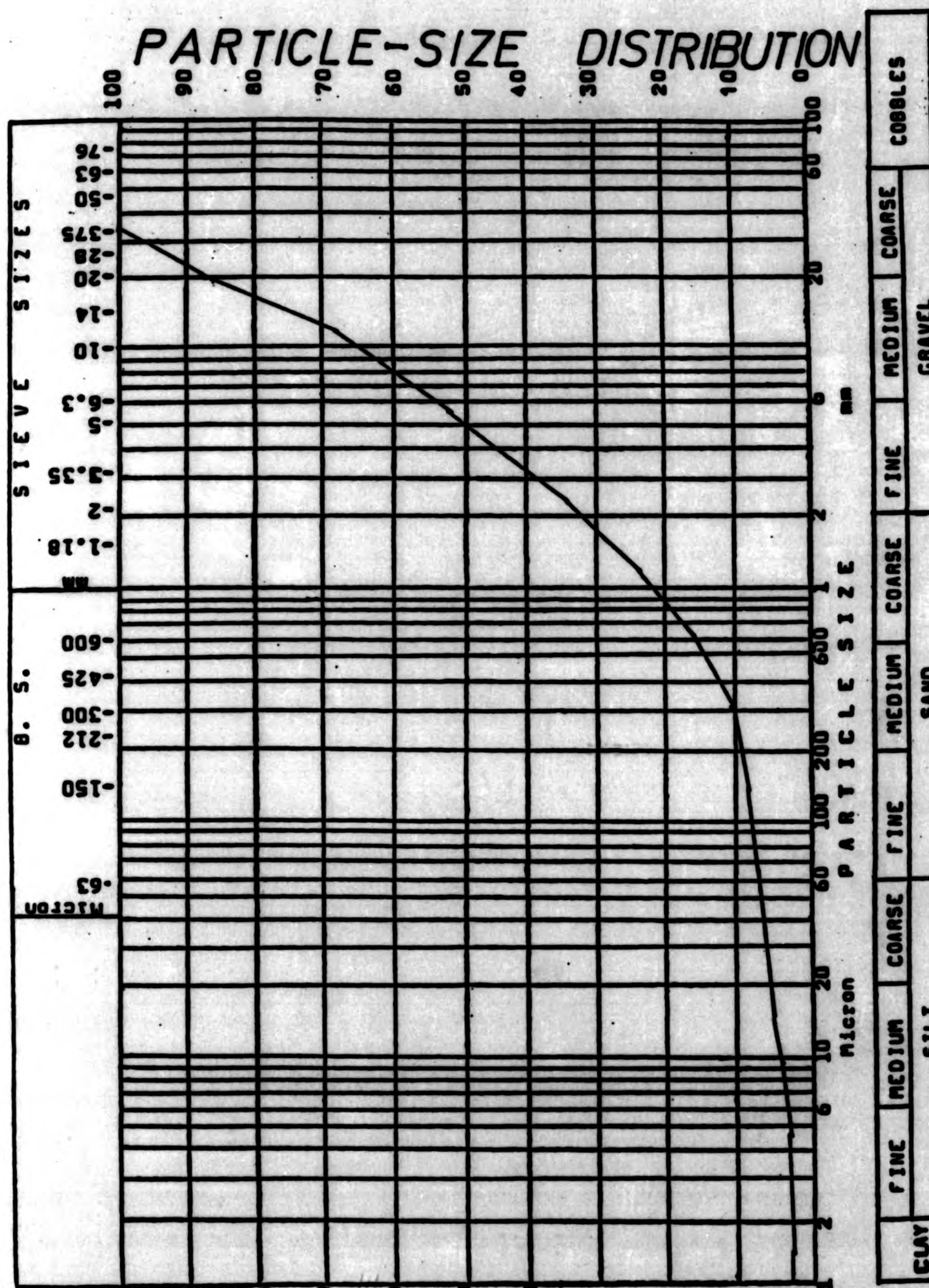
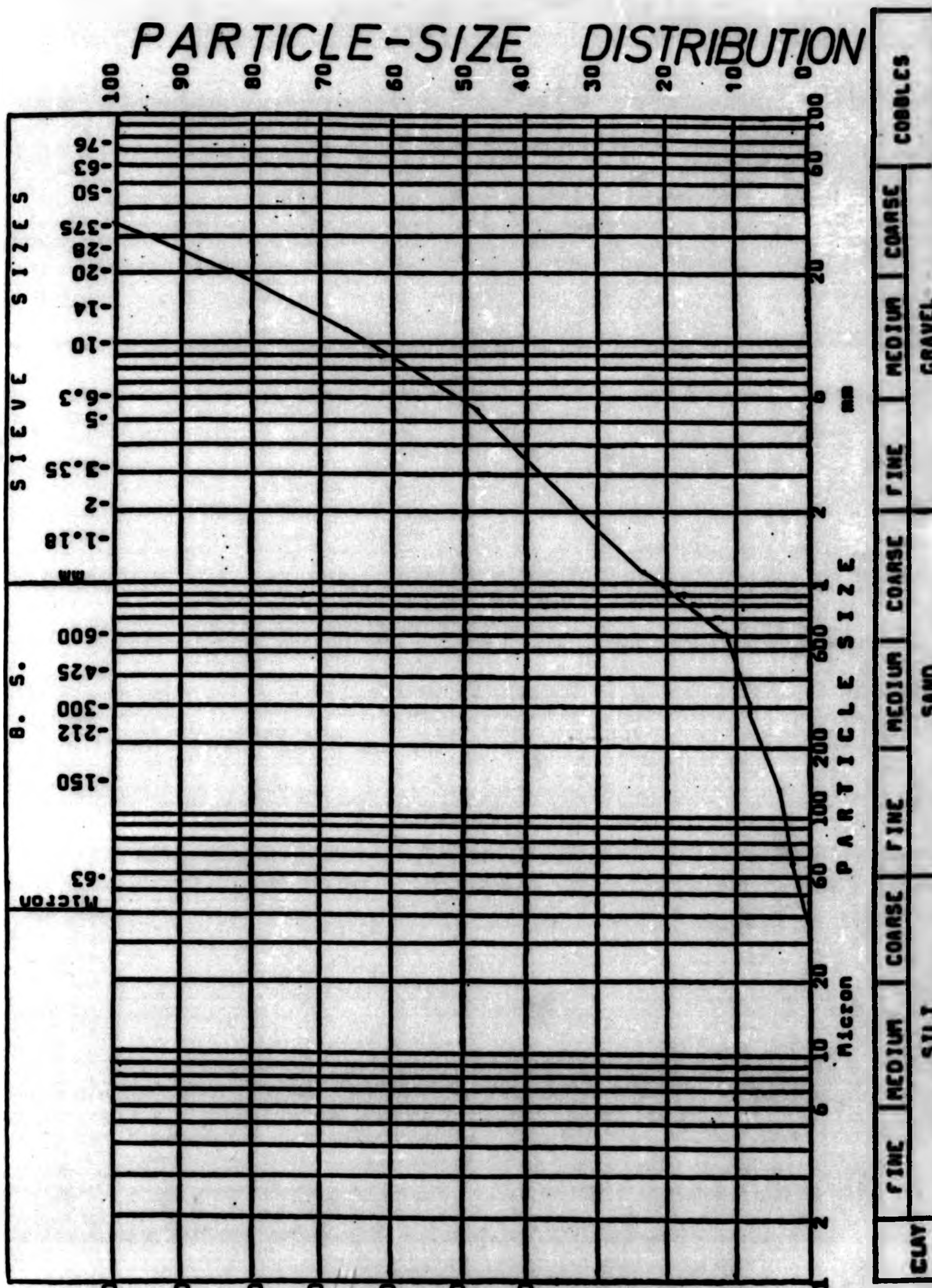



PARTICLE-SIZE DISTRIBUTION
B. S. SIEVE SIZES
mm
micron
76
63
50
37.5
28
20
14
10
6.3
5
3.35
2
1.18
600
425
300
212
150
63
PARTICLE SIZE
mm
micron
100
60
20
6
2
600
200
100
60
20
10
6
2
1
0
10
20
30
40
50
60
70
80
90
100
CLAY
FINE
MEDIUM
COARSE
SILT
FINE
MEDIUM
COARSE
SAND
FINE
MEDIUM
COARSE
GRAVEL
COBBLES


PARTICLE-SIZE DISTRIBUTION
B. S. SIEVE SIZES
76
63
50
37.5
28
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14
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6.3
5
3.35
2
1.18
mm
600
425
300
212
150
63
Micron
100
90
80
70
60
50
40
30
20
10
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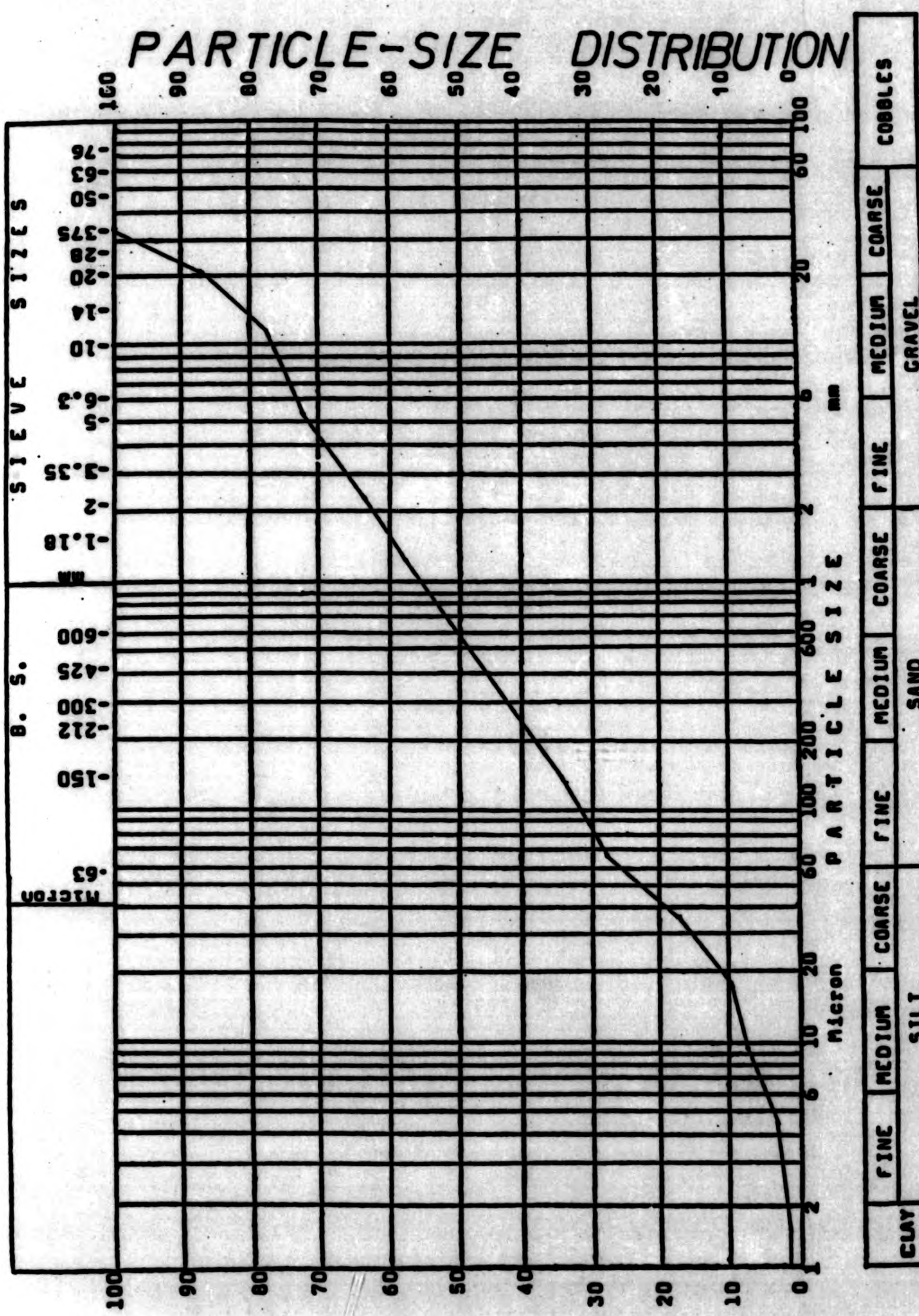
PARTICLE SIZE
mm
Micron
CLAY
FINE
MEDIUM
COARSE
SILT
SAND
GRAVEL
COBBLES

PARTICLE-SIZE DISTRIBUTION



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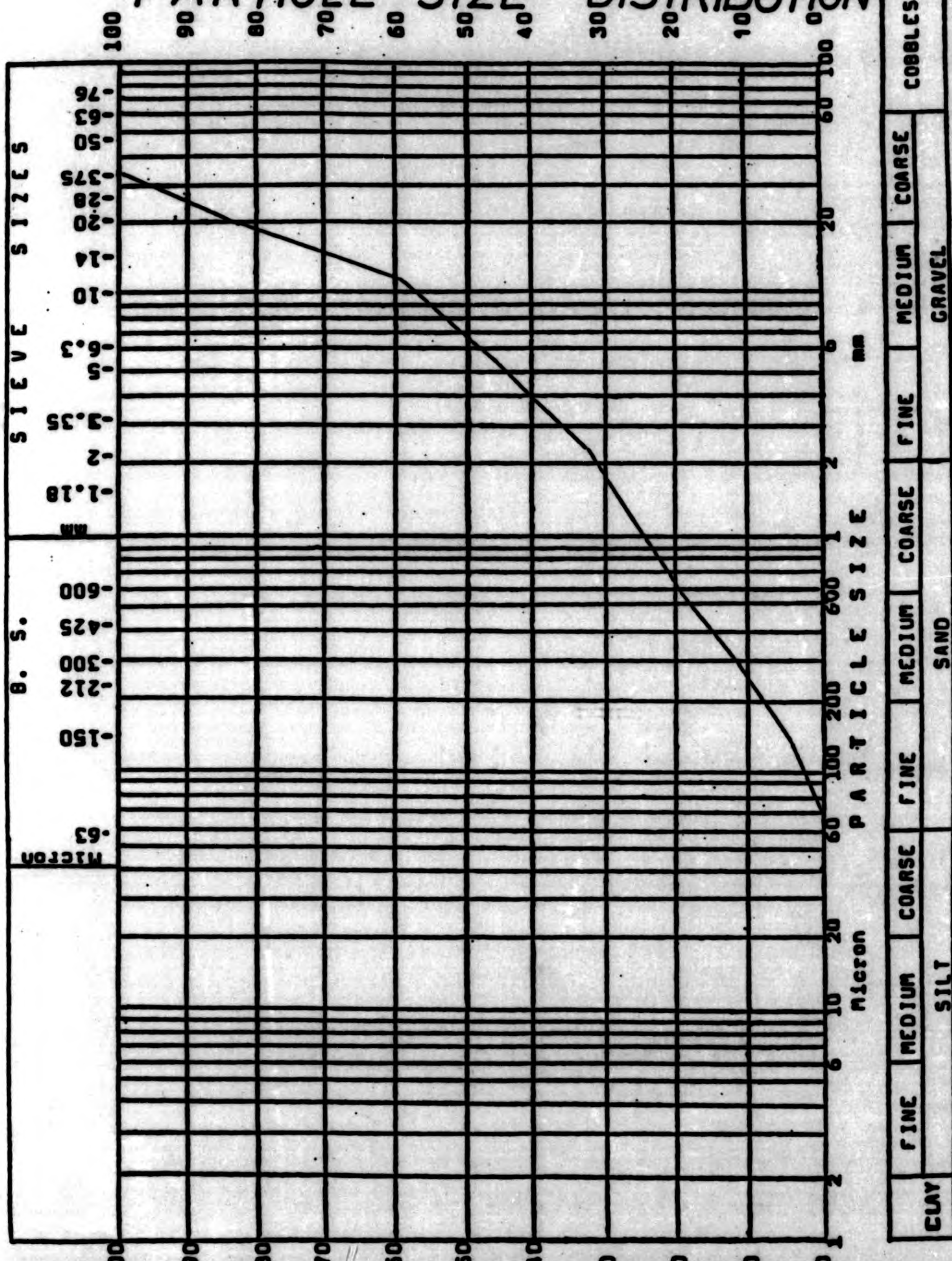

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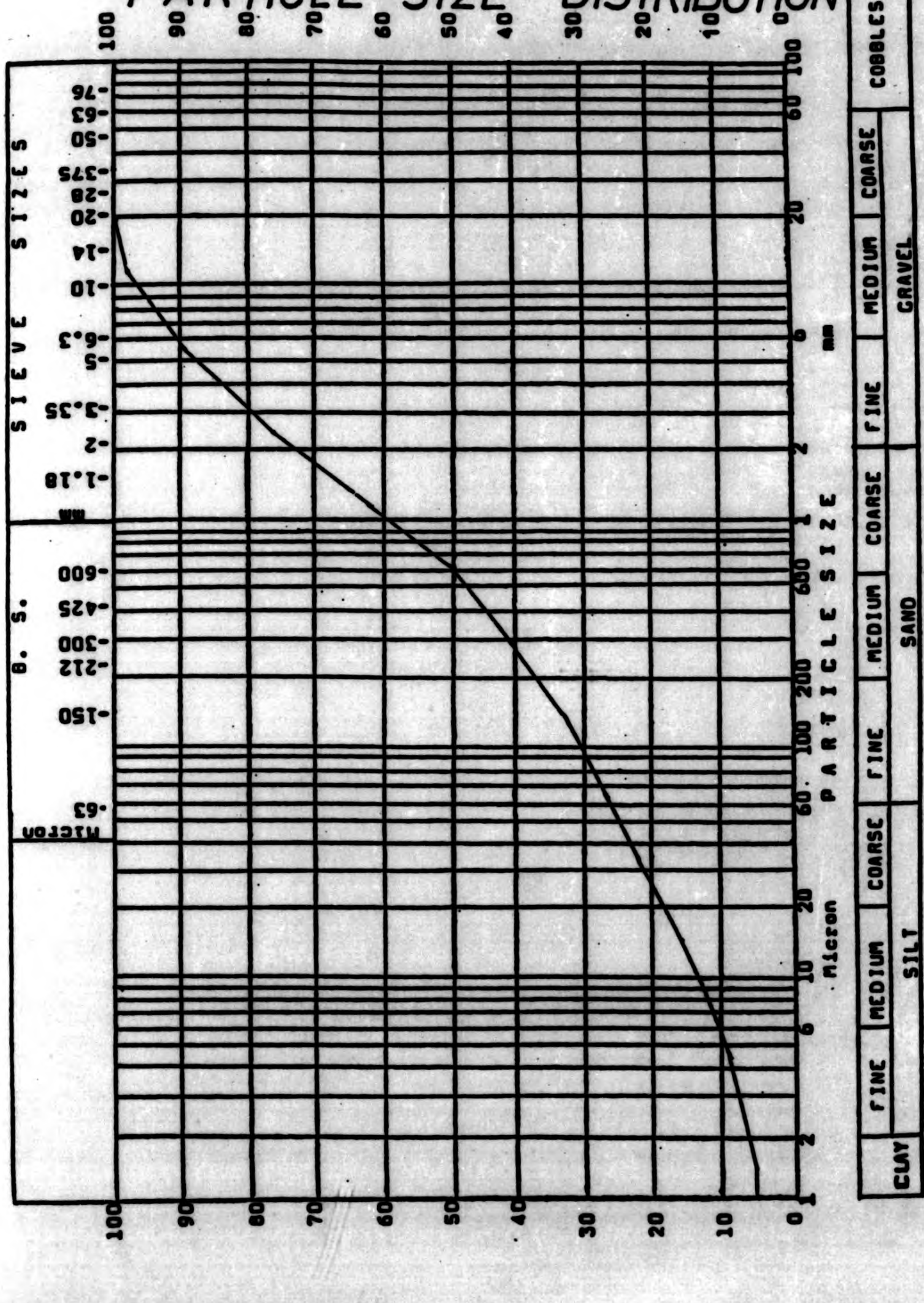

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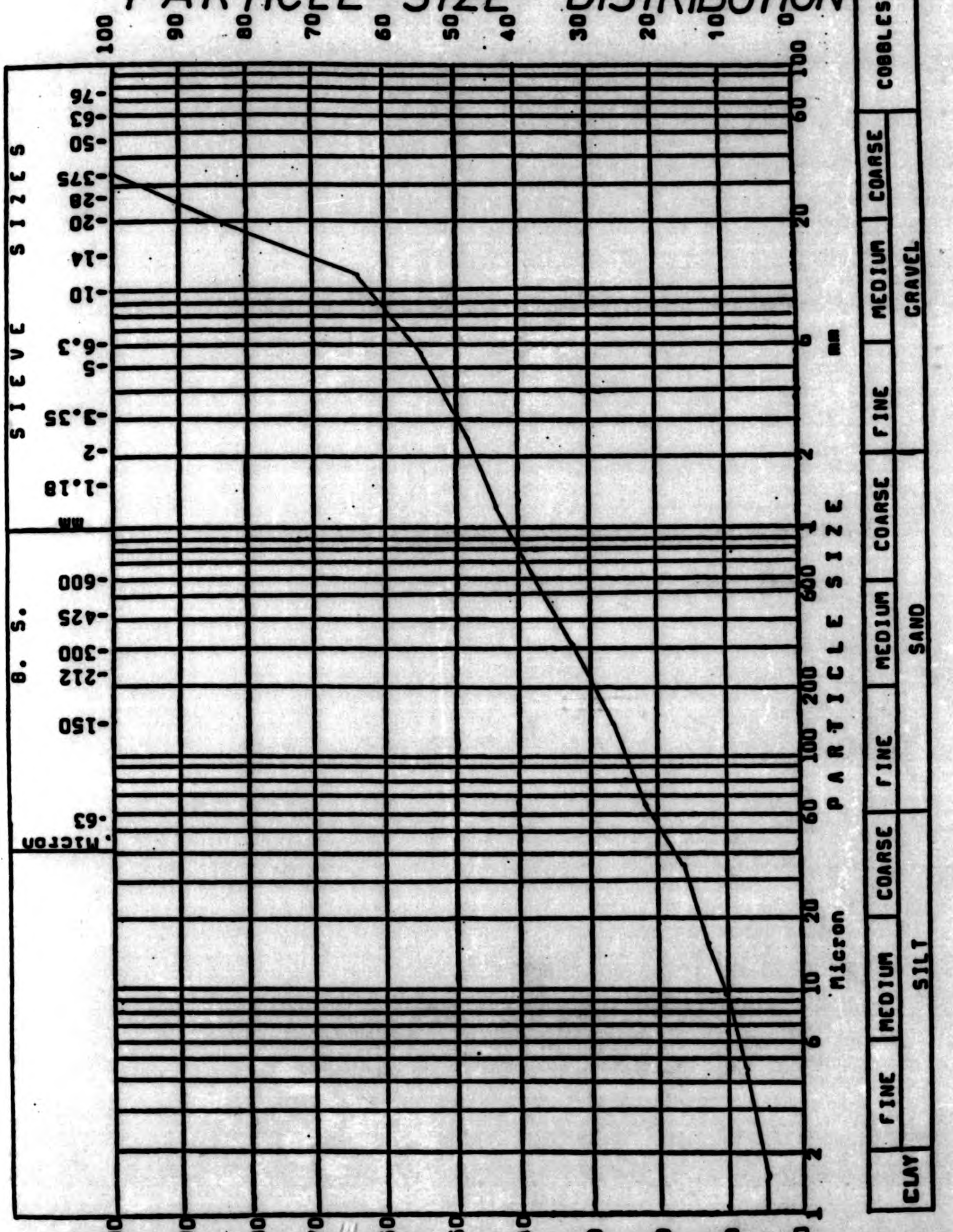

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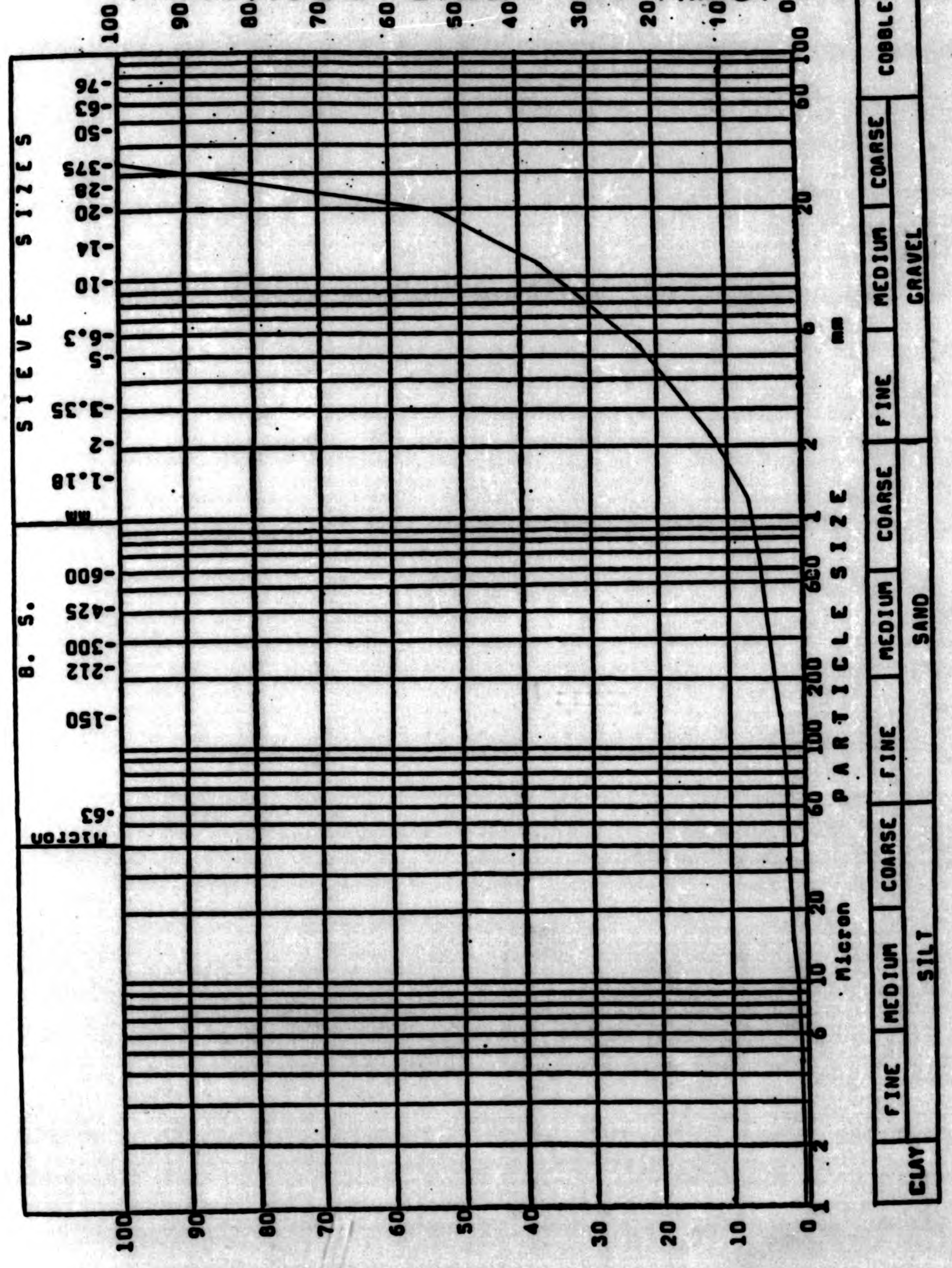

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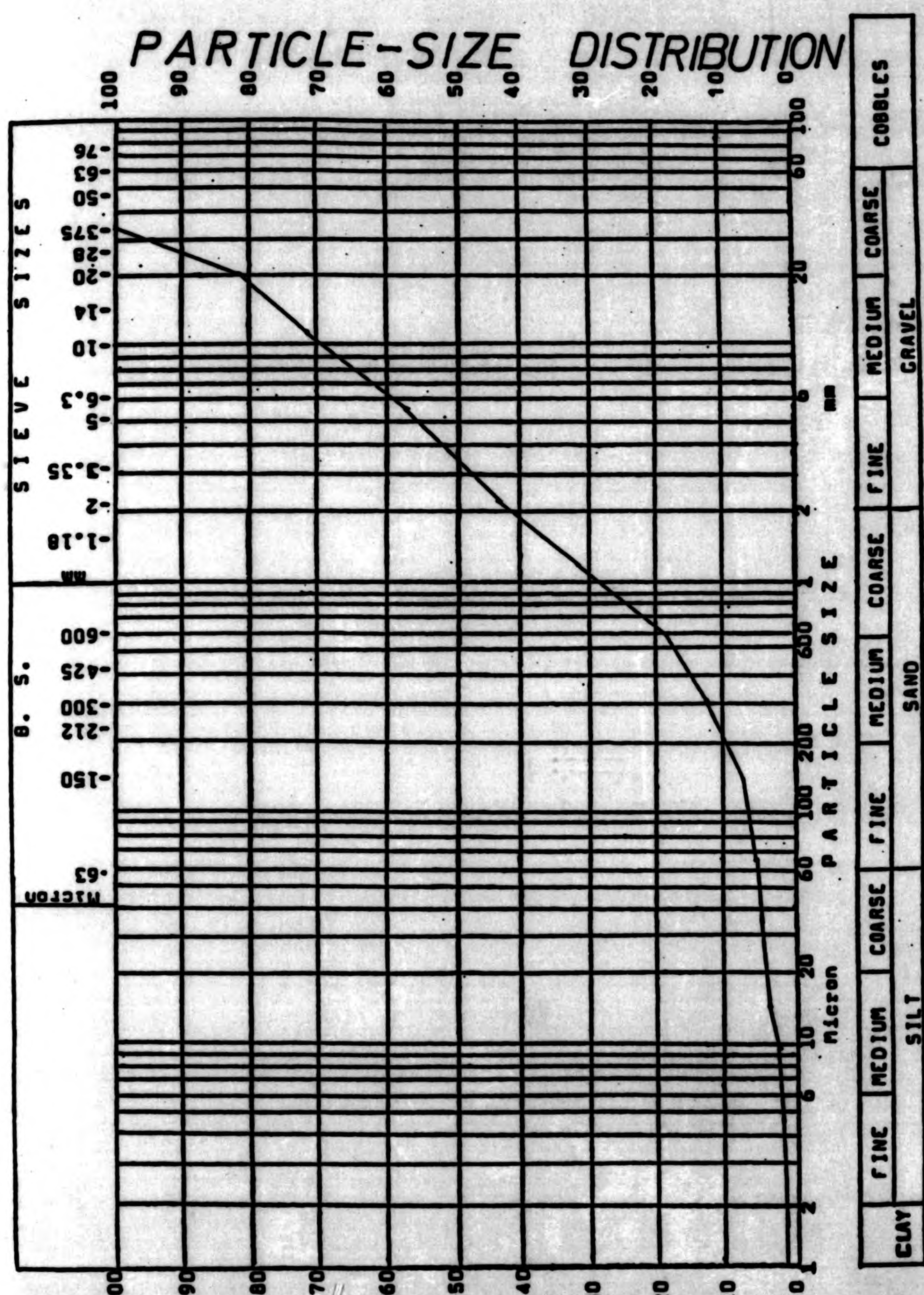

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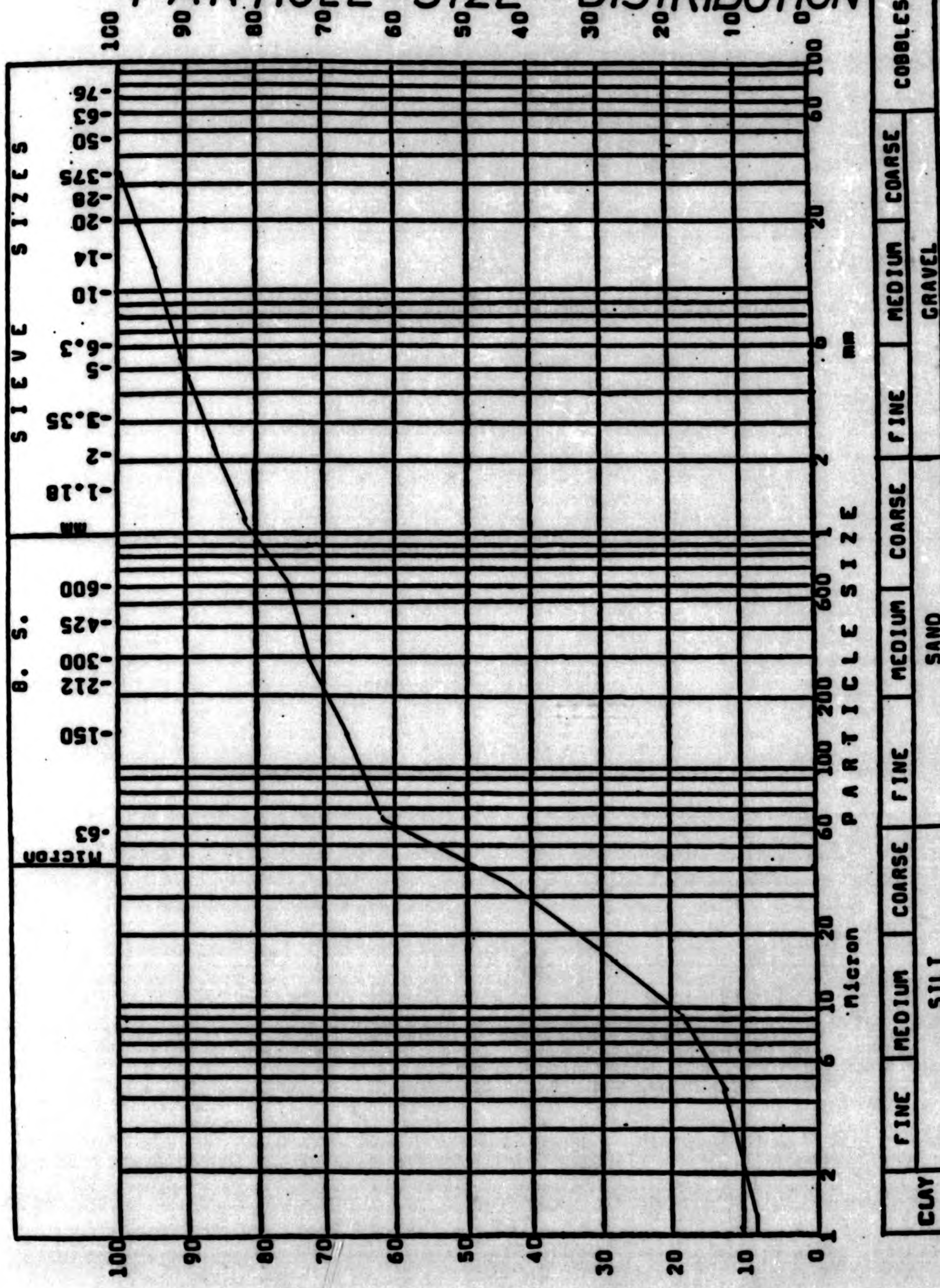
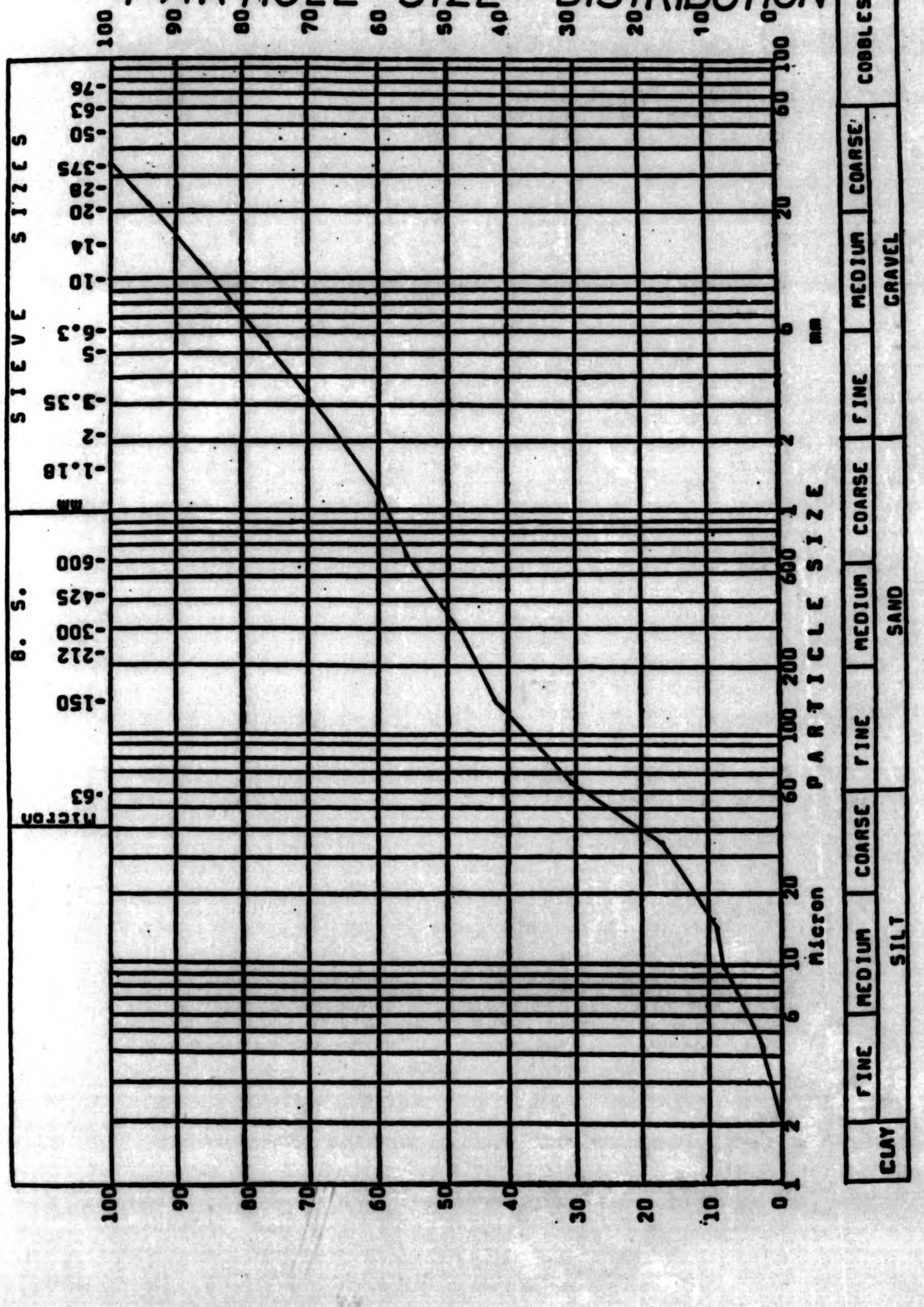
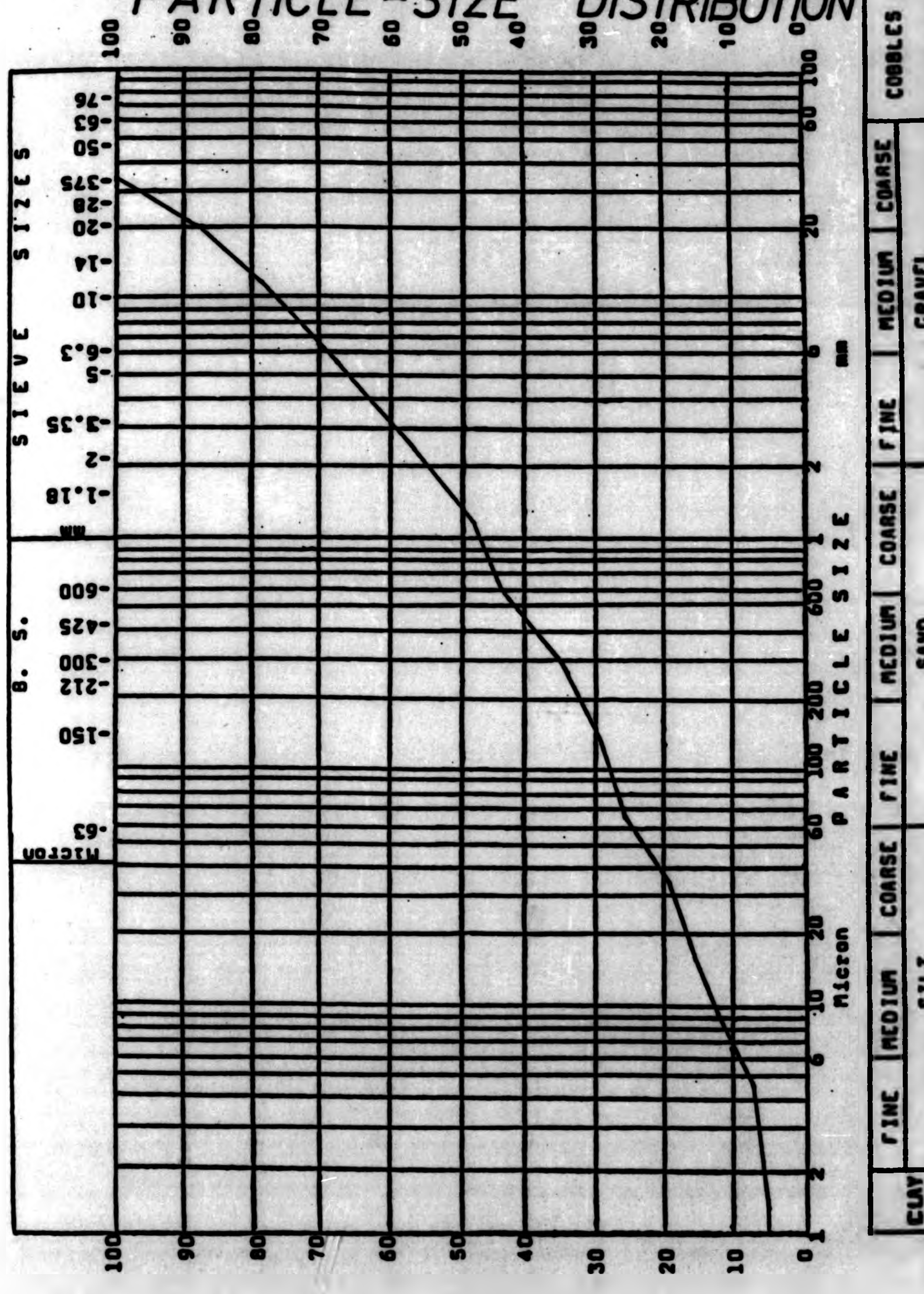


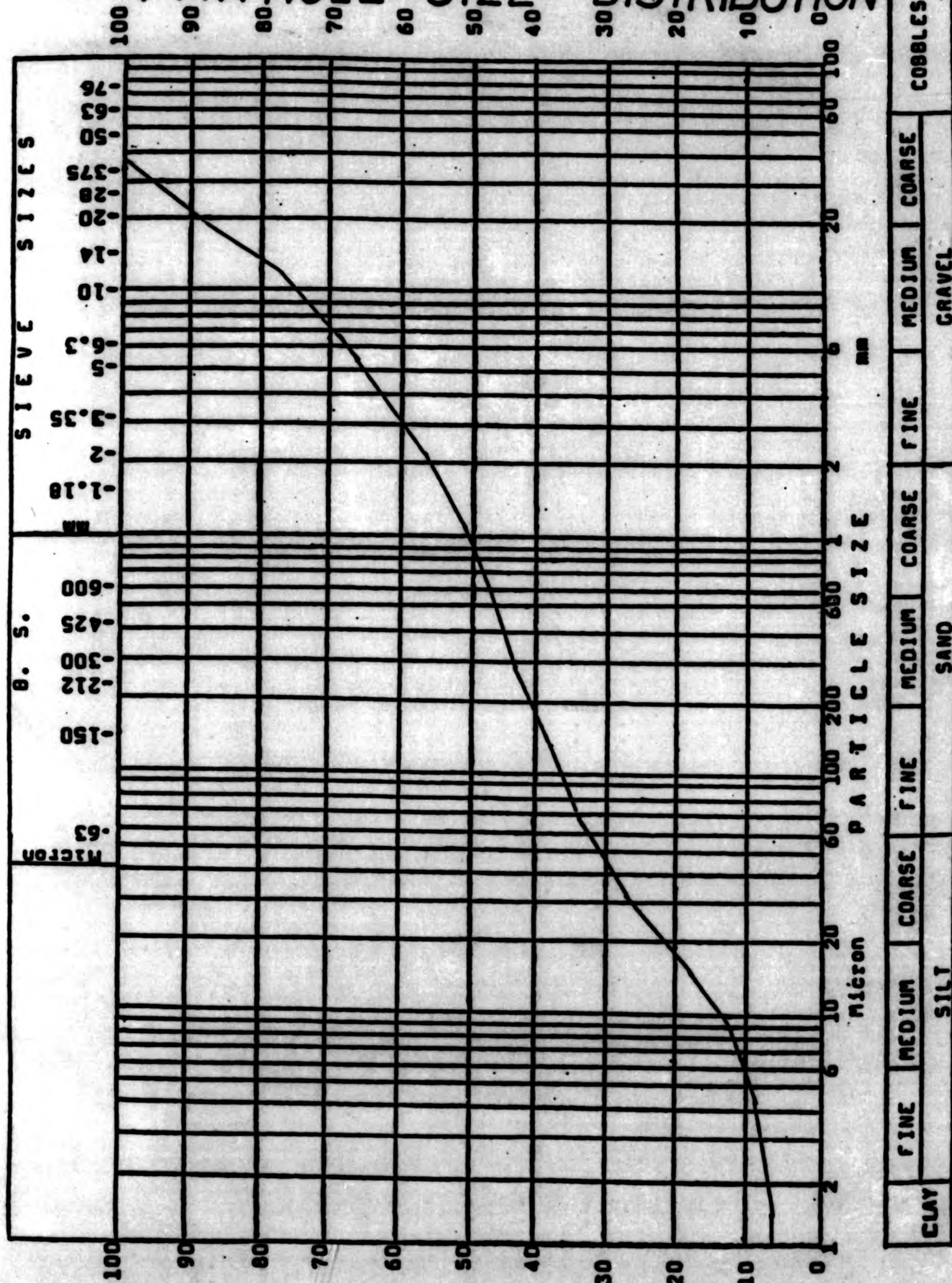
PARTICLE-SIZE DISTRIBUTION



PARTICLE-SIZE DISTRIBUTION



PARTICLE-SIZE DISTRIBUTION



PETROGRAPHIC SAMPLES

Petrographic sample number, 6" O.S. map and grid reference.			Townland
1	7/4	S610125	Glenaphuca
2	7/3	S362101	Knockaturnery
3	21/3	X040097	Ballyin Lower
4	31/1	X241046	Ballinamuck Mid.
5	31/2	X263066	Mosarud
6	31/1	X259046	Ringaphuca
7	31/1	X277055	Knockmaeallia
8	30/2	X210065	Ballylemon Lr. (L)
9	30/1	X176076	Knockgarraun
10	7/1	S362136	Ross
11	36/1	X286087	Rweelaharna (U)
12	22/2	S196066	Tinalira
13	21/3	X039092	Ballyin Lower
14	7/2	S406150	Whitestown West
15	31/4	X290040	Scart
16	6/3	S270130	Knockmaffria
17	7/2	S393145	Clones
18	7/1	S365139	Munsburrow
19	16/1	S453065	Ballyshonock
20	16/2	S496090	Ballyduff West
21	16/3	S432057	Whitestown
22	16/3	S437053	Georgestown
23	17/1	S547064	Orchardstown
24	16/4	S490067	Johnstown
25	17/3	S553057	Slieveroe
26	30/4	X212004	Ballyquin
27	17/3	S542049	Baisk
28	16/2	S526076	Powersknock
29	16/2	S523072	Loughdeheen
30	26/1	X537986	Islandikane
31	26/2	S580010	Tramore
32	5/4	S226133	Shanballyanne (L)
33	5/1	S156165	Rawafune
34	1/3	S195145	Russellstown
35	5/2	S210150	Knockalisheen
36	5/1	S161166	Rawafune
37	5/4	S196106	Curraghteskin
38	5/1	S160146	Clonanav
39	1/3	S152173	Russellstown
40	1/3	S167192	Russellstown
41	14/4	S317047	Knockanacullia (L)
42	14/4	S317047	Knockanacullia (M)
43	14/4	S317047	Knockanacullia (U)
44	23/2	S319037	Gortnalaght (L)
45	1/2	S167202	Kilmacomma (L)
46	14/2	S317063	Coumnahon
47	23/2	S319037	Gortnalaght (U)
48	36/1	X286087	Rweelaharna (L)
49	31/3	X277036	Shahacrine
50	1/2	S167202	Kilmacomma (U)
51	31/4	X309024	Ballynacourty (U)
52	31/4	X313037	Tallacoolmore (L)
53	31/4	X320043	Clonea Lower
54	31/4	X313037	Tallacoolmore (U)
55	31/4	X309024	Ballynacourty (L)
56	34/4	X466960	Ballydowane East
57	33/3	X364975	Ballyvoony
58	27/3	X020964	Coolum
59	27/3	X045967	Coolum
60	27/4	X074969	Fornally
61	27/3	X055968	Ballynacaw
62	26/4	X023996	Lisnalty
63	27/4	S092006	Tynghill
64	27/2	S703036	Knockaveelish
65	25/4	X533960	Kilfarrasy
66	27/1	S034012	Kinsclogue East
67	25/4	X482960	Seavoy
68	25/3	X477964	Dunabrattin
69	27/2	S527065	Summerville
70	5/4	S226133	Shanballyanne (U)
71	40/3	X130766	Monatray East
72	38/4	X194786	Ballyquin (U)
73	38/4	X194786	Ballyquin (L)
74	40/1	X170765	Ardoginna
75	40/1	X166764	Ardoginna
76	36/4	X234805	Ballyvoolinan
77	36/4	X235805	Crobally Lower (U)
78	36/4	X235806	Crobally Lower (M)
79	39/3	X240806	Crobally Lower
80	40/1	X163774	Cappagh (U)
81	39/2	X266534	Ballynamona Lower
82	36/4	X207855	Rathmoyneenagh
83	39/3	X263810	Ballynaharda
84	39/1	X277626	Monagoush
85	39/3	X254806	Ballykilmurry
86	35/1	X183980	Toor North
87	21/3	X045092	Ballyin Lower
88	40/1	X147777	Ballymallagh
89	2/1	S207222	Ourteen Upper
90	38/4	X212004	Ballyquin (lens)
91	5/1	S180136	Kilcreggane
92	26/3	X547964	Caher (U)
93	18/2	S703061	Newtown (M)
94	30/2	X216055	Ballylemon Lr. (T)
95	31/2	X320046	Clonea Middle (M)
96	18/2	S703061	Newtown (U)
97	30/2	X216055	Ballylemon Lr. (U)
98	26/3	X547964	Caher (L)
99	26/3	X544965	Islandikane E. (U)
100	18/2	S702077	Newtown (B)
101	21/3	X062066	Ballyvoo West
102	22/1	S156024	Lyrattin
103	13/3	S169063	Curradoon
104	7/1	S364160	Ballythomas

FABRIC AND IMBRICATION SAMPLES

Fabric sample number, 6" O.S. map and grid reference.			Townland
1	31/4	X312939	Tallacoolmore (U)
2	31/4	X306933	Ballymacourty (L)
3	31/4	X301922	Ballymacourty (L)
4	31/3	X277936	Shehoorine
5	31/4	X319946	Clonea Lower
6	31/2	X332980	Knockyoolahan W. (U)
7	31/2	X331950	Knockyoolahan W. (L)
8	40/1	X147775	Ballymallagh
9	38/4	X210803	Ballyquin (L)
10	38/4	X210803	Ballyquin (U)
11	31/2	X333950	Knockyoolahan W. (M)
12	31/3	X320950	Clonea Middle
13	18/2	S701080	Newtown (M)
14	18/2	S700078	Newtown (B)
15	18/4	S700070	Raheen
16	18/4	S700060	Dromina
17	27/2	S702030	Knockavelish
18	18/2	S706081	Crooke (L)
19	18/2	S705081	Crooke (U)
20	18/2	S706085	Crooke (U)
21	18/2	S705084	Crooke (L)
22	18/2	S704080	Crooke (L)
23	18/2	S702080	Crooke (M)
24	39/3	X253810	Ballykilmurry
25	25/4	X526981	Kilferragy
26	26/3	X545985	Caher (L)
27	26/3	X546985	Caher (U)
28	26/3	X545985	Caher (M)
29	26/3	X547985	Caher (B)
30	26/3	X541985	Islandikane East
31	24/4	X397977	Killelton
32	24/4	X410979	Ballydowane
33	25/4	X459986	Boavey
34	25/3	X474984	Dunabrattin
35	25/4	X481988	Boavey
36	24/4	X332975	Ballyvooney
37	26/2	S530009	Tramore West
38	27/1	S632081	Kilmacleague East
39	27/3	S629006	Summerville
40	26/4	X622996	Brownstown
41	27/3	X656988	Ballymacaw
42	27/3	X646990	Coolum
43	27/4	S693009	Rymphall
44	27/4	X673989	Portally
45	27/3	X686984	Rathmoylan
46	27/3	X628984	Coolum
47	38/4	X206857	Rathnameenagh
48	83/1	S196227	Raheen
49	39/2	X290836	Ballycurreen South
50	39/1	X278810	Monagoush
51	39/3	X288888	Ballynaharda
52	39/3	X236805	Crobally Lower
53	38/4	X234804	Crobally Lower (U)
54	38/4	X224803	Ballyeelinan
55	38/4	X193785	Crushea
56	40/3	X137766	Monatray East
57	40/1	X160795	Ardoginna
58	40/1	X169794	Ardoginna
59	14/2	S017063	Coumnahon
60	83/1	S196226	Clonmel
61	83/1	S196225	Clonmel
62	15/2	S412066	Newtown
63	38/1	X182686	Toor North
64	30/2	X216856	Ballylemon Lr. (T)
65	5/1	S103136	Kilcreggane
66	22/2	S196066	Tinnalira
67	13/3	S100063	Corradoon
68	31/2	X290872	Garranbaun
69	31/1	X241946	Ballynamuck Middle
70	31/4	X290940	Seart
71	6/3	S270130	Knockanaffrin
72	38/3	X248848	Barranastook
73	23/2	S319087	Gortnalaght
74	23/2	S301086	Boolatin
75	16/1	S453085	Ballyshonock
76	5/4	S236133	Shanballyanne (U)

Imbrication sample no.			
1	2/2	S067232	Curteen Upper
2	30/2	X216856	Ballylemon Lr. (U)
3	31/1	X277958	Knocknacalla
4	30/1	X178976	Knockgarraun
5	14/4	S317047	Knockanacullin (L)
6	14/4	S317047	Knockanacullin (M)
7	14/4	S317047	Knockanacullin (U)
8	21/3	X036992	Ballyin Lower
9	21/3	X042990	Ballyin Lower
10	21/3	X043986	Ballyin Lower
11	21/3	X062985	Ballyea West
12	21/3	X062985	Ballyea West
13	31/1	X259946	Ringaphuca
14	31/2	X263986	Monarud
15	7/1	S352136	Rose
16	30/1	X244904	Bawncarrigmaun
17	1/3	S155177	Russellstown
18	83/1	S198225	Clonmel
19	30/3	X180835	Canty

U = Upper part of exposed facies or uppermost facies present.
M = Middle part of exposed facies or middle facies.
L = Lower part of facies or lowest facies present.
T = Uppermost facies where more than one facies is sampled.
B = Basal facies where more than one facies is present.

TITLE The Stratigraphy And morphology of Pleistocene Deposits In County Waterford (with Special Reference To The Ballyvoyle Till)

AUTHOR I. M. Quinn