THE DISTRIBUTION, ORIGIN AND USE OF SAND AND GRAVEL DEPOSITS IN CENTRAL LANARKSHIRE

By

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PREFACE

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Shanks & McEwan

Tinto Sand & Gravel Co.Ltd.

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CHAPTER I

INTRODUCTION

1. The Subject

This thesis is an investigation into the "Distribution, Morphology, Origin and Use of Sand and Gravel Deposits" in a specific area of Scotland. It therefore concerns a wide range of topics, from the location, external form and composition of sand and gravel deposits, to economic factors affecting their utilisation. All of these topics, from physical to economic, are inseparably interrelated, and for each, a separate study is required before any general conclusions can be made.

Most of the sand and gravel deposits in Scotland are the result of fluvioglacial action during the melting of the last ice sheets. For a full understanding of the distribution and qualities of these deposits, it is therefore necessary to determine the source and directions of movement of the ice sheets and the conditions during deglaciation when the deposits were being laid down.

In short, the first task was a complete survey of the glacial geomorphological evidence throughout the area.

The Scottish Sand and Gravel Industry, which utilises the deposits of this glacial period, is very much involved in meeting the requirements of Scotland today. New houses, factories, motorways, redevelopment and expansion, all require the basic products/

products - sand and gravel. This thesis, therefore, not only links the glacial period with the present, but also permits the application of academic research to a problem of economic importance.

2. <u>The Area</u>

The extent of the area to be studied was determined by the time allotted for field-mapping (two summer field seasons). The actual location of the area was determined by three factors:

(1) The occurrence of considerable sand and gravel deposits.

(2) Proximity to Glasgow and the Clydeside Conurbation. (The largest market for sand and gravel in Scotland).

(3) An interesting, yet uncertain, glacial history which indicated a need for further study.

An area of three hundred square miles in Lanarkshire was finally selected. It excludes the northern and southern sections of that county and, although it includes small parts of eastern Ayrshire and Renfrewshire, the area will henceforth be designated Central Lanarkshire. (Fig. 1).

Central Lanarkshire admirably satisfies the first two conditions, as it contains numerous sand and gravel deposits, many of which are already being extensively worked, and it is nowhere more than forty miles from the centre of Glasgow. As a result, this area is of great importance for the supply of concreting material to the Clydeside conurbation area. The third condition, too, suggested/

suggested this area. A survey of the relevant glacial literature indicated that Central Lanarkshire is presumed to have been glaciated, probably contemporaneously, from at least two different directions. Considerable controversy exists, however, as to the areas affected by ice of Highland and Southern Upland origin respectively. Despite this uncertainty, the glacial and fluvioglacial features of the larger part of the area have never been mapped in detail.

Central Lanarkshire, therefore, appeared to offer considerable interest in all three decisive aspects.

3. The Need for the Study

The rapid growth of the sand and gravel industry since the Second World War has left many people unaware of its importance. In 1938 one million tons of these two commodities were produced in Scotland, but by 1965 this figure had increased to an annual output of seven and a half million tons. (Ministry of Public Building and Works Annual County Production Figures). A recent report, (The Scotsman, Edinburgh, p.2. February 2nd, 1966) suggests that the Scottish Sand and Gravel Industry will supersede coal, over the next few years, as the biggest extractive industry north of the border. The Economist (p.1444 December, 1965) contains a report on "Dwindling Resources", and discusses abnormalities arising from the acute shortages which are already occurring, e.g. crushed rock from Wales is being used to build roads in South East England. Peculiarities/

Peculiarities such as this are also found in Scotland. One Loch Lomondside pit has frequently delivered gravel to Dunbar on the east coast of Scotland, whilst gravel has been brought by rail from Inverness to Glasgow, a distance of almost two hundred miles.

The following statistics indicate the huge quantities of sand and gravel which are required by the construction industry; One ton of concrete contains seventeen hundredweights of sand and gravel, one mile of modern road requires eleven thousand tons of sand and gravel, and a major airport would require three million tons. (Sand and Gravel Association Publication No. 2). It is not surprising therefore, that, with the tremendous redevelopment schemes of the Clydeside Conurbation and the Government and Local Authority industrial and road programmes, an enormous demand is being made on the sand and gravel resources in Central Scotland. Nowhere is this more evident than in Lanarkshire where production of Sand and Gravel exceeds that of all other Scottish counties. (One and a half million tons in 1965).

Yet despite the undoubted importance of this industry there are only a few detailed sources of information on Scottish sand and gravel. These include, the annual county production statistics, published by the Ministry of Public Building and Works, a report by the Department of Scientific and Industrial Research, published as part of the Wartime Pamphlet Series (No. 30, 1946) and also published separately by Professor J.G.C. Anderson, who carried out the survey in a booklet entitled "Scottish Sands and Gravels" (British Limemaster).

A/

A third publication by the Monopolies and Restrictive Practices Commission, on "Sand and Gravel in Central Scotland" (1956) is mainly concerned with investigating the pricing structure of the industry and only superficially with the raw materials. There exists, therefore, in the literature very little information on the distribution of resources, the rate at which they are being exploited and the expected life period of those remaining.

The production of sand and gravel is an integral part of the construction industry and a knowledge of the preceding facts is essential to the future wellbeing of both. The present investigation would seem not only necessary but long overdue.

It is probably relevant at this point to indicate another way in which this thesis is felt to be necessary. The reasons for the geomorphological investigation have already been stated, but the available literature on this subject offers several contradictory theories. Much of this uncertainty appears to have been caused by theories of regional glaciation which have been based on only localised research. The present work has the advantage of a now more abundant literature than before of landforms and stratigraphy throughout the area. These advantages together with the availability of new concepts in the theory of glaciation and deglaciation have made this an opportune time to have a "fresh look" at the regional pattern of glaciation in Lanarkshire.

4. Methods and Techniques

The first major task was the mapping of the glacial and fluvioglacial deposits and landforms by stereoscopically studying air photographs, on the scale of 1: 10,000 and transferring all the relevant identifiable landforms on to the appropriate Ordnance Survey six-inch sheets. These maps were than taken into the field and additions and alterations made where necessary. During fieldwork all the available sections were noted and the information on the nature of the superficial deposits and their stratigraphy was recorded.

A number of good exposure sites were chosen which appeared, by their distribution, to afford a fairly representative sample of drift conditions throughout the area. It was hoped that a close examination of these sites would provide detailed information on the different directions of ice movement and on the characteristics of the superficial deposits in the area. The detailed investigations were of two types. Firstly, for the tills, an orientation analysis of the till fabcic was taken. Fifty stones whose "a" axis was notably longer than the "b" axis were normally chosen and for these the direction and degree of dip of the longer axis was measured and the results recorded on a three hundred and sixty degree Polar Equidistant Projection. (Dr. J.T. Andrews in a personal communication, 15.6.66, indicated that a sample of fifty stones taken in this way is as valid as one of one hundred). Other authors too have agreed on the validity of this/

this sample size. (C.A.M. King, 1965, p. 75). Since, however, there is still much dispute as to the significance of fabric studies (J. Young, Analysis of Glacial Deposits near Tala, Midlothian, unpublished Ph.D. Thesis, University of Edinburgh, 1966) no statistical investigations were carried out. Two basic assumptions were made. If the till fabric has a "good pattern" then, (1) the strongest (preferred) orientation indicates the alignment of the movement, and (2) the dip maximum indicates the source of the ice movement. To give an approximate idea of the strength of the orientation the apparent peak maximum is shown on the till fabric diagrams and the percentage number of stones which lie in the associated "peak maximum" quadrant (i.e. within 45° on either side of the apparent maximum) is calculated.

Random field observation of erratic distribution and rock type contents was thought to be an unsatisfactory method of collecting data which has considerable potential in explaining ice movement directions. To attempt to place this on a firmer statistical footing the following procedures were carried out. To assess the percentage composition of the rock types found in tills a representative sample of fifty stones greater than three sixteenths of an inch in diameter was taken. (obtained during laboratory sieving operations). For gravels, a random sample was obtained in the field and after washing and quartering in the laboratory, the rock types of a sample of fifty stones was noted. Where the gravel deposit concerned was being actively worked, washed and/

and graded samples of coarser and finer gravels were also made available by the owners which allowed a fuller inspection of the factors affecting the variation of rock types in commercial gravel. In all of these tests it was found, by repeated experiments, that fifty pebbles gave a representative sample of the rock types involved. Some orientation studies were carried out on sand and gravel deposits, particularly when these were well stratified. Particle size analyses of lake deposits, fluvioglacial outwash, eskers and other distinct morphological features were undertaken in the hope that they might provide further information on the conditions of deposition and commercial potential of different landform features. The actual procedures involved are described in the relevant chapters of the text.

The sieving programme was also extended to the tills. From thirty of the sites already mentioned representative samples were obtained, (conforming to British Standards 1377 p. 17), in an attempt to determine any relationships between the till characteristics of colour, particle size composition, rock types, source and regional variation. These samples were sieved under laboratroy conditions using coarse sieving and hydrometer analysis methods. (See Appendix 1). The results of all the particle analyses were plotted in graph form.

Another source of useful information into the sub-surface conditions, even when exposures are not available, is borehole records. Unfortunately, since most of Central Lanarkshire is to the/

the south of both the main coalfield and the Clydeside Conurbation Area, this borehole information is more limited than is usual for Central Scotland. Two main sources of records are available. The Geological Survey of Scotland headquarters in Edinburgh has collected a large number of these records mainly from the private coal mining companies prior to nationalisation. Many of these bores were put down in the last century with the main purpose of determining the location of coal seams. As a result the evidence they contain relating to drift deposits is often sketchy and requires care in interpretation. More recently, however, several important road, sewer and aqueduct developments have been carried out by public and private authorities and the boreholes put down for these projects are usually of a much higher standard than those mentioned previously. They are of considerable assistance in establishing the nature of stratigraphy of the superficial deposits.

In the Upper Avon Valley there is a particularly well defined association of fluvioglacial landforms, the interpretation of which is essential to the understanding of the deglaciation of this area. The only available large scale map, the O.S. six inch series, has a one hundred foot contour which does not help in the understanding of the relationships of these forms. The area also contains one of the two largest sources of sand and gravel in Central Lanarkshire. For these reasons it appeared to merit considerable attention and much of it was accurately surveyed using a Kern automatic level. With the O.S. six inch map providing a base for the location of the levelled/

levelled points, a grid of points, whose height was accurately determined, was constructed. From this data a map with a ten foot contour interval was constructed. This map provided much useful information on the origins of the landforms and the commercial potential of the sand and gravel resources in the area.

5. The Organisation of the Thesis

Chapter I has so far presented introductory matter on the scope of the thesis, the need for the enquiry and the methods used. The remaining sections of this chapter contain background information essential for a clear understanding of the text of the thesis itself. This section reviews the organisation of the thesis.

Many of the areas mapped have a great wealth of geomorphological detail and for ease of presentation the area was divided into three sections. Thus chapters II, III and IV contain the relevant information derived from the fieldwork evidence in the separate areas. Chapter V presents the overall circumstances of glaciation in Central Lanarkshire as indicated by this evidence.

These conclusions on the glaciation and deglaciation of Central Lanarkshire lead directly on to a discussion of the deposits of sand and gravel in this area. The relationships between their fluvioglacial origin, distribution and morphology will be indicated in the regional chapters but in Chapter VI the factors influencing the sand and gravel industry in Central Lanarkshire, whether physical or otherwise, are discussed.

Chapter VII presents a summary of the main conclusions arrived at in the thesis.

II Central Lanarkshire: Relief and Drainage

In its location and terrain Central Lanarkshire has a certain measure of distinctiveness (Fig. 1). It is neither Lowland nor Southern Upland in aspect but combines certain features of both being a transitional area between the two. Its core is composed of a series of plateau-like surfaces stretching between Glassford, Lesmahagow and Braidwood at altitudes ranging from four hundred and fifty to six hundred feet. These plateaux are surrounded by a discontinuous ring of hill masses, Corse Hill (1,330 feet) in the north-west, and Dungavel/Hagshaw Range (1,500 to 1,700 feet) in the south-west, the frontal ranges of the Southern Uplands proper to the south, Cairn Table/Tinto (1,900 to 2,300 feet) and the less continuous foothills of the Pentlands (800 feet) on the east (Fig. 2).

Both the plateaux and the hill masses have been greatly dissected by rivers, which, as a result of the disposition of the hill areas, tend to flow towards the north centre of the area, e.g. the Avon, Nethan, Douglas, North and South Medwins and the Mouse. All of these are tributaries of the north flowing Clyde. The only exception is the Irvine which flows westward to the sea, via the gap at Loudoun Hill. Most of these rivers breach the encircling/

encircling hills to form notable channels of access, as important today as in the distant glacial past.

III Central Lanarkshire: Geology

Since the area is transitional between the Southern Uplands and the Central Lowlands it might have been expected that the rocks would become younger to the north. Due to the severity of folding, faulting and erosion, this is not the case. Instead, Silurian rocks, the oldest, are frequently found adjacent to Carboniferous rocks, the youngest. (Fig. 3). The middle series, in age, Old Red Sandstone, occurs as discontinuous though sometimes extensive outcrops throughout the area.

Whilst the north-east to south-west Caledonian trend, first initiated in Silurian times, can still be seen to influence the surface configuration of the southern areas, e.g. the orientation of the Douglas Valley, most of the area is without any marked orientation of geological origin. Nevertheless the varied scenery so characteristic of the region, (M. and A.G. MacGregor 1948 p.1), can be directly related to the geology and for this reason the main groups of rocks will be discussed in some detail.

The oldest rocks in the area are Silurian and largely of Downtonian age. They occur in two districts, (a) the anticlinal inlier of the Hagshaw, Nutberry and Dungavel Hill areas, and (b) an interrupted belt along the southern boundary of the area. They consist of grey sandstones, grey, flaggy and sandy shales, blue shale and bands of hard greywacke (A. Geikie et al 1873 p.9).

In/

In the first area they occur as an upland or hilly district. In the second area a less perfect relationship is found, and the Silurian strata frequently underlie valleys, e.g. in Carmichael Parish to the north of Tinto Hill.

The next formation found in the area is the Old Red Sandstone series. The actual junction of the "Old Red" and the Silurian strata is conformable and has led to considerable dispute as to the age classifications of the various beds concerned. A good example of this is the very distinctive conglomerate beds with their peculiar features, viz. an abundance of well-rounded quartz rock fragments. (These quartz pebbles are important in the study of erratic distribution in later chapters). These beds were described by Peach, (A. Geikie et al 1873 p. 13), as Old Red Sandstone in age but appear on more recent geological maps as being of Downtonian (Upper Silurian) age. The sedimentary beds of this age are basically chocolate, grey, green or purple in colour and range from mudstones to coarse conglomerates. A separate volcanic series of old Red Sandstone Age is found along a fault zone marking the southern boundary of the thesis area.

A very important group of igneous rocks is found intruded into the lower Old Red Sandstone and Upper Silurian strata. The largest of these intrusions is that forming the Tinto Hill mass, but they also occur at numerous localities in a south-west to north-east belt from Muirkirk to Lesmahagow and reach the river Clyde at Hazelbank. They "consist chiefly of felstones of various shades, from/

from white or cream-coloured, through hues of pink into dark brown". (A. Geikie et al 1873 p. 16). The locations of these outcrops are usually strikingly conspicuous, especially where they are surrounded by less resistant sedimentary rocks, for they always form isolated, upstanding, hill masses, e.g. the three Black Hills, Tod Law, Auchrobert Hill and the more widely known Cairngryffe and Tinto Hills. (Fig. 2).

As already mentioned Carboniferous rocks occur extensively in the area and underlie at least part of its boundaries in the north, east, south andwest. There are three main locations; a northern one from Kilcadzow to Loudoun Hill in a belt which widens towards the west; the Carstairs/Pettinain/Carnwath area and an extensive basin to the south and south east of Lesmahagow extending by a narrow corridor into the Douglas Valley. Where the boundary lines of the Carboniferous strata are not faulted they invariably rest unconformably on the rocks of the Old Red Sandstone Age. Sandstones, clays, shales, limestones, coal and volcanic rocks are all represented.

The different types of rocks tend to have their own particular topographic expression. The coal, limestone, clay and shale groups form the lowest ground in the thesis area. This is especially true in the north-central area where the combined erosive effects of the main rivers have led to valley floors as low as two hundred and fifty and one hundred and fifty feet above sea level in the Avon and Clyde valleys respectively. "The Millstone Grit/

Grit series, where not covered by drift deposits ... everywhere gives rise to bleak moorlands as in the Brokencross Muir and Poniel Hills" (A. Geikie et al 1873 p. 37).

The volcanic rocks are either in the form of bedded lavas or intrusive "plugs". The lavas are found particularly in the north-west and to a lesser extent in the extreme east. "They form part of the long bank of porphyrites, metaphyres and tuffs which sweeps round the western margin of the Clyde coalfield". (A. Geikie et al 1873 p. 138). They generally appear as craggy hill masses rising to just over one thousand feet. Of the intrusive "plugs", so characteristic of Central Scotland, there is only one of any morphological importance, Loudoun Hill, which rises as a rugged, craggy, circular mass on the western boundary of the thesis area at the Irvine/Avon watershed.

These are the most important of the rock formations and the types of terrain with which they are associated. Many of them are vital to the study of glacial history and as such will be mentioned in their relevant contexts in later chapters.

IV Resume of Previous Work

There has never been a complete and detailed account of the glaciation and deglaciation of Lanarkshire but a great deal of useful material has been published on this subject. Most of it, however, consists of descriptions of stratigraphy and deposits gained from one or more exposures. Frequently this purely localised research has been used as the basis for regional interpretations.

interpretations./

interpretations.

This chapter is an attempt to review all the literature specifically relevant to the thesis area. The intention is to try to introduce the background of previous and present ideas on the area in the light of which the present work was performed.

The literature available covers a period of just over one hundred years, from 1863 to 1966. Prior to 1863 considerable confusion existed as to the origin of the "drift deposits" which cover extensive areas of Scotland. The Great Flood and other cataclysmic events were widely held as the reasons for their existence. Gradually, however, after the visit of Agassiz to this country in 1840 and with the spread of his ideas, the theories of glaciation assumed greater prominence. This process took place step by step and to fully understand its development in Lanarkshire it will be useful to look at the literature in a similar manner, dividing it into three parts according to the date of publication 1863 to 1901, 1902 to 1950, and 1951 to 1966.

The First Period - 1863 to 1901

The general realisation of glaciation and its role in the explantation of the evolution of the landforms of Scotland occurred during this period. The development which took place at this time probably owes more to Archibald Geikie than to any other man. In 1863 he published his paper on the "Glacial Drift of Scotland"/

Scotland" and in this he gave a general yet detailed account of the processes and effects of glaciation. This remarkable work could, with only minor alterations, be as useful an introduction to glaciation today as it was then. The key to Geikie's revolutionary insight was certainly his astute and accurate observations, many of which were recorded in Lanarkshire.

He was first to introduce perhaps the most important characteristic of glaciation in Lanarkshire; that it was effected simultaneously from at least two different directions. "The (ice) streams would abut against and overflow the chain of the Kilpatrick, Campsie and Ochil Hills; so as to debouche upon the long central undulating plain of the Clyde and Forth. From the high ground in Lanarkshire and Peebles, extending north-eastward ... the ice would, in like manner, descend upon the plains and join the Highland stream. The united mass would thus cover the wide area of the Central Lowlands" (A. Geikie 1863, p.83). This conclusion was only reached after a careful investigation of the directional evidence of glacial striae, erratics and the source areas of stones found in tills (Fig. 4).

Geikie also noted and accurately described many of the most conspicuous localities where the drift of Lanarkshire, till, sand and gravel, laminated and brick clays, could be examined. One immediate result of his work and its tremendous influence on his/

his followers was that much of the research undertaken since has been confined to the deposits and sites to which he refers.

Thus, the "Kames of Carstairs", "a network of anastamosing sand bars and mounds, enclosing an endless succession of basins", (Geikie 1863 p. 113) are probably more discussed in the literature than any other Scottish geomorphological features. Other features in Lanarkshire which he found "exceedingly puzzling", despite further attention and discussion, have been in many cases no more satisfactorily explained since his time, e.g. the abandoned gorges of the Mouse Water at Lanark.

Other researchers of this period, e.g. Bryce, 1865, Hunter 1877 and Smith 1899 described various sections and localities, all of which provide useful local background material, as well as information on the nature of the deposits. None of them, however, advanced the explanation of the deposits any further and were even more uncertain than Geikie as to the relative importance of land ice, icebergs and marine submergence in their formation. Their conclusions, therefore, tend to be at variance with each other and are often misleading. Even in 1900 J. Smith, who presented an extensive catalogue of exposure descriptions, in his paper, "The Drift or Glacial Deposits of Ayrshire" still asserted that, "the great vertical cliff on the South side of Loudonhill was very likely the work of waves, perhaps assisted by shore ice" and that the smooth bench below, at an altitude of seven hundred feet, was a "marine terrace". (Pl1) Indeed, because of the misleading origins deduced/

deduced for the shelly drifts, the concept of marine submergence up to an altitude of 1,100 feet was still held by at least one other author in the nineteen twenties. (Gregory 1927).

It is from J. Geikie, the brother of Sir Archibald Geikie, and the regional officers of the Geological Survey in Scotland that the remainder of the information of this period is obtained. J. Geikie provides more evidence as to the directions of ice movements in Lanarkshire. "The general trend of these striae show that the ice has moved from the south; but in the upper reaches of the Avon Valley and in the hilly district to the west of Strathaven, the ice markings point away from north-east to south-west. In the Muirkirk district the direction is from south-east to north-west. At Douglas and Lesmahagow the direction is from south to north; and from south-west to north-east, on the flanks of Tinto". (J. Geikie 1873 p. 41).

He also introduced in his book "The Great Ice Age" another characteristic fundamental to the understanding of the glacial history of Lanarkshire. "The ice currents were occasionally deflected and forced to go another way. The great stream that crept across the Central Valley of Scotland was certainly at times turned out of its normal course - now towards the south by the pressure of the powerful current of ice that poured from the Highlands and again towards the north when the ice stream coming from the Southern Uplands overpowered and forced back the other; in short there was a "debatable ground" between the north and south over which sometimes the/

the one and sometimes the other prevailed" (J. Geikie 1894 p.77). It can be seen therefore that even by the end of this first period several very definite impressions of glaciation of Lanarkshire had emerged (Fig. 4) a variety of deposits had been described and evidence presented, in the form of beds containing animal and vegetable remains intercalated in the till, which indicated warmer phases during the glacial period. (J. Geikie 1894 Chapter IX). Publications on glaciation and its effects were abundant in journals. The "submergence theory" was only maintained by a few individuals. The prospect for the future looked bright indeed.

The Second Period - 1902 to 1950

During the years preceding 1902 the Lower Clyde and its estuary had absorbed much of the attention and the energy of workers investigating the regional glacial history as the great number of catalogues of shell information, collected during this period, still testify. From this time, however, despite a general decrease in the "glacial literature", more thought and effort was applied to the wider implications of glaciation in the Middle and Upper Clyde areas. Two authors in particular emerge as providing the main attempts at regional interpretation, Gregory and Charlesworth. Their publications, concentrating again on the areas described by the Geikies, provided further material and new ideas on the outlines of glaciation already provided by the workers of the first period.

Gregory was still trying to formulate definitions and a terminology/

terminology for glacial and fluvioglacial forms (Gregory 1912a, 1912b) and his interpretations and now generally discarded terms, e.g. pseudo-kames and glacieluvial deposits, have lead many authors to discount his conclusions (Charlesworth 1926, Linton 1933). He maintained that the Carstairs deposits were "The typical examples of Scottish Kames and this, despite many points of external resemblances to some Swedish eskers ... for they show no seasonal banding." (Gregory 1915a p. 187).

In his description of the Carstairs deposits Gregory noted the marked difference between the three main ridges of coarse gravel, with their sharply defined north-facing slope, and the moundy, less angular, sandy area to the south. "In the ridges amongst the bedded gravels with the layers of coarse pebbly sand ... the stones are always thoroughly waterworn; I have never found a glacially striated pebble."(Gregory 1915b p. 471). The irregularly undulating area to the south composed of finer sands and clays containing many boulders with "well-preserved glacial striae" he regarded as "clear evidence of deposition in the quiet waters of a lake" (Gregory 1915b p. 472) and as a result of this evidence he concluded that the Carstairs deposits were kames laid down by meltwaters along the edge of two confluent glaciers from the Southern Uplands. The more southerly inter-kame sands and lacustrine clays were laid down in a proglacial depression left on the recession of the ice front. The external form of the kames he explained by the denudation of the fluvioglacial sheets by meltwaters issuing/

issuing from the ice.

Probably the most concerted attempt to explain the events during the last glaciation of Lanarkshire was that of Charlesworth (1926). His "preliminary attempt at broad generalisation", (M. Macgregor 1948), had the advantage of the then more abundant literature, which he used to the full, but, apart from his new idea of a general readvance of the ice sheet, his conclusions on the relative distributions of the different ice masses tend to be a reversal of those of all previous work; he disagrees especially with Gregory's conclusions.

Charlesworth concludes that during the last glaciation of Lanarkshire, the ice streams from the Southern Uplands and the Highlands were confluent and that the limit of the Highland ice advance was in the neighbourhood of Symington, i.e. beyond the southern boundary of the thesis area. From the evidence of numerous very widespread localities he recognised the existence of a "Marginal Kame Moraine" stretching from St. Abbs on the east coast to Stranraer on the west coast (Fig. 5). An essential part of this system was the "Carstairs Kames" of Gregory. After reviewing all the previous literature he concludes that "in the face of this apparently overwhelming evidence, the writer contends that the Carstairs Moraine was formed, not by a glacier issuing from Upper Clydesdale but by Northern ice of Highland origin". (Charlesworth 1926 p. 35).

His main evidence in support of this conclusion is that the Carstairs system is continuous with similar deposits to the north-

east/

east and south-west which are also part of his "Readvance Moraine". The steep north-facing slope of the "kames" he regarded as being an ice contact face and from his map (Fig. 5) it seemed obvious that expansion of Highland ice from its "Eaglesham - Carluke stage" would thrust forward to the position of the "Carstairs Moraine" (Charlesworth 1926 p. 37).

His reinterpretation, therefore, envisaged a much greater incursion of Highland ice into Lanarkshire than had been considered by his predecessors. All the surface deposits as far south as Symington and including those at Thankerton, were regarded as being due to the advance of Highland ice. His ideas on this latter area were substantially reaffirmed by Linton in 1933.

The most notable among other contributors during this period were the regional officers of the Geological Survey. Their contributions, however, are usually confined to a few paragraphs on new borehole evidence (Ross 1926) on pre-glacial buried river channels (Dinham 1921) or on additional information on the more controversial topics, e.g. Macgregor's paper on Carstairs (M. Macgregor 1927). In some cases material collected in localities beyond the boundaries of the thesis area provides an insight into the events within its limits. Bailey, for example, in 1930 adds some new information on the Ayrshire areas covered by ice from the Highlands and the Southern Uplands respectively. He also coins the phrase, "Southern Uplands Sanctuary" for that area, which, because of its covering of ice derived from the south, escaped invasion by Highland ice./

ice. (Fig. 6).

Phemister's paper in the Summary of Progress for 1925 is an exception in that his was the first comprehensive work on the vast sand and gravel deposits of Upper Avondale (Fig. 7). He visualised the ice mass covering the area as melting downwards, leaving the highest areas as the first to become ice-free. The retreating ice frequently left behind "stranded rotting cakes of ice" and this accounts for the moundy spreads left behind chiefly at higher levels. "The ice margin melted northwards and after the ice disappeared from the tributary valleys, the evidence shows that the ice in the through valley (Irvine/Avon) was split into two lobes, the one continuous with western ice in the Kilmarnock area and the other with eastern ice in the Clyde". Thus Phemister envisaged an extensive lake damned by ice to the east and west and having as its earliest overflow, the gap at Deadwaters (710 feet). It is to deposition of this lake, by streams from the west, that he attributes the extensive terraces at or about seven hundred feet between Loudoun Hill and Drumclog.

Whilst many additional techniques and much application of new ideas had taken place during this second period, the most influehtial work was undoubtedly that of Charlesworth. The most significant fact of his work in the thesis area was that he completely discounted the geomorphological importance of Southern Upland ice despite the considerable evidence of previous workers to the contrary. His work,too, had great influence on succeeding workers/

workers and his conclusions have been widely accepted and repeated in subsequent literature.

The Third Period - 1951 to 1966

The literature of the third period is limited and largely composed of the works of two authors, Goodlet and Sissons. In an early paper, written in co-operation with McCall (Goodlet and McCall 1952) Goodlet uses the erratic contents of the drifts of Peeblesshire and Midlothian, areas to the east of the thesis area, to determine the source and carry of the local ice streams. Two main conclusions are reached:

(1) Highland erratics are normally only found in the most easterly area and then only in the lower boulder clay and sands and gravels, while rocks from the Southern Uplands, viz. Tinto Felsites predominate almost to the exclusion of Highland rocks thoughout the Peeblesshire area and in the most recent boulder clay (Roslin), of the Midlothian area.

(2) The most recent readvance of ice in the area was an ice stream from the south-west (Southern Uplands). A similar conclusion was arrived at in a later paper by Bailey and Eckford in 1956.

It is, however, in J.B. Sissons' papers of 1961(a) and (b), 1963 and 1964 that a new approach, to the old problems of glaciation in Lanarkshire, is found. His 1961 (a) and (b) papers present some of the first attempts at accurate geomorphological mapping in Central Lanarkshire (Fig. 8). By applying the concepts of stagnation and downwastage and using the evidence of fluvioglacial erosion and deposition/

deposition (ideas already hinted at by Phemister 1925 and Charlesworth 1926 but more fully developed by Flint 1929 and Mannerfelt 1945), he was able to present a more detailed account of the events and landforms produced during deglaciation. Using these "new ideas", a more precise terminology and a clearer assignment of certain processes to associated landforms he was able to arrive at certain definite conclusions about the area and about the work of earlier authors.

In the Carstairs/Thankerton area he reaffirmed the south-west to north-east ice movement envisaged by the Geikie brothers in the previous century. In the same area he indicates additional evidence of an extensive lake (Lake Clyde of Charlesworth 1926) caused by the blockage by ice of the Lower Clyde. He also points out that "the absence of end moraines and the existence of wide spreads of almost featureless till mantling hill slopes accord with the view that the last ice sheet to cover the Southern Uplands decayed in situ without significant movement" (Sissons 1961 (a) p.192).

Sissons 1961 (b) paper provides a reinterpretation of Charlesworth's "Lammermuir/Stranraer Moraine". The central part of this "moraine" is dominated by the Carstairs system and Sissons concludes that "The Carstairs ridges are, in fact, a complex esker and, like the Thankerton esker system further south, form part of the extensive glacial drainage system of the Southern Upland ice sheets which trend towards a direction between north-east and north".

An earlier worker, J.B. Simpson, had in 1933

distinguished/

distinguished two late glacial ice readvances in the Highland margin districts of Scotland. His penultimate readvance has come to be known as the Perth Readvance. On the evidence of stratigraphy and landforms, Sissons, in his 1963 and 1964 papers presents considerable evidence indicating that all of Lanarkshire except for certain nunatak hill masses, was inundated by this sheet. Although the limit of this readvance in Central Lanarkshire is not entirely shown in his 1963 and 1964 papers, Sissons in a later publication (The Geology of Scotland 1965 Edited by G.Y. Craig Chapter 14) suggests that the whole area of Central Lanarkshire was overrun by this readvance. In a personal communication, (11-10-66), he suggests that considerable detailed fieldwork is required before the limit of this readvance could be shown with certainty.

The most recent paper on the area is by Goodlet on "The Kamiform Deposits near Carstairs, Lanarkshire" (Goodlet 1964). In this he presents new stratigraphic evidence made available by extensive sand and gravel excavations. His conclusions differ slightly from those of Sissons. He maintains that "the deposits are part of a moraine, deposited during a relatively protracted halt in the retreat of the margins of ice originating in the Southern Uplands and emanating from the Clyde and Douglas Valleys" (p.194). Goodlet therefore, like Sissons, agrees that the last ice mass in the area originated in the Southern Uplands and not, as Charlesworth suggested, in the Highlands.

It can be seen from this summary that the work previously

done/

done in the Central Lanarkshire area has been concentrated in certain specific localities, from which broader generalisations about the regional pattern of glaciation and deglaciation have been deduced. It seems therefore that it is an opportune time for an extension of the detailed mapping and an examination of the whole area which would permit a comparison to be made with the patterns of glaciation and deglaciation suggested by the previous workers.

CHAPTER II

AREA I

1. Location and Extent

Area I occupies the southern central part of the thesis area. On the north, east and west it has common boundaries with AreasII and III (Fig. 1). These boundaries are arbitrary and do not follow the alignment of any particular landform features. This is not true of the longer, more irregular, southern boundary. In its western section this border follows the Dungavel/Hagshaw Hill watershed and is in fact the Lanarkshire/Ayrshire boundary. (Fig.2). The remainder of this southern boundary is formed by the hills which rise above and to the south of the Douglas Valley. This almost encircling boundary of hill ranges is broken at only three localities. The first break is formed by a steeply entrenched valley at present occupied by Glenbuck Loch and containing, to the east, the headwaters of the Douglas Water. (Fig. 9). The second and third breaks are where the Glespin and Parkhead Burns, major tributaries of the Douglas Water, enter from the south. (Fig. 9).

From Figure 1 it can be seen that the upland areas of Area I, despite the deep valleys of the Rivers Ayr and Nith, are virtually continuous with the higher, more extensive, western Southern Uplands.

2. Relief and Drainage

The main upland areas of Area I occur around its

southern/

southern and western boundaries. (Fig. 9). To the west an extensive dissected hill area has summits well in excess of one thousand feet, Auchengilloch (1515 ft), Nutberry (1712 ft), Auchenstilloch (1610 ft) and Hagshaw Hill (1500 ft). A few detached remnants of these hills occur to the north and east, e.g. Harlow Hill (1108 ft) and Auchrobert Hill (1134 ft). In general, however, these hill areas give way to long, smooth slopes which decline to a central depression between Lesmahagow and Coalburn. This depression has a remarkably smooth floor with an altitude of between 700 and 800 feet. Its regularity is disrupted by the deep dissection of some of the valleys incised around its periphery, notably the Poniel Water and River Nethan. (Fig. 9).

The main streams of this district, the Birkenhead Burn, the Logan Water, the River Nethan and the Poniel Water tend to flow from the south-west to the north-east. Thus the major stream, the Nethan, rises on the slopes of Nutberry Hill, flows north-eastward down the long north-east facing hillslopes and around the edge of the central depression before flowing north-ward out of the area. The central part of the basin is an area of indeterminate drainage and is extensively peat covered.

Occasionally, however, the river valleys lose this orientation and follow courses which are oriented from west to east and are, therefore, frequently at right angles to the general regional gradient. Where the rivers behave in this way their crossprofiles generally show a much greater degree of incision and may/

may even attain gorge-like dimensions, e.g. the Poniel Water. Figure 10 shows the contrast between the south-west to north-east and the west-east oriented sections of the Logan and Poniel Water respectively. The significance of these variations of crossprofile and direction will be discussed in greater detail in Section Six.

The Poniel, with its orientation transverse to the general slope gradient, flows in an easterly direction and finally in a wide, open valley, (Fig. 10), which joins that of the Douglas at Douglas Water. (Fig. 9). The drainage of the southern hill areas and the southern part of the Lesmahagow/Coalburn basin is thus tributary to the Douglas rather than the Nethan.

The Douglas Valley dominates the relief pattern of the southern and eastern parts of Area I. This broad, yet steeply incised valley, as much as four miles wide and five hundred feet deep, (Fig. 10), contains the only extensive area of land below seven hundred feet in Area I. The floor of the Douglas Valley is at six-hundred and fifty feet near Glespin in the extreme south-west, and five hundred and eighty feet at its confluence with the Clyde ten miles to the north-east. On either side of this valley the ground rises sharply and the valley sides are broken at only three locations where major tributaries join the Douglas Water viz. The Glespin Burn, the Parkhead Burn and the Poniel Water (Fig. 9).

In general, therefore, Area I consists of a semicircular ring of uplands, which together with an isolated outlier, Broken Cross Muir, almost encircle a central basin around Coalburn. From this/

this upland fringe the two main rivers, the Nethan and the Douglas Water flow in a north-easterly direction before joining the River Clyde.

3. <u>Geology</u>

In common with the rest of Central Lanarkshire, there is no simple distribution of the major rock groups, Silurian, Old Red Sandstone and Carboniferous. (Fig. 11). The oldest rocks, Silurian in age, are contained in two extensive anticlinal inliers, the most important of their kind in the Midland Valley of Scotland (Macgregor M and Macgregor A.G. 1948 p. 10). The first continues into Area III and is the more extensive. It forms the high ground of the Dungavel/Nutberry Hills. The second, to the south, is smaller but similarly gives rise to an upland area in the Hagshaw Hills. Together they form the larger part of the western watershed boundary.

The Old Red Sandstone series occurs as several discontinuous lenses between the Silurian and the Carboniferous strata. On the south flank of the Douglas Valley the most northerly of the Southern Upland Boundary faults, with its Caledonian (south-west to north-east) trend, brings volcanic rocks of Old Red Sandstone age into direct contact with Carboniferous strata. The other Old Red Sandstone outcrops in the east (Fig. 11) are largely of sedimentary origin.

Felsite intrusions of Lower Old Red Sandstone age are widely distributed in the older rocks. (Silurian and basal Old Red Sandstone). Each of these felsite intrusions has its own individual/

individual characteristics. They have been used in Peeblesshire as indicator stones (McCall and Goodlet 1952) but because of the wide distribution of their source areas, (Fig. 11), and the considerable range of variability between the separate intrusions (although often indistinguishable in hand specimen), it is felt that interpretations of ice movement based on their presence as erratics in drift should be treated with caution and should at least involve thin section analysis.

The Carboniferous strata occur as a belt running through the centre of Area I. They are found on the southern boundary of the area in a small basin around Glespin. This basin extends by a narrow neck through the Douglas Valley before swelling out to form a broad basin extending across most of the area and northwards to Lesmahagow. Apart from underlying most of the Douglas Valley, Carboniferous rocks are also associated with the basin around Coalburn and the low moorland areas around its periphery.

The problems of numerous and widely distributed "exposure areas" of rocks similar in age and character throughout Central Lanarkshire have already been discussed (Chapter I). This is equally true of Area I and involves considerable difficulties in the interpretation of erratic patterns. More will be said about this in Section Five of this chapter.

The deposits most important to the present study are those of Pleistocene age. Together these cover more than one half of the surface area of Area I. The Geological Survey, (1" drift sheets Nos. 23 and 15), shows these classified as follows; "Boulder/

"Boulder Clay", (Usually referred to as "Till" in the present work) "Moraine and Earthy Angular Drift","Brick Clay", "Sand and Gravel". The latter category is further sub-divided into "Kames", "Terraces" and "Other Deposits".

The writer observed till up to altitudes of 1600 feet but generally it is of no great depth except on the lower hillslopes and in the main valleys. The sand and gravel distribution is more restricted. These deposits occur as isolated patches, classified by the Geological Survey as "Other Deposits", in the upper valleys or as more extensive and thicker sheets and spreads, often including so-called "Kames" in the valley floors of the main rivers. Where fluvioglacial deposits are found they generally overlie till. Exceptions occur where the sand and gravel is found to form the basal member of the drift deposits. "Brick Clays" are not found in Area I but "Moraine and Earthy Angular Drift" are shown in the upper reaches of the Logan Water.

Since most of the literature dealing specifically with the processes and conditions during the melting and decay of glaciers post-dates R.F. Flint's 1929 paper, it is hardly surprising that in this area, which was originally surveyed in 1852/59 and only once revised in 1901/02, the classification of the fluvioglacial deposits is found to be unsatisfactory. Present knowledge of the forms and processes of fluvioglacial deposition permits and demands a much more satisfactory classification than that of "Kames", "Terraces" and "Other Deposits". In several cases areas marked on the Drift Sheet as/

as "Recent Freshwater Alluvia" were found to be of unquestionable fluvioglacial origin. Sections in the "Moraine and Earthy Angular Drift" deposits were inspected and here too the interpretation made by the Geological Survey officers can be questioned. This latter material is discussed further in Section Six of this chapter. It was concluded that the larger part of Area I has a covering of drift. The distribution of this as shown by the Drift Sheets of the Geological Survey is remarkably accurate but the classification of the deposits is frequently misleading and incorrect.

4. Glacial Erosion

It is much easier to assess the effects of glacial deposition than those of glacial erosion. In the case of deposition the evidence is usually still available for inspection, whilst with erosion the material removed is no longer visible and the extent of erosion is therefore much more difficult to measure. In addition, in a landscape now extensively covered by superficial deposits and subject to post-glacial modification by a wide range of processes, it is difficult and often impossible to recognise, and assess accurately, the effects of a more distant period of glacial erosion.

There is also the problem of multiple glaciation. If the literature on glacial chronology is correct then Central Lanarkshire has been overrun by ice during several different occasions during the Quaternary (Sissons 1965). These periods of renewed glacial activity are thought to have been of decreasing severity and length./

length. Between the periods of active ice cover, periglacial processes and river erosion would modify the shapes of the valleys. The result is that erosional features have often been produced by more than one agent of erosion and have frequently been utilised and/or altered during successive periods of ice erosion.

Whilst the surface forms of glacial and fluvioglacial deposits in Central Lanarkshire can be more certainly attributed to the last ice cover, it is obvious, from what has already been stated that it is a more difficult task to gauge the erosive effects of the same ice. The features to be discussed in this section almost certainly owe their origin, at least in part, to the earlier and more vigorous periods of ice activity.

The watershed boundary on the west, between Auchengilloch and Auchenstilloch Hill is breached at several points (A,B,C and D Fig. 9). These through cols have their floors at altitudes ranging from 1360 feet to 1430 feet, generally between 100 feet and 200 feet below the adjacent summit levels. All are oriented from south-west to north-east and some of the adjacent hills have a streamlined form parallel to this trend e.g. Nutberry and Mannoch Hills. Further south the two valleys which delimit the Hagshaw Hill range from the other hills in this area also show this south-west to north-east trend. The relative relief, however, is much greater. The Monk's Water valley has a through col at its head, the floor of which is at an altitude of 1060 feet. The adjacent summit levels are in excess of 1400 feet (Fig. 9). To the south is the Douglas Valley, the lowlying/

lowlying nature of which has already been discussed. Colliery boreholes, however, (Fig. 12) indicate that this valley has a very uneven floor which in places has been infilled to a depth of at least one hundred and forty feet with fluvioglacial deposits. This may well indicate local overdeepening as a result of glacial erosion.

The Hagshaw Hills themselves exhibit, at a higher level, another set of glacial erosion features. Several through cols breach the summit areas at altitudes from 1225 feet to 1480 feet. All of these are oriented not in the normal south-west to north-east direction but from north-west to south-east (Fig. 9). The summit hills also have a streamlined appearance parallel to this trend. If these cols are the products of glacial erosion, the implication is that an earlier, thicker ice sheet passed over these hills in a north-west, south-east direction before the later ice movement from the south west.

Throughout this hilly district of Area I there are very few outstanding spurs, the absence of which may well indicate a relatively recent period of vigorous glacial erosion. Glacial striae have been recorded at several localities by the officers of the Geological Survey (Fig. 9). On Nutberry and Auchenstilloch Hills and on the flanks of the Douglas Valley, these all agree with and confirm the south-west to north-east direction of ice movement as shown by the majority of the through cols.

The hills on the northern boudary of Area I also exhibit/

exhibit through cols. Those around Auchrobert Hill (Fig. 9), suggest a movement of ice to the south-east. This is further substantiated by a striation, with this orientation, recorded on the west side of Dunside Rig by the Geological Survey. (Fig. 9) The neighbouring through valley feature to the west of Black Hill, with an orientation from south-west to north-east is possibly along the line of a valley cut by a predecessor of the present Logan Water and is not necessarily of glacial origin.

The directional evidence of all these cols and striae indicates that the ice-source was outside Area I. In the northern part of the area it appears to have moved from north-west to south-east, whereas in the south, despite evidence of a north-west to south-east direction at higher levels, the dominant ice movement appears to have been from south-west to north-east. The origins and chronologies of these ice streams will be dealt with in subsequent sections.

Several striae recorded by the Geological Survey on Broken Cross Muir and the hills to the south of Sandilands Station (Fig. 9) confirm the south-west to north-east trend of ice movement. Throughout the remainder of Area I, however, the main effects of the glacial period appear to have been depositional rather than erosional and there is little surface indication of glacial erosion.

5. Glacial Deposition

As has been already suggested, the evidence of the depositional effects of glaciation are much more prominent than those of glacial erosion. Another contrast is found in the distribution of/

of the evidence. Just as the signs of erosion were particularly marked in the upland areas, so glacial deposition achieved its greatest effect in the lowlands.

In Area I till covers at least one half of the land surface. It is found at altitudes up to 1600 feet in the hill areas and is proved at depth of 60 feet below the surface of the Douglas Valley. (Fig. 12). At higher altitudes the thickness of the till decreases and many of the hills above 1000 feet, and in some cases less, have bedrock exposed at the surface. On the lower hillslopes its thickness increases to as much as ten feet, especially where there is a hollow or an indentation in the hillside e.g. a stream course. Only in the valley floors, however, does the thickness of the till ever exceed ten feet.

The colour of the till varies according to locality. In some areas it has a bright red/brown hue whilst in others it is more blue/grey. Although field observation suggested that the finer material (Matrix) of these tills varied considerably, this was disproved by a particle size analysis programme which paid particular attention to the relationship between textural and colour variations, in tills. Similar samples of red and grey tills were analysed by coarse sieving and find sedimentation(hydrometer) analysis. The results when plotted on graph paper show that there is no significant difference between the particle size compositions of the different colours of till. (Appendix I Section B). The results do, however, show that although by nature till is unsorted, containing particles from/

from clay size, (1/256 mm), up to and exceeding boulder size (256 mms), there is, however, an overall similarity compared with other glacial and fluvioglacial deposits. When good field exposures were available, the writer found no trouble in differentiating till from any other deposit.

In the hill areas of the south and western parts of Area I, till reaches its maximum altitude, approximately 1600 feet, on the flanks of Nutberry Hill (Exp. 12 Fig. 13). However, even above 1000 feet the till mantle is rarely more than two or three feet thick, and probably for this reason does not itself give rise to any specific landforms but rather appears to smooth out any pre-existing irregularities by thickening in hollows and thinning on more prominent slopes.

The till matrix is sticky and clayey to the touch and the included pebbles display a large variety of rock types, some of which, especially the Silurian Shales, distinctly retain the marks of glacial striae (one pebble in every three retained striae visible without the aid of magnification). In these hill areas Carboniferous strata are generally absent and Silurian and Old Red Sandstone rocks are predominant. The thin nature of the till makes it difficult to find sites suitable for sampling. (All the sampling sites were required to have a minimum, apparently unweathered till thickness of five feet. This rule was applied in an attempt to avoid the bias of results by the effects of surface movements and weathering). As a result the till sites investigated in hill areas conversely tend to/

to be located in valley bottoms where, not only is the till depth greater but also streams have frequently undercut their banks affording a fresher section.

In the upper Nethan Valley, although a good till exposure is found at Exposure 16 (Fig. 13), in the lea of an upstanding dyke, it is not until Exposures 2 and 4 (Fig. 14), four miles downstream, that a depth of till suitable for sampling becomes available. Exposures 2 and 4 are in the undercut bank of the River Nethan and at both sections the exposed face is in excess of seventy-five feet. Although separated by only three hundred yards and in what is apparently the same geomorphological feature, a valley-fill terrace, formed by the dissection of the glacial and fluvioglacial deposits mantling the floor of the valley, they exhibit one of the fundamental characteristics of glacial and fluvioglacial deposits - irregularity.

TABLE I

Exposure 2 (840') (Fig.14)	6 - 10 ft. coarse gravel 80 ft till	Exposure 4 (825') (Fig.14)	2 - 10 ft. coarse gravel 2 - 10 ft. till 30 ft. coarse gravel

At exposure 2 (Fig. 14), six to ten feet of very coarse, roughly sorted gravel overlies eighty feet of grey/brown till. At exposure 4, (Fig. 14), however, two to twelve feet of coarse gravel overlie two to ten feet of till (which even over this short distance has/

has changed its colour to the greyer hues more characteristic of Carboniferous sediments).These in turn overlie a further thirty feet of coarse gravel (see Table I above).

Till fabric, rock type content and particle size analyses were carried out on the till at Exposure 4 (Fig. 14). The fabric diagram (No. 1 Fig. 15) shows a very strong preferred orientation from south-west to north-east, with 72% of the stones dipping to the south-west. This latter figure is calculated from the percentage number of all the stones located within the quadrant, (90° sector), which contains the largest number of oriented stones. This maxima quadrant normally contains the stone distribution peaks and will hereafter be called the peak maxima quadrant. All these features are shown on Polar Equidistant Projections (Fig. 15). Geologically the site (No. 1) is at the margin of the extensive Carboniferous basin and is bordered immediately to the west by the first of the "Old Red Sandstone and Silurian Hills" (Fig. 11). Perhaps surprisingly the till (No. 1 Fig. 16), contains 68% Carboniferous, 26% Old Red Sandstone and 6% Silurian rocks. Whilst these figures probably indicate the very "local nature" of most the component material in tills, it is felt that they, together with the fabric information, substantially confirm the argument for a south-west to north-east moving ice mass.

In the moorland and lower, less dissected areas to the east, centred on the Coalburn/Lesmahagow Carboniferous basin, the till cover is almost continuous. Only occasionally does bedrock appear at/

at the surface and then only in the more upstanding moor areas or the sides of the Poniel Gorge (Exps. 13 and 14 Fig. 14). The underlying rocks have an immediate effect on the till characteristics. The red, brown colour of the hills to the west gives way to the greys of the Carboniferous areas. (These colour changes, dependent on underlying bedrock, were early recognised as a characteristic of Scottish tills by the officers of the Geological Survey e.g. A. Geikie et al 1871, p. 38 and by the same author 1873, p. 42).

The long smooth slopes to the west of Coalburn (Fig. 9) frequently have a very even mantle of drift. From borehole evidence (Fig. 12) it appears that the normal situation is for about ten feet of till to form the central stratum in a threefold sequence. Sand and blue clay are said to form the upper and lower layers respectively. The generally slight gradient has probably aided the development of a thick peat cover (Ph2) which increases the difficulty of finding good sections. Although no one exposure was found which revealed all three strata, they were verified at several different sites. Exposure 8 (Fig. 14) shows five feet of grey till overlying three feet of blue/grey stoneless and apparently unstratified clay. Exposure 6 (Fig. 14) shows three or four feet of stratified sand and gravel overlying at least two feet of boulder clay.

At till analysis site 2 (Fig. 11) a fresh, forty-foot section in the undercut bank of the Nethan reveals fifteen to twenty feet of grey till overlying/

TABLE II

Till Analysis Site 2 (Fig.11)	10-15 ft coarse gravel 2 Ft. of laminated clay and sand. 7 Ft. stratified gravel 15 - 20 feet till.

overlying bedrock. (Carboniferous limestone at this locality). As Photograph 3 and Table II opposite show, the till is overlain by a series of water-laid deposits - seven feet, of coarse, but stratified gravel, two feet of laminated clay and fine sands and ten to fifteen feet of very coarse gravels with little evidence of sorting. The till fabric analysis (No. 2 Fig. 15) indicated several interesting features. The strong preferred orientation from south-west to north-east, found in the previous till fabric analysis upstream, was not found. Instead a rather weaker, more dispersed preferred orientation indicating a movement from south-east to north-west was found. (56% of the stones were in the associated maxima quadrant). At this site, however, this fabric orientation is exactly parallel to the direction of the Nethan Valley. This is perhaps a reflection on the important influence of irregularities in the underlying land surface on the local orientation of basal ice movement.

The rock type analysis, (No. 2 Fig. 16) gives a similar result to that found in the till three miles upstream. The main difference is that the percentage of Old Red Sandstone pebbles has decreased and is partially replaced by 6% of Highland erratics.

In the Douglas Valley, along the southern boundary of Area I conditions are slightly different. The till cover extends up the north-facing slopes to heights of 1,100 feet (Good exposures in the Ponfeigh Burn, above Rigside (Fig. 9) show that the till cover dies out above 1,100 feet). On more prominent hillslopes bedrock may even outcrop at lower levels e.g. Stone Hill (Fig. 17). On the south-facing/

facing slopes of the Douglas Valley a similar distribution is found and the abundance of old quarry sites suggests a very thin drift cover even on the lower slopes.

On the lower valley sides the valley floor, where not covered by sand and gravel, the till cover often has a drumlinoid or fluted appearance with ridge crests orientated from south-west to north-east i.e. parallel to the valley orientation. These are well shown above and below Rigside, (Fig. 9), where they are from 15 - 30 feet high. Although no sections are available in them, surrounding exposures indicate as much as ten feet of till.

The main till accumulations in the Douglas Valley are, as to the west, on the valley sides and floor. As already noted, however, the valley floor area is liable to be covered by fluvioglacial deposits. Thus of the two best till exposures on Figure 17 only the lower one, (Exp 8) has a covering of sand and gravel. The other, (Exp 7), shows twelve feet of till and is used for further analysis.

Three till exposure sites were investigated in the Douglas Basin. All three are in undercut stream banks where the till which covers the valley floor is well exposed. The first two, Nos. 3 and 4 (Fig. 11) are in the south-western extension of the central Carboniferous basin. The till fabric of No. 3, in the valley of a south bank, tributary of the Douglas, the Glespin Burn, has a very strong preferred orientation from south-west to north-east with a dip maximum, (63% in maxima quadrant), indicating a Southern Upland ice source (Fig. 15).

The till fabric of site No. 4, (Fig. 15) at the junction

of/

of the Douglas and Glespin Valleys, is much less definite and whilst a south to north trend is suggested, there is no true dip maximum. (Only 42% of the orientated stones are in the apparent maxima quadrant). The rock type contents of both tills are almost identical (Nos. 3 and 4 Fig. 16). Carboniferous fragments are the main constituents amounting to 60% and 56%, Old Red Sandstone pebbles amount to 22% and 24% and 'Southern Upland Rocks' to 14% and 20% in Nos. 3 and 4 respectively. In both these localities therefore, although the 'Silurian and Old Red Sandstone hill areas' immediately to the west of Glespin (Fig. 11) have a covering of distinctive red till, the tills on the Carboniferous sediments are of greyer shades and are largely composed of these latter rocks. The evidence of these two till analyses certainly agrees with that of glacial erosion, that, "the dominant ice movement appears to have been from south-west to north-east".

The third till exposure which was analysed in detail, (No. 5 Fig. 11) is at the north-east extremity of the Douglas Valley and is on the eastern margin of the extensive Carboniferous basin. It is perhaps surprising therefore that the exposure reveals twelve feet of sticky, red till and that the percentage of Carboniferous rocks should be only 44% (cf 60% and 56% at two previous sites). This deficit is largely made up by an increase in Old Red Sandstone rocks, 40%. The remaining 16% of the stones were of Southern Upland extraction (Fig. 16). The high proportion of Old Red Sandstone material and the colour of the till is largely explained by the orientation/

orientation of the till fabric. This shows a very strong preferred orientation from the south-south-east to the north-north-west. This suggests that the main south-west to north-east Douglas Valley ice stream was being supplemented by tributary ice streams emerging from the Old Red Sandstone hill areas to the south. The additional evidence of the high percentages of 'Southern Upland rocks', 14%, 20% and 16% at sites 3, 4 and 5 respectively, the north-south orientation of the elongated till mounds on the sides of the valley of the Parkhall Burn, (Fig. 9), and the striation, recorded by the Geological Survey at Tinto End (Fig. 9) pointing from south-south-west to north-north-east further substantiates this argument. This theory could also account for the peculiar situation at Douglas Water, (Exposure 8 Fig. 17) where a red till appears to rest directly on a grey till without the apparent intervention of fluvioglacial deposition. It might be suggested that the main Douglas Valley ice stream which deposited the grey till was gradually displaced northwards by an increasing volume of ice being contributed by the southern, Old Red Sandstone floored, tributary valleys. The ice emanating from these latter valleys could explain the overlying red till. With the addition of further ice streams from the south the main Douglas Valley ice stream may have eventually been completely confined to the northern side of the valley. The southern slopes would then be occupied only by ice from the tributary glaciers thus allowing only the deposition of red till. This is exactly the implication derived from the previously described section/

section (No. 5 Fig. 11).

It may be relevant at this point to discuss the effects of periglacial action, for the resultant deposits have frequently been erroneously mapped as "earthy angular moraine" (Galloway 1961 p. 77) and till. According to Galloway (1961 p. 77), the Southern Uplands and hills of Central Scotland "apart from the rugged hills of Galloway were not heavily glaciated, were probably freed of ice at a fairly early stage during the glacial retreat, and so were exposed to periglaciation for several millenia before the final termination of the Ice Age." Thus it might have been expected to find in Central Lanarkshire, extensive "head", "slope" or "solifluction" deposits such as workers in more southern and eastern parts of the Southern Uplands have found. (Tivy 1962, Price 1961, Ragg and Bibby 1966). This is not so, however, and deposits which could be classified as the product of periglacial action have been found at only three localities in Central Lanarkshire, two of which are in Area I.

At the first site, (Exposure 3 Fig. 13) at a height of 1,000 feet and in a dissected valley terrace, between five and eight feet of waterlaid, rounded gravels overlie three to four feet of shattered, bedrock material. (only rarely was an erratic fragment found) This latter material was highly angular and did not display glacial striae.

TABLE III

Exposure 3	5-8'	coarse but rounded gravel
Fig. 13.	3-4'	shattered bedrock
	2-5'	fine stratified sand and clay
	12'	shattered rock with included clay layers.
		shattered solid rock

Beneath/

Beneath it, two to five feet of fine bedded sands and clays, displaying varve-like variations and topset and foreset bedding, were found. Underlying these stratified deposits there were a further twelve to fifteen feet of shattered bedrock material exactly as in the second stratum but including within it numerous lenses of stratified fine sand/clay material. Below this, bedrock outcropped. The distinctiveness of this section was emphasised by the fact that higher exposures (8 and 10 Fig. 13), revealed normal till sections.

At exposure 15 (Fig. 13), in the headwaters of the River Nethan a section showed rubbly, angular material containing many erratic fragments (Ph4). This material which appeared to be neither fluvioglacial nor glacial was tentatively classified as "slope deposits".

The third area where periglacial deposits were identified was on the flanks of Tinto Hill (Phs 5 and 6). Here on the red felsite intrusive massive extensive sheets of angular bedrock material are found. These are comparable in composition to the angular material at exposure 3 (Fig. 13).

On Tinto Hill, however, (Fig. 2) the higher altitudes (Tinto Summit is at 2,335 feet) and very steep slopes have allowed the stone stripes (Phs 5 and 6) to actively form under present conditions (Miller et alia 1954). At the other two sites the material appears to be a fossil deposit, dormant under the present conditions.

One or two of the other summits in Central Lanarkshire may have a capping of shattered rock suggestive of periglacial conditions/

conditions e.g. Dungavel Hill (1503 feet) (Fig. 2). The conclusion remains, however, that throughout Central Lanarkshire there is little evidence of periglacial deposits compared with the vast deposits left behind by glacial and fluvioglacial processes. In this light Central Lanarkshire appears to have more in common with the Western rather than the Eastern Southern Uplands, as described by Galloway 1961.

SUMMARY

Glacial deposition is widespread throughout Area I. Although till may be thin or absent at higher altitudes, it frequently exceeds ten feet in depth in sheltered localities and in valley floors. Normally the till occurs as a single unit but in the valley floors and lower hillsides it is frequently covered by a mantle of fluvioglacial deposits. Only at two sites were deposits seen to underlie the till. At exposure 4 (Fig. 14), in the valley of the Nethan thirty feet of coarse, roughly sorted gravel is found beneath the till, although, as already remarked, equally good sections upstream and downstream show no sign of this stratum. At the nearby Exposure 8 (Fig. 14) on the edge of the extensive, till covered Coalburn basin, three feet of stoneless, unstratified clay was found beneath the till. In both these cases the underlying material does not appear to be of widespread occurrence and there is insufficient evidence to suggest either the mode of formation or the relative ages of the deposits.

6. Fluvioglacial Erosion

There/

There is abundant evidence of the powers of erosion of glacial meltwaters in Area I. This is possibly a result of the frequent contact between Upland and Lowland, a situation particularly suitable to the formation of meltwater channels (Sissons 1961 p. 16).

There appear to be three main areal concentrations of meltwater channels (Fig. 9); in the lea, or on the north-east facing slopes of the Auchengilloch/Hagshaw Hills, in the Coalburn Basin and on the flanks of the Douglas Valley. The orientations of these systems reveal only two major trends, from west to east and from south-west to north-east. The characteristics of the channels, however, show considerable variation. They are eroded in rock, till or sand and gravel. Those eroded in rock tend to have the sharpest cross-profiles and the greatest dimensions. At lower altitudes, in the main depositional areas, the channels frequently have more rounded cross-profiles and where found in sand and gravel they are often short, little incised and without any steep associated breaks in slope. These latter channels as a consequence tend to be more difficult to recognise, especially where they have small streams in their floors.

Although some of the features of meltwater channels e.g. abrupt beginning and termination, absence of streams and up and down profiles facilitate their identification, other channels which do not show these characteristics, may be more difficult to positively identify. Where a meltwater channel is occupied by a present day stream, (Ph. 7), unless its form and relationship to other meltwater channels are helpful, its meltwater origin may be difficult to establish/

establish. Storm gullys, like the one in photograph 8 eroded by the concentrated efforts of run-off from artificial drainage ditches, may also provide problems of interpretation.

In the watershed and hill areas of the south and west the directions of meltwater channels indicate that meltwaters flowed into Area I from the south-west at nine separate localities. (A - I) (Fig. 9). At some localities the channels occupy through cols (A and C) although, as at A, (Fig. 13) they need not necessarily be confined to the col floor. Their anastomosing patterns, (A) (Phs 9 and 10) abrupt beginnings and terminations, steep gradients and degree of incision and occasional up and down profile e.g. channel 2 (Fig. 13), suggest that they were cut by subglacial meltwaters which concentrated their efforts at the weakest (lowest) points along the watershed.

More commonly, however, channels are found running obliquely down the valley sides. In these circumstances they often arise on north-east facing hill slopes or in the lee of more prominent valley side projections. (There are few true spurs in Area I) Their position, steep gradients and abrupt beginning and frequently more abrupt terminations are also suggestive of a sub-glacial origin. Both these channel types are frequently found in association. (Fig. 13)

At A, (Fig. 13), two neighbouring channels, streamless and 'V' shaped in cross-profile, begin immediately north-east of the watershed (Phs. 9 and 10). They run very steeply downhill into the floor of the col where they combine to form one larger 'V' shaped channel/

channel, sixty feet deep and sixty yards wide. Towards the bottom end of this channel system, at about 1,300 feet, the hill slope gradient noticeably decreases. Associated with this break in slope are two distinct features. The single meltwater channel branches to form several, smaller, less incised, distributary channels and below the point at which these channels disappear several elongated mounds of fluvioglacial deposits are found. Some of these mounds are partially submerged by the surrounding peat moss. This relationship between fluvioglacial erosion and fluvioglacial deposition is frequently found and often appears to be related, as in this example, to a decrease in gradient.

The three channels at 15 and 16, (Fig. 13), differ from those already described in that their alignment is parallel to the slope contours. Two of these are one-sided benches, twenty feet wide and ten to fifteen feet deep, eroded into the hillside. Their form and position imply that they were formed by marginal or sub-marginal meltwater streams running between the ice and the valley side. Their alignment is continued to the west, although at a slightly lower altitude, by a series of sand and gravel mounds, the Birk Knowes, whose position, composition and relationship to the channels suggest that they were laid down, in the manner of kame terraces, by meltwater streams, running between the ice and the valley sides, similar to those which cut the channels at 15 and 16.

The transverse position of these latter features to the meltwater channel occupying the col at C, (Fig. 13), might imply that the latter/

latter was no longer in use. This would happen when the downwasting regional ice surface approached 1,375 feet, the altitude of the col. At this stage the ice to the north and to the south of the col would become separated, and the ice to the north, now cut off from perhaps its main source, would become stagnant. Under these circumstances conditions conducive to the establishment of marginal/sub-marginal drainage are likely to have occurred. It is interesting to note that at this locality, although ice and meltwaters must have been present at higher levels, the present limits of glacial and fluvioglacial deposition are below the level of the channels at 15 and 16 (Fig. 13).

Figure 14 illustrates the meltwater drainage pattern on the till covered Coalburn Basin. Channels generally enter the area from the west, although their individual orientations vary between north-south and west-east. All the channels are eroded into till but most of them have penetrated to the underlying bedrock. They all appear to drain towards the two large river systems in the area, the Nethan and the Poniel Water. The channels between the Scots Burn and Coalburn, 5,6,7,8 and 9, (Fig. 14) are frequently infilled at their heads by a deep peat cover, sometimes exceeding ten feet in depth. Photograph 2 shows the thick peat lying in the bottom of the meltwater channel, No. 5, which runs off in a direction away from the camera. In their lower courses, however, these channels, which are from 30 feet to 60 feet deep and 30 to 50 yards wide are incised through the till cover into the underlying bedrock. All of them normally exhibit a very sharp 'V' shaped cross-profile and only rarely/

rarely do they widen to permit the development of a flat floor.

These channels, (5 - 9), are succeeded to the east by an even greater meltwater system (13 - 23 Fig. 14). It is tempting to suggest a continuous and connected origin for the two systems and the valley of the Poniel Water, which flows between them. All three have an orientation transverse to the regional slope, a feature often diagnostic of drainage patterns initiated by fluvioglacial meltwaters. Many of the channels of both systems after dropping into the Poniel Gorge, terminate abruptly suggesting that the latter was also used by meltwaters at this time. However, the irregularity of the course of the valley of the Poniel Water between the two systems is a feature not particularly associated with a meltwater origin.

The eastern system of channels, to the south and east of Coalburn 10 - 23 (Fig. 14), occurs on the north and south flanks of an east-west ridge of moorland. The upper surface of this moorland is driftless and has possibly been washed free of drift, although no channels are available to prove this. The main part of the channel system, on the south flank of the moorland, is cut, except for a very thin layer of drift, entirely in bedrock. This is a coarse, yellow sandstone and where eroded by meltwaters it has in one locality (18 Fig. 14) left small, but precipitous cliffs in which the marks of water scouring and potholing can still be seen. (Ph. 11) At this locality the adjacent channel, 16, is from sixty to eighty feet deep and has a flat floor about twenty feet wide. The sides and floor of this/

this channel are partially covered by an enormous accumulation of sandstone blocks, many of which are as much as six feet in diameter. The dimensions of this channel are in contrast to the delicate network of small channels, 5 - 10 feet deep and less than 10 feet wide which course the sandstone bluffs above (See Ph. 11).

The relative dispositions of the southern set of channels seem to provide a clue to their origin, for channels, 19, 18, 16, 20 and 17 all appear to have been progressively abandoned in favour of a lower adjacent course to the south. Thus the floor of the small, intricate channel system, 18, is twenty feet above the large, adjacent channel 16. (Ph. 11) Channel 17, with a slightly lower intake, in turn appears to have captured the meltwaters of channel 16. Lastly there is the impressive, one hundred foot deep gorge of the Poniel, with a course parallel to that of the meltwater channels and without the irregularities seen to the west. It is into this gorge that many of the channels seem to have finally discharged.

This suggested pattern of progressive abandonment may have also operated on the north flank of the moorland ridge, but the lack of intercommunications between channels does not allow for a similar reconstruction of their history. It is probable that the development of this eastern meltwater drainage system took place as the ice downwasted and the meltwaters came into contact with the moorland which eventually emerged as a nunatak mass. Although it is possible that some of the channels were initiated in a sub-marginal environment, the up and down profiles of some, (e.g. 14 and 13 have uphill sections of/

of about 5 ft. and 15 ft. vertical relief respectively), imply a sub-glacial origin. As with the upland meltwater system, (1 - 4 Fig.13), the erosional phase of fluvioglacial drainage gives way eastwards at lower levels to a landscape where depositional forms, of fluvioglacial origin are more prominent.

Figures 17 and 18 indicate the importance of the Douglas Valley, by far the largest in Area I, as an area of concentration for meltwater drainage. Some of the channel systems in the valley itself are not greatly incised e.g. the system at G, (Fig. 18), consists of round-bottomed channels, fifteen to twenty-five feet deep and from thirty-five to sixty feet wide, running between elongated till mounds. Similarly channel 5 (Fig. 18) occupies a smooth, little incised, linear depression running parallel to a fluvioglacial ridge (Ph. 12). Others, however, are deeply cut into solid rock with steep sides and have a 'V' shaped cross-profile, although occasionally they may have a flat floor e.g. channel 1, interrupted due to railway construction, and channel 6 (Fig. 17). All of the channels, however, tend to be directed obliquely down the valley sides towards the floor of the main Douglas Valley but terminating at heights varying between ten and one hundred and fifty feet above the floor. Where this situation is found the lower end of the channel is frequently seen to be associated with the upper limit of fluvioglacial deposition e.g. system at G, (Fig. 18). Although certain parts of these channels may be sub-marginal, their generally steep gradients again imply a sub-glacial origin.

Occasionally on the lower valley slopes or valley floors, within/

within the area of fluvioglacial deposition, another channel-type is found. The cross-profile of this channel-type is rounded and without the sharpness noticed in some of those already described. They usually run between dissected mounds of fluvioglacial material and appear to have been eroded contemporaneously or subsequent to the time at which these were deposited, (9,5 and 7 Fig. 18). It may well be that these are the last traces of the streams which deposited the associated sand and gravel spreads. This latter implication may mean that many of them were eroded in a pro-glacial environment.

SUMMARY

It appears, therefore, that whilst many different types of channels are found in Area I, their general orientations were brought about by only two major ice gradients. The first is from the south-west to north-east and is found particularly in the watershed areas and in the Douglas Valley. This corroborates the information derived from the study of glacial erosion and deposition. At a latter stage, however, during deglaciation, when the ice sources in the south-west were cut off from some areas by the emerging watersheds, much of the meltwater drainage in their lee, especially in the Coalburn basin, appears to have drained directly eastwards towards the Douglas Valley.

7. Fluvioglacial Deposition

The features considered under this title include, eskers, kames, kame terraces and dissected and undissected outwash sheets/

sheets. All of these normally exhibit a varying degree of stratification and are composed of varying proportions of sand and gravel. Clay layers are also found included in the deposits but are much less common. The distribution of extensive sand and gravel deposits in Area I is restricted to the floor and sides of the Douglas Valley and the lower part of the Poniel Valley, north of Happendon (Fig. 9). Elsewhere only smaller, isolated fluvioglacial deposits are found and these also tend to congregate in the floors or on the sides of the other river valleys. e.g. the Nethan and the Logan. The depth of the sand and gravel deposits is more difficult to assess and only where definite records are available or good sections are found can this be done. The borehole records of Figure 12 infer a considerable depth, in excess of one hundred feet, for at least some of the deposits in Area I.

It has already been demonstrated that there is often a significant relationship between fluvioglacial erosion, fluvioglacial deposition and the present drainage pattern. In upland areas, however, fluvioglacial deposition appears to take place with less regard for the underlying terrain and here as already stated it is generally restricted to isolated mounds rather than extensive sheets. The Birk Knowes, (Fig. 13), are an example. Here several elongated mounds of fluvioglacial deposits not only run parallel to, rather than down, the slope contours but also run from west to east across the present valley, the significance of which has already been discussed.

Elsewhere/

Elsewhere the lower slopes and floors of the main valleys contain the major share of fluvioglacial deposits. In the valley of the Nethan numerous pockets of sand and gravel are found. The largest of these is at Auchlochan, (Fig. 9) where an undulating hill of fluvioglacial deposits stands about seventy-five feet above the valley bottom. A fifteen foot exposure at the base of this hill did not reach the bottom of the deposit. The material ranges from coarse, unsorted gravel, as much as one foot in diameter to fine, stratified gravel and sand but several boreholes and trial excavations carried out in January, 1967 showed occasional till lenses within the deposit. (Kings and Company Limited) The irregular form and internal composition of the hill suggest that it is a remnant drift deposit which originally completely infilled the Nethan Valley and has only been partly removed by subsequent river erosion. It hardly fits the Geological Survey description - a "low river terrace" !

In the Douglas and Lower Poniel Valleys dissected sheets of sand and gravel are found. (Fig. 9) These are well stratified with considerable sorting of the individual layers. Occasionally more prominent, irregularly shaped, kame-like masses occur, occasionally containing enclosed depressions in their surface. A rare opportunity to examine the entire, internal structure of one of these masses was lost when, in 1962, a construction company completely removed the eighty foot high Boncastle Hill in the Douglas Valley floor south of Happendon (still shown on O.S. maps). Some information on the external form and internal composition of this hill,

as/

as provided by the company concerned, (Jas. Anderson and King Limited), is shown in Figure 19. The contoured plan and the cross-profile diagrams indicate the circular, steep-sided nature of this hill with indentations in its upper parts. These features imply an ice-contact position during its formation. Stratification was frequently observed in the mound and the particle size analysis of the component material showed 35% of gravel and 60% of sand. All the material was used to construct the adjacent sections of the A.74 dual carriageway. In the Geological Survey, Drift Sheet 23, this hill, is classified as an "alluvial cone". The characteristics, as presented here, suggest it was a kame, possibly formed after the manner of a perforation deposit. (Cook 1946).

In the lower Poniel and Douglas Valleys numerous, subdued, elongated mounds of sand and gravel between twenty and forty feet high and up to three hundred yards long give the landscape a rolling appearance and suggest an origin due to the dissection by meltwaters of an extensive sheet of sand and gravel. One associated, but isolated, ridge of fluvioglacial deposits, two miles east of Coalburn, (Fig. 9) with a maximum height of twenty feet, thirty to forty yards in width and four hundred yards long, has the external form and the internal composition characteristic of an esker, (steep sided, narrow, elongated and undulating ridge, composed of alternating and irregularly stratified beds of sand and gravel). The ridge has an unusual right angled bend perhaps suggesting control by structures within the ice. It is interesting to note that over a wide area this esker and the neighbouring, more kame-like sand/

sand and gravel mounds, some with flat tops, appear to have a uniform summit level at approximately seven hundred and five feet, suggesting, perhaps, control over deposition by an englacial water table (Sissons 1960 p. 135). This conclusion is further added to by the consistent heights, again just over 700 feet at which the associated meltwater channels terminate (23,21,19,12,11 and 10 Fig. 14).

The greatest concentration of fluvioglacial, depositional forms in Area I is in the Douglas Valley near its confluence with the Clyde. At this locality an undulating terrace of sand and gravel overlying till begins near the end of a series of meltwater channels. (8,7 and 4 Fig. 17) These undulations increase in dimension and the terrace gives way eventually to a series of distinct, elongated ridges as much as eighty feet high (Ph 13). The ridges vary in height from twenty to eighty feet and in breadth from thirty-five to one hundred yards and usually have quite sharp ridge crests. (Ph 14) Although the whole system parallels the orientation of the Douglas Valley, the individual ridges branch frequently and often run at right angles to one another. (Fig. 17) Their internal composition, stratified sands and fine gravels, their elongated ridge form, sharp crests and steep sides suggest an esker origin.

Associated with this complicated pattern of linear ridges are two isolated conical hills and several, small, completely enclosed, circular depressions. Two similar but more-elongated depressions are also found and the larger of these is interpreted on/

on the Geological Survey, Drift Sheet 23, as a"glacial meltwater channel." Its morphology, shallow and broad-floored, and its abrupt termination against one of the elongated ridges, suggest that they too, like the nearby kettle-like depressions, might owe their origin to the melting out of buried ice masses. Taken together all these features present impressive evidence for a stagnant ice mass of considerable thickness downwasting in this position. (The interconnecting ridges would have been destroyed had the ice been active). The rock-type content; 42% Carboniferous, 36% Old Red Sandstone and 22% 'Southern Upland', (No. 9 fig. 20) and the elongation of the ridge crests parallel to the main valley are completely in agreement with the evidence of a south-west to north-east ice movement of ice originating in the Western Southern Uplands.

Eight other rock-type analyses were carried out on the gravels of Area I. (Fig 11). In the heart of the "Silurian Hill" area in the headwaters of the Logan, a stone count (No. 1 Fig. 11 and 20) revealed that 90% of the pebbles were local, 8% were of Old Red Sandstone derivation and only 2%, the second lowest total for any gravel deposit in Central Lanarkshire, were of Carboniferous material.

In the lower stretches of the Upper Nethan Valley at Over Stockbriggs three rock type analyses were performed at one exposure, (Exp. 4 Fig. 14), the stratigraphy of which has already been described. The following table shows the results in their stratigraphical position.

TABLE IV

Rock Type Analysis No. (Fig. 11)	Percentage of Pebbles derived from:-			
	Highland	Carboniferous	O.R.S.	S.Uplands
No. 2 (Gravel)	-	36%	34%	30%
No. 1 (Till)	-	68%	26%	6%
No. 3 (Gravel)	-	42%	38%	20%

The main differences in the two sets of gravel results are the higher and lower percentages of Carboniferous and Southern Upland pebbles respectively in the lower gravels. (No. 3). The simplest explanation might be that the lower gravel was laid down by meltwaters which were in direct contact with the Carboniferous bedrock, whereas the waters depositing the uppermost gravels were running on an already drift covered surface (Table I).

These fairly balanced proportions of different rock types probably reflect the geological position of the site - three miles east of No. 1, (Fig. 11) in a position more removed from Silurian source material, underlain by Carboniferous strata, yet within a mile of Old Red Sandstone sources.

Two further stone counts of rock-types were made downstream. At Auchlochan, (No. 4 Fig.11), the anomalously high figure of 48% of 'Southern Upland' material was obtained, whilst Old Red Sandstone and Carboniferous rocks contributed 28% and 24% respectively. At No. 5 (Fig. 11 and 20) the Carboniferous and OldRed Sandstone rocks, 42% and 40%/

40% respectively, had increased at the expense of 'Southern Upland' material (18%). The overall pattern of these results certainly indicates a movement of meltwater away from the south-west 'Silurian Hills' to the north-east, with the percentage of Southern Upland rocks decreasing from 90% to 18% in the process.

In the Douglas Water drainage basin four rock-type analyses were completed, Nos. 6,7,8 and 9. (Fig. 11 and 20). Nos. 6 and 7

TABLE V

Gravel Rock Type Analysis (Fig. 11)	Percentage of Pebbles derived from:			
	Highland	Carboniferous	Old Red Sandstone	'Southern Upland'
6	-	56	22	22
7	-	50	30	18
8	2	46	40	12
9	-	42	36	22

are very similar with the difference in the proportion of Old Red Sandstone material probably closely reflecting the proximity to the nearest source areas. At site No. 7, noticeably further from Southern Upland rocks than any of the others, the proportion of Southern Upland rocks is correspondingly depressed. At site No. 8 only one mile east of the extensive Carboniferous basin, (Fig. 11) the proportion of Carboniferous rocks is less than at any of the other sites and the figure for the Old Red Sandstone proportionately higher./

higher.

It is proposed that all of these gravel rock-type analyses can be explained by, and therefore help to confirm, the patterns of ice movement and meltwater drainage already presented. In particular the consistently high, but decreasing north-eastwards, percentage of 'Southern Upland' rocks agrees with a Western Southern Upland ice source and a strong south-west to north-east ice movement through Area I.

Several of the exposures in Area I allowed the examination of gravels overlying till (Fig. 11). It is interesting to compare the rock-type contents of glacial and fluvioglacial deposits which occur at the same site.

TABLE VI

Comparison of Rock-Type Contents of Gravels and Tills occurring in the same exposure

Location	Site No.	Glespin Burn				Site No.	Glespin				Site No.	Over Stockbriggs				Site No.	Lower Nethan			
		H.	C.	O.	S.U.		H.	C.	O.	S.U		H.	C.	O.	S.U.		H.	C.	O.	S.U.
Gravel	6	-	56	22	22	7	2	50	30	18	2	-	36	34	30	5	-	42	40	18
Till	5	-	60	22	14	4	-	56	24	20	1	-	68	26	6	2	6	66	18	6

From this, albeit rough, guide it can be seen that in all four examples, the local bedrock, Carboniferous, comprises a smaller proportion of the pebbles in the gravels than in the tills. The average decrease is 16.5%. In each case there is a similar increase (19%), in the proportion of non-local, i.e. non-bedrock, pebbles in the/

the gravels compared with the tills. Without considering the vexed question of the true source of the gravel pebbles, the obvious implication is that the source area of rock types in fluvioglacial deposits is much more extensive than that of the tills on which they rest. It is unfortunately impossible to give any exact indication of the distances involved in the transport of till and gravel pebbles for reasons which have already broached upon, viz. the difficulty of establishing the true source of any individual pebble and the problem of multiple transport of the same pebble not only at different periods but by different transporting agents.

8. Glacial History

Although, there is some evidence to suggest that ice from the north may have at some time penetrated Area I, (Orientation of through cols in the higher levels of the Hagshaw Hills and on the north-west boundary (Fig. 9), and the occasional Highland erratics), the bulk of the evidence indicates that the invading ice masses were generally of Southern Upland origin. If one assumes that the surface till is the product of the last ice advance then the results of the till fabric and rock, type analyses and the morphology of the features certainly indicate that the main ice streams during the last ice advance came from the south-west.

The conditions during the wastage and decay of the ice, as revealed by meltwater drainage patterns and fluvioglacial deposits, accord with this conclusion. At an early period during deglaciation, when ice still covered the watersheds, the drainage was directed from south-west/

south-west to north-east indicating an ice gradient in this direction and therefore a source to the south-west. Even during later stages of deglaciation, when large areas were covered by stagnant ice and conditions were more influenced by local relief, the same orientation remained common. In the Coalburn and Upper Logan Water areas (Fig. 9) the deflection of meltwater drainage to a more west-east direction, sometimes with a south-easterly component, may indicate a tributary ice stream entering Area I, from the Avon Valley to the north-west, via the low through cols on either side of Dunside Rig. (Fig. 9). (1200 ft. and 1,100 ft. respectively). This ice stream would certainly have been more effective when the higher through cols of the Auchengilloch/Hagshaw Hills to the south-west no longer allowed ice penetration from this quarter. The striation on Dunside Rig, (Fig. 9), may support this argument.

SUMMARY OF CONCLUSIONS:

(1) The whole of Area I was overrun during the last glaciation by ice originating in the Western Southern Uplands. The highest till occurrencies are at ca. 1500 ft. on the slopes of Nutberry Hill in the west. (Exp 12. Fig. 13) In the eastern parts of Area I, with lower altitudes, bare rock frequently outcrops above 900 feet (Fig. 9). The highest meltwater channel, at, 1,450 feet, gives a minimum altitude for the ice surface in the west. Eastwards, although admittedly with lower altitudes, there is no evidence of fluvioglacial features above 700 feet on Broken Cross Muir and above 950 feet at the eastern end of the Douglas Valley (Fig. 9).

(11) Whilst there are indications of an earlier ice advance, in the presence of high level north-west to south-east through cols in the Hagshaw Hills, this is nowhere confirmed by definite stratigraphical evidence.

(111) The general pattern of meltwater drainage suggests a south-west to north-east ice gradient and therefore a Southern Upland source. Locally, however, in the Coalburn area the orientation of meltwater channels suggests a tributary ice stream from the north-west. (Fig. 9).

(IV) During deglaciation there were three main areas of fluvioglacial deposition. These were on the floors of the three main valleys of the Nethan, the Poniel Water and the Douglas Water.

(V) The fluvioglacial deposits are of variable composition and origin. Many are of considerable volume and contain sufficient sand and gravel to have a commercial value under present conditions. They will be considered from this point of view in a later chapter.

CHAPTER III

AREA II

1. Location and Extent

Area II occupies the entire eastern section of Central Lanarkshire. Its boundaries are geometrical rather than natural. The border with Area III is a north to south line almost midway through the thesis area as a whole. (Fig. 1) The south-western boundaries with Area I are such that they exclude the drainage basins of all the streams, apart from the Drumalbin Burn, (Fig. 23) which flow to the Douglas Water. The southern boundary is partially delimited by the watershed of the dominating felsite massif of Tinto Hill and its neighbours. On the east and north the straight-line boundaries are those of the thesis area as a whole.

Area II, therefore, extends from north to south across the whole of Central Lanarkshire. Its northern parts became progressively more "Central Lowland" in character whilst the southern margins are directly in contact with the Southern Uplands. It is, however, important to note that Area II is further removed from the more western and wetter ranges of the Southern Uplands than Area I.

2. Relief and Drainage

In many ways Area II is the most varied of all these regional divisions. In the floor of the Clyde Valley to the north (Fig. 23) it contains the lowest altitudes in Central Lanarkshire. (ca.150 feet)/

(ca.150 feet). On its southern boundary, Tinto Hill (2,335 feet) rises high above all other hills in Central Lanarkshire. Extensive smooth plains, (Thankerton), almost featureless, till-covered, plateaux, (west and east of Crossford); bleak, sparsely drift-covered moorlands, (Cartland Muir and the south-western foothills of the Pentlands); and igneous intrusions, forming bold, upstanding hills, are all found. (Fig. 23)

Perhaps the only unifying feature of Area II is the valley of the River Clyde which runs diagonally across it from south-east to north-west and in doing so collects the drainage of all its streams. The present course of the Clyde is complex. It enters Area II at its south-east corner and after flowing northwards in a broad, flat-floored but steepsided valley (Ph 15) between the isolated hill masses of Tinto, (2,335 feet), Quothquhan Law (1,087 feet), and Cairngryffe Hill, (1,131 feet), the river emerges into the Carstairs Basin (Fig. 23). This extensive basin is almost completely covered by fluvioglacial deposits. The surface of these deposits is generally undulating and the basin has a flat floor only where subsequent river erosion has smoothed the irregular surface. The altitude of the basin varies from 600 feet to 700 feet except where a few more prominent fluvioglacial ridges protrude above this level. On all sides, except where streams enter or leave, it is surrounded by rising ground. The several large streams flowing into the basin occupy deep and often wide valleys e.g. the Douglas and the Medwin Valleys, (Fig. 23). In contrast there are only two drainage exits and both of these occupy canyon-like valleys. The first and major/

major exit is that of the Clyde at Bonnington/New Lanark, where the Bonnington and Corra Linn waterfalls have a combined drop of 189 feet "the greatest waterfall in Britain" (Ogilvie 1928 p. 417) (Ph 16). The lesser, but equally spectacular exit, is that of the Mouse Water which at Cartland Crags, one and a half miles north of Lanark, shows a vertical incision in excess of 300 feet. (Air Photo 17).

From Lanark to Crossford, the Clyde continues to flow in a narrowly confined valley with rapids and bedrock frequently seen on the valley floor. In this section, at Stonebyres, the third and final waterfall of the Clyde can be seen. At this stage, on the west bank of the Clyde, there is the triangularly shaped massif of Black Hill, (960 feet), Dillar Hill, (1,013 feet), and Darnfillan Hill (1,060 feet). On the east, beyond the conspicuous, but unoccupied trench, hereafter termed the Nemphlar Channel, rise the moorlands and hills of Cartland and Kilcadzow (Fig. 23).

Below Crossford, the valley of the Clyde, although retaining its steep sides, has a broad valley floor across which the river meanders widely. (Ph 18). The steep, flanking valley sides, in excess of 200 feet high, give way on either side to the extensive, smooth, plateaux surfaces so common around the periphery of the "Glasgow Basin". (cf. "the Higher Lowland Peneplane" of Ogilvie 1928 p. 413). The plateaux surfaces here range from altitudes between 400 feet and 600 feet. The rivers which drain them frequently run in steeply incised ravines, and often have the suffix "gill" attached, indicating their great degree of incision e.g. Rae's Gill, Carcain Gill, Maregill Burn. All of these, apparently very "youthful" streams, flow/

flow into the River Clyde and their characters presumably reflect changes in conditions which have also affected the trunk stream.

The River Clyde, therefore, not only appears to give some degree of unity to this otherwise diverse area, but also through its complex history probably contains the answers to many of the problems of landscape evolution in Central Lanarkshire. It will, therefore, be appropriate at this point to look at the Clyde in greater detail.

In its upper course, above Hyndford Bridge, (Fig. 23) the Valley of the River Clyde exhibits all the characteristics associated with the Davisian concept of "maturity". (Davis 1909). The broad valley floor has an extensive flood-plain track (Fig. 21) over which the Clyde meanders widely. Artificial and natural levees help restrict the river to a course which, however, shows frequent abrupt changes in direction. Textbook examples of migrating meanders, cut-off lakes and offset confluents can all be seen. (Ph 19). From Thankerton to Hyndford Bridge, a distance of approximately thirteen miles, the river falls 68 feet. The gradient, therefore, is of the order of 5.3 feet per mile. In the whole of this stretch the smooth, long profile is unbroken and bedrock is not seen except where a series of rock outcrops cross the river's course just above Hyndford Bridge. (The gradients quoted for the various sections of the Clyde's course are approximations. Altitude data was obtained from the 2½" and 6" O.S. sheets and the length of the river's course in its appropriate section was obtained from the 2½" O.S. maps).

Below Hyndford Bridge, after taking a pronounced

southward/

southward loop, the river again flows northwards. Here, however, all the signs associated with "maturity" suddenly disappear. Throughout its course to Crossford the river is incised into solid rock and at three separate localities, Bonnington, Corra Linn and Stonebyres, it plunges over waterfalls. The ravine-like nature of the valley with precipitous, almost vertical, slopes is maintained as far as Kirkfieldbank. (Ph 17) Beyond this village, as far as Crossford, although the valley is conspicuously less gorge-like, there is again a complete absence of the "mature" features of its upper course. The overall gradient of this section including the falls, is about 418 feet in six and a half miles, i.e. 65 feet per mile.

North of Crossford, where the Clyde is incised into the plateaux surfaces, the valley combines some of the features of both "youth" and "maturity". The valley sides are again extremely steep and as much as 300 feet high, yet despite this there is a well developed flood plain across which the river meanders, frequently being maintained in its present course by artificial levees. Bedrock is seen neither in the valley floor nor the valley sides and the river gradient is as little as 8 feet per mile in the stretch from Crossford to Rosebank (Fig. 21).

The course of the Clyde through Central Lanarkshire is a very complex one. The course which formerly joined the upper and lower more "mature" sections is obviously not the present one and although the Nemphlar Channel may be a remnant of this abandoned course, there is no similar evidence of the abandoned course in the vicinity of Lanark./

Lanark. It will be shown later that many of these features can be related directly to glacial "interference". At present, however, two conclusions already arrived at by researchers, (e.g. (Stark 1902 and Gregory 1915) can be repeated: (1) The Nemphlar Channel is a former course of the River Clyde, which connected the section below Crossford with one, now buried and no longer visible, in the vicinity of Lanark. (2) The present gorge section from Crossford to Bonnington post dates the abandoned Nemphlar Channel and is the most recent course of the Clyde, although not necessarily of the same age along its whole length. The full evidence of these conclusions and their implications on the events of glaciation and deglaciation will become clearer in the discussions of the ensuing sections.

Even in the more remote corners of Area II the influence of the Clyde can be seen. In the extreme south, in the area adjacent to and north of Tinto, isolated hills, 900 feet to 1,200 feet high, alternate with broad and deeply incised valleys the floors of which are generally below 750 feet (Fig. 25). Linton (1934 p. 84) maintains that these west/east oriented valleys were once occupied by streams which flowed eastward through the "Biggar Gap" to join the Tweed drainage system. All of these streams have now been diverted by the encroachment of a "pirate" Clyde.

The north-western part of Area II also drains to the Clyde. The main stream here is the River Nethan which emerges from Area I. This river flows in a deeply incised gorge which is eroded into and drains the extensive remnant plateaux surfaces (450 feet - 700 feet) and/

and the more upstanding hills composed of felsite intrusions e.g. Black Hill 960 feet.

Borehole information and other evidence (presented in subsequent sections) indicate another complication in the already complex history of relief and drainage evolution in Central Lanarkshire. At numerous localities the main rivers, now in ravine-like courses, run parallel or adjacent to valleys, often of greater dimensions, which are now infilled by glacial and fluvioglacial deposits. These buried valleys, the Nethan, the Clyde and the Mouse all possess examples of them, reveal a drainage pattern similar to that of today, with the Clyde forming the major trunk stream. The buried valleys are normally designated "Pre Glacial" although it is uncertain whether this implies that they were cut prior to the last readvance of ice into Central Lanarkshire or before even greater, earlier ice advances. Their significance to the glacial history of Area II will be fully discussed in later sections.

Deep dissection by rivers is especially noticeable in Area II. To the south there is a greatly dissected upland area whilst to the north the rivers are deeply eroded into the otherwise often featureless plateaux. The extensive Carstairs Basin is anomalous in that it forms a large area of lower land, is not greatly dissected by rivers and yet has its own distinctive landform pattern. The regional differences and complexities of relief and drainage evolution in Area II suggest a long and complex history.

3. Geology

The most simple description of the geological structure of Area II is that it is a broad syncline dipping northwards. As a consequence the oldest rocks should occur in the south and the youngest in the north. That this is only part of the story can be seen from Figure 22. Folding, frequent and severe faulting and lengthy periods of erosion have led to the present much more complicated pattern. Along the southern boundary of the area the dominating Tinto Hill indicates the presence of the largest felsite intrusion in Central Lanarkshire. (Fig. 22) Around its periphery Old Red Sandstone sedimentary and volcanic rocks form an almost complete ring. To the north-west, however, the Carmichael Fault brings a wedge of Silurian strata, the only one in Area II, into direct contact with the felsite intrusion. To the north of this older inlier Old Red Sandstone sediments, occasionally containing felsite intrusions, e.g. Cairngryffe and Black Hill, occupy a broad central belt in Area II with an associated outlier east of Kilcadzow. The remaining areas, the extensive Carstairs Basin and the lower plateaux to the north are composed of Carboniferous strata. It should be noted that to the north (Central Lowlands) and to the south (Southern Uplands) of the area shown on Figure 22, Carboniferous and "Southern Upland" rocks respectively become increasingly dominant, eventually to the exclusion of other rock types. The course of the River Clyde in Area II reflects the complicated rock outcrop pattern by successively passing over, Old Red Sandstone, Silurian, Carboniferous, Old Red Sandstone and Carboniferous rocks in its passage from south-east to north-west across the Area.

Although/

Although in general the felsite intrusions form the dominant hill masses, (an important exception is found where the newer gorge course of the Clyde, at Crossford, occupies a trench carved out of this rock), Old Red Sandstone rocks also occasionally give rise to hill areas e.g. Dillar Hill, (1,017 feet), Quothquhan Law, (1,097 feet), and Hill Rig (906 feet) (Fig. 23). The lower plateaux and basins are everywhere best developed on Carboniferous rocks.

The Geological Survey Drift map, (No. 23), shows an almost complete surface covering of drift. Solid rock generally only appears at the surface on the high ground above 850 feet or in the many deeply incised rock gorges. Field observations show that the till cover frequently approaches 1,000 feet in altitude but only rarely exceeds ten feet in thickness. In contrast, however, extensive areas are covered by fluvioglacial deposits which not only exceed those of Area I in extent and variety of surface expression, but also exceed a depth of 50 feet over wide areas. Despite this considerable extent, however, (at least equal to one half the till covered area) there are only three main areas of fluvioglacial deposition. The first occupies a hill enclosed basin around Thankerton, the second, and one of the most extensive in Scotland, extends from Lanark to Carnwath in the Carstairs Basin. (Although in fact it appears to be continued beyond the boundaries of Area II in both an easterly and westerly direction). The third concentration, and the smallest, occurs as discontinuous belts along both banks of the River Clyde below Lanark.

Smaller, isolated pockets of fluvioglacial deposits do exist/

exist e.g. Lesmahagow/Brocketsbrae and Blackwood Draffan (Fig 23) and these frequently are considered to have great significance in explaining the pattern of deglaciation as will be shown later. A particularly noticeable feature of the distribution of fluvioglacial deposits in Area II is their concentration in lowlying basins and in the main river valleys. There is little evidence of fluvioglacial deposition having taken place regardless of the underlying relief (contrast Area I Fig. 13).

Unlike Area I there are no areas of "morainic and earthy angular drift". There are, however, several widely distributed localities in which "brick clays" are found. These are generally blue/grey coloured clays, well sorted, (proved by laboratory experiment), but occasionally containing pebbles. The clays are usually stratified and their name is derived from the fact that they were formerly used in brick making although their present use is mainly in the making of tile drains. On the Geological Survey Drift Sheet, No. 23., these clays are only shown at sites where they are, or have been commercially exploited (Ph 20). Field observation and hand augering have proved an even wider distribution. Their occurrence, however, appears to be as isolated pockets rather than widespread sheets. Their distribution and mode of origin has considerable importance in determining deglaciation conditions and will be discussed in detail later. (Section 6).

The origin and distribution of slope deposits in Central Lanarkshire were discussed in the previous chapter. Such deposits are found at only one locality in Area II. Not surprisingly, perhaps, this is on Tinto Hill, (2,335 feet), which towers above the surrounding countryside. The deposits are widespread on this hill.

On/

On the summit area they form sheets of angular shattered bedrock, but where they are found on the very steep flanks of the hill well-formed stone stripes (Phs 5 and 6) can be seen. The slope deposits on Tinto are not fossil. Miller et alia (1954) indicated that the stripe phenomena are actively forming at the present day. (This contrasts with the slope deposit already described at Logan House (Chap. II Section 3) which, being covered by a mantle of waterlaid gravels appear to be a relic of an earlier cold period). The continued absence of encroaching vegetation and the fresh appearance of the rock fragments fully accord with Miller's conclusions.

With the till mantle extending up to altitudes of 1,000 feet and with only limited areas above this height, Area II has an even more extensive and complete drift cover than Area I. In its depth, composition and variety of surface expression it also exceeds that of the previous area.

4. Glacial Erosion

The south-west to north-east streamlining of hill masses, as seen to the south-west of Area I, is again noticeable in Area II. This is particularly true of the upland areas in the south where, however, there are geological reasons which would also promote this trend. The through col between Longmoor Hill and Tinto End (Fig. 23) suggests an ice stream moving from a south-west source and overriding these hills to a minimum depth of 1,200 feet.

To the north-east of these hills several streamless valleys are found, e.g. on either side of Cross Ridge and between Whitecastle/

Whitecastle and Black Hill (Fig. 23). These are broad valleys almost one mile wide and about 500 feet deep. Their origins are obscure but their present form might, at least in part, be due to glacial erosion. To the north the steep south and west facing slopes of the Dillar/Black Hill massif, developed without a break on two different rock types, sandstones and felsite of Old Red Sandstone age, and overlooking lower, smooth plateaux surfaces, might well be the product of glacial streamlining and oversteepening. Glacial erosion by ice from the south-west might also explain the shape and orientation of Hill Rig, one mile to the east of Kilcadzow. (Fig. 23). Professor Linton (Presidential Address to I.B.G. 1963 p.13) attributes the form of the valley of the Clyde between Hamilton and Crossford, (Fig. 21), "with its steep and rectilinear slopes and discordantly low base-level" to glacial erosion. This valley he maintains is an "ice-cut trough" of the "intrusive" type. Throughout the remainder of the Area, however, there is little definite evidence of glacial erosion.

Further information about the direction of ice movement in Area II can be derived from the distribution and orientation of glacial striae as recorded by the Geological Survey. Four striae in the Tinto/Carmichael area confirm the south-west to north-east ice movement. On the summit of Quothquhan Law, (1,097 feet), however, an isolated striation indicating an ice movement from south-south-east to north-north-west implies a vigorous glacier, emanating from Upper Clydesdale, strong enough to resist the push from the south-west (Fig.23).

In/

In the northern parts of Area II, around the periphery of Cartland Muir (Fig. 23), four striae indicate an ice movement from the south-east to the north-west. Within three miles to the north of Cartland Muir three further striae all show similar orientations without indicating the source of the ice. Further northwards, towards the centre of the Glasgow Basin, all the directional evidence, striae and drumlin orientations, imply an ice movement from the north-west. The inference from this evidence is that Highland and Southern Upland ice have both invaded the area north of Carluke.

5. Glacial Deposition

Evidence of glacial deposition is widespread in Area II. Even the highest moors and hillsides show indications of till cover. (Geikie,(1894, p. 79) found "relics of till near the top of Tinto Hill"). At lower altitudes in the valley floors the till cover normally becomes not only thicker but more continuous. In many areas, however, the till cover is hidden beneath thick deposits of sand and gravel and its character can only be inferred from borehole information.

Field observations reveal a marked division between grey/black tills in the north-west and red/brown tills in the south. The line of division runs approximately from Kilcadzow through Crossford to Lesmahagow (Fig. 24). Only at one section, No. 13 (Fig. 22) was one colour of till found to have trespassed this boundary for any distance, implying perhaps a northerly penetration of ice at this locality. The close association of this line with the geological boundary between Old Red Sandstone and Carboniferous strata can be seen on Figure 24. Unfortunately/

Unfortunately a lack of deep and fresh exposures makes difficult the recognition of definite red or grey tills over considerable areas and make it impossible to study in detail the relationships of the different colours of till to the geological boundary. It was originally thought that there was a relationship between till colours and till textures. In the field the matrix of red till seems grittier than the more clayey feeling of grey till. (Geikie 1894 p. 78). For this reason particle size analyses were carried out on several red and grey tills. The results show that there is no apparent textural difference between the different coloured tills. (Appendix I - B).

To the south the till has a characteristic sticky, compact, red/brown nature, exactly like that found in neighbouring parts of Area I. It extends up the hill slopes to altitudes of 1,100 feet and is found on the summits of hills of lower altitudes e.g. Chester Hill 1,000 feet. It is everywhere thin except in the valley bottoms. On the hillslopes bedrock frequently appears on the surface. On Cairngryffe Hill, (Fig. 23), a large felsite rock quarry affords good exposures on the hillside. No till is found from 975 feet to the summit, (1,100 feet) except on the lee, north-east facing, slope where it reaches 1025 feet. The highest till exposure on the west facing slopes is in a burn course, where a minimum of six feet of fresh red/brown till can be seen. On Cartland Muir and the hills beside Kilcadzow any prominence, as a consequence of the thin till cover, reveals solid rock at the surface, e.g. Kilcadzow Law. Although depressions in the rock surface of the Muir allowed a greater accumulation of till, frequent disused/

disused quarry sections show a general maximum till cover of only three feet. This forms a thin sheet which very rarely has any definite topographical expression.

In the valley floors the till is usually overlain by fluvioglacial deposits and because of this good, deep sections are difficult to find. As a consequence, in the southern part of the area "it is often difficult to differentiate between till and stratified drift since the till often contains numerous rounded and partly rounded stones from the Old Red Sandstone conglomerate" (Sissons 1961 p. 177). The fine material derived from this rock may also be misleading for it provides a gritty feeling to the till matrix. Where good fresh exposures are available however, there is no difficulty in differentiating between glacial and fluvioglacial deposits.

Three good sections in the valley of the north-flowing Carmichael Burn provide a clear picture of the valley floor drift deposits (Exps. 8,10 and 11 Fig. 25).

TABLE VII

Exp. 8 Fig.25	2 ft. stratified sand and fine gravel 7 ft. red brown till	Exp.10 Fig.25	10 ft. redbrown till	Exp.11 Fig.25	10 ft. red brown till 20 ft. stratified sand and fine gravel

The middle exposure, Exp. 10 is also shown on Figure 22 as No. 6. The other two sections are also in the side of the Carmichael Burn/

Burn one half mile to the north and south respectively. At the northern-most section seven feet of red/brown till is overlain by two feet of stratified sand and fine gravel. At the middle section only till is present. The southern-most site shows ten feet of till, exactly comparable in appearance to that of the other two. The till overlies a further twenty feet of stratified sand and fine gravel. The almost horizontal stratification, lack of disturbance and fineness of the material in the underlying fluvioglacial deposits are suggestive of an extra-glacial, calm water, depositional environment. The till at this section can be traced northwards without a break to the other two sites.

At the middle site the character of the till was investigated in detail. The till fabric diagram No. 6 (Fig. 15) shows a very strong orientation south-south-west to north-north-east. The percentage of stones falling into the maxima quadrant, 46%, is rather less than might have been expected, but this is only so because of the high proportion of stones, (40%), in the opposite quadrant. The till fabric, therefore, gives an excellent indication that ice moved through this area from south-south-west to north-north-east. The red brown colour of the till agrees with this origin and the result of the rock type analyses, 10% Carboniferous, 76% Old Red Sandstone and 14% Southern Upland rocks is exactly what one might expect from an ice movement, with this trend, passing over the surrounding rocks (Fig. 22).

The most simple explanation of the stratigraphy of the southern-most exposure (Exp.11 Fig. 25) is as follows. The low through col, 840 feet, between Stone Hill and Black Hill (Fig. 23) and the/

the valley of the Douglas Water to the north would allow an earlier penetration of ice from the south-west than the through col at 1,125 feet between Longmoor Hill and Tinto End. This means that any drainage along the present course of the Carmichael Burn would be ponded back by the active ice streams in the valleys to the north. Thus a lake would tend to form at the site of the southern-most exposure. The sediments here are, therefore, quite possibly meltwater deposits laid down during the advance of the ice. When the thickness of ice increased sufficiently, the through col at Tinto End would be overridden and the ice moving over and eclipsing the lake would deposit the overlying till. The disappearance of the ice, without further deposition, would leave the stratigraphy as it is seen today.

From the evidence of striae orientation, streamlining of relief, till fabric orientation and rock type content of tills alone, a south-western ice origin seems to be the only likely possibility in this part of Area II. In the absence of any contrary evidence it is assumed that this ice was of the same age and origin as that which laid down the deposits of the adjacent Douglas Valley in Area I.

Over the extensive Bonnington/Carstairs Basin the extent of glacial deposition is obscured by the thick mantle of fluvioglacial deposits. All information about the till is derived from exposures marginal to the main basin and borehole records. On the high ground, (650 feet) above the Clyde gorge at Lanark a recent excavation, Exp.7 Fig. 26, revealed fifteen feet of drift without striking solid rock. The till in this exposure was very compact, tough and red/brown in colour/

colour. It occurred in lenses of up to twelve feet in length and several feet in diameter rather than as one continuous stratum. The larger part of the exposed face (one hundred yards long and ten feet deep) was composed of irregular masses of sand and sandy clay material. These deposits only rarely showed any indication of stratification. The character of the deposit was consistent with the above description throughout its length.

To the east of Lanark several exposures on the north-western margin of the Carstairs Basin exhibit solid rock at the surface. (Exps. 11,12 and 13 Fig. 27). . Solid rock also occurs in all the exposures on the high ground to the north and east of the basin. (Exps. 3,7,8,23 and 26 Fig. 27). The lower slopes, however, normally have a cover of till several feet deep e.g. Exps. 15,16,9,1 and 4 (Fig.27). The till cover tends to terminate above 875 feet. Below 750 feet the till becomes increasingly covered by fluvioglacial deposits and in the floor of the basin itself, (i.e. below 700 feet) two boreholes more than 50 feet deep and penetrating to bedrock failed to show the presence of till.

Two of the sites, peripheral to the Carstairs Basin, where till is exposed, were further investigated. Both of these are on the northside of the basin. The first, Exp. 1 Fig 27, shows a minimum thickness of eight feet of red/brown till. The till fabric shows a strong preferred orientation from south-west to north-east, although with three separate peaks (No.7 Fig. 15). Fully 69% of the stones were contained in the peak maxima quadrant. The rock type content analysis, (No.7 Fig. 16), shows 96% Carboniferous and 4% Southern Upland rocks.

All/

All the Carboniferous pebbles are of a relatively soft marly sandstone found locally in the underlying Calciferous Sandstone Series. Almost the entire bedrock of the Carboniferous Carstairs Basin is composed of this series. Further outcrops of this rock type are found several miles to the west. However, in this case the rock type content and the till fabric orientation do not accord. The exposure site is on Old Red Sandstone and the south-west origin indicated by the till fabric would certainly suggest a considerable proportion of these rocks in the sample and yet no Old Red Sandstone fragments are to be found.

Other peculiarities are found in the till of this area. At an altitude of 700 feet in the western edge of Cartland Muir, near Braidwood, (Fig. 23) a deep deposit of clay is found. This was formerly worked for the making of 'Terra Cotta' bricks. Renewed excavations have revealed fresh exposures and together with borehole records obtained from the National Coal Board and the local contractor allow a detailed examination of the clay's distribution and depth.

TABLE VIII

Bore 1 700.2ft O.D.		Bore 2 686.9ft. O.D.		Bore 3 682.4ft OD		Bore 4 681.8ft OD	
7 ins	Soil	8 ins.	Soil	8 ins	Soil	9 ins	Soil
6ft.5 ins	Yellow clay	13ft.3ins	Red Clay	15ft.9ins	Red Clay	7ft.3ins	Soft Clay
8ft.8 ins	Hard Packed Sand	13ft.11 ins	Solid	16ft.5ins	Solid	8ft.5ins	Red Clay
10ft.4ins	Red Clay					16ft.5ins	
26ft.	Solid						

Bore 5 669.7 ft. O.D.		Bore 6 657 ft. O.D.	
6 ins	Soil	6ins.	Soil
7ft.6ins	Red Clay	15ft8ins.	Red Sandy Clay
8ft.	Solid	21ft.8ins.	Solid

(The boreholes are arranged almost in a line from north to south (Nos. 1 - 6 respectively). The distance from No. 1 to No. 6 is 400 yards).

The clay has a colour which ranges from bright yellow on the surface, possibly due to weathering, to a more characteristic deep, reddish purple beneath. It contains occasional stones, which however, are often soft and friable and with their reddish purple staining are difficult to recognise. Almost all of these are again soft marly sandstones and the underlying rocks are shown on Sheet 23 as the Cementstone Group described by Geikie as "lower limestone resting upon a similar series of red and grey grits, sandstones, fireclays, shales etc" (A. Geikie 1873 p.20). This highly distinctive and uncommon clay material is not described in any of the Geological Survey reports. It's origin therefore is problematic and although samples were shown to various authorities none of them were able to offer definite conclusions. From its appearance, as already suggested, it was thought that it might be a weathering product of the local bedrock. This conclusion was discarded for several reasons: (1) Nearby exposures of bedrock did not show signs of extensive weathering. (2) The clay was not widespread but appeared to occupy an elongated depression. (3) Several erratic fragments of coal and one ironstone nodule, like those of the Coal Measure Series, were found in the clay, implying that it was not of purely local origin. (4) Borehole No. 1 indicates a sand layer separating two clay layers suggesting that the whole series is a drift rather than a weathering product.

Although/

Although at the Cartland Muir site the clay appeared to be located in a pocket, it was also found at site No.8 (Fig. 22) (Ph 21). Here, however, its colour was of mixed purple and green hues and it contained numerous boulders. A sample of the clay was subjected to a particle size analysis and the results, (No.8 Appendix I A), were indistinguishable from those of the other tills sampled. The rock type content (No. 8 Fig.16), was almost exactly the same as its neighbour, No. 7 Fig. 22 and showed 96% Carboniferous rocks and 2% Old Red Sandstone rocks. It was concluded therefore that the clay material found on Cartland Muir (Fig.23) and at site No.8 (Fig. 22) is in fact a glacial deposit the various bright colours of which are a result of the highly coloured Calciferous Sandstone Series. The appearance of the tills in the field, however, is suggestive of extensive and thorough leaching. Despite the fact that the source rock - the Cementstone Series, contains a large proportion of calcareous material the tills give no reaction with dilute hydrochloric acid, again, perhaps, a sign of weathering. It is significant, however, that only in this area are these weathered tills to be found, a point which will be returned to later.

The great depth and extent of fluvioglacial deposition in the Carstairs/Bonnington area makes it difficult to assess the extent and character of glacial deposition. Fortunately, however, there are several reliable borehole records in the area. Thus, in the western part of the basin the boreholes put down during the construction of the Bonnington Hydro Electric Power scheme tunnel (Fig. 26) in the 1920s are of great importance. Borehole No. 3 (Fig. 31) shows 48 feet of sand/

sand, clay and gravel overlying a minimum thickness of five feet of boulder clay. Ross, (Summary of Progress. Geol. Survey 1926 p.158), concluded that this latter deposit was "the ground moraine of the Douglas Valley Glacier which entered the Clyde Valley from the south-west". None of the nine other boreholes put down, nor the records of the opencast workings show any evidence of the till deposit, Three other boreholes in the flood-plain of the Mouse, i.e. in the central part of the Carstairs Basin, all penetrated to bedrock without showing a till stratum (Section 6).

Although the till cover in Central Lanarkshire is generally much thinner than in the "Drumlin Belts" of Central Scotland, the plateaux surfaces in the northern parts of Area II have a fairly uniform till cover, about ten feet in depth, dependent on local relief configuration. In the extreme north this cover achieves its maximum depth. Fresh sections in the new motor way (M 74) construction north of Draffan, reveal till depths ranging from 15 feet to 35 feet over extensive areas. Despite this depth few true drumlinoid forms are found. Only two well developed samples are to be found (north-west of Draffan Fig 23) and both of these display a north/south orientation.

In these northern plateaux areas the till is uniformly grey/black in colour (Fig 24). Its tough, compact nature and high content of Carboniferous rocks give it an appearance comparable to those tills found in the Glasgow area. At most of the exposures visited there appears to be neither over nor underlying fluvioglacial material and the till is normally seen to rest on solid rock (Exp.9 Fig.22).

The/

The till cover of the plateaux surfaces to the west of the River Clyde is generally thicker than on the comparable east bank plateaux. At Exposure 10, (Fig. 22), in a fresh motorway cutting to the north-west of Netherburn a till fabric study was undertaken. (This site is on the boundary between Areas II and III and will be mentioned in Chapter IV). At Exposure 10, (Fig. 22), the till fabric shows a distinct concentration of stones in the south-west quadrant. Although the fabric shows a rather widespread peak, the south-western peak maxima quadrant contained fully 63% of all the stones orientated. (No. 10 Fig. 15). The rock type analyses of the till reveal 82% Carboniferous, 14% Old Red Sandstone and 4% Southern Upland. This composition of rock types, especially with the absence of Highland erratics is certainly in accordance with an ice source to the south-west as suggested by the till fabric. At first, this conclusion appears to be contrary to the generally held belief that ice from the South Western Highlands ,shown diagrammatically by Charlesworth, (1926 Map opp. P.50), penetrated these plateaux areas via the Glasgow Basin.(Fig. 5) Sissons, however, in his paper on the Perth Re-advance in Central Scotland (1963, Pt I p.154) suggests that the ice stream from the Glasgow Basin was added to by a strong ice movement from the south-west via the Avon Valley, a conclusion which supports the conclusions already stated.

A till analysis was carried out at a comparable site on the plateau level at 760 feet on the east bank of the Clyde. (No.9 Fig.22) Here again there is a minimum thickness of ten feet of grey/black till./

till. A stone orientation at this locality, however, reveals a fabric which for the first time has a north to south bias. The north-west peak maxima quadrant with 38% of all the stones has a slight majority over the opposite quadrant. (35%). (No. 9 Fig. 15). The rock type content analysis reveals 94% Carboniferous, and 6% Old Red Sandstone pebbles. The nearest Old Red Sandstone outcrops are to the south and east but the nearest outcrops of the tough white sandstone and grey shales, which together supply the whole Carboniferous contribution, are all to the north and west. However, as has already been pointed out, no less than five glacial striae between Lanark and Lesmahagow, (Fig. 23), contradict this conclusion by indicating an ice movement from south-east to north-west. Three further striae, also recorded by the Geological Survey, within two miles to the north but outside the thesis area indicate a similar orientation without suggesting the ice source. It has already been indicated that fabric orientation may or may not give conclusive results dependent on factors which are as yet unexplained. A similar difficulty arises from the problem of ascertaining ice sources from glacial striae alone. For an ordinary striation there are two possibilities. In view of the uncertain nature of the evidence from this one site Geikie's description of a "debatable ground" seems very apt.

The best exposures, however, are often found where the larger rivers have incised themselves into their valley floors and by their meanderings undercut their banks which, as a consequence, often reveal fresh sections. Such is the case at the River Nethan below Kirkmuirhill/

Kirkmuirhill where a 125 foot face reveals an interesting stratigraphical record.

Two grey tills of exactly similar appearance are separated by 30 feet of fluvioglacial sediments. The upper till, ten feet in depth, shows at its upper end an intricate interdigitation with the overlying sands.

TABLE IX

5'	coarse gravels
20'	Unstratified sand with lenses of till
10'	till
10'	very coarse gravel
10'	Stratified sand and gravel
10'	Stratified fine and coarse sands
10'	till
30'	obscured by slumped material
20'	stratified sand and gravel possibly slumped
125'	

Continuous fingers of till penetrate as much as five feet in to these sands. Isolated lenses of till several feet long and up to one foot thick are also found enclosed in the sands. Only ten feet of the lower till is exposed but it may well be as much as 40 feet thick (see table above). Both these tills were analysed for fabric orientation and rock type content. The lower one, (No. 11 Fig. 22) shows a strong preferred orientation along the north-south axis. A slight dip maxima in the northern (Peak) quadrant of 42% compared with 38% in the opposite quadrant suggests a northern origin. However, the rock type content with 92% Carboniferous, 4% Old Red Sandstone and 2% Southern Upland rocks, that is erratics from the south only, might favour a southern origin.

The upper till, (No. 12 Fig. 22), has a slightly stronger

peak/

peak maxima quadrant (56% of pebbles) and again indicates a northern origin, this time from the north-north-west (No. 12 Fig. 15). The rock type analysis reveals a composition remarkably similar to its underlying neighbour. (No. 12 Fig. 16). Again, however, the erratic fragments are mainly of Old Red Sandstone and Southern Upland derivation. (2% Highland, 88% Carboniferous, 8% Old Red Sandstone and 2% Southern Upland). So although the till fabrics at this site suggest a northern origin, the rock types present, with a larger percentage of erratics from the south, indicate a Southern Upland ice origin. Again Geikie's comments about the "debatable ground" of Central Lanarkshire seem appropriate.

Another good river valley exposure was found in the floor of the Clyde south of Rosebank. At this point the Clyde takes a wide meander which is incised into the valley floor deposits to a depth of 60 feet. The core of the meander thus preserves an exposure of deposits which elsewhere have been removed by river erosion. At the base of this meander core, a 20 feet section shows the following, five feet of coarse sand and gravel, overlying five feet of till with a brown clayey matrix. This in turn overlies six feet of gravel the appearance of which is quite remarkable being composed almost entirely of rounded coal cobbles. This gravel is very compact and similar in appearance to the underlying layer of grey/black till which has an exposed depth of six feet. The difficulty of differentiating till from gravel is complicated further by the interdigitation of the till into the gravel.

The fabric of the upper till, (No.13 Fig. 15), is

rather/

rather dispersed, with a weak dip maxima indicating a south-east origin. (The orientation of the Clyde Valley at this locality is also north-west to south-east). The rock types present in the till are 4% Highland, 82% Carboniferous, 4% Old Red Sandstone and 10% Southern Upland. This is, however, the only recorded site in Area II at which a brown till is found in a position markedly north of the line dividing the distribution of the two main till types. (Fig. 24). The weight of the evidence therefore infers that the last ice in the area was of southern derivation, especially since the underlying till is of the more normal grey/black colour.

The evidence of the origins of the glacial deposits of Area II as presented so far, is complex and varied. Generalisations, unlike those formulated for Area I, tend to be true only of localised, rather than wider, regional areas. There is some evidence that the area has been invaded by ice from both the north and the south. The separation of two till horizons by considerable thickness of fluvioglacial deposits, 6 feet - 40 feet at sites already described, suggests at least one intervening period during which the ice cover melted and withdrew before a later ice readvance and a further period of till deposition. In an attempt to clarify or at least separate the glacial events in this area attention was paid to four separate information sources (1) the so-called "Pre-Glacial Valleys" (2) Borehole stratigraphy (3) Topographical breaks in the drift cover (4) Dateable Deposits.

<u>The "Pre-Glacial"or buried valleys of Area II.</u>

The "Pre-Glacial" valleys of Central Lanarkshire are well/

well known in the literature (Geikie 1873, Stark 1902, MacGregor M. 1940), and are a common occurrence in other glaciated countries (Flint 1956 p. 112, Adams 1961 p. 406). They are generally filled with glacial detritus in the form of till, sand, gravel and mud. (The latter term is one frequently found in borehole journals of these buried valleys.) They are particularly well known because of their occurrence in the coalfield districts where they present danger hazards, to deep mining. (Under pressure they may break through and flow into mine shafts). To prevent such accidents their locations have been charted by boring. The Geological Survey Drift Sheet No. 23 shows two major buried valleys in the thesis area, those of the Avon and the Nethan.

In both cases where the river has not "discovered" its former course the old channel remains blocked by glacial and fluvioglacial deposits whilst the present river has cut a new course. This new channel is invariably gorge- or ravine-like in character e.g. see the Nethan Crags, near Crossford (Fig. 30). Numerous examples of these ravines are found throughout Central Scotland and although often 200 feet or more in depth and eroded in solid rock they have all been interpreted as being the effect of post glacial river erosion. The gorge course of the Clyde from New Lanark to Bonnington (Fig. 21), is the best known example. (Ph 16) Where, however, the river "rediscovers" its former course it has cut very rapidly through the unconsolidated valley fill deposits and eventually produces a more open, although frequently steep-sided valley which always displays a greater extent of flood plain than its gorge sections. (Ph 18) Geikie

(1894/

(1894 p. 108 - 116) was one of the first authors to realise the full significance of these buried valleys, and he described numerous examples in Central Scotland, several of which are in the thesis area. Even where the rivers have rediscovered their "Pre-Glacial" courses the work of reexcavation is not always complete e.g. the boreholes in the Douglas Water Valley (Fig. 12) show a considerable depth of glacial and fluvioglacial debris still remaining. Similarly, at Crossford, in the floor of the Clyde Valley, boreholes show a further 80 feet of untouched 'drift deposits'. Numerous examples of these buried "Pre-Glacial", re-occupied "Pre-Glacial" and gorge-like post-glacial valleys, can be found at various localities along the lengths of most major rivers in Central Scotland and their presence is often easily recognisable even from the Ordnance Survey 1" sheets. Many others, as yet unrecorded in the literature, can easily be identified in the field.

The three major rivers of Central Lanarkshire, the Clyde, The Avon and the Nethan all exhibit an alternation of "Pre-Glacial" and "Post-Glacial" sections. The buried valley of the Nethan, being entirely within the Productive Coal Measures, is well charted but outside the Coalfields the absence of deep borehole investigation leads to a lack of definite information on the buried sections of the other two rivers.

It is perhaps not unexpected that this particularly complicated area of Central Lanarkshire should provide at least one exception to the generalisation that all the river course of Central Scotland/

Scotland are; (1) Buried "Pre-Glacial" Valleys, (2) Re-excavated "Pre-Glacial" Valleys or (3) "Post-Glacial Valleys. The outstanding exception is the Nemphlar Channel which is a large valley, one mile broad - 300 feet deep but displaying a flat floor up to 300 yards across (Fig. 21). At its lower end, near Crossford, the Nemphlar Channel takes a wide sweep to the east before continuing southwards for two and a half miles to the point opposite Kirkfield Bank where it rejoins the present Clyde Valley. (Fig. 23). This Nemphlar Channel has been identified both as the "Pre-Glacial" course of the River Clyde (Geol. Survey Drift Sheet No. 23) and as "an ancient water course of the Mouse Water" (Hunter 1882 p. 94) but despite its present streamless condition and its virtually unaltered condition since the time of its abandonment, the Nemphlar Channel, is not infilled by glacial or fluvioglacial detritus. The long and cross-profiles, dimensions, position and orientation of this valley indicate a former connection with the "gutter" course of the Clyde below Crossford. In contrast to the neighbouring, gorge-like present course of the Clyde the Nemphlar Channel has an apparently unaltered flood plain floor much of which is still covered by alluvium. (Exp. 11, Fig. 30). Its floor is at an altitude of 325 feet in the north and 400 feet in the south and is now 150 feet to 225 feet above the valley floor of the present Clyde from Crossford to Kirkfield Bank. There seems, therefore, little doubt that this valley was once occupied by the Clyde, (carrying also the tributary waters of the Mouse) but why should it, unlike other "Pre-Glacial" river courses to the north and to the south, have escaped infilling by glacial and fluvioglacial/

fluvioglacial deposition? The most simple explanation is that it was never occupied by ice and there is considerable evidence to support this statement.

At both its southern and northern ends the Nemphlar Channel contains glacial and fluvioglacial features. (Figs. 29 and 30). At the south end, (Fig. 29), several esker-like ridges and mounds of sand and gravel are found in association with several small meltwater channels. (Ph, 22). These features, however, terminate abruptly and do not penetrate northwards into the interior of this valley. At the north end the Channel is completely blocked by a barrier composed of several elongated drift mounds. (Fig. 30). The view of these mounds from the north (Phs. 23,24 and 25) gives no indication of the large concealed valley beyond (Ph. 26). This drift barrier is penetrated at one point only where it is cut through by the sinuous, incised, gorge course of the Fiddlers Burn which enters the Nemphlar Channel near its northern end. (Fig. 30). The inset in Figure 30, shows a cross-profile of the relief features through the drift barrier blocking the north end of the Nemphlar Channel (Heights from 2½" O.S. Sheet). The prominent elongated mounds appear to be largely composed of sand and gravel. The surface material, perhaps as a consequence of the steep slopes and the unconsolidated nature of the drift, is prone to slumping, (See Phs.23, 24,25 and close up Ph. 27), and no exposures of fresh material are available. Solid rock is only exposed on the north bank of the Fiddlers Burn where it is incised into the side of the "Nemphlar Channel". One exposure, (Exp.9 Fig. 30), at the base of a drift mound/

mound reveals numerous rounded cobbles and a sandy silt matrix but the texture and appearance of this material has probably been affected by surface creep.

To the west and east the drift mounds terminate abruptly. (Ph.26). One good exposure, (Exp.10 Fig. 30), in material which appears to run back under the mounds shows seven feet of till-like drift. This deposit contains numerous rounded pebbles of different rock types a few of which show striations. The matrix seemed rather silty and the deposit appeared less compact than is normal for tills but a particle size analysis, (No.14 Appendix 1-A), indicates a typical till composition. The till overlies at least two feet of graded gravels. At first it was thought that the till may have slumped from the valley sides but this is not borne out by a fabric analysis. A preferred orientation from the west, (i.e. from the direction of the mounds and not from the valley sides), is found. This preferred orientation has distinct twin peaks, albeit a rather dispersed orientation, (only 38% of the stones were in the peak maxima quadrant) indicating ice movement from the west (No. 14 Fig. 15). The rock type content of 58% Carboniferous, 24% Old Red Sandstone and 18% Southern Upland rocks certainly indicates the presence of southern rather than northern ice. Within 200 yards to the east, into the Nemphlar Channel proper, another section, (Exp.11 Fig.30), shows several feet of stratified gravel overlain by three to four feet of silty clay (alluvium) but no sign of till.

The disposition of the drift mounds to the west (transverse to the valley orientation), their apparent composition of fluvioglacial rather than glacial deposits, their localised distribution and lack of penetration into the Nemphlar Channel proper, certainly indicate that, as to the south, ice did not occupy the interior of this valley. From the evidence presented it is suggested that these drifts mounds are, in fact, ice marginal accumulations which according to Flint's definitions, (1950 p.131,2 and 3) would fit the description of an end moraine. The reasons for its limited penetration were probably due to the local thinness of ice and the steep reverse gradient of the northern entrance to the Nemphlar Channel the floor of which, consequent to the continued downcutting in the "new" Clyde Valley, was now left at a higher level. As yet there is no satisfactory explanation why, as in this case, marginal deposits, with the topographical expression of moraines, should form in a marginal ice position at one locality and not in another. Perhaps in this case the combination of reversed gradient and thinness of ice promoted the accumulation of deposits at a position where ice remained virtually stationary for some time.

At the Stonebyres Falls Hydro Electric Power Scheme, in the course of the Clyde which now bypasses the Older Nemphlar Channel, a tunnel section reported by Ross, (1925 p.115-6), revealed 20 feet of coarse gravels and fine sands overlying 23 feet of laminated clays. Ross concluded that the clays were laid down in a "temporary ice-blocked lake" and that the sands and gravels were typical of those "deposited by meltwaters from the Southern Uplands ice". These statements/

statements completely accord with the conclusion that during the last ice cover of Central Lanarkshire marginal ice tongues blocked both the north and south ends of the Nemphlar Channel but did not penetrate the area in between. The extent of fluvioglacial deposition at Stonebyres, (till is noticeably absent), indicates that this section of the Clyde Valley was already a major river valley before this late stage of glaciation in Central Lanarkshire. Thus it is certain that the Nemphlar Channel had been abandoned in favour of a newer Clyde course to the west before this last local ice advance.

Both the rock type contents and the fabrics of the tills at the north end of the Nemphlar Channel and in the floor of the Clyde at Milton Lockhart, (No.13 Fig. 22), indicate that the last ice to occupy the area originated in the Southern Uplands. The absence of till and the presence of lake deposits in the present Clyde Valley between Crossford and Lanark and the evidence of the Nemphlar Channel, certainly confirm the presence of an ice free area in Central Lanarkshire during the last glacial phase. (It may be recalled that the till on the Cartland Muir area above and to the east of the Nemphlar Channel has a distinctive weathered appearance, perhaps again an indication of an ice free condition during this colder period). This ice-free condition must have been caused by the splitting of the advancing Southern Upland ice into two lobes by the barrier of the extensive Black Dillar and Darnfillan Hill massif which stood as a nunatak area immediately to the south-west of the ice free Zone. (The deflection of the ice stream on the south and west of this hill mass/

mass has already been suggested by the presence of over steepened slopes developed equally on different rock types on its west facing slopes. (Section 4).

The implications of the preceding discussion is that, as has been suggested by the majority of workers, (Geikie 1873, Gregory 1915 a, Ross 1925, MacGregor 1940, Sissons 1961 and 1963 and Goodlet 1964), Charlesworth's (1926) suggestion of a late glacial readvance with Highland Ice advancing up the Clyde Valley to Carstairs is misleading. If there was a late glacial ice readvance in Area II then the bulk of the evidence indicates that the ice emanated from the Southern Uplands.

The significance of the Nemphlar Channel, has however, been almost totally disregarded in the literature. This probably arises from the difficulty of explaining a "Pre-Glacial" valley which was not subsequently drift filled. However, with Charlesworth's, (1926) widely accepted concept of readvance stages during the recession of the last ice cover it has been shown above that the Nemphlar Channel holds the key to some of the problems of glaciation in Central Lanarkshire. One problem yet remains unanswered. Why was the Nemphlar Channel abandoned in favour of a more western course? An answer can now be suggested.

If Linton's statement, (1963 p.13), that the "gutter" course of the Clyde from Hamilton to Lanark, (Fig. 23), is an "ice-cut trough" is accepted, (Although the "steep rectilinear slopes" which Linton implies were "ice-cut" are in fact composed of thick marginal accumulations of sand and gravel (Ph 28) the precipitous slopes of which are the result of ice contact and subsequent river erosion), deep

boreholes/

boreholes at Crossford, (Hunter 1882), show that the rock floor of the Clyde at this point is fully 80 feet lower than the present flood plain and only 80 feet above present sea-level. Such overdeepening certainly suggests glacial erosion of the scale found in other Central Scotland valleys (e.g. The Kelvin and the Blane Valleys)), then this glacially breached valley would form the obvious route for advancing ice from the South Western Highlands which, in view of the distribution of Highland erratics as far south as Carstairs, must have occurred at some stage. This ice stream, being less able to mould itself to geological and relief conditions than water may have bypassed the sharp east-ward loop of the old Clyde course, (at this point following an eastwardly outcropping series of the less resistant Limestone Coal Group), and maintained a more direct southern course. Thus glacial breaching as suggested by Linton could well account for the fact that the Clyde immediately to the south of Crossford cuts through a resistant felsite intrusion, (an unlikely occurrence under normal circumstances of river development) and could explain the abandonment of the more devious Nemphlar Channel for the present more direct Clyde course.

The east bank tributary of the River Clyde, the Mouse Water, displays features similar and perhaps even more complicated than those of its trunk stream. Figure 29 shows what appear to be no less than three earlier courses of the Mouse Water. (A.B. and C.). The first two, (A and B), are broader, have more rounded profiles and are till floored. Channel A is almost completely infilled by drift and is only revealed at its eastern and western margins where present stream

excavation/

excavation is rapidly removing the unconsolidated drift (Dougall 1871 p.49). A borehole at Jerviswood Mains, (Fig. 32), a mile to the east proves its continuation as a completely buried valley in this direction. (Borehole Journal, (Geol.Survey), shows one foot soil, five feet brown clay with stones (till?), 31 feet dark muddy clay, 9 feet silt and stones, 39 feet dark clay and stones, (till?) and bedrock in descending order). The possibility of two distinct till horizons might suggest a very early infilling of this channel before a second ice readvance. Channel B has only a thin mantle of till and has a much sharper cross-profile than channel A. Its steep sides imply only limited deposition. Channel C has the steepest sides and sharpest cross-profile of all three (Ph 17). It contains no till and the only sign of occupation by ice is a small esker-like ridge on its floor. At its eastern end the subsequent incision of the Mouse has left this channel 60 feet above the present river level. At the western end an even greater drop of about 100 feet connects the channel with the present Mouse Water/River Clyde flood plain. The present ravine of the Mouse Water at Cartland Crags, (D. Fig. 29), has a 200 feet vertical face on its north side which is incised in solid rock. Above this a very steep slope continues for a further 200 feet giving a total incision of 400 feet. A. Geikie, (1866 p.51), noted the "exceedingly puzzling" features of the Mouse and its neighbourhood but did not mention the two almost completely buried channels A and B. The progressive sharpening of the cross-profiles and the associated lessening of the effect of glacial and fluvioglacial deposition from Channel A to Channel D suggests a rather unique sequence of events the causes of

which/

which will be more properly treated in Section 6.

Even this short section has shown some of the complexities of landscape evolution in Central Lanarkshire. The buried valleys indicate some of the disruptions due to glacial interference. On the disappearance of the ice most of the major streams resumed courses similar to those of the "pre-glacial" period. Some, however, have not rediscovered their former courses and have since cut the familiar ravines or gorges. The Nemphlar Channel appears to be an exception in that this "pre-glacial" river course has neither been rediscovered nor infilled by glacial and fluvioglacial deposits and is taken to indicate a limit of ice penetration in the late-glacial period. The significance of this conclusion is vital to the explanation and chronology of events during the last ice cover of Central Lanarkshire.

DEEP BOREHOLES

In Central Lanarkshire the drift cover is generally less than 20 feet in depth. Normally there is evidence of only one glaciation in the form of one till stratum, with or without a covering of fluvioglacial sediments. It is fortunate therefore that buried valleys exist, for where these are cut through by streams, cross-sections in a greater depth of drift reveal a fuller and more detailed stratigraphical record. Exposures such as that already described at Kirkmuirhill (Table IX), are unfortunately rare. Boreholes, however, help to increase the stratigraphical information from these valleys. It should be pointed out that many of the bores were not

put/

put down to establish the drift stratigraphy and in all of them the nomenclature of the material brought up tends to vary according to the operator. This is especially true of the many early bores put down by the private coal mining companies. The sentiments of the recording officers, sometimes recorded in verbal form on the borehole logs, leave considerable doubt as to the accuracy of some of the results. (One journal found during the investigation of borehole records in the Geological Survey Offices in Edinburgh and filed prior to 1865 had the following inspiring appendage "This borehole was by Claud Anderson, a rotten borer and a liar"). However, even with these deficiencies, boreholes can provide valuable information otherwise unobtainable.

Many of the features of Figure 32 are only known because of deep-borehole investigations. Some of the best known boreholes in Lanarkshire are those drilled during the construction of the Bonnington aqueduct tunnel. These and associated excavations were checked by Geological Survey Officers and reported by G. Ross in the Summary of Progress for 1926. They revealed a general drift depth of about 60 feet and an even greater depth, 98 feet, where this overlies a buried valley (e.g. Bore No.9 Fig. 31). This 98 foot borehole showed 14 feet of sand, clay and mud overlying in turn a foot clay bed, 9 feet of gravel, 3 feet of sandy clay and boulders and 25 feet 6 inches of muddy sand and clay, before striking sandstone bedrock. The floor of this buried valley is at 497 feet O.D. and the present surface expression is also in the form of an elongated hollow (No.15 Fig. 26). It may therefore/

therefore be probable that the other peculiar elongated hollows, (7,8,9,12 and 13, Fig. 26), in these Bonnington/Lanark drift deposits also denote the presence of buried channels. (Stark 1902). The features already described for the Mouse Water channels, (1,2 and 3 Fig. 26), also supported by borehole information, confirm this conclusion.

Stark (1902) attempted a reconstruction of the former course of the Clyde in the Lanark area using the information and alignments of these large elongated depressions. (Nos. 2 - 6 Fig. 26). With the present increased information of boreholes and knowledge of events during glaciation, a fuller description of earlier drainage patterns in this complicated Crossford/Bonnington area can be reconstructed. As has already been suggested, however, the old idea of there being <u>one</u> "Pre-Glacial" and <u>one</u> "Post-Glacial" course of any river in this complex area is misleading and should be discarded. As a consequence it is difficult to prove the contemporaneity of two non-continuous buried valley sections. The resulting reconstructed drainage pattern is open to criticism. It does, however, closely agree with Stark's conclusions (1902) and is shown in Figure 32. One major difference emerges. The present writer and Gregory,(1926), consider that the alignment followed by Lanark Loch and the Sandy Burn is the more likely course of the buried Clyde Valley, for surface rock outcrops immediately to the east of Hyndford Bridge indicate the absence of an entrenched valley in this locality. The floor of the depression to the south of Lanark is at 400 feet O.D. a similar height to that of the Nemphlar Channel immediately to the north. It is not,

however,/

however, possible, without further information to suggest the relative ages of these two abandoned valleys. A tributary depression joining the depression south of Lanark from the north is taken to indicate a former course of the Mouse Water, the confluence of which with the River Clyde must have therefore been some distance south of that found at present. A more extensive borehole or seismic resistivity survey at specially selected sites would quickly confirm or disprove this complex history of river development - certainly one of the most intriguing in Britain.

The Nethan buried valley deposits, while less complicated are no less spectacular than those already described. One borehole at Tillietudlem Station (Exp.2 Fig. 28), at an altitude of 400 feet is more than 150 feet deep. It reveals 29 feet 6 inches of muddy clay and sand overlying in turn 14 feet 6 inches of sand and gravel, 35 feet 6 inches of sandy, muddy,clay, 7 feet 6 inches of sand and gravel, 14 feet 3 inches of sandy clay and stones, 4 feet 3 inches of hard bound gravel and 47 feet of mud and sandy clay. The surface material in the locality of this borehole is till and yet the borehole log description is muddy clay. The rather unhelpful borehole descriptions at this site could obviously be concealing a very interesting stratigraphical record. The Kirkmuirhill section (Table IX) already referred to, is in the same buried valley of the Nethan and clearly/

TABLE X

29 ft. 6 ins.	muddy clay and sand
14 ft. 6 ins.	sand and gravel
35 ft. 6 ins.	sandy,muddy clay
7 ft. 6 ins.	sand and gravel
14 ft. 3 ins.	sand, clay and stones
4 ft. 3 ins.	hard bound gravel
47 ft	mud and sandy clay
152 ft. 6 ins.	bedrock

clearly shows two separate till layers (Exps.11 and 12 Fig. 22). A second borehole again in the buried valley at Southfield (Fig. 28), north of the Kirkmuirhill section and between it and the Tillietudlem bore (Exp.2 Fig. 28) is 140 feet deep and again appears to have two separate till strata. It is interesting to note that the depth of drift shown by these boreholes suggest that the buried Nethan Valley is at least as deep as its present valley.

In a deep borehole in the Clyde Valley floor at Crossford "a peat bed four feet thick and containing nut-shells". (Hunter 1882 p.94), was discovered below 40 feet of surface clay. This important discovery is the only indication in Area II that the last period of glacial activity was preceded by a phase of milder climatic conditions during which the area was ice-free. Elsewhere the borehole logs, even with their more complete stratigraphical record, reveal only two periods of glacial deposition separated by a period of meltwater deposition.

<u>Topographical Breaks in the Drift Cover</u>

Often in glaciated areas there are distinct localities at which numerous mounds or hillocks are concentrated. In Highland districts these mounds are often ~~of~~ composed of angular stones and are normally designated moraines. In Central Scotland similar topographical breaks in the drift cover are found but their origin is not always so easily explained. Charlesworth, (1926), however, used these areas to determine his ice recessional stages in Central Scotland. Thus he joined up the numerous, but frequently isolated areas,/

areas, containing conspicuous hillocks and drift mounds which give a rolling appearance to the land surface. He noted that their composition was very variable. "Boulder clay, sand and gravel are found frequently in intimate association". (Charlesworth 1926 p.26).

The accurate identification of such moraine stages, or ice limits, would obviously do much to help disentangle the glacial history of Central Lanarkshire. However, with their variable composition and uncertainty as to their origins it is not surprising that the features mapped by Charlesworth as moraines have frequently been the subject of considerable dispute. Thus the Lanarkshire constituent of his major readvance stage in the South of Scotland, the "Carstairs Kame-Moraine" has been otherwise interpreted by every other worker in this area. (Chapter I Section 3). The present work has shown that the Carstairs deposits are completely composed of fluvioglacial sands and gravels and show numerous features which indicate that Sissons' (1961) conclusions are correct. "The kettle-moraine" which Charlesworth, (1926 p.32), describes in the Douglas Valley has been shown in Chapter II, (Fig 17), to be an area of stagnant ice topography.

Other "moraine stages" which he noted, although certainly not as continuous as his map suggests, (Fig. 5), are more difficult to dispute and reinterpret. Two such locations are found in Area II at Blackwood and Lesmahagow/Brocketsbrae respectively (Fig 23). At both sites the landforms are composed of numerous drift mounds dispersed without any particular orientation. At both localities the more numerous occurrence of meltwater channels indicates a localised concentration of/

of meltwaters. The composition of the mounds is, as Charlesworth suggested, variable. Near Brocketsbrae a recent aqueduct excavation through one elongated mound showed three feet of sand overlying six feet of material which was largely composed of sand but also contained wisps and lenses of till. This in turn overlay a further three feet of sand. A rock type analysis of stones in the till lenses (No.15 Fig. 22) showed 2% Highland, 12% Carboniferous, 36% Old Red Sandstone and 50% Southern Uplands rocks - very strong evidence for deposition by ice derived from the Silurian hills to the south-west. Another exposure in a flat area among the mounds immediately to the south of the previous exposure showed 5 feet of sand and stratified fine gravel over 4 feet of varved clays overlying a further sand and gravel series of unknown depth.

The form and composition of the mounds at the second concentration to the north at Blackwood, (Fig. 28), appear identical to those at Brocketsbrae. At both localities eskers and kettlehole depressions, two certain indicators of stagnant ice, are notably absent. The Blackwood mounds again show the same variety of composition as those at Brocketsbrae. Borehole No.13 at the junction of the Strathaven and A74 roads, Kirkmuirhill, showed 2 feet of top soil overlying 3 feet 6 inches of brown sand and gravel with some clay, which in turn overlies 3 feet 6 inches of brown clayey sand, 2 feet 6 inches of brown sand/gravel with some clay and sandstone and 5 feet 6 inches brown boulder clay overlying bedrock. Both the Blackwood and the Brocketsbrae sites straddle two recent developments, the A74 dual carriageway/

carriageway construction and the Daer Valley Aqueduct, the boreholes of which were made available by the construction company and planning authorities involved. A close inspection of these recent and apparently very accurate boreholes indicates that in the areas to the north of Blackwood, to the south of Brocketsbrae and between both Blackwood and Brocketsbrae till overlying bedrock is the rule and yet at these two localities, as was demonstrated above, the stratigraphy and topography become much more complicated.

To summarise, these two localities are characterised by the following features; (1) A localised concentration of drift mounds (2) A concentration of meltwater channels in the same area (3) A variety of drift composition which easily separates the two localities from the surrounding areas. With these characteristics in mind and in particular the close association of till, a true glacial deposit and sand and gravel, fluvioglacial deposits, it is suggested that an ice marginal position would provide an environment capable of explaining all the features. One is forced to return to Charlesworth's conclusion that these landforms,whilst not having the ideal end moraine topographic expression,are certainly end morainic in origin. The other major landform of Area II which has in the present work been designated an end moraine at the north end of the Nemphlar Channel, appears to have escaped Charlesworth's attention and is not mentioned in his 1926 paper. It should be again emphasised that the rock type contents of the Brocketsbrae and Crossford, (North end of Nemphlar Channel) morainic accumulations indicate a Southern Upland ice source.

The/

The derivation of the Blackwood deposits is more doubtful and will be discussed later.

<u>Dateable Deposits</u>

When a particular topographical relationship or stratigraphic correlation permits the determination of the relative age of any isolated strata, an absolute date determination would further advance the chronological information. Radio-Carbon dating and Pollen Analysis are the two main methods whereby such precise dating can be achieved. With these thoughts in mind a constant watch was kept during field work for drift deposits containing suitable animal or vegetable material. In general, however, as with most areas of Scotland such inter-stratified remains are absent. (At the beginning of 1967 very few late-glacial Scottish Radio-Carbon dates had been published and not one was available in Central Lanarkshire).

As already mentioned lake clays are frequently found in association with the morainic, or ice marginal areas described in the previous section. (Both Brocketsbrae and Blackwood have several associated varved clay deposits). In general the clays occupy depressions in the land surface and may be from 10 feet to 25 feet thick. Their occurrence therefore is as pockets rather than widespread sheets (Fig. 28). Most of the clays appear to be varved and typical of proglacial areas. (Ph 29,30,31). The varves may not be readily apparent, especially in freshly cut sections, (Ph 29 and top of Phs. 30 and 31), but usually become visible if the face is allowed to dry out, particularly under cold conditions. At many of the sites stones, from small pebbles up to boulders more than one/

one foot in diameter, can be found in the clays. (Ph 32 shows a dried out clay section at Carlüke. Near the bottom left several pebbles can be seen). Many of these are striated and wefe presumably dropped into the clays from ice rafts floating on the lake surface. (Flint 1957 p.144).

At two localities, near Auchenheath and Carluke, the clays are being actively worked and fresh sections are constantly becoming available. (Ph 33 and 34). At both sites peculiar discoid and globular nodules are found lying parallel to the varves. (Phs 35 and 36) These objects are very hard and stone-like but are apparently composed entirely of material derived from the clay. They are variously described in the literature as "Fairy Stones", "Creckers" and "Hudson's Playthings". (Proceedings of the Geological Sociéty of Glasgow 1879 p. 298). Mr. J. Young commenting on the exhibition of one of the nodules at this meeting, stated that they are "formed by a sort of chemical segregation of lime and clay in the deposit, while its components, were in a soft unconsolidated condition". He compared them with chalk flints and Carboniferous clay/ironstone nodules. The nodules he said were "Characteristic of brick (lake) clays". The growth by segregation theory is suggested by two characteristics (1) The discoid nodules show a marked laminar composition suggesting growth within the clays (Phs 37 and 38). (2) When tested with dilute hydrochloric acid the nodules all give a very vigorous chemical reaction whereas the clay itself gives little or no reaction. This indicates a segregation and concentration

of/

of calcium particles.

In the clay pit to the south of Carluke, (Grid Reference 838/497 O.S. 1" sheet No.61), plant remains are found. These are concentrated in the clay in an area 12 - 15 feet below the surface of the pit. Hand augering at the base of this pit showed a further 3 feet of clay overlying 1 foot of coarse sand with pebbles which in turn rested on bedrock. The plant remains appear to have floated in this lake until they became waterlogged whereupon they sank to become deposited in the clay. The remains consist of branch and root segments up to six inches in length. The diameter of the segments found never exceeded half an inch. The plant remains were examined by Dr. K. Thomson, Department of Botany, University of Glasgow, who recognised both branches and roots of Birch and less frequently - Alder. All of the Birch remains showed rhyzomorphs of Armillaria Melca which indicated an unhealthy condition of the trees. His conclusion was that the material was probably derived from dead trees which had been washed into the lake. He also indicated that the large proportion of silica/clay present would make it difficult to obtain sufficient pollen grains per slide, (150 per slide advisable), to give an accurate and reliable pollen count. Two visits to the site provided sufficient material for a Radio Carbon dating. Fifty grams of the plant material was dispatched to Geochron Laboratories Inc. Cambridge, Mass. U.S.A. Their result indicated that the plant material was "4,815 ± 135 C-14 years B.P. in age". This result is completely unexpected and unhelpful in unravelling the date of the last/

last ice cover in Central Lanarkshire.

The topographical relationships of the clay deposit, (Fig. 33), indicate that the lake in which the sediments accumulated must have been dammed to the west, for in this direction at present the land surface falls into a gorge 200 feet deep connecting Jock's Gill with the Clyde. An ice dam in the Clyde Valley, (Marginal kame-terraces up to heights of 400 feet proves its presence) would provide the most simple solution and yet the date obviously belies the presence of ice.

6. Fluvioglacial Erosion

On Figure 23, it can be seen that there are relatively few meltwater channels in Area II. No strong regional patterns of meltwater flow emerge, instead the channels appear to be related to local relief conditions. Most channels are only slightly incised into fluvioglacial deposits rather than solid rock or till. In all these features Area II differs markedly from Area I.

The most important exceptions are; (1) A single channel to the east of Carnwath (No.5 Fig 27), 35 feet deep, 100 yards wide with a flat floor 20 yards broad incised into solid rock. (2) The channel, already mentioned, opposite Kirkfieldbank on the eastern slopes of the Clyde (No.1 Fig.29), of similar dimensions to the previous one but having a much increased gradient. (3) The Carmichael/Tinto Hill area forms the only extensive area where numerous meltwater channels are found cut in till and solid rock. The details of this latter group have been thoroughly discussed by Sissons (1961). The present/

present field work confirms Sisson's conclusions in all but minor details. The important characteristics of this meltwater drainage pattern are that all of the channels confirm the strong south-west to north-east directional trend already established in the adjacent districts of Area I. Their altitudes vary from 750 - 1,250 feet and indicate the presence of an ice sheet at least 500 feet thick, (Sissons 1961), which eventually coalesced with an ice stream emerging from Upper Clydesdale. (Striation on Quothquhan Law and evidence of landforms mapped by Sissons in the Clyde Valley above Thankerton (Fig. 8)). (4) Another smaller series of channels on the hillslopes to the south of Kirkmuirhill has a general trend from west to east, (Fig. 23), and is incised into both till and solid rock. They indicate an incursion of ice from the Avon Valley into Area II. Throughout the remainder of Area II there is no dominant directional pattern of meltwater drainage and individual channels often follow erratic courses between mounds and ridges of fluvioglacial origin.

Figure 26 is fairly characteristic of Area II. In the north meltwater channel system 4 is incised into an upstanding area thinly covered by sand and gravel (Ph 39). These channels are succeeded to the north-east by the first of the prominent Carstairs ridges. This association and the up and down profile of the channel shown in Photograph 39 indicate a sub-glacial origin. The neighbouring channel systems to the south and south-west, however, show no consistent orientation. (5 and 6 Fig 26). Instead of following the trend of system 4 and penetrating the low ridge between them and the Carstairs Basin, the channels appear to be determined in their/

their courses by minor relief irregularities.

Similar local orientations are found in the many small channels, with rounded cross-profiles and depths rarely in excess of 40 feet which are found in the area included in the southward loop of the River Clyde between Bonnington and Langloch. (Fig 26) The orientations of most of these small channels appear to be controlled by the many depresions in the area into which the channels are directed. In the same area, however, there are numerous elongated channel-like depressions which have considerably greater dimensions (7,8,9,12,13 and 15 Fig. 26). Some of these are, as has already been suggested, related to buried valleys like those of the Mouse Water (1,2 and 3 Fig. 26). Unlike these latter channels, however, channels 7,8,9,12,13 and 15 show great variation in their width along their length and frequently, as in 13 and 15, have an abrupt termination. Most of them contain in their floors and sides kettlehole depressions, which together with the fact that many small meltwater channels are directed into them indicates their contemporaneity with the deglaciation period.

The sheer size of these channels, their occurrence only in Bonnington/Lanark fluvioglacial deposits and their consistent orientation towards the present, Bonnington/New Lanark, gorge section of the River Clyde gives them a singular appearance which the writer has not seen elsewhere. A close examination of their characteristics suggests a possible origin.

Numbers 15 and 12, (Fig 26), are similar in breadth, 250 yards, but vary widely in depth. Number 15 is uniformly 30 -

40/

40 feet deep and No. 12 varies from 30 feet at its source to 100 feet at its lower end. Both have spring sources in their floors or sides. (No. 12 contains no less than four of these sources shown on the O.S. $2\frac{1}{2}$ inch series). Channel No. 15 has several isolated mounds of sand and gravel on its floor whilst channel No. 12 clearly shows another peculiar characteristic in that it is wider at its head than at its lower end.

The third channel, (No. 13 Fig. 26), is also large, 100 feet deep, 200 yards broad and half a mile in length. It terminates at a much higher level, 600 feet, than any of the other channels. Like all its neighbours it is cut entirely in fluvioglacial sediments and although it appears less conspicuous in Figure 26 this is only because of the numerous landforms within it. The generally smooth slopes of the sides and floor are interrupted by kettlehole depressions and ridges of sand and gravel up to 40 feet in height, some of which are elongated parallel to the valley floor and others of which run transverse to the channel direction, in one case completely dividing the channel into two sections. (Fig. 26). Some of the kettleholes still contain water which may, (c.f. spring sources), be added to by drainage from within the sand and gravel.

Channels Nos. 9 and 7 are the most spectacular of all. Number 9 has two definite sections. The upper part has its floor at 600 to 640 feet, is a maximum of 100 feet deep and contains fluvioglacial ridges and numerous elongated kettleholes, most of which still contain water (Ph 40). The lower section of the channel is

fully/

fully 400 yards wide and 125 feet deep at its maximum. It is separated from the upper section by a small escarpment or headwall 20 feet high at the base of which there issues a very vigorous spring flow. (S Fig. 26). Channel 9 also has the characteristic constriction at its lower end. Channel No. 7 is situated immediately below the town of Lanark. (Fig. 26). Its depth exceeds 150 feet along most of its length. Its width is as much as 300 yards but varies considerably, narrowing towards its head and also towards its exit. Although part of its floor is flat and only slightly incised its headward areas are rather atypical in that they have an extended steep gradient. Its other peculiarity is that it has a major tributary channel of comparable character entering from the north.

As has already been stated, Stark (1902) maintained that channels 9 and 7 followed the course of the "Pre-Glacial" Clyde at this point. He also indicated that Channel 15 follows the orientation of a "pre-glacial" Douglas Valley. This latter conclusion was not proven until the Bonnington Tunnel was constructed (Ross 1925). It seems, therefore that these very large channels follow the orientation of buried valleys of the Clyde, Mouse and Douglas Waters as suggested earlier in this chapter. The present absence of streams in the channels and the numerous kettleholes, however, indicate that the channels are not merely due to contemporary stream erosion. Their characteristics suggest the following origin. The presance of the former river valleys would allow a greater accumulation of ice along their courses than on their flanks. As the ice in this area stagnated and wasted in situ

(Fig.26/

(Fig 26 contains in this locality classic examples of stagnant ice topography), it was foreseeable that the depth of buried ice in the, now buried, valleys should exceed the depths of buried ice on the valley flanks. As these buried ice masses melted out the depressions which they left would attract any remaining surface meltwaters. (Channels 15,13 and 9 and their associated kettleholes all have meltwater channels draining into them). Spring sapping in the hollows because of the aquifer properties of the fluvioglacial deposits (well illustrated after periods of excessive rainfall), and, initially, the melting out of the buried ice masses themselves, would help to break down the unconsolidated drift barriers between the kettleholes. Meltwater drainage and buried ice being particularly concentrated in the courses of the buried valleys, it is here that these processes were most effective. The main formative process, spring sapping, breaking down the weak drift barriers between depressions can in fact be demonstrated at present. As already mentioned the spring (s), at the base of the small headwall separating the two sections of channel 9 (Fig. 26), is about to release the waters of the kettleholes immediately to the east. Eventually a less irregular profile and form will be achieved by the formation of a single base level of erosion and the two sections will be united.

This explanation could certainly account formany of the peculiarities of these channels. For example the irregularities in the floor and in the channel sides are often related to the melting out of buried ice and the sudden release of water from breached kettleholes. It/

It could also account for the great range in altitude of the different channels, e.g. for channel 13 the base-level of erosion is the kettlehole at its mouth, whereas for channels 12,9 and 7, with their connections to the River Clyde, (via the restricted exits, which are probably the result of more normal stream erosion), their base level of erosion has lowered with that of the streams connecting them to the Clyde gorge. To distinguish these channels and their distinctive origin from other more normal meltwater channels they will be referred to as kettle-channels.

It has already been noticed that the main east bank tributary of the Clyde, the Mouse Water, also exhibits buried "pre-glacial" courses. Thus, in this sense they are related to the kettle-channels of the area south of Lanark. However, the origin suggested for the kettle-channels cannot explain the channels 1,2 and 3 (Fig.26). These buried valleys of the Mouse appear to be of remarkably consistent dimensions along their length, are not cut in sand and gravel and do not have the close relationship with kettleholes and other meltwater channels so typical of the kettle-channels. The deposits which infill channels 2 and 3 (Fig 26) certainly are, at least in part, comprised of till. These channels therefore are more like the normal "pre-glacial" buried valleys of Central Scotland. Their distinctive characteristic is that they are aligned in a parallel/adjacent series which becomes progressively less infilled to the north-west (Fig. 26). This characteristic suggests the following origin. The northward advance of Southern Upland Ice, perhaps simultaneously engulfing the now abandoned/

abandoned course of the Clyde beneath Lanark, led to its encroachment on the original "pre-glacial" course of the Mouse Water (Channel A Fig 29). Further northward movement of ice filled this valley and a new channel, B, was eroded by the marginal drainage of the Mouse. This situation was repeated, glacial deposition took place in channel B and a further displacement of the marginal drainage stream eroded channel C. The gradual filling of this channel by ice, (esker in valley bottom), diverted the marginal drainage for a third time northwards into its present Cartland Crags course (D).

Although these events may all have taken place during one ice advance, it is equally possible that one or more of the earlier channels may have been occupied and abandoned during an earlier period of ice advance. (The possibility of two separate till horizons in the bore at Jerviswood Mains, (Fig 32), would certainly accord with this latter suggestion). Channel C although occupied by ice for the shortest period and with the least depositional effect, was not reoccupied by the Mouse drainage on the disappearance of the ice. This indicates the rapid downcutting of the marginal drainage in its new course, channel D. Two features help account for this rapid incision. Firstly, channel D, if the theory outlined above is correct, occupied a course marginal to the maximum limit of penetration of ice at this late glacial stage. As such it was initiated just when ice ablation was beginning to outpace ice accumulation i.e. when the greatest volumes of meltwater were being released. Secondly there is considerable evidence that an extensive ice dammed lake occupied a/

a large part of the Carstairs Basin to the east (Section 7 of this chapter) and this may have in part utilised the Mouse Water Course as an overflow.

All the evidence indicates that the marginal drainage of the Mouse Water flowed into the present Clyde Valley at this period e.g. (1) The lake and fluvioglacial deposits at Stonebyres and the large meltwater channel at Kirkfieldbank, (No.1 Fig 29), show that this valley was utilised by meltwaters. (2) Almost all the meltwater channels at the south end of the Nemphlar Channel indicate a movement of meltwaters back under the ice margin and into the present Clyde Valley. (Fig 29) (3) The very steep western exit from Channel C (Fig 29), perhaps occupied by a waterfall at one stage, indicates that even before the ice had reached its limit of penetration, the waters utilising Channel C had cut down to a level of 350 feet i.e. 120 feet below the entrance to the Nemphlar Channel. The utilisation of this Lanark to Crossford section of the Clyde by meltwaters, at a time when the adjoining southern section, Bonnington to Lanark, was still ice covered may partially account for the much greater dimensions of the former over the latter (Fig 21). The alternative explanation is that the present gorge course of the Clyde from Bonnington to Lanark is in fact entirely "post-glacial", while the Lanark to Crossford section was already initiated, as has been shown, before this last period of glaciation in Central Lanarkshire. Along the steep valley sides of the Clyde, north of Bonnington, there is often a mantle of sand and gravel. Although this unconsolidated material is subject to slumping/

slumping and many of the landforms can probably be attributed to this process, occasional evidence points to the movement of streams over its surface. The channels left are never deeply incised and some of them might well be due to periodic storm run-off rather than glacial meltwaters (Phs 41 and 42 show two rather more incised than normal examples). They form no clear patterns but tend to trend downhill avoiding even quite small drift mounds. Although many examples can be seen on Figs 26,28,29 and 30 they are considered to be of little significance in the interpretation of the glacial history.

A much larger channel is found on the east bank of the Clyde at Crossford (No.1 Fig. 30). This channel is incised 150 feet into solid rock. Its course is winding and its cross-profile "V" shaped. Its present floor is accordant with a Clyde terrace 20 feet - 30 feet above the present flood plain but its bedrock floor was proved by a borehole, (Hunter 1882 p.94) to be at least 52 feet lower. The stratigraphy of this borehole, (see Deep Borehole section of present Chapter)., proves the existence of this channel before the last glacial period in Central Lanarkshire. Its dimensions and the grading of the present floor to the high level terrace of the Clyde probably indicates that it is part of a buried valley, possibly the Clyde or an east bank tributary, which was reexcavated by meltwaters or river erosion towards the end of the last glaciation in Lanarkshire.

Perhaps of greater significance are the very deeply incised but short meltwater channels which course the east bank of the Clyde/

Clyde above Milton Lockhart (Nos. 1 - 4 Fig 33). Channels 2,3 and 4 are steep gullies as much as 100 feet deep. Their heads begin gradually from almost insignificant depressions but enlarge rapidly as they plunge down the steep, Clyde valley side. Significantly, however, none of them contains a sizeable stream and all tend to die out between 20 feet and 50 feet above the present Clyde flood plain. These features suggest an early origin rather than one due to contemporary stream gullying.

Channel No. 1, Jocks Gill, is the largest in this group. It begins on the plateau surface to the north, outside the thesis area, at a height of 500 feet. The source area appears to be extensively covered by brick (lake) clays, the characteristics of which have been described already. Although shown at two localities on the Geol. Survey Drift Sheet No. 23, their distribution has been proved more extensive by hand augering and field observation. The dimensions and cross-profile of Jocks Gill are shown as an inset in Figure 33. Its dimensions suggest that it is a reexcavated valley which formerly contained unconsolidated drift deposits. (The reference of Hunter (1882 p.320), to a reindeer antler "found in boulder clay at Raes Gill" an area no longer exposed due to mineral tipping, indicates that the valley certainly was in existence prior to the last ice cover in the area).

The large lake, indicated by the fairly extensive area of lake clays and their 20 feet depth, could well have facilitated this reexcavation. As the damming mass of ice in the Clyde Valley melted, the/

the ponded waters of the lake must have eventually penetrated down between the ice and the valley sides into the Clyde Valley. This release of the lake waters may have been very sudden and would account for the steep sub/glacial chute-like courses which were eroded at 2,3 and 4 (Fig 33). Raes Gill, too, could have been excavated in this way.

The three "moraine areas" of Blackwood, Brocketsbrae and Crossford are also areas of concentrated meltwater activity. The channels at these three sites are normally short, little incised and have irregular courses which run according to the distribution of the main drift mounds. They are suggestive of a proglacial environment free of the influence of ice. At the north end of the Nemphlar Channel, the Crossford Moraine, (Fig 30), shows different characteristics. All the meltwater channels are directed back down the west facing slopes of the moraine ridges. This indicates that meltwaters ran back down under the ice probably as a result of the local reversed gradient, (see inset Fig 30) which the moraine ridges must have emphasised. A similar situation is found elsewhere and will be referred to later.

It can be seen, therefore, that strongly directed patterns of meltwater drainage are developed only locally in Area II. Figure 25 shows part of the western end of the best of these, in the Tinto Hill area. Here the southern system of meltwater drainage begins at a col (1,200 feet), the trunk channel of which has an up and down profile proving the complete overwhelming by ice of land in this locality up to altitudes of 900 feet. The pattern emerging from the channels shown on Fig 25 implies a continuation of the south-west to north-east ice movement found in Area I. A rather poorer developed series of channels south of/

of Blackwood (Fig 23)also implies that ice moved generally west to east. Elsewhere, however, local relief dominates the pattern of fluvioglacial drainage a feature which may indicate a lesser dominance of ice because of its increasing thinness. One important point which emerges is that the present Clyde was in use prior to the last ice cover of Area II and probably collected a large part of the meltwaters released by the melting ice.

7. Fluvioglacial Deposition

The evidence so far presented has already indicated that whilst meltwater channels are few in number in Area II, their effect implies vigorous although localised fluvioglacial erosion. The features of fluvioglacial deposition are no less spectacular and in many ways help to unravel the deglaciation history although they frequently provide further complications.

Only the fluvioglacial deposits of Carstairs and Thankerton have been described in detail in the literature. The Carstairs deposits as mentioned in Chapter I, have attracted more attention and discussion than any other geomorphological features in Lanarkshire - perhaps to the detriment of the geomorphological knowledge of the remainder of this area. Despite the numerous articles specifically dealing with the Carstairs deposits from Dougal (1871) onwards, Figure 27 is the first detailed landform map of the area to be published. Together Figures 26 and 27 show the landform detail of what is certainly one of the largest sand and gravel accumulations in Scotland.

In/

In Chapter I, Section 4, it was shown that the fluvioglacial deposits of Bonnington/Carstairs are directly continuous with those of the Douglas Valley. There is, however, another focus from which these deposits spread. This is the Linnhead Esker (South-west corner of Fig 26). It begins as several discontinuous ridges of sand and gravel, 10 - 20 feet high, lying in the floor of a valley descending from a col over Broken Cross Muir at 800 feet (Fig 23). The esker increases in height and breadth eastwards and becomes a continuous, sinuous ridge, except where interrupted by stream erosion, which stretches for one and a quarter miles. At Exposure 20, (Fig 26) the ridge crest is 40 feet above the land on either side and its breadth at its base is 50 yards. At Exposure 21, Drummond Hill, the ridge is almost 100 feet high and exceeds 100 yards in breadth. The height of the crest at the eastern end, 692 feet, is similar to that of its western extremity, 700 feet, although the adjacent land surface falls at least 75 feet in the same distance. Again as with the fluvioglacial deposits in the Lower Poniel Water, (Chap. 2) there appears to be some altitudinal control over fluvioglacial deposition by an englacial water-table.

Exposure 20 (Fig 26) allows an examination of the stratigraphy of the upper part of the ridge. One foot, 3 inches of well sorted gravels overlies a clay/silt band 1 to 2 feet thick which in turn overlies 5 feet of mixed material from rounded cobbles 1 foot in diameter down to particles of sand size. No stratification was visible in the lower 5 feet. The morphology of the ridge, its composition and/

and its association with other stagnant ice landforms, viz. kettleholes, leave no doubt that it is an esker. (Charlesworth 1926 p. 26).

At its western end the esker lies directly on till but at Exposure 21(Fig 26), where it abruptly terminates on the west bank of the River Clyde, it is seen to overlie at least 30 feet of sand and gravel. On the east bank of the Clyde at Bonnington, this sand and gravel spread continues but of the esker there is no sign. Instead an almost completely enclosed depression is found. (Fig 26).

It is normally assumed that eskers are orientated parallel to the last direction of ice movement (Flint 1957 p.153). This would mean therefore that the Linnhead esker, noted as such by Charlesworth, (1926 p. 26), the longest, isolated esker in Central Lanarkshire, was related to a strong ice tongue which penetrated the col at Hawksland, (700 feet) Fig 26), and moved directly eastwards. In the light of the very strong south-west to north-east orientation of both glacial and fluvioglacial forms in the adjacent valley to the south, the Douglas Water, the west-east trend of the Linnhead esker is rather unexpected and appears to have been caused by the deflection of the ice stream around the southern edge of the Black/Dillar/Darnfillan hill massif. The rock type analysis of the gravels in the esker (No.10 Fig 20) shows 22% Carboniferous, 72% Old Red Sandstone and only 2% Southern Upland rocks (c.f. this last figure with 22% Southern Upland rocks at Sandilands, (No.9 (Fig 20), in the Douglas Water valley immediately to the south), and certainly confirms the west to east flow of meltwaters as indicated by the orientation of the esker.

The presence of several large buried valleys and an extensive area of lower elevation than the surrounding districts, (proved by boreholes) at least partially accounts for the very great depth of fluvioglacial deposits found in the Bonnington/Lanark area. The highly irregular surface of the area east of the Clyde (Fig 26) is composed of the large kettle-channels already described, completely enclosed depressions i.e. kettleholes, elongated ridges which may frequently branch in an irregular manner, more conical kame-like hills and small meltwater channels. The surface altitude varies from above 700 feet to below 500 feet. The largest kettleholes (Ph 40), are 100 feet deep and 200 yards across. The conspicuous ridges commonly stand from 30 to 60 feet above the adjacent land and their directions change so frequently that no pronounced orientation can be recognised. This chaotic assemblage of features taken together affords an excellent example of stagnant or "dead" ice topography.

The stratigraphy of borehole No. 9 (Fig 31) at the deepest part of these Bonnington Deposits has alreadybeen described (Deep Borehole Section) and indicates only fluvioglacial material. One of the shallowest boreholes, in the same series on the rising ground to the south (Fig 31), similarly reveals only fluvioglacial deposits with 12 feet of sand with occasional clay and gravel layers overlying 28 feet 6 inches of pure sand.

There is a noticeable change in the appearance of the land surface to the east of the line markedA-B (Fig 26). The ridges, so prominent to the west, terminate against an irregular escarpment about

30/

30 feet high. To the east of this escarpment line the ridges are entirely absent, the fewer kettleholes are noticeably shallower, none more than 20 feet deep, and only one meltwater channel, 50 yards broad, and 25 feet deep is found. (No. 14 Fig 26). This latter surface is remarkably smooth and declines very gradually eastwards past Langloch Farm, across Lanark Race Course with a fall of only 25 feet in a distance of one mile. (This contrast in landforms can be seen by comparing the areas to the east and west of the railway shown on Ph 43).

A new sand and gravel pit opened early in 1966 allowed a continuous examination of fresh exposures in the material composing this eastward sloping plateau. The surface 12 feet to 15 feet was consistently coarser than the underlying material. In the upper 15 feet well sorted gravels were found to lie in uniform almost horizontal beds which dip slightly eastwards with gradients between 0° - 10°. Beneath this coarse material a further 15 feet is exposed which is almost completely composed of sand with only occasional gravel lenses. The dips measured in these stratified sands were consistently higher, 20°- 30°, than the overlying gravels by which its upper surface appeared to be truncated . Figure 34 shows the suggested correlation between the areas east and west of the escarpment. The landforms of the area west of the escarpment imply the presence of a considerable thickness of stagnant, melting ice. The smooth plateau to the east with its steeply dipping sand beds, (suggesting delta-like depositions in a ponded lake) and its overlying gravel beds (suggesting faster flowing outwash streams) might be taken to indicate the gradual infilling/

infilling of a proglacial lake. Thus the gravel layers would form the topset beds overlying the sand foreset beds. The single meltwater channel (No. 14 Fig 26), may indicate the course of the last stream carrying eastward flowing meltwaters away from the ice front.

The smaller kettleholes imply the burying of smaller ice masses washed out from this ice front and lodged in the gravels. If these conclusions are correct then the escarpment is an ice contact slope, marking the position at which the ice front remained stagnant for some time.

This last statement has great significance, for, in the absence of undoubted, ice marginal moraines, it is difficult to determine the position of the ice front at any particular time. In this locality, however, it is suggested that the ice front can be determined accurately. The available evidence does not indicate whether this ice front marks; (1) The limit of a general forward ice movement. (2) The limit of a more local re-advance. (3) A temporary halt in a general recession of a formerly greater ice cover.

The owners of this new quarry (A. Russell and Company (Glasgow) Ltd) allowed full access to their records on this sand and gravel deposit. Eighteen trial pits, average depth 16 feet, located in the triangular area between A, in the north, B, in the south and Langloch Farm in the east; (Fig 26) all agree with the exposed faces in the pit that the upper layers of sand and gravel gradually become finer at depth. The results of an associated geo-physical resistivity/

resistivity investigation have now been partially disproven and are not used here. At one point a depth of sand and gravel greater than 25 feet has been excavated and the exposed face indicates that the material again becomes coarse at depth with sand and gravel layers of irregular dimensions and an often discontinuous nature being found in complete disorder. Several beds even show a dip back towards the west and the evidence suggest that this lower phase of sedimentation was earlier than, and unrelated to, the more regular lake/outwash deposition period. A rock type analysis of 400 pebbles showed 4% Highland, 25% Carboniferous, 44% Old Red Sandstone and 22% Southern Upland pebbles (11 - 13 Fig 20). This general similarity with the Sandilands deposits in the Douglas Water Valley to the south, (42% Carboniferous, 36% Old Red Sandstone and 22% Southern Upland rocks), amply justifies Ross's (1925 p.115), conclusions that these deposits were laid down by the meltwaters of the Douglas Valley Glacier.

The smooth, gradually declining surface is terminated east of Lanark Race Course by a steep but terraced slope, 30 feet high, leading to a lower area where small, remnant masses of sand and gravel, 15 ft - 20 ft high and numerous meltwater channels present a contrasting dissected appearance. (Fig 26) The irregular orientations of these channels and the sand and gravel mounds do not suggest any particular direction of ice movement but rather a deglaciation stage when meltwaters flowed between drift mounds and remnant ice masses. Bedrock and till, (Exposures 2,3 and 12 Fig 26) appear on the rising ground to the north and east and there is therefore a distinct

topographical/

topographical and stratigraphical break between the Bonnington fluvioglacial deposits to the west and the Carstairs deposits to the east.

On the northern margin of the area shown on Figure 26 a series of meltwater channels, No. 4 (Ph 39) from 20 - 40 feet deep are cut into the drift surface. All of them, together with several adjoining sand and gravel mounds, show a consistent orientation from south-west to north-east and contrast with the irregular orientation of the features to the south (5 and 6 Fig 26). The meltwater channel system No. 4 and the associated drift mounds mark the beginning of the well-known, if misnamed "Carstairs Kames".

Figure 27 shows that the meltwater channels (No.4 Fig 26), terminate at about 675 feet (A Fig 27),and are almost immediately superceded by the first of the Carstairs ridges which then run almost continuously in the same direction, west-south-west to east-north-east, for a distance of five and a half miles. The first of the "Kames" are elongated mounds (Ph 44), with summit heights 670 feet to 700 feet rather than true ridges but they very quickly assume the form of steep sided sinuous ridges with undulating crest lines, so typical of the Carstairs deposits (Ph 45). Some of the ridges, although sinuous and anastomosing can be traced as distinct features for distances of up to three miles. More commonly, however, they branch and rebranch so frequently that individual ridges are lost in the maze of tributary ridges many of which die out as suddenly as they commence. Enclosed between the ridges and frequently seen on their sides are numerous

kettlehole/

kettlehole depressions,(Ph 45) some of which still contain water e.g. White Loch and Red Loch. (Fig 27) Many others, however, are now marked by marshy hollows some of which (see Ph 45), are artificially drained by the breaching of the enclosing ridge. The highest ridges are about 80 feet high and others are of all heights down to mere undulations a few feet in height. The highest ridges tend also to have the greatest widths. Some of the ridges, however, have more massive proportions and would be more properly termed elongated mounds, (e.g. that immediately north of Carstairs Village is 200 yards broad) in contrast to the more linear narrow ridges often as little as ten yards broad.

Most of the workers who have described the Carstairs system have noticed that the ridges are generally replaced southwards by more massive, often flat topped "kame-like masses". (Gregory 1915, MacGregor 1927, Sissons 1961, Goodlet 1964). The flat-topped kames, composed of sand and gravel, are usually explained as having been deposited in a lake ponded between the ridges to the north and a southward retreating ice mass (Gregory 1915). Sections in this markedly different southern area (Exps. 21 and 22 Fig. 27), the exposures in the Carstairs Station sand pit and the laminated clays, no longer observable, but found by the officers of the Geological Survey just to the west of the Carstairs Station sandpit, all confirm the fine nature, typical of lacustrine sediments, of these deposits. Four boreholes, sunk at the Carstairs State Institution, showed "six inch to 1 foot of topsoil followed by loose sand to between 2 feet and

4/

4 feet below ground level, then a very soft to soft clayey or sandy silt to between 6 feet to 21 feet below ground level and finally the boreholes were terminated in a medium dense to dense and very dense sand" (Geo. Wimpey and Co.Ltd. Central Laboratory Report on Soil Investigation at Carstairs Institution, Lanarkshire, 1966 p.3). The difference between the landforms and the component material of the northern ridges and the southern area implies an important change in the depositional environment and certainly in the latter case imply the lacustrine conditions suggested by most researchers.

Many of the descriptions of the Carstairs ridges, however, suffer from a lack of detailed investigation and mapping and these deficiencies probably account for some of the confusion as to their origin. Gregory, for example, states that the deposits are "normally divided into three ridges, rising 70 feet above the adjacent plain and overlying boulder clay". (Gregory 1915). The mapping of the complex, anastomosing series of ridges, (Fig 27) certainly indicates that this statement is very much an~~d~~ over-simplification. The more massive "kames", although certainly more numerous to the south, are also found among the ridges themselves, (B Fig 27) and on their north flank at Ryeflat Moss (C Fig 27).

Even the composition and stratigraphy of the true ridges are the subject of dispute. Gregory has stated that they are underlain by till. All the workers have agreed that the ridges are largely composed of water-deposited sand and gravel. Goodlet, however, with a more detailed study of the deposits than any previous author, made possible/

possible by the recent extension of sand and gravel workings, not only has produced a stratigraphic succession for the deposits as a whole, but also suggested the presence of a previously unsuspected material - Boulder Drift (Goodlet 1964 p.181).

TABLE XI

Stratigraphic Correlation of the Carstairs Deposits (Goodlet 1964 p.181)

3.	Later Beds	Peat Sand Gravel
2.	Middle Beds	Carstairs Station Sands
1.	Earlier Beds	Upper Gravels Main Sands Lower Gravels Boulder Drift

The basal boulder drift "shows no apparent orderly arrangement of materials. The matrix is extremely variable but may be broadly described as a very clayey sand varying in grade from fine to coarse and gritty. Embedded in the matrix in complete disorder are fragments of all sizes up to boulders 3 - 4 feet in diameter .... it includes, however, rafts of bedded sands". (Goodlet 1964 p.181) Goodlet implies (p.194), that all the "steep sided ridges ... are composed of boulder drift and are in fact not kames but part of a moraine deposited during a relatively protracted halt in the retreat of ice originating in the Southern Uplands". Both his stratigraphic correlation and conclusions as to the origins are, in the light of new evidence, unlikely.

Good/

Good sections, available at present, show that many of the steep sided ridges are composed of well stratified sands and gravels. That the northernmost ridges are not moraines "composed of boulder drift" is well shown by a series of trenches dug along the length of the northernmost ridge in the east/central part of the Carstairs system (E to F Fig. 27).

TABLE XII

E (southwest) 880 yards F (north-east)

Pit 1.	Pit 3.	Pit 5.	Pit 7.	Pit 9.
9" soil	9" soil	2 ft. soil	1 ft. soil	6ins soil
8 ft. stratified sand and gravel	5 ft. coarse sand 5 ft. sand and gravel predominantly sand	8 ft. fine sand	5 ft. fine sand	12 ft. fine sand

Only the results of every alternate excavation are shown in the above table but the others exactly correspond to those shown. Two main points emerge; (1) The ridge is composed of stratified sands and gravels and not boulder drift. (2) The constituent material becomes progressively finer from west to east along the ridge.

A stone orientation was carried out on the pebbles exposed in the face of a supposedly boulder drift section in the East End sand and gravel pit (Fig 27). The appearance of the section and the fabric diagram, (Carstairs Fig 15), show an imbricated structure with a strong preferred orientation which indicates that the water which deposited the gravels flowed from west-south-west to east-north-east i.e. exactly

parallel/

parallel to the orientation of the ridges in this locality. These facts taken together with the morphology already described certainly indicate that the ridges are eskers (c.f. Sissons 1961). Their sub-glacial origin is implied by their continuous relationship with the channel system at A (Fig27) which has already been shown to be of sub-glacial origin. Once it is realised that the Carstairs ridges are a sub-glacial esker system the evidence of the trenches in ridge E F, (Fig 27), that the constituent material becomes finer in a distal, easterly, direction, becomes logical. Like all normal streams, it might be expected that sub-glacial streams with a decrease in velocity must inevitably deposit progressively finer material. It is now understandable why Goodlet, (p.181), found his boulder drift in the western, coarser material, sand and gravel pit but could not find it in the eastern pit which contains much finer material.

In the light of these conclusions Goodlet's stratigraphical correlation is also suspect. A present deep excavation in the West End Wood pit, (Fig 27), shows 40 feet of fine, often clayey sand with no obvious stratification, lying below the base of the overlying ridges. In the moss to the north at Eastshield Bridge, (Exp 6 Fig 27), two 50 feet boreholes put down in 1965 showed a similar depth (38 feet and 40 feet respectively of sand/silt overlying solid rock. These boreholes compare favourably with those to the south of the eskers at the Carstairs State Institution already described. At Cowford, on the opposite bank of the Mouse from the East End Sand pit, a single borehole indicates 15 ft 1 inch of sand and gravel overlying 20 feet 11 inches of stoneless clays/

clays. It seems therefore that if there is a definite stratigraphic succession at Carstairs, the basal member of it consists of fine silt/clay material rather than the coarse boulder drift suggested by Goodlet. If these fine sediments denote calm water or lake deposition, (c.f. ice ponded waters of Lake Clyde, Charlesworth 1926) then it seems that these conditions existed both to the north and to the south of the Carstairs esker system.

The conclusions of all the authors, save Charlesworth, who have written about Carstairs was that the deposits there were deposited by meltwaters from glaciers which originated in the Southern Uplands. (Geikie 1873, Gregory 1915b, Ross 1925, MacGregor 1927, Sissons 1961 and Goodlet 1964). Rock types analyses were carried out on gravels collected at the site of both the East End and the West End Wood sand and gravel pits (Fig 27). Three separate counts, each of 100 stones were completed for each site.

TABLE XIII

	1 East End Pit Carstairs					2 West End Pit Carnwath				3 Gregory (inCharlesworth 1926)			
Sample	High	Carb	ORS	S.Up.		High	Carb	ORS	S.Up.	High	Carb	ORS	S.Up.
14	4%	20%	68%	8%	17	-	10%	52%	28%	2%	4%	64%	30%
15	3%	26%	59%	7%	18	4%	20%	52%	22%				
16	6%	16%	63%	15%	19	-	19%	50%	31%				

The rather low proportion of Carboniferous bedrock fragments, (Fig 22), might well be accounted for by the deep covering of sand/silt/clay which has been shown to underlie the whole of the Carstairs area. The rock types present are strikingly similar to those at Bonnington, (11 - 13 Fig 22 and 20), and indicate an origin in the hills to the west and south.

It has already been shown that, despite the wealth of evidence to the contrary, added to in the present work, and the dissimilar conclusions of all previous authors, Charlesworth's influential work maintained that the Carstairs system was an end moraine related to a readvance of Highland ice. His main piece of local evidence indicating this conclusion was the topographical expression of the Carstairs deposits and especially the steep and abrupt north facing slope of the Carstairs ridges which he maintained was an ice-contact face. (Charlesworth 1926 p.36). Detailed field mapping, however, suggests an alternative origin and one moreover which does not disagree with the other evidence. The flats to the north of the Carstairs ridges, now occupied largely by peat mosses, are the flood plain tracts of the Mouse and the Dippool Water (Abandoned meanders of these rivers can clearly be seen immediately to the north of the Carstairs ridges in Phs 46 and 47). The past and present meanders of these two streams indicate their extensive migration over the surface of these flats and it is suggested that these migrations at once explain both the level nature of the ground to the north and the abrupt, steep,north slopes of the northernmost ridges in the Carstairs system.

There/

There is other evidence to support this conclusion. Firstly the remnant ridges of Sheaffyknowe (H. Fig 27), standing well above the Cranley and Blacklaw Mosses and separated from the Carstairs ridges by the Mouse flood plain, indicate that the Carstairs ridges at one time extended into the area now smoothed by the meanders of the Mouse Water. Photograph 48 shows the smooth flood plain tract immediately to the north of the steep north facing slopes of the Carstairs system (in the background). Photograph 49 shows the remnant ridges at Sheaffyknowe, to the left and the Carstairs ridges in the right background. The area between them is again the flood plain tract of the Mouse Water.

At D (Fig 27) a great crescentic hollow bites deep into the northern face of the ridges terminating abruptly several of the ridges to the west. This area, now occupied by the Clydesdale Forest, appears to be a meander scar caused by an earlier migration of the Dippool Water.

It is perhaps now relevant to comment on the relative age of the Carstairs Eskers. Dr. J.B. Sissons, the first author to promote this origin, has also reinterpreted the chronological events suggested by Charlesworth. In his papers on the "Perth Readvance in Central Scotland" (1963 and 1964) Sissons indicates that the Carstairs Esker system was probably deposited near or at the limit of the Perth Readvance. (Map on p.154). In his 1964 and 1965 publications (Maps on p.134 and p.476 respectively), he confirms this statement. However, an ice readvance limit in this position meets with several problems/

problems.

Geikie as early as 1873,(p.43), indicated that the Carstairs ridges are continued north-eastwards to a height of 900 feet by the ridges on Stallashaw Moss. In the same publication he states that the "Carnwath and Carstairs sands and gravels creep eastward up the Medwin valley, to join those at the south end of the Pentland Hills in the basin of the Lyne". Both these statements were substantiated by Goodlet (1964 p.176). The field mapping of the present writer has confirmed the connection of the fluvioglacial features of the Carstairs Basin with those to the east. Channel 5 (Fig 27), leads to an extensive fluvioglacial spread the dimensions and forms of which compare with those at Carstairs. Stallashaw is fully seven miles further north and 200 feet higher than the last of the Carstairs ridges as shown at G. (Fig 27). The Lyne Water is no less than 12 miles east of Carnwath. Thus for fluvioglacial deposition to have occurred at these two latter sites the ice must have been at least several hundred feet thick in the Carstairs Basin proper. Two possible conclusions emerge; (1) If the Carstairs Eskers are related to a readvance, as suggested by Sissons, then its limit was much further east than Carstairs itself. (2) In the absence of stratigraphy or surface features indicating this readvance in the Carstairs Basin, it is possible that the ridges are related to the general wastage of a greater and therefore earlier ice advance than the Perth Readvance. If a "Perth Readvance", (Zone I), ice limit is present in Central Lanarkshire then the definite ice limit position already established at Bonnington (Fig 34)/

(Fig 34) must have as much claim to this title as the less certain limit to the east.

Fraser and Godwin 1955 tested the pollen contents of the peat bogs at Carnwath Moss and showed that they began growing at least as early as Zone VI. This suggests a useful way of investigating the relative ages of the Carstairs and Bonnington deposits. Both have numerous kettleholes many of which still contain water. By examining the pollen contents of the basal layers of these kettleholes lakes it may be possible to establish the minimum ages of the fluvioglacial deposits at these sites. This might help establish the time scale significance, if any, of the ice limit at Bonnington (Fig 34). It is hoped that this line of investigation might be followed at a future time.

Apart from several discontinuous esker segments on the lower north facing slopes of Tinto Hill, (Fig 25), the fluvioglacial deposits of the Thankerton area can be classified into two groups; (1) the almost featureless Thankerton Moor and (2) the more complex features to the south of Thankerton Village. (Extensive workings in this latter deposit since 1961 have removed most of these features and do not permit the detailed mapping of Sissons' 1961 paper. (Fig 8).

Sissons maintains that the Thankerton Moor fluvioglacial spread was deposited in the waters of the lake ponded by ice further north in the Clyde Valley, (c.f. the lake to the south of the Carstairs Eskers). (p.189 1961). Stereoscopic inspection of air photographs, however, reveals numerous small channels meandering over the surface of/

of this moor. Exposures in the Spittle Burn which crosses this Moor, (Fig 23), show coarse gravels up to one foot in diameter with little evidence of stratification. There is no sign of sediments characteristic of lacustrine deposition. It is therefore suggested that at least the surface deposits and features of Thankerton Moor are due to outwash streams issuing from an ice mass to the west.

The remaining evidence of the speedily disappearing deposits south of Thankerton Village fully agrees with Sissons' conclusions and mapping. (Fig 8) The deposits appear to be "an esker system that shows clearly the courses of several subglacial streams that flowed from the slopes of Tinto and along its flanks to the low ground of the Clyde Valley". (Sissons 1961 p.187) Three gravel samples were obtained from the Thankerton sand and gravel pit, (from the flat ground adjacent and west of ridge S. (Fig 8), and the results obtained from the rock type analysis are shown below.

TABLE XIV

Rock Type Analysis of Gravels - Thankerton

	Highland	Carboniferous	Old Red Sandstone	Southern Upl.
Sample No. 20	-	-	8%	86%
Sample No. 21	-	-	20%	76%
Sample No. 22	-	2%	12%	86%

More than three-quarters of all the stones in the Southern Upland category were greywackes from the Clyde Valley region to the south. The adjacent Tinto Hill felsite intrusion yeilded only 6% of the/

the total. This evidence implies a strong ice movement northwards out of Upper Clydesdale and corroborates the movement indicated by the glacial striae on the summit of Quothquhan Law. (Fig 23)

The only other major concentration of fluvioglacial deposition in Central Lanarkshire is in the Clyde Valley below Lanark. The steep sides of this valley are frequently covered by a mantle of sand and gravel which commonly contains particles of all sizes from clayey/sand up to large boulders one foot or more in diameter. Although usually stratified, the strata are always discontinuous, even the coarsest gravel often being interrupted by lenses of fine sand. (Ph 50). The surface of these deposits is usually undulating and is occasionally channelled by the former course of meltwater streams. (Phs 41 and 42). Many of the undulations, however, are the result of slumping, surface creep and storm gully erosion. Although forming only a thin veneer in many localities and being of discontinuous distribution in others, boreholes in some of the deposits show considerable depth. At Nethanfoot, north of Crossford, 100 feet of sand and gravel is found. The vertical range of the sand and gravel on the valley sides is in excess of 300 feet at sites north and south of Crossford. Dip measurements on the strata are so diverse as to be unhelpful in determining the origin of the material. Most of them in fact dip immediately down slope towards the valley floor.

Several rock type analyses were carried out on these Clyde Valley gravels in an attempt to determine their origin. Five sites, Nos. 23,24,25,26 and 27, (Fig 22) from south-east to north-west/

west respectively give a representative sample of the gravels from Lanark to Rosebank.

The first site, No.23, is in a short esker ridge,(one mile to the north of the Linnhead esker (Fig 26)), 20 feet to 30 feet high and 30 yards wide which lies above the valley slope deposits, at Overhall, west of Lanark. The second, No. 24, is in the Clyde Valley side north of Lanark adjacent to several elongated kame-like mounds. (Exp 6 Fig 26) The third sample, No. 25, was obtained at Exposure 1 (Fig 30), and is again from the valley slope deposits. The fourth sample, No.26., was obtained from the site, already described, where brown till overlies grey/black till. The final sample, No. 27., was obtained from Mauldslie Estate on the northern boundary of the thesis area. An especially good exposure was found at this locality, (Exp 1 Fig 33), and this showed in descending order five to six feet varved lake clays, (presumably the same lake in which the plant remains were found), 10 feet to 12 feet fine sand containing a lens of well sorted coarse sand, 10 feet to 12 feet of well-stratified, fine to coarse, gravels containing a lens of coarse sand. At the bottom of the exposed face 20 feet of coarse gravels were exposed. The more regular stratification of the fine sands allowed the measurement of the dip and orientation of the beds at different heights in this horizon. Three of the measurements showed a 12° - 18° dip from north-east to south-west, one dipped 12° from north-north-east to south-south-west and the remaining three dipped 8° - 18° from south-south-west to north-north-east. The sands therefore appear to have been deposited

deposited by waters flowing occasionally from the south-west and occasionally to the south-west.

TABLE XV

Rock Type Analyses of Gravels

Sample No.	Highland	Carboniferous	Old Red Sandstone	S.Upland
23	-	12%	68%	20%
24	6%	54%	20%	20%
25	12%	60%	18%	10%
26	4%	78%	12%	6%
27	10%	64%	24%	2%

The rock type analyses show several interesting features. The results of the Overhall Esker, No.23, are strikingly different from the remainder. The lack of Highland erratics and the large proportions of Old Red Sandstone and Southern Upland fragments indicate an origin similar to that of the larger Linnhead Esker one mile to the south i.e. by eastward flowing streams.

The remaining sites, Nos. 24,25,26 and 27 have more comparable results. The outstanding features are the increased number of Highland erratics and the decreasing proportion of Southern Upland pebbles in a northerly direction. Here again one is reminded of J. Geikie's concept of "a debatable ground between north and south over which sometimes the one (ice mass) and sometimes the other (ice mass) prevailed". (J. Geikie 1894 p.77).

The presence of Highland erratics, sometimes in numbers exceeding those of the Southern Uplands, (Table XV) throughout the gravels of the Clyde as far south as Carstairs, indicates two possible origins; (1) An earlier glacial advance, (the latest ice in this area has already been shown to be of Southern Upland origin), during which Highland Ice penetrated up the Clyde Valley, (perhaps excavating, at least in part, the present Clyde Valley from Crossford to Lanark,) as far as Carnwath. Later ice readvances, even if derived from the Southern Uplands, would therefore rework and redeposit the Highland erratics. (2) The second possibility is that both Highland and Southern Upland ice streams were confluent and, according to their individual contemporary strengths, waxed and waned, forwards and backwards over the "debatable ground". Thus the ice and meltwaters of one ice mass would inevitably contain erratics derived from the other.

The sand and gravel deposits of the areas interpreted as morainic in origin have already been described. The last remaining important fluvioglacial deposits are those found interstratified with the till at Blackwood (Nos. 28 and 29 Fig 22). The exposure has already been discussed in Section 5. The lower gravel, No.28, has the highest percentage of Highland pebbles, (18%), recorded anywhere in Central Lanarkshire. (c.f. Gregory 1915b p.158, found only 14% Highland erratics in the <u>till</u> at Hamiltonhill Glasgow). In the upper gravel, (No, 29), only 2% of Highland erratics were found. It must be concluded that Highland Ice was more dominant during an earlier/

earlier glacial phase than during the most recent one.

TABLE XVI

Rock Type Analyses of Gravels

Sample No.	Highland	Carboniferous	Old Red Sandstone	S. Upland
28	18%	64%	14%	2%
29	2%	88%	8%	2%

Area II therefore contains some of the deepest and most extensive fluvioglacial deposits to be found in Central Scotland. They are, however, restricted to several distinct localities. The first and greatest is part of a continuous series which is centred on the Carstairs Basin, but continues in both a south-west and north-easterly direction. It has two distinct divisions, the Bonnington and the Carstairs systems. The second major concentration is in the Thankerton area, an area where ice from the south-west and from the south became confluent. The third concentration occurs as discontinuous banks on both sides of the Clyde below Lanark. Smaller concentrations occur in areas which Charlesworth designated morainic. Unlike his larger correlations these areas are difficult to explain otherwise. Although Highland erratics are dispersed widely throughout the gravels in Area II, it has been shown that this in no way disputes the conclusion that the last ice in Area II emanated from the Southern Uplands.

8. Glacial History

Normally there is only one stratum of glacial deposits in Area II. This consists of a single till layer which may or may not be overlain by fluvioglacial sands and gravels. At particularly favourable localities, however, a fuller stratigraphical record is preserved. At several such localities two separate tills are shown with an intervening fluvioglacial stratum. This indicates therefore that there were at least two periods of ice cover in Central Lanarkshire.

Of the earlier glaciation there is little evidence. The rock type analyses and till fabric studies indicate that the origin of the ice was not necessary dissimilar to that during the later period. There appears to have been, however, one important difference. The extent and influence of Highland Ice was much greater in the earlier phase. The distribution of Highland erratics as far south as Carnwath shows the extent of penetration and suggests that some of the glacial striae, (on Geol. Survey Drift Sheet No.23), around the periphery of Cartland Muir (Fig 23) might be more logically shown pointing north-west to south-east instead of south-east to north-west. (This is especially so if, as suggested earlier and shown on Figure 35, the late glacial readvance of ice did not cover the Cartland Muir area). After a period of ice free conditions (peat bed below till, Hunter 1882), Southern Upland Ice again held sway over all the land south and west of Carstairs. There is some evidence that Highland Ice may not have entered Area II. (Distribution of different coloured tills and the fabric/

fabric and rock type content analysis of tills). Southern Upland Ice appears to have reached even to the northern boundary of the thesis area in the Clyde Valley (Fig 24). The important moraine at Crossford and the absence of glacial deposits in the Nemphlar Channel imply that the interior of the channel, like some of the surrounding hills and Cartland Muir, remained ice free during this later period of ice activity. It is suggested that the corresponding ice limit in the south may be at Bonnington rather than, as suggested by Sissons, east of Carstairs. Only topographic evidence, however, supports this latter conclusion. It is concluded that Area II occupied a location marginal to the limits of ice penetration during this late glacial readvance. Despite the unfortunate absence of precise Radio-Carbon datings to prove this, it appears that the ice readvance during Zone I - the Perth Readvance, would most closely fit the above conclusions. This would involve slight modifications in the ice limit of this age proposed by Sissons (1963, 1964).

The fluvioglacial landforms mapped in Area II afford impressive evidence that deglaciation was brought about by the ice stagnating and melting in situ. This conclusion was first made by Sissons (1961a p.192) who stated that "the last ice sheet to cover the Southern Uplands decayed in situ without significant movement".

At Bonnington there is evidence that the ice preserved a distinct margin for some time. It is not, however, clear whether this, like the Crossford Morainic deposits, represents the furthest penetration of an ice advance, or is merely a stage during recession.

9. Summary of Conclusions

(1) Area II has been glaciated on at least two separate/

separate occasions. The earlier glaciation was effected by ice from both the Highlands and the Southern Uplands. During the most recent glaciation the ice cover was more restricted and some areas remained ice free. This latter ice cover was almost entirely, in Area II, derived from the Southern Uplands.

(2) During this last glacial phase the southern hills were ice covered to at least 1,200 feet (c.f. distribution of striae, till and meltwater channels). To the north and east the distribution of these features declines in height and as suggested some areas were completely ice-free.

(3) During deglaciation fluvioglacial erosion was concentrated on the flanks of valleys and on the valley floors. The main valleys were the main centres of meltwater activity.

(4) Fluvioglacial deposition was closely associated with fluvioglacial erosion. As a result the main sand and gravel deposits, often of great extent and depth, are concentrated in the main valleys. The present Clyde Valley in its three recognisable sections, below Crossford, Crossford to Bonnington and Bonnington to Thankerton, has served as the major focus of fluvioglacial deposition.

CHAPTER IV

AREA III

1. Location and Extent

By its location Area III is the counterpart of Area II forming as it does the western wing of the thesis area. Its shape and extent are also similar to Area II. (Fig. 1). The northern, eastern and south-eastern boundaries are formed by straight lines the positions of which are not related to any particular landforms. On the north the boundary is that of the thesis area as a whole and separates the rising slopes of Central Lanarkshire from the lower ground of the "true" Central Lowlands to the north. The eastern boundary is entirely artificial and not only divides two comparable sections of Ogilvie's "Higher Lowland Peneplane". (Ogilvie 1928) but also cuts through the drainage basin of the Cander Water (Fig. 2). The south-eastern boundary fringes the rising ground of the Dungavel/ Hagshaw Hills but cuts across watersheds and valleys alike. In these two latter areas the boundary lines are shared with Area II and Area I respectively.

The southern and western boundaries of Area III contrast with those first described as being sinuous rather than straight lines and by being more related to the surrounding relief. The southern border maintains an irregular, but generally east-west course, which follows the Ayrshire/Lanarkshire county boundary. This boundary follows a drainage watershed along its whole length and separates those streams flowing north to the Avon Water and those flowing south

to/

to the River Ayr. (Fig. 36).

The western boundary, while not following a well-marked physiographical feature like its southern continuation, generally follows the watershed which separates the Avon and the Irvine drainage basins. (Fig. 36) However, due to the particularly interesting fluvioglacial features of this watershed, at its lowest point just to the south of Loudounhill, the boundary has been displaced to the west at thislocality. Thus, a part of Ayrshire, the landforms of which are of vital significance in the study of deglaciation in the Upper Avon Valley, is included in this western division of the thesis area.

The remaining section of the western boundary of Area II is aligned north to south and follows for the most part the Lanarkshire/Ayrshire county boundary. To the north it includes a marginal part of eastern Renfrewshire. At two localities therefore along its western boundary Central Lanarkshire, or the thesis area, includes small areas ofcounties to the west. This emphasises an important point about the location of Area III, it extends further westwards than the other two regional divisions, and although its eastern margins are very much tied to Clydesdale, its western reaches, particularly Upper Avondale, are in closer contact with western districts, notably the Ayrshire Plain.

2. <u>Relief and Drainage</u>

Area III has several features in common with Area I. Like the earlier described area it contains a large proportion of dissected upland terrain but equally like Area I it is dominated by a/

a major valley, that of the Avon. The Avon Valley therefore provides a well-marked topographical break between a northern and a southern hill area.

The southern hilly district is similar in form and elevation to that of the adjacent districts in Area I to the south. Numerous semi-isolated hills occur all of which have the smooth, unbroken slopes and appearance so characteristic of the Southern Uplands. The elongated and streamlined appearance well-displayed by Nutberry Hill (Area I) is again found, e.g. Anderside Hill, Bankend Rig and Kypes Rig (Fig. 36). The general summit levels, however, are much lower with Dungavel Hill (1,503 ft.) and Auchingilloch Hill (1,515 ft.) being the only summits above 1,500 ft. The highest hills are those closely associated with the Dungavel/Hagshaw watershed already referred to in Area I. Elsewhere almost all the summits are between 1,000 ft and 1,200 ft.

The northern upland area serves as a direct contrast to that of the south. Instead of a multitude of semi-isolated hills the northern area is composed of only one massive ridge. The backbone of this ridge is aligned almost west-east from Corse Hill, (1,230 ft) to Ardochrig Hill (1,130 ft). There are few separate outlying hills of this main ridge and its slopes decline almost continuously to the north, south and east. To the west the ridge is continuous with the generally lower parts of the Eaglesham Moors and eastward too it decreases in altitude towards the Avon Valley.

Despite the upland nature of the two areas so far

described/

described, each has an extensive cover of peat. The distribution of the peat is, however, different in each case. In the southern area it is greatest in depth and extent in the almost completely hill enclosed basins which although rarely at high altitudes often form the watershed areas, e.g. Black Loch Moss in the south-west and the Feeshie and Berry Mosses in the south-east (Fig. 36). In the northern upland district, however, peat forms an almost continuous mantle over the whole area. At higher levels peat is especially predominant and even on the lower slopes where there is no effective natural drainage, and artificial drainage has not been attempted, extensive peat mosses often occur e.g. Mossmulloch and Cladence Moss. (Fig. 36)

The drainage system of the southern hills forms a complex, dendritic pattern which reflects very closely the distribution of the hills themselves. All of the streams occupy marked depressions, the dimensions of which seem large in contrast to the small streams or burns which occupy them. The Powbrone Burn, the main source of the Glengavel Water, although by no means a large stream, occupies a valley more than one half mile wide and 300 ft. deep. Other valleys too, although occupied by only short streams are both deep and wide, e.g. the Woolen Burn and the Kype Water (Fig. 36).

The northern hill area as already indicated consists of one elongated ridge, and although more than six miles broad at its widest part, it has only two main slopes, to the north and to the south. The ridge narrows and falls in altitude eastwards and the drainage pattern as a consequence has a generally radial appearance. The/

The northern slopes are shorter and steeper and the streams drain directly northwards out of the thesis area. To the south, however, the streams drain much longer and gentler slopes. The headwaters again drain at right angles to the contours but they are collected by a major trunk stream, the Calder Water, (Fig 36), which drains from west-south-west to east-north-east, i.e. parallel to the regional slope before turning southwards to join the Avon Water.

The Black Burn, (Fig 36), follows a peculiar course, oriented parallel to the main part of the Calder, but almost exactly along the ridge crest of the northern hill area. It too eventually turns southwards, where, as the Powmillon Burn, it follows an interesting course, treated more fully later, before joining the Avon. The northern streams in comparison with those to the south follow more regular and less incised courses with only two major streams, the Calder and the Powmillon, contributing to the Avon. In contrast the much more numerous streams from the southern hill group have several large streams and contribute a much greater volume of water. (Fig 36) The Glengavel Water the major south bank tributary of the Avon is in fact a larger stream than the Avon at their confluence. The Avon too rises in the extreme south-west but is also added to by the Lochar and Kype Waters to the east. The Avon Water therefore is in terms of volume rather less dominant than might be expected. Its real dominance arises from the dimensions of the valley in which it flows.

In its upper reaches, at Drumclog, the Avon Valley is five miles wide and is so broad that its 500 feet depth seems by comparison/

comparison insignificant. In size it far exceeds the valleys of the other major rivers of Central Lanarkshire, the Douglas, the Clyde and the Nethan. (Fig. 10 and Fig 21) Its direction, from south-west to north-east is parallel to the orientation so firmly established in the features of glacial and fluvioglacial erosion to the south. Westwards, how however, the Avon valley shows several interesting features. While the Avon Water enters the already large valley from a comparitively insignificant southern tributary valley, (a perfect example of a misfit stream), the main valley continues westward to the watershed at Loudoun Hill Its width at this point becomes restricted by the Cairnsaigh and Loudoun Hills (Fig 36).

The widest part of the Avon Valley is therefore in its upper reaches around Drumclog, for eastwards of this locality it becomes increasingly restricted into a course which eventually occupies a deeply incised and narrow gorge. The dimensions of Upper Avondale, i.e. the Avon Valley west of Strathaven, imply a much greater antiquity than its lower course to the east. Upper Avondale, however, is perhaps even more remarkable in its development of numerous, often extensive, clearly defined terraces or benches. These are of three main types. The first and the lowest occupy the present valley floor from Waterhead in the west to Caldermill in the east. (Fig 36). Their heights decline from 660 feet in the west to 575 feet in the east. These lowest terraces extend into the main tributary valleys, (e.g. the accordant terraces of the Glengavel/Avon and the Calder/Avon), a feature which indicates that the majority of them are related to recent or contemporaneous/

contemporaneous flood plain expansion by the present rivers.

At a slightly higher level, normally 15 feet to 40 feet above these flood plain terraces, a second terrace suite is found. These too, like their lower counterparts have remarkably flat surfaces and often abrupt, steep, front slopes. Their development is especially conspicuous south and west of Drumclog although they extend in a linear fashion along the north bank of the Avon almost to Caldermill. Their heights, like those of the lower suite, fall from 725 feet in the west at Loudoun Hill, (Ph 1), to 625 feet south of Caldermill. The terrace at LoudounHill with its smooth gradient eastwards,(it is at present dissected by the River Irvine which flows westwards in a gorge 120 feet below the terrace level), and the absence of any nearby eastward flowing stream indicates an origin different from that already ascribed for the lower terraces.

A third set of terraces or benches, although less continuous can be recognised on the steeper north facing slopes of the Avon Valley to the east of the Glengavel Water. They are particularly well-developed at Kepple Moss and Gainer Hill where their lack of gradient has led to the development of an extensive peat coverage. (Fig 36) At the western locality the bench is at 825 feet fully 200 feet above the valley floor, whilst to the east the height has dropped to 725 feet, although still as much as 175 feet above the present river flood plain. Although frequently covered by glacial and fluvioglacial deposits these latter benches have a rock base at no great depth. They recall George's, (1958 p.52), explanation of landform/

landform evolution in the Central Lowlands that although..... "at lower altitudes the cover of glacial drift becomes thicker and more widespread ....regionally the landscape is benched." These benches he explains may be of marine origin and of later Tertiary age but certainly pre-date the last period of glaciation. Thus the Avon Valley presents a whole range of terrace/bench landforms which are, in ascending order, probably progressively older features. Their characteristics and distributions are of great significance in interpreting the events of glaciation and deglaciation and will be discussed at length later.

The only extensive tract which does not fit the descriptions of the three areas already described is found to the east of Strathaven and centred mainly about Stonehouse. (Fig 36) Here the Avon Valley is now a restricted and deeply incised gorge. To the west the land rises rapidly to form the eastern termination of the northern hill mass. To the south, however, there is an extensive area of relatively little relief. A broad plateau area (500 feet to 550 feet) extends south-east of Stonehouse (Stonehouse Plateau) to the south-west it is terminated by the low but massive Yards Hill, (783 feet), to the north-west by the Avon gorge, whilst the Cander Water, a comparitively little incised stream, drains northwards as its eastern margin. Above and to the east of the Cander Water a smooth but pronounced slope of about 100 feet leads to the well marked "High Lowland Peneplane" surface of Ogilvie at about 600 feet.

Apart/

Apart from this latter area, Area III can by simply but reasonably accurately described as being largely composed of; (1) A broad and dominant central valley with a distinct south-west to north-east trend. This Avon Valley separates two upland zones, to the north and south respectively. (2) The northern area, is formed almost entirely of one elongated ridge, oriented east-west, and has very few distinct and isolated upland areas within it. (3) The southern area in contrast is composed of a loose association of separate hill masses which have been subject to considerable dissection. All of these three main divisions and the plateaux areas to the east were affected by, and in turn affected, the patterns of glaciation and deglaciation in Area III. Their significance will be fully appreciated in the following sections of this chapter.

3. Geology

The geology map, (Fig 37), shows what is an apparently very simple pattern (c.f. Areas I and II Figs 11 and 22). The area is dominated by two extensive rock outcrops. The first, of Silurian strata, is restricted entirely to the area south of the River Avon. To the north is an even greater area over which Carboniferous rocks are found and these almost everywhere tresspass south of the River Avon. In the central area Carboniferous and Silurian strata are in juxtaposition but to the east and west narrow outcrops of Old Red Sandstone rocks form a thin wedge separating the two dominant rock groups.

The extensive area floored by Carboniferous rocks can, however, be subdivided into a sedimentary and a volcanic division.

The/

The significance of this division to Area III is such that they are separately shown on Figure 37. The volcanic series, part of the Clyde Plateau Lavas, covers a greater area than elsewhere in Central Lanarkshire and forms almost all of the northern upland area. The included rocks, however, extend across the Avon Valley in the Central part of Area III, (Fig 37), and in this area they, in contrast, underlie the land of lowest elevation. Although of Calciferous Sandstone age throughout the area their lithologies are by no means everywhere similar. As is normal for Central Scotland the Olivine-basalt lavas are by far the most prominent. Although the microporphyritic basalts are shown, (Geol. Survey Sheet 23), to cover the larger area, the best developed flows are "transitional between the Dalmeny and Dunsapie types", (Macgregor and Macgregor 1948 p.53), i.e. transitional between micro- and macro-porphyritic types. Locally these basalts provide examples of slightly bolder relief in the form of craggy knolls, but these differences may be due to a localised concentration of meltwater or glacial erosion rather than lithology and nowhere in the volcanic hill areas are the vertical crags or stepped appearance of the Kilpatrick or Campsie lava plateaux displayed. The most striking lithological difference is between the basalts already described and the numerous agglomeritic ash accumulations. These latter are particularly concentrated on the western margins of Area III, to the north of Loudoun Hill. Occasional burn sections in the agglomeritic rocks show soft friable marly material which normally has a green or purple colour. (Richey et al 1930 p.133) Even at a depth of 15 feet the writer found that these rocks/

rocks could be easily dug out by a spade. The only other lithologic variation in the volcanic rocks which has any significance to landform evolution is found at Loudoun Hill. Here a trachyte volcanic plug "ofhard, compact, fine crystalline rock" (Geikie 1873 p.38) stands as an impressive isolated hill (Ph 1).

Apart from a small remnant of Carboniferous sediments extending as a narrow belt westwards from Drumclog, all the sediments of this age are found in a triangular area around the northern and eastern slopes of the Corse Hill-Ardochrig Hill Upland. (Fig 37) All the main Carboniferous sediment groups, except the Barren Red Measures are represented.

The Silurian rocks are entirely of Upper Silurian (Downtonian) age "and consist of grey sandstones, grey, flaggy, and sandy shales, blue shale and hard bands of greywacke". (Geikie 1873 p.9). The very distinctive quartz pebble conglomerate is occasionally found in this Silurian district and appears to represent the conformable transition of Silurian into Lower Old Red Sandstone rocks. (Geikie 1873 p.9).

The restricted outcrop area of rocks of Old Red Sandstone age is composed almost entirely of red and grey sandstones and red mudstones. (Geikie 1873 p.9) One or two hills to the south-east indicate the presence of small felsite intrusions but these are of much smaller dimensions than those in the neighbouring areas to the south and east (Area I and II). The prominent Cairnsaigh Hill on the western boundary of Area III is a diorite intrusion of Lower Old Red Sandstone/

Sandstone age. Apart, therefore, from the complications within the Carboniferous series the distribution pattern of the three major geologic divisions in Area III is much less complicated than in the two previous regional divisions.

There is no simple distribution pattern of the drift cover. Large areas of both the southern and northern upland districts are peat covered but in the south, bedrock tends to outcrop above 1,000 feet whilst in the northern hill area solid rock is frequently exposed above 800 feet. In both areas, however, till can be found on watersheds above 1,000 feet whilst solid rock is exposed on valley sides down to 650 feet. The altitudinal distribution of till and bedrock outcrops appears to vary according to locality and exposure rather than with any regional trend. The till cover, as elsewhere, tends to become thicker at lower altitudes. Conversely , however, its exposure area contracts, for at lower levels it is frequently covered by extensive fluvioglacial deposits.

The largest and deepest of the fluvioglacial spreads are those of the Avon Valley but their regional distribution reveals an interesting pattern. In the Silurian hills to the south they are found in two particular locations. The first is on the watershed boundaries in the south-western part of the area. Here, several mounds of sand and gravel (970 feet - 1,000 feet), the most prominent of which is Twopenny Knowe, are found to be continuous with spreads to the south in the River Ayr drainage basin. Similar deposits are found at Hangyshaw Knowe (1,000 feet) on the watershed at the head of the/

the Glengavel Valley. The other fluvioglacial deposits in this hill area consist of elongated ridges which although lying in the lower parts of the valleys show little relation to present drainage or relief conditions. They may occur as marginal belts lying parallel to the valley floor, (Kype Water), as linear accumulations running obliquely across the valley floor, (Woollen Burn), or even at angles of 90° to the present stream. (Avon headwaters). (Fig 36).

In the Carboniferous, northern hill area there is an almost complete absence of fluvioglacial deposits in the watershed area. At lower altitudes, however, sand and gravel accumulations are found. On the north-facing slopes there is a discontinuous linear series of fluvioglacial ridges aligned roughly parallel to the east-west watershed. These ridges decline in altitude from 850 feet, at Cleughearn in the west to less than 600 feet east of Glassford.

The main concentrations and most extensive areas of sand and gravel deposits are in the Avon Valley and its two major tributaries the Glengavel and the Powmillon Valleys. Smaller concentrations are found on the valley slopes and floors of the Lochar and Calder Waters. The deposits in the main valleys, however, in contrast to those of the upland areas consist largely of extensive sheets rather than discontinuous mounds and ridges. Although some of the sheets have undulating, moundy surfaces, the majority are as shown on the Geol. Survey Drift Sheet No. 23.as "Terraces of Sand and Gravel". Although generally these valley deposits are at heights of less than 750 feet, they conspicuously occur at higher altitudes in the tributary valleys,/

valleys, particularly that of the Glengavel Water.

Two localities are shown on the Geological Survey Drift Sheet No. 23, where "Moraine and Earthy Angular Drift" is found. The first is at the headwaters of the Kype Water where two isolated elongated mounds are classified, like the Birk Knowes two miles to the south-east (Area I), as being composed of "Moraine and Earthy Angular Drift". No exposures are avilable in these mounds but their appearance and disposition are comparable to the Birk Knowes which have been shown to be fluvioglacial ridges and there seems no reason to suspect a different origin for the Kype Water Knowes. The second locality is on the lower north-facing slopes of Ardochrig Hill near Cleughearn. At this site a wide spread of "Earthy and Sandy Angular Drift" presumably an eastern extension of the well-known deposits at Eaglesham, is shown. Although much of the Eaglesham district, just to the west of Cleughearn, is covered by fluvioglacial lake terraces (J.Geikie 1894 p.175 and J.E. Richey 1930 p.334) a much wider area, including this outlier at Cleughearn, is shown on the Geol. Survey Drift maps No. 23 and No.22 as being of morainic derivation. Richey (1930 p.336), describes these deposits as being "mainly angular fragments of the country rock set in an earth or sandy matrix. In many exposures foreign rocks are also to be found, but they are scarce". He concludes that the "brecciation of the solid rocks in situ" was brought about by "repeated freezing and thawing of water in their joints and crevices when the ice-sheet was in process of melting". The moundy forms of the deposits he attributes to the ice being "at times - perhaps seasonally - subject to melting, at times actively pushing forward and

rearranging/

rearranging to some extent the loose angular materials". An examination of these deposits is made later in this chapter.
On the Geol. Survey Drift Sheet No. 23 the Stonehouse Plateau is shown as being mainly till covered but displays at two localities "Brick Clays". At one of these sites a brick and tile works formerly utilised the clays but this has since disappeared (presumably with the exhaustion of the clays for the writer could not find any evidence of them during the investigation of the site).

The only other drift deposit of any significance is alluvium. This is shown on Drift Sheet No. 23 as occupying considerable stretches of the main valley floors. Even in their upper courses, however, the streams often traverse flat bottomed basins which are shown as having an extensive cover of alluvium. Again as in Areas I and II the classification of deposits under the title of alluvium is occasionally found to be incorrect or misleading. Often it might be suggested that contemporary and recent river erosion and deposition have played only a minor part in the formation of the "alluvial flats". A good example of this will be referred to later.

Great credit must, however, be given to the Geological Survey Officers who first surveyed and revised the mapping of the drift deposits of Area III. In particular the accuracy with which the distribution and extent of fluvioglacial deposits are shown is quite remarkable. Even the most detailed investigation by the writer has rarely revealed omissions and these are never of any great significance. It is to the quality and high standards demanded by the/

the regional officers - the Geikie brothers, Peach, Clough, Hinxman, Carruthers, Read, Richey, and many others equally well known, that the general excellence of the Geological survey maps available during this investigation is due.

4. <u>Glacial Erosion</u>

The evidence of glacial erosion in Area III is scanty and difficult to interpret. The drift-floored through cols, and the streamlining or moulding of hillslopes are not as well-developed as in Area I to the south but two slight trends are visible. The south-western hill areas tend to have cols and hills aligned roughly west-south-west to east-north-east e.g. the cols at the head of the Woollen and Spoutloch Burns, and Bankend Rig and Anderside Hill respectively. (Fig 36) To the east this west-south-west to east-north-east orientation is still observable but the trend occasionally appears to have a southerly component, e.g. the cols to the north and south of Auchrobert Hill are oriented from west-north-west to east-south-east.

The northern hill area bears even less evidence of glacial erosion. Hairshawhill, two miles north of Loudoun Hill (Fig 36) has a rather indeterminate alignment from west-south-west to east-north-east. Within a few yards of the base of Loudoun Hill on its north side a narrow outcrop of trachyte lavas ~~have~~ has a surface expression reminiscent of poorly-developed roches moutonees. Their orientation is parallel to that of Hairshawhill.

Loudoun Hill itself is less helpful than might have been expected. (other volcanic plugs in Central Scotland often give rise to textbook/

textbook examples of crag and tail formations, e.g. Edinburgh Castle Rock and Dunglas Hill in the Blane Valley). Its south facing slope is by far the steeper with a craggy vertical face of 250 feet. The "terrace apron" around its south and east-facing slopes indicates that this cliff is not the result of river erosion by the Irvine. (Ph 1) These craggy slopes are suggestive of glacial plucking rather than glacial polishing and might perhaps indicate ice moving from north-west to south-east. On the other hand if there is a tail to this crag it is composed of bedrock and drift and is to the north and east indicating an ice movement from the south-west. Evidence, to be presented later, will show that both these ice movement directions have probably operated in this locality at different periods.

A study of the few striae recorded by the Geological Survey officers provides additional information but yields similar complexities. Just beyond the southern boundary of Area III a striation shows an orientation south-south-west to north-north-east without indicating the direction of ice movement. In Halls Burn to the north of Dungavel Hill a striation oriented from east to west is recorded. This latter striation is most peculiar for as in the previous two chapters almost all the evidence suggests ice movements from west to east. In fact it has already been shown that in the neighbouring Auchengilloch Hill district, (Area I Fig 13), impressive evidence, provided by glacial and fluvioglacial erosion and deposition <u>all</u> favours a west-east ice movement. It must be concluded therefore that in this instance, as elsewhere in Central Lanarkshire, the orientation/

orientation of the striation shows quite clearly the alignment of the ice movement but in the more difficult problem of interpreting the direction of the ice movement the wrong conclusion has been made.

Two neighbouring striae north of Drumclog (Fig 36) show an orientation from south-west to north-east without suggesting the direction of movement. On the western boundary of Area III to the south of Corse Hill a striation is oriented west-east with only a slight bias to the south. No direction of ice movement is suggested. To the south and west of this last striation, within one mile of the boundary, four striae have been recorded. Two are exactly comparable to the one shown on the boundary (Fig 36). The other two have south-west to north-east orientations but while one does not indicate the direction of ice movement the other indicates a movement from the north-east.

The evidence of glacial striae by no means simplifies the picture of ice movements in Area III, but information derived from areas outside the thesis area and new evidence found during the present investigation, will be shown to help clarify the very interesting, if complex, pattern of glaciation in Area III as suggested by the features of glacial erosion.

5. Glacial Deposition

Till is found as a discontinuous sheet of varying thickness over a large part of Area II. Its widespread distribution is, however, masked by two other deposits. In the Avon Valley and some of the tributary valleys fluvioglacial deposits, sometimes of considerable thickness, frequently conceal the underlying till. At higher/

higher and lower levels the till is often covered by peat.

Despite this peat cover till can often be observed at great heights. This is particularly true of the much dissected hill area to the south of the Avon Water. In the south-west, (Fig 38), till covers the summits of two hills rising above 1,000 feet, Mill Rig and Anderside Hill. In the adjacent hill area to the east the summits are higher and the altitudes at which till is found are correspondingly increased. In Figure 39 till is found above 1,200 feet on Bibblon Hill to the west of the Glengavel Water and at Exposure 16 in the headwaters of the Powbrone Burn to the east of the Glengavel Water. The highest summit, however, Dungavel Hill, has a mantle of shattered bedrock and is not till-covered.

In the northern and eastern parts of this southern hill area the hilltops become progressively lower. On Figure 40 the highest exposures at which till was observed were on Hawkwood Hill and Kypes Rig, (Exps. 18,20 and 13) at heights of just over 1,000 feet. On Figure 41 even further to the east till was absent from all those areas which exceeded 1,000 feet in height.

In the northern hill area the height of the land also declines to the north and east. The extensive peat cover makes it difficult to find good till exposures but in burn courses on Ellrig Hill, (Exp 10 Fig 42), till was seen at a height exceeding 1,100 feet. In the same area, (Exps 4 and 11 Fig 42), at lower levels bedrock appears at the surface. Eastwards the ridge nowhere exceeds 1,000 feet in height but the till distribution is again not merely related to altitude. At Exposure 12, (Fig 43), till is found at 840 feet whilst a large area around/

around Exposure 15, well below 800 feet, shows bedrock exposed at the surface. The till cover on higher slopes appears to be related more to the pre-existing topography before the onset of glaciation. Thus, burns and streams reexcavating former valleys may provide exposures revealing several feet of till whilst the adjacent and more exposed valley shoulders and slopes may reveal only scanty traces of till. A similar situation is found on Figure 43, one half mile to the south-east of Chapelton. Here an almost enclosed depression is found in the surface of the Carboniferous lavas. To the west two upstanding rock ridges are found and behind this buttress the depression is floored by glacial till. To the east, as the shelter afforded by this rock buttress and the associated depression decreases, so the till becomes thinner and rock again outcrops. These characteristics of till distribution take place irrespective of altitude.

In the main Avon Valley all these till characteristics are repeated. Sand and gravel, peat and alluvium cover wide areas in the valley floor and on the valley slopes. Most of the till cover, however, is found on the valley sides. Figure 40 shows these features well. Sand and gravel covers the lower slopes and the floor of the Avon Valley whilst on the valley sides to the south-east of West Linbank till is found, (Exp 8), in close proximity to solid rock and peat covered areas. Despite solid rock outcropping here at 700 feet, till extends up to 1,000 feet on the hillslopes above (Exp 18 Fig 40).

To the east on the Stonehouse Plateau till is found almost everywhere on the surface. Occasionally a small spread of fluvioglacial deposits/

deposits may be found (Exp 34 Fig 43). As has already been stated brick (lake) clays were formerly worked in Stonehouse but of these there is now no trace. The very regular surface of this plateau yields few good exposures but at its north-western margin the deep dissection of the Avon Water has drift exposures almost unrivalled in Central Lanarkshire. Exposure 33 (Fig 43), is a 100 foot section in the undercut bank of the Avon Water. It has not been recorded in the literature and appears to have been exposed only recently, in fact it is still actively forming. Solid rock is exposed only in the bottom 15 feet. Two till horizons can be seen. The uppermost , "surface" till appears to be only four to five feet thick. A lower till, separated from the upper till by a considerable depth of water laid deposits, may be as much as 15 feet thick. (Fig 45) At this locality, therefore, the "surface" till cover is more extensive than deep. To the south and east of Stonehouse Productive Coal Measures underlie much of the area and the resulting concentration of boreholes allows an examination of the drift stratigraphy.

Seven boreholes recorded on sheets 24 NW and 24 SW of the Geological Survey 6" Drift Maps and located immediately to the south of Stonehouse show an average minimum drift depth of 66 feet. The exact locations and drift classifications of these boreholes have in some cases been lost or been unsatisfactorily logged but they do indicate that this drift-occupied depression is elongated from Stonehouse southwards towards Boghead (Fig 36). The drift stratigraphy of the several boreholes cannot be exactly correlated. Stratified clay, sand/

sand, gravel, mud and boulder clay appear to alternate in rapid succession. This irregularity and the great depth of the drift, (the greatest depth recorded was in a borehole one mile to the south of Stonehouse where 100 feet of drift was logged), suggests a comparison with the buried valley of the Nethan, in Area II, three miles to the east (c.f. Flint 1956 Fig 7 p.112). Two more recent boreholes obtained from theGeological Survey Headquarters in Edinburgh (74 NE Nos. 240 and 241) give a clearer impression of the drift characteristics at depth. Both are located in Stonehouse village. It is interesting to note that the first borehole log

TABLE XVII

Borehole 240	Ft.	Ins.	Borehole 241	Ft.	Ins.
Soil	-	6	Soil	-	6
Brown Boulder Clay	15	-	Brown and Grey (lake?) Clays	49	6
Cobbles	13	6	Gravel	7	-
Sand and Gravel	8	-	Boulder Clay	3	-
Brown Boulder Clay	13	-	Gravel	8	-
Depth	50	-	Boulder Clay	3	-
			Gravel	8	-
			Boulder Clay	13	-
				92	-

records two separate tills and the second no less than three.

T o the south and west several other good till exposures are available in the Avon gorge. At Exposure 32 (Fig 43) 20 feet of grey till is shown but slumping and vegetation do not permit its stratigraphical/

stratigraphical relationship to the waterlaid deposits of Exposures 33 and 34 to be established. On the west bank the river appears to be eroding into the deposits which at this point infill its earlier "pre-glacial" course. (Geol. Survey Drift Sheet No.23). Two good sections are available. The first, (Exp 26 Fig 43) shows ten feet of grey till at the surface overlying a similar depth of stratified gravels with occasional sand lenses. This stratum in turn is seen to overlie a further eight feet of grey till exactly comparable in appearance to the tills on the east bank of the Avon. (Exps. 32,33 and 34 Fig 43). A nearby exposure, (Exp 27 Fig 43) shows 30 feet of grey till with one or two bands of red till included. The red till appears to be completely incorporated in the grey till, is nowhere more than one foot thick, is not separable along the line of junction and appears to be in lenses rather than a continuous layer. Its significance will be discussed later.

In the northern and southern hill areas of Area III the till is never more than ten feet thick. Its thickness, as has been already shown is a reflection of local variations in relief as much as of altitude. For example at 1,030 feet and 980 feet in the headwaters of the Calder Waters, (Nos 19 and 20 Fig 37), four feet and ten feet of grey till overlies solid rock respectively. In contrast the meltwater channels at East Browncastle , (800 feet), lower in the course of the Calder, are incised into solid rock and there is no drift cover. Although the till on this northern hill area is generally sparse it is always, (except for a few important exceptions), grey in colour. The southern hills in contrast have a covering of red/brown till which, however,/

however, shows similar characteristics of distribution. The thickest till is found in the floor of the largest tributary valleys. In the Kype Water valley, (Exps 11,12,13 and 15 Fig 41), at least 15 feet of tough red/brown till is found. The matrix is very fine and clayey but the often angular larger fragments can be up to 18 ins in diameter.

In the Glengavel valley, the largest of the Southern tributaries of the Avon Water, several excellent exposures can be seen. At Exposure 5, (Fig 39), 60 feet of stratified sands and gravels are seen to overlie 25 feet of grey brown till which in turn overlies bedrock. Photograph 51 clearly shows the underlying darker coloured till which being more resistant to erosion forms a well developed terrace. At higher levels in the Powbrone Valley a similar sequence is found although the drift thicknesses are much reduced. At Exposure 12, (Fig 39), four feet of coarse gravel overlies seven feet of till exactly comparable to that found in the Kype Valley. Lower in the Glengavel Valley (below Ph 51) the till stratum decreases in thickness but the overlying waterlaid sediments continue to form considerable thicknesses. At Exposure 1 (Fig 39) a particularly important section is found. Forty feet of fine, waterlaid sediments, (ripple bedded sands and laminated clays almost certainly indicating a quiet water or lacustrine environment), overlie a much coarser sequence the middle stratum of which, (with a gritty clay matrix and well-preserved striae on the larger fragments), is almost certainly till./

till. The two feet of stones overlying the till possibly represents

TABLE XVIII

	Exposure 1 Figure 39 Glengavel Water (725' O.D.)	
	20'	stratified sand and silt with layers of coal fragments
fine	15'	laminated clays
	4'	stratified sand/silt
	2'	stones up to 6" diameter with few fines
coarse	4'	stones in clay matrix (till?)
	3'	stratified sand and gravel

the washed upper surface of the latter deposit. The 15 feet of laminated clays may be taken to indicate the presence of a lake the gradual infilling of which allowed the deposition of the overlying,coarser, sands and silts.

On the northern side of the Avon Valley the tributary Calder Water enters in a position comparable to that of the Glengavel. In the lower reaches of the Calder Water two particularly good exposures reveal an interesting drift stratigraphy. The upstream section at Brownhill, (No 23/24 Fig 37), shows two separate till layers. The upper layer is itself composed of red and grey components loosely compacted together and red till is also found to penetrate downwards in irregular but continuous lenses into the unstratified sand horizon.

The underlying till is a compact, grey deposit which is exactly/

exactly comparable in appearance to the till at Caldermill downstream (Table XIX).

TABLE XIX

Exposure No.23/24 Fig 37 Brownhill	Exposure No.25 Fig 37 Caldermill
6' Red till, sandy upper layers	4' fine stratified gravel and sand
6' Grey till with fine gravel lenses	10' grey black till
5' Very coarse stratified gravel	
6' Unstratified fine sand with coal fragments and wisps of red till	
6' Tough grey/black till	

In the extreme west of the Avon Valley at the Kames of Avon, (Exp 2 Fig 38), 13 feet of stratified sand and gravel overlie eight feet of red boulder clay which is identical in appearance to that in the Kype Valley. In the eastern and lowest reaches of the Avon Water the till is almost everywhere grey in colour. Red till is occasionally found, however, on the lower north-facing hill slopes. (Exps. 5 and 8 Fig 40) and, as has already been mentioned, lenses of red till are found as far east as Stonehouse.

Several important points arise from the distribution of tills of different colours in Area III. (1) Again the underlying geology is a major influence. The northern hills composed as they are of Carboniferous lavas give rise to a grey till similar to that found on the Carboniferous sediments in the north-east. (2) The southern hill/

hill areas composed of Old Red Sandstone and Silurian rocks yield a highly distinctive reddish brown till. (3) The broad Avon Valley and the lower courses of its larger tributaries occupy positions where rocks of all three geological periods are frequently to be found in contact. Despite the occurrence of Carboniferous rocks on the south bank of the Avon Water, no definite grey coloured tills are found at the surface. In the lower Glengavel Valley, however, the tills are grey/brown rather than the more characteristic red/brown colour. At Exposure 13 (Fig 40), in a valley, opening to the north-west, seven feet of the red/brown till is seen to overlie eight feet of grey/black till containing lenses of laminated clay. Thus although grey tills are found on the periphery of the Silurian Hill area these appear to pre-date a later deposit of red till. On the northern slopes of the Avon Valley, an area entirely within the province of the Carboniferous rocks, a similar overstepping till relationship is found. Here, in the Calder Valley at Brownhill, red till directly overlies grey till. Thus during an earlier phase of glacial deposition grey tills from the north were carried southwards into the southern hills whilst a later red till stratum, indicating an ice movement from the south, is occasionally found to overlie the grey till, sometimes in localities well to the north of the area where Silurian and rocks of Old Red Sandstone age outcrop.

Since the colour of tills reflect the paths taken by the depositing ice streams and the rocks over which they traverse, their distribution allows two conclusions. In the Avon Valley either an earlier ice advance from the north overrode the southern hills and was/

was followed at a later date by a forward movement of ice from the southern hills, or, the Avon Valley was occupied by confluent ice streams from both north and south the fluctuations of which allowed the present overstepping relationship of the tills. In either event the evidence suggests that the last ice to occupy Upper Avondale came from the south.

Area III, in contrast to the previous two areas, has numerous good examples of drumlins (Fig 36). Most of these are from 200 - 700 yards long, 50 - 200 yards broad and up to 50 feet high. They are generally much elongated, whale-backed ridges rather than the "dumpier" shaped variety of the Glasgow Area. Their stoss ends are to the west and their tails to the east. On the lower hill slopes their occurrence might have been expected to be related to the thicker till deposits in these localities. This, however, is not borne out by the field evidence. Many of the drumlins are in areas where the local relief configuration has led to little or no till deposition e.g. the drumlin at West Linnbank (Fig 40). Good sections in drumlins are rare but those available indicate only a thin layer of till. Exposure 7 (Fig 40), in the tail of a drumlin shows only six feet of till over bedrock and Exposure 6, although perhaps as a result of meltwater erosion, shows no drift whatsoever. Some of the best drumlinoid ridges are shown on Figure 43. The ridge at High Carnduff is fairly typical, if rather larger than most. It is 1,200 yards long, 300 yards broad and 80 feet high at its maximum. Numerous large blocks of basalt, the country rock, are scattered over its surface, possibly/

possibly indicating their dumping in these positions from a downwasting ice surface. Exposure 11 shows 18 inches of stratified gravel over bedrock. Most of the elongated, drumlinoid features of Area III therefore appear to be rock covered with only a thin drift cover. (They may therefore indicate different subglacial conditions from those responsible for the "more depositional" drumlins of the Glasgow Area). As such they probably yield a good picture of the direction of ice movement during an early period of glaciation when the vigorous ice movements were capable of considerable erosion and moulding of solid rock.

The orientations of all the well-formed drumlinoid ridges have been plotted on Figure 36. On the north facing slopes of the Corse/Ardochrig Hill ridge the ridges are almost without exception oriented from west-south-west to east-north-east. On the south facing slopes of this ridge the drumlinoid ridge orientations are comparable except in one locality. On the west bank of the Powmillon Burn, several ridges are oriented from west-north-west to east-south-east (Fig 43). It is rather interesting that this same orientation is found in the only two drumlinoid ridges which do not conform to the general trend in the north and these too are on the west bank of the Powmillon Burn (near Cladence Fig 43).

With the south-west to north-east alignment of the Avon Valley it is perhaps less surprising that this orientation dominates the trend of the drumlinoid ridges in the Avon Valley and especially on its north facing slopes. Minor discordances are easily explained by the peculiarities of the local relief.

The/

The trend of these drumlinoid ridges, unlike that of the striae, is reasonably consistent throughout Area III. The dominant orientation is from west to east indicating that the main ice streams moved in this direction. In the southern hills and the Avon Valley the trend is from south-west to north-east whilst to the north of the northern hill ridge it is from west-south-west to east-north-east. Only at one locality, south and west of Chapelton, and the only major break in the east-west Corse Hill/Ardochrig Hill watershed, do the ridges show a southerly bias.

These conclusions are based, so far, on exactly the type of evidence which the Geikie brothers used with much success almost 100 years ago. In this one instance, however, the writer finds himself in disagreement with their conclusions. In the Explanation of Sheet 23, (Geikie et al 1873 p.41), James Geikie states that "the hilly tracts present that flowing outline and rounded form so characteristic of ground over which ice has passed; .... Where the turf and drift, however, have been recently removed, the rock-surface is usually found to be well striated and smoothed. The general trend of these striae shows that the ice has moved from the south; <u>but in the upper reaches of the Avon Valley, and in the hilly district lying to the west of Strathaven, the ice-markings point away from north-east to south west.</u>" This appears to overlook the fact that of the 12 striae recorded in the areas mentioned by Geikie only two agree with this statement. (Fig 36) One of these, on Dungavel Hill has already been shown to imply an ice source in a direction contrary to <u>all</u> the suggested theories of glaciation/

glaciation in Central Scotland. It has, for additional reasons, been shown earlier in this chapter that the opposite direction would not only be the more likely but almost the sole possibility. Other evidence to be presented in the following sections fully substantiates that the last ice movement in Area III was from west to east rather than from east to west.

Fabric analyses, particle size analyses and rock type content analyses were carried out at numerous till exposures. The locations of these sites were chosen so as to give a representative picture of the till characteristics throughout Area III.

Four analyses were carried out in the southern, - Old Red Sandstone/Silurian, hill area. The first was at site No.15, (Fig 37) in the Glengavel Valley. Here, as already described, the deep incision of the Glengavel Water has left several fine exposures. At the exposure already described in Table XVIII the grey/brown till has a strong preferred orientation from west-north-west to east-south-east. (No. 15 Fig 15) Two thirds of all the orientated pebbles occur in the western quadrant indicating an ice movement from this direction. The rock type analysis shows 2% Highland, 76% Carboniferous, 4% Old Red Sandstone and 18% "Southern Upland" rocks (all but two of the "Southern Upland" rocks are Silurian fragments derived from the local bedrock). With fully 76% of the contained pebbles being Carboniferous erratics a north-west to south-east ice movement appears to be the most satisfactory explanation, (Fig 37), and complements the evidence of the fabric analysis.

In/

In the nearby Hall's Burn, (Exp. 3 Fig 39), the till is only slightly more red coloured than in the Glengavel Valley below. The fabric analysis (No.16 Fig 15) reveals an unsatisfactory, dispersed orientation. There is, however, a slight concentration of stones in the south-west quadrant. Fully 80% of the pebbles were Carboniferous basalts and 16% of the remainder were also of Carboniferous origin. Only 2% Highland erratics and 2% of the more local Old Red Sandstone rocks were found. Both these rock type analyses and, to a lesser extent, the fabric analyses indicate an ice movement from the north-west. The unusually high percentage of erratic rocks and correspondingly low proportion of local material might suggest that this was a very vigorous ice movement which may have overridden an already drift-covered surface thus avoiding the inclusion of large numbers of local rocks in the till deposit. (Table XVIII shows that the till in the Glengavel exposure, (No.15 Fig 37), does indeed overlie a gravel deposit). This ice movement is almost certainly the one which penetrated the adjacent north-west boundary of Area I and influenced the glacial and fluvioglacial landforms as far as the Coalburn Basin (see Chapter II).

At both sites, No.15 and No.16 (Fig 37), the high percentage of Carboniferous rocks accounts for the absence of the distinctive red/brown colour so typical of the southern hill areas. At the third till investigation site in the Kype Water Valley, however, the characteristic, compact, red/brown till is found. (No. 17 Fig 37). No strong isolated preferred orientation emerges from the fabric diagram/

diagram (No. 17 Fig 15), but two main concentrations exist. The first is in the western quadrant and the second in the north-eastern quadrant. The rock type analysis (No.17 Fig 16) shows 24% Carboniferous, 4% Old Red Sandstone and 72% Southern Upland rocks. (68% local Silurian bedrock fragments). The large proportion of Silurian material is explainable only by a west-east moving ice mass. (Fig 37). Most of the included Silurian rocks are sub-angular fragments of purple silt/sandstone. On many of the fragments flat surfaces display well-preserved glacial striae which normally show a considerable degree of variation in their alignment.

Especially in their western parts therefore these southern hills appear to have been overrun by ice from the western extremity of the Avon Valley. This is particularly noticeable in the very high percentages of Carboniferous rocks in the till deposits of the Glengavel Valley.

In the complementary northern hill area equally significant results were obtained from the till analyses. The first site, on the southern edge of this hill area, is located at the base of the Loudoun Hill terrace (Ph 1). The fresh section at which Smith, (1898 p.60), measured 71 feet of sand,gravel and shingle overlying one foot of rusty, laminated clay and 30 feet of boulder-clay is no longer available but the boulder-clay can still be seen. This, in section, appears to have fairly average clay matrix but contains a very high proportion of flaky angular fragments of the local rock. The fabric orientation (No. 18 Fig 15) shows that 48% of the stones indicate a north-north-west to south-south-east ice movement (30% in/

in opposite quadrant). This is exactly parallel to the local gradient and with fully 96% of the rock fragments being derived from the Loudoun Hill intrusion itself and the high degree of angularity of most of the stones, there is some evidence to suggest that the deposit may not be a true till. One fragment of Carboniferous sandstone and one of Silurian origin complete the rock types present.

A rock type analysis of the till found above 1,000 feet in the headwaters of the Calder (No.19 Fig 37) showed 100% Carboniferous rocks (74% basalts and 26% sandstones). The thinness of the till and the possibility of slope creep did not permit a suitable orientation site. However, 200 yards downstream an undercut bank exposure reveals ten feet of till which has a very weak dip maximum to the north-west, (38% in peak maxima quadrant), indicating a possible ice movement from this direction. The rock types at this exposure, nor surprisingly, are similar to those found at the previous one. Ninety-six per cent of the pebbles are of Carboniferous material whilst 2% are of Old Red Sandstone and Silurian derivation respectively.

In the lower reaches of the Calder Water four further till exposure sites were investigated. At site No. 21, (Fig 37), (Ph 52), the fabric orientation is very dispersed with no single preferred orientation. (21 Fig 15). Concentrations of oriented pebbles are found in the south, the north and the west. The rock type analysis shows 100% Carboniferous material with basalts (84%) being/

being the dominant rock type.

At Caldergreen, site No.22 (Fig 37) the till has a rather dispersed but nevertheless pronounced alignment from north-west to south-east. These two quadrants contain between them 80% of all the stones orientated. The south-east quadrant, however, contains 42% of all the stones compared with the 38% of the opposite quadrant which would normally be taken to indicate ice moving from south-east to north-west.

The fabric analyses so far presented in this section appear to show that they, like "striations, as individual features, are not very useful direction indicators" (Flint 1956 p.59). Although a pronounced alignment is often found, (No.22 Fig 15), in many cases, the direction of the ice movement is not so obvious. In the present investigation three methods are used to offset these deficiencies and help solve the problems. Firstly, as many striae and fabric investigations as possible were recorded in an attempt to determine regional patterns, if any. Secondly, other field evidence, e.g. the distribution of the different coloured tills and the orientation of drumlinoid ridges may help prove, or disprove, the conclusions. Thirdly, the tills themselves were analysed in an attempt to record regional variations in rock types or other characteristics of composition.

These problems are well illustrated by the till investigation just described, (No.22 Fig 37), where despite abundant field evidence indicating an ice movement from the west, the till fabric (No.22 Fig 15) indicates the possibility of an ice movement to the north-west. The rock/

rock type analysis (No.22 Fig 16) shows 78% Carboniferous rocks, (66% local basalts), 4% Old Red Sandstone and 16% "Southern Upland" rocks, a combination which indicates an ice movement from either the south-west or the south-east (Fig 37). During the laboratory particle size analyses of till samples from this site, however, several pieces of what are clearly shell fragments were found. This raises an important point for although thirty till samples from areas distributed throughout Central Lanarkshire, to the north, east, south and west of this site, were similarly examined, not one revealed any trace of shell material. There are two main districts in Central Scotland in which marine fossils have been found in till; Wright (1896 Table p.268), and Neilson, (1896 p.275), discuss salt water foraminifera in the tills of the Glasgow district. Despite some controversy there is some evidence that marine shells may even occur in or beneath the till as far east as Chapelhall,near Airdrie (A. Geikie,1865). Smith, (1898), presented an impressive catalogue of "shelly drift" sites throughout Northern and Central Ayrshire. All of these shelly drifts are now regarded as having been deposited by ice moving from the south-western Highlands, across the then, as now, sea-occupied Firth of Clyde, eastwards into the Ayrshire and Glasgow Basins. The significance of the shells in the till at Caldergreen, therefore, is that they indicate a western ice source. Since shells are "uniformly absent" in the drifts occupying the area covered by Southern Upland Ice during the last glaciation of Central Scotland, (Richey et al 1930 p.321), it must also be concluded that the till at Caldergreen was deposited by ice whose origin was in the south-west Highlands.

The/

The next till investigation site (No.23. Fig 37) in the Calder Water is at Brownhill, only one mile to the south and yet it presents complications not met with at site No.22. At this exposure (No.1 Table XIX) a loosely compacted red sandy till overlies a tougher more compact grey till. The lower grey till shows a fabric pattern similar to that of its near neighbour (No.22). Sixty-two percent of the pebbles orientated were in the eastern peak maxima quadrant and only 28% in the opposite quadrant (No 23 Fig 15). Fully 92% of the pebbles were of Carboniferous derivation, with 2% of both Highland and Southern Upland rocks. The evidence here again is inconclusive but the extensive outcrops of Old Red Sandstone and Silurian rocks to the east and south and their general absence in the till suggest that a movement of ice from this direction is unlikely. The upper till, No.24, (Fig 37), does not have the compact nature of the lower till and a till fabric orientation was not attempted. The distinctive red colouring also separates it quite clearly from the underlying till. The rock type content of 88% Carboniferous, 6% Old Red Sandstone and 6% Southern Upland rocks,(24 Fig 16), and its anomalous colour clearly indicates ice derived from the south-west rather than the north-west. The fact that there are grey tills to the south which, by their colour and rock type content, imply a deep penetration in that direction of ice from the north-west, (e.g. No.15 Fig 37 indicates the overstepping nature of the areas covered by the different ice streams. Again. however, as in Areas I and II the only exposures where the two tills are found together show the red (southern) till overlying the grey (northern) till and indicate the later incursion

of/

of ice from the south. The absence of a fluvioglacial horizon between the red and grey (upper) tills again, as in Douglas Valley, suggests the possibility of semi-contemporary glacial deposition without an intervening time interval.

The last till site investigated in the Calder Valley (No. 25 Fig 37) is at Caldermill near its junction with the Avon. Here a north-east peak maxima quadrant contains 48% of the oriented stones whilst the opposite quadrant to the south-west contains only 36% (25 Fig 15). The simple statistical measurements of orientation strengths in the tills at sites Nos.18,22,25, and to a lesser extent 23, are all remarkably similar but only the alignment of No.25 approaches the trend (west-south-west to east-north-east) inferred by the general field evidence already presented. This trend notably accords with the two striae recorded by the Geological Survey to the south west. Therock type analysis, (No.25 Fig 16), shows 6% Highland, 84% Carboniferous and 8% Old Red Sandstone. The Old Red Sandstone rocks would suggest a south-west source but, perhaps even more significant, the proportion of Carboniferous sediments exceeds that of the basalts, in contrast to all the other sites in the Calder Valley. Of the 84% Carboniferous rocks, 6% were basaltic and 78% sedimentary. The only local exposures of Carboniferous sediments are just over one mile to the west-south-west in a band stretching east-west through Drumclog. (Fig 37) This fact and the presence of Highland erratics suggests again the intrusion of Highland ice into this area. The suggested south-west to north-east ice movement appears/

appears to recur in several different sources of information and will be mentioned again later in this section. It is perhaps appropriate to recall the confusion in this area as to the direction, rather than the agreed alignment, of ice movement. J. Geikie (Geikie et al 1873) whose work has subsequently been shown to be remarkably far-sighted and accurate suggested an ice source to the north-east whilst later workers (Phemister 1926, Sissons 1964) have cited the opposite direction. This confusion acknowledged by Geikie (1894 p.828) has been shown above to stem from the nature of the evidence itself but the present writer believes that the weight of the evidence undoubtedly favours an ice movement from south-west to north-east. (This will be shown to be fully vindicated in the light of the regional pattern of glaciation presented in Section 8).

Several till analyses were performed on tills found on the north facing slopes of the Corse Hill/Ardochrig Hill Ridge. The first (No. 26 Fig 37) is to the west near High Cleughearn. The till fabric diagram (No.26 Fig 15) shows an east-west orientation with 50% of the orientated pebbles in the eastern peak maxima quadrant and only 26% in the opposite quadrant. All of the pebbles in the rock type analysis sample are of Carboniferous origin and only 10% are of sedimentary origin. Due to a series of faults the sediments outcrop within a few yards to the north of site No.26, in a wide belt to the east of it, but not to the west. This indicates that, despite the evidence of the fabric maxima quadrant, the low percentage of sedimentary rocks would be more feasible with an eastward rather than

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a westward moving ice mass. This conclusion would accord with the now widely recognised fact that the "wetter" west coast areas of Scotland were the source of ice accumulation and ice dispersal during glacial times. (Sissons 1965 p.147).

Two nearby till exposures were also analysed for fabric orientation mainly to check the method of analysis. The results, however, are rather interesting and are therefore included here, No.26b (Figs 37 and 15) fully accords with the pattern of No.26, whilst the peak maxima quadrant of No. 26c is almost at 90^{o} to the other two. The significance of this latter discordance will be suggested later. Sites Nos. 26, 26b and 26c occur in areas supposedly covered by "Earthy and Sandy Angular Drift" (Geological Survey Drift Sheet No.23) but apart from the inclusion of occasional sand lenses the deposit appears little different from normal till.

The fourth till analysis was located to the east of Chapelton at the junction of the Carboniferous sedimentary and basaltic series. The till fabric diagram, (No.27 Fig 15), shows a well-marked east-west alignment. Although the individual peak orientation is to the east, both the eastern and the western quadrants contain equal percentages, 46%, of the orientated stones. Again all the stones are of Carboniferous derivation but the sedimentary/basaltic proportions 96%: 4% are almost exactly the reverse of the proportions at site No.26.

The consistency with which the peak maxima quadrants occur on the opposite side to the suggested ice source direction in the northern hill area is especially remarkable. The till fabric

diagram/

diagrams of sites No.22,23,25,26, and to a lesser extent No.27, (Fig 15), are all good examples of this peculiar characteristic. It therefore appears that in the tills of Area III that whilst "the longer axis of the stone is often directed in the line of glaciation" as was first noticed by Miller, (H. Miller 1884 p.167), the "generalisation" of Harrison, (1957 p.281), that there is a tendency to "preferred imbrication upstream to former glacier flow", and confirmed by Dreimanis and Reavely (1953 p.243) and Wright (1957 p.27), does not seem to apply. Instead, as in Hoppe's work (Hoppe 1952) there appears to be a tendency for pebble dips to reflect the local downhill gradient. (The possibility that the till sites occur on slopes where the surface has a gradient greater than the dip of stones, thereby giving an artificial effect,of slight dip upstream appearing to dip downstream, only applies at two of the sites and therefore cannot account for the widespread recurrence of this effect).

The very interesting stratigraphical records and the frequent occurrence of more than one till in the excellent exposures in the Stonehouse district led to a concentration of till analysis in this area. The sites are all located on the over-deepened sides of the Avon Gorge and its tributary gorges.

On the west bank of the Avon two grey tills separated by ten feet of fluvioglacial deposits are found. (Exp 26 Fig 43). The uppermost till, No.28, has a poorly-developed northern peak maximum whilst the lower till has a rather better-developed alignment from north-north-west to south-south-east, with the north-north-western quadrant/

quadrant containing 52% of all the measured stones. The rock type contents of both tills are similar (Table XX). The uppermost,

TABLE XX

Till No.	Percentage of Rock Types Found			
	Highland	Carboniferous	Old Red Sandstone	Southern Upland
28	-	96	4	-
29	2	90	4	4
Avon West Bank 30	2	98	-	-
Avon West Bank 31	4	88	2	2
Avon East Bank 32	2	84	4	4
Avon East Bank 33	2	92	2	4

contains 96% Carboniferous and 4% Old Red Sandstone fragments. The lower one again had a large proportion, 90%, of Carboniferous rocks and small proportions 2%.4% and 4% of Highland, Old Red Sandstone and Southern Upland rocks respectively. The weight of erratic contents favours a southerly ice origin but is hardly conclusive especially in the light of the till fabrics.

Within a few yards to the north a small west bank tributary stream of the Avon has cut a narrow gorge through the deposits which at this locality infill the buried valley of the Avon. Although no complete exposure was available the grey till again appears to be dominant. At the bottom of the gorge, however, a small fresh exposure, (Exp 27 Fig 43), shows an unmistakable lens of red till and a distinct stratum of grey stoneless/

stoneless clay within the grey till. A fabric orientation of the grey till (No.30 Fig 15) shows a distinct peak maxima quadrant to the north-west containing fully 55% of the measured stones.

The rock type content of the grey till, (No.30 Table XX), with its very high percentage of Carboniferous rocks is typical of those on the north side of the Corse Hill/Ardochrig Hill watershed and the districts south-east of Glasgow.

The complete absence of Old Red Sandstone and Southern Upland rocks is equally distinctive for it is a characteristic never found in Areas I and II to the south and east. The red colour of the lens of red till immediately suggests an origin to the south where, in the absence of Carboniferous rocks, red is the prevailing till colour. The detailed laboratory investigation of the component rock types, however, indicates an interesting alternative. Of the 88% Carboniferous material 30% is formed by fragments of Barren Red sandstones. These stones often have a soft, weathered coating which imparts its red colouring to everything with which it comes in contact. This staining appears to be the reason for the bright red till colour, for the surrouding grey till when analysed shows only 10% of these Barren Red fragments. The nearest possible source of these fragments is five miles to the north in a basin around Hamilton. The implication is that both tills were deposited by ice moving southwards. Although this evidence is strongest in the red till it is the only one to contain both Old Red Sandstone and Southern Upland erratics (No.31 Table XX). This situation, where adjacent, or even the same, till samples contain evidence of both/

both northern and southern origins to reminiscent of the conclusions arrived at after an examination of the till deposits at Blackwood/ Auchenheath to the south-east. (Area II). It should be remembered that Stonehouse lies athwart the "debatable ground" of Geikie, (Geikie 1894), and as he suggested, and the present fieldwork fully confirms, both northern and southern ice streams have passed over the area during the glacial period. Indeed that this "debatable ground" occupies a major part of Central Lanarkshire is shown by "the presence of boulders, whose source can confidently be placed amongst the rocks of the Southern Uplands" as far north as Glasgow. (Clough et al 1911 p.179). On the other hand Highland erratics have been found during the present investigation throughout Clydesdale as far south as Carstairs/Carnwath.

One of the finest exposures available in Area III is that found on the east bank of the Avon Gorge below Stonehouse. A close examination of this exposure showed that two distinct grey tills are separated by more than 20 feet of lake clays and fluvioglacial sediments (Fig 45). The lower till, probably about 15 feet thick, was normally obscured by slumped material but was clearly seen to be resting on a prominent rock buttress at the base of the section. This part of the section is inaccessible due to the undercutting of the valleyside by the Avon Water. The upper till is about four feet thick and is in turn overlain by as much as 15 feet of stratified sands and gravels. Beneath this till there is a well-developed red/brown iron pan layer one inch thick. It is unlikely that this tough layer could have been formed by mineral laden waters percolating through the normally impermeable overlying/

overlying till. An alternative suggestion is that it was formed during a period of sub-aerial weathering prior to the deposition of the overlying till. (The pervious nature of the sands would promote rapid podsolization). If this latter alternative is true then this is a highly significant piece of evidence for it implies a considerable period of time during which ice withdrew before a later ice advance. Definite evidence of this event is rare in Central Lanarkshire. Assuming that the upper till is the product of the most recent ice cover then this thin till layer would appear to represent the Perth Readvance (Zone 1) ice cover as postulated in this area by Sissons (1963/1964). A lower hardpan overlying the lower till might also suggest a period of ice-free conditions after an extensive glacial period at the end of which at least one ice advance followed. The complex and detailed stratigraphical record of this exposure make it worthy of further investigation.

The till fabric diagram of the upper till,(No.32 Fig 15), shows a peak maximum quadrant to the north-north-east containing 42% of all the orientated stones. The results of the rock type analyses, shown on Table XX, illustrate the similarity of the tills on both sides of the Avon Gorge. Highland stones form 2%, Carboniferous 84%, Old Red Sandstone 4% and Southern Upland stones 4%. Again there is a mingling of erratics from both north and south. At a nearby grey till exposure a further rock type analysis,(No.33 Fig 16), was carried out and this again reveals a comparable result of 2% Highland, 92% Carboniferous, 2% Old Red Sandstone and 4% Southern Upland rocks.

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To the south and east of Stonehouse, (Fig 36), there is the extensive area of the Stonehouse Plateau. The deep drift conditions shown by boreholes throughout this area indicate that this is not one of the erosion plateaux of the Central Lowlands recognised by Ogilvie (1928) and others. The borehole records are comparable to those recorded by Flint in drift filled valleys in Ohio (Flint 1956 p.112). Their depths and drift stratigraphies are exactly like those found in the other buried valleys of Central Lanarkshire. The only buried valley located in this area according to the Geological Survey (Drift Sheet No.23) is that of the Avon. This has been well charted to the north of the Avon Gorge and therefore cannot account for the present subdrift depression which lies wholly to the south of the gorge. A forerunner of the Cander Water may have helped erode this now infilled valley but its excavation may also have been helped by the waters of a stream which no longer flows in this direction - the Kype Water. There are several lines of evidence which suggest this, some of which will be presented later in the chapter. At present, however, it will be sufficient to note that the Kype Water (and its south bank tributaries) flows in a course aligned from south-west to north-east until it reaches the present east-west valley between Sandford and Deadwaters at which point it turns abruptly westwards. (Fig 36). A continuation along its south-west/north-east course would see the Kype occupying the conspicuous wind gap east of Deadwaters and only a few feet above this latter locality in height. Two other facts indicate that the Kype may formerly have utilised this gap. The wind gap is continued to the north-east by an unoccupied/

unoccupied depression whose alignment matches that of the Upper Kype and may mark the position of the former, lower course of this river. To the east the suggested newer course of the Kype is completely discordant to the trunk stream of the Avon Water. Beyond Sandford (Fig36), the river plunges over the Spectacle Ee waterfalls with a descent of nearly 100 feet. This therefore appears to be a very recently cut course and like the numerous other gorge courses of Lanarkshire rivers may be taken to indicate a locality where the river has not rediscovered its "Pre-Glacial", now buried, valley.

To the east of the Cander Water, however, the ground rises sharply and the drift cover consists only of a single layer of grey till. This till cover, normally 10 feet to 15 feet thick probably emphasises the smooth, plateaux like nature of the higher ground (550 feet - 600 feet) which forms part of Ogilvie's Higher Lowland Peneplain (Ogilvie 1928). Its consistent colour, depth and continuous nature throughout this area imply that it was deposited by a single ice sheet. A till fabric analysis at site No.10, (Fig 37), (The site is on the boundary between Areaa II and III and was reported earlier in Chapter III) shows a definite concentration, 63% of all oriented stones, in the south-west quadrant. The rock type content, (No.10 Fig 16), with 82% Carboniferous, 14% Old Red Sandstone and 4% Southern Upland rocks would certainly suggest an ice movement from the south-west.

The inference derived from the till fabric and the till rock type content studies is that atleast two main ice streams affected glacial/

glacial deposition in Area III. One from the north-west affected particularly those areas north of the Corse Hill/Ardochrig Hill watershed and seems to have penetrated at least as far as the Stonehouse district. The other ice stream from the west but moving mainly to the north-east utilised the broad through valley of the Avon Water. It appears to have had two components. At times in Upper Avondale the ice seems to have pushed to the south-east whilst at other times the more normal north-east direction was dominant.

The mingling of erratics from both the Highlands and the Southern Uplands and the overstepping of red and grey tills outside their normal geologically defined areas (Fig 24) suggest that these two ice streams have not always occupied the same territorial areas. Again as in Areas I and II sites are found where red till, presumably deposited by ice coming from areas to the south, overlies the more local grey till. This may indicate that as in these areas the last local push of ice was from southern rather than northern ice sources.

6. Fluvioglacial Erosion

The evidence of fluvioglacial erosion in Area III is not only of particular academic interest, because of the great variety of meltwater channel types found, but also vital to the explanation of events during glaciation and deglaciation. Meltwater channels, however, are not found throughout the area. They are normally found as inter-related features which are concentrated in certain favourable localities. The ice streams which occupied Area III have already been shown to be dominantly from the west, sometimes moving to the north-east and sometimes/

sometimes to the south-east. In either event the largest concentrations of meltwater channels are invariably found on slopes which either face north, north-west or south-east (Fig 36). Often the lee, east-side, of a more prominent hill slope or projecting spur has provided the focus for meltwater erosion (Channels 5,6,7 Fig 40). The pattern suggested by the meltwater drainage system, despite the complexities introduced during the previous discussion, is a simple one. All of the major systems and even the main isolated channels are directed from west to east. In the northern part of Area III a south-easterly component is frequently discernible whilst the channels to the south are almost invariably directed to the north-east (Fig 40). The west-east direction of the ice streams passing through the Area III is fully borne out by the pattern of fluvioglacial drainage.

As in Area I, the westernmost meltwater channels occur on the western watershed/boundary itself (Ph 53). Figure 38 shows the meltwater channels and their relationships to the other landforms in the extreme south-west. Meltwater channels course the lee, (north-east and north facing), slopes of the main watershed boundary. (Channels Nos. 13,14,15,16 and 17 Fig 38). The Channels at 15 and 17 (Fig 38) are particularly interesting. Two of them begin as very small incisions, only a few feet deep, on the watershed. These two channels are directed from south to north and are joined after 400 yards by two adjacent channels with similar orientations. The easternmost part of this system is less incised and shows a tendency to form branching tributaries. The longest channel in the east (No.17)

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is incised into drift all along its length and no bedrock exposures are visible. Just before its confluence with channel No.15 (Fig 38), this channel is 40 feet deep, 50 yards wide and has a flat, peat-covered floor 30 feet wide. Although it is at present occupied by a stream some of its near neighbours are streamless. This is particularly true of the "up and down" tributary channel immediately to the east.

The longest channel in this system is No.15 (Fig 38). In its lower reaches it is 120 yards wide, incised up to a depth of 40 feet in a flat peat-covered surface and contains a flat floor 70 yards wide. It has a lesser gradient than its eastern neighbours and is the "trunk channel"of this drainage system. In its lower course Channel 15 takes a very pronounced swing to the north-east. The degree to which the meltwaters which cut this channel were responsible for the engorged section of the valley of the Woollen Burn (12 Fig 38) cannot be accurately assessed. For reasons which will be discussed later, however, it is assumed that the downstream gorge course of the Woollen Burn (No.12 Fig 38), was initiated by meltwaters. Channels 15 and 17 show the overriding of the nearby watershed by ice. (This is a good example of Sissons'argument of the exceptional rather than the widespread occurrence of lake overflow channels (Sissons 1960). The different altitudes of the several intakes of this small system show the impossibility of a purely subaerial overflow origin. Other features indicative of a subglacial origin are the anastamosing pattern, their non-occupation of the lowest parts of the col watershed, the ice contact nature of the kames at their heads and the up and down profile developed/

developed in channel 16 (Fig 38).

Although the orientations of almost all the channels in Figure 38 emphasise the general south-west to north-east meltwater drainage pattern and fully substantiate the greater thickness of ice to the south-west, another series of channels 8,9,10 and 11 shows a local discordance. These channels are all on the lower, south-facing slopes of the Graystone Hill/Mill Rig hill mass. Their lower altitudes, the occurrence of a marginal bench and discordance with the regional pattern (which as has been shown was initiated when ice still covered the watershed), suggest that these channels may have been eroded at a later period during deglaciation when the nunatak hill area of Graystone Hill/Mill Rig presented an obstacle to meltwater flow. Thus the meltwaters would have been diverted to the west and east. This emphasises the greater influence or control exerted by relief during the later stages, rather than the earlier stages, of deglaciation. Even at this late stage, however, the hydrostatic pressure of the meltwaters was sufficient to cut up and down profiles in two of the channels (9 and 10 Fig 38).

Most of the channels mentioned so far 8,9,10,13,14,15,16 and 17 (Fig 38) are cut in till, although occasionally they have also been incised into the underlying bedrock e.g. 14 (Fig 38). At lower levels, however, on the flanks of the two main valleys, the Avon and the Glengavel, the meltwater channels are normally cut only in fluvioglacial deposits e.g. 6 and 7 (Fig 38). These channels, however, have often sharply defined cross-profiles. Some of them are incised into/

into flat or only slightly undulating spreads or terraces of sand and gravel. Channel 7 (Fig 38), is one of the longest. It is almost 200 yards broad, as much as 60 feet deep and has a well-preserved flat floor 100 yards wide. Channel 7 and some of the nearby channels already described can be seen in their relationships with associated landforms in the air photographs Nos. 54 and 55.

The northern hill range is also penetrated by meltwater channels from the west. On the southern side of the Corse Hill/Ardochrig Hill watershed these are generally directed from north-west to south-east, e.g. at Browncastle Fig 36. These channels are normally incised 15 feet to 25 feet into till but occasionally, as to the east of Browncastle, the channels may be cut in solid rock. This system is continued with the same orientation by a series of meltwater channels at the headwaters of the Glen Water (outside the thesis area) which flows southwards to the River Irvine. These latter channels begin at a height of 1,000 feet on a secondary watershed, of the Eaglesham Uplands and by their great incision of up to 60 feet imply a strong movement of meltwaters from the north-west.

On the northern side of the Corse Hill/Ardochrig Hill range meltwater channel No.1 (Fig 42), begins at an altitude of almost 900 feet. This channel, like those in the southern hills, (Fig 38), also trends from south-west to north-east. It is 40 feet deep, 40 yards broad, has a flat floor 30 feet broad and is cut in solid rock. Other channels continue this eastward directed sequence of fluvioglacial drainage at progressively lower altitudes (see adjoining Fig 43 channels 1,2,3,4 etc).

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On the south-facing slopes of the northern hill range there is no comparable semi-continuous fluvioglacial sequence. The channels at Browncastle terminate at Brownhill (Fig 36). To the north-east, however, at Carnduff a new system of meltwater channels commences (Fig 43). These begin in the floor of a south-west to north-east oriented valley to the south of the main watershed. The orientation of the channels, however, has changed from the south-east trend found at Browncastle, to one which is directed generally to the north-east (Fig 43).

Both the channel system to the north and that to the south of the Ardochrig Hill watershed consist of single or small groups of semi-continuous channels. Since the drift cover is sparse in this upland tract the channels are normally incised in solid rock. Perhaps as a consequence they are only rarely as much as 20 feet deep, in fact their presence might easily be overlooked in this undulating lava plateau area.

South of Chapelton there is the first major gap in the west-east watershed (at 760 feet) and some of the channels, e.g. Nos. 1 and 4 and that now occupied by the headwaters of the Powmillon Burn, indicate that meltwaters penetrated the former watershed at this point. The occupation of this gap by ice is shown by the ice contact depositional features which occupy its floor. It is almost certain that, as the pattern of meltwater drainage suggests, northern ice moved across the watershed through this gap. This penetration would account for the local tendency for landforms normally related to ice/

ice movement e.g. drumlinoid ridges to have an orientation from north-west to south-east. The very great incision of the Powmillon Valley at its headwaters, the tributary nature of some of the neighbouring meltwater channels to it and the general absence of meltwater channels east of it, probably indicate that this channel carried a large proportion of the meltwaters derived from the now confluent ice streams from noth-west and south-west (Fig 43). The Powmillon channel, (No.3), appears to have occupied the position of a sub-glacial chute/trunk channel similar to that proposed by Sissons (Sissons 1961b Fig 7 p.20).

Meltwater channel No.4 (Fig 43), also indicates the greater ice thickness to the north of the watershed and the overriding of the latter by the northern ice. The three distinct tributary channels of No.4 have uphill gradients. The floor of the large channel itself has a very slight downhill gradient. It is incised entirely in solid rock and at its maximum is 20 feet deep, 40 yards broad and has a flat floor 20 feet wide. At its exit some of the meltwaters were directed westwards into the Powmillon Channel and some continued to the east utilising another gap in the watershed immediately to the north of High Coldstream. (Fig 43)

Further east there is a continuation of the linear concentration of meltwater channels extending to Glassford. Apart from interesting features such as one meltwater channel, (No.10), being incised into the floor of another, (No.11), this system helps prove the confluent contemporaneous nature of the two ice streams in this area. The fluvioglacial landforms mapped on Figure 43 show the continuity/

continuity of this system with those to the west of Chapelton i.e. with areas to the north of the watershed and occupied by ice from the west-north-west. At Nos. 9,12 and 13, however, the channels become one-sided sub-marginal/sub-glacial benches (being continuous with ridges of fluvioglacial deposits with ice contact faces on both sides suggest an origin under the ice edge) incised into the south-facing hillside i.e. the ice was certainly now also to the south of the meltwater system. Thus whilst there is no evidence that the two ice streams were confluent to the west of the Powmillon Burn it has already been shown that northern ice breached the watershed at this point. The pattern of meltwater drainage also confirms this and suggests a contemporaneity of the two ice streams. To the east again there appears to be a confluence of meltwaters from the west with an ice mass in the Avon Valley. (This will be discussed later).

On the north-west facing slopes of the Avon Valley two distinct concentrations of meltwater channels are found. Both of these are shown on Figure 40. To the west of the Lochar Water there is a remarkable series of meltwater channels, (Nos.10,11 and 12 Fig 40), each of which declines very gradually from south-west to north-east in a direction at 90° to the slope gradient. The gradients of the channels themselves, measured from end to end in their parallel sections, using the contours and spot heights on the O.S. maps, are; 1 : 31.4 (No.12), 1 : 79.8 (No.11), 1 : 80 (No.10). (Sissons(1961b p.15) quotes channels with a gradient of 2% (1 : 50) as being at least partly marginal in origin). The increased gradient of channel No.12 is due to the lengthy downslope/

downslope bend which it takes at its north-east end. The gradient of the remainder of the channel would almost certainly be similar to those of No.10 and 11. The channels have fairly uniform dimensions. They are normally 20 feet - 30 feet deep, 40 - 50 yards wide and have flat floors 40 feet - 70 feet wide. Channel No.11 has two smaller distributaries leading off it. Neither of these is greatly incised. The southern one has the greater dimensions but even it is only 4 feet - 5 feet deep on the downhill side and 10 feet - 15 feet deep on the uphill side. Its width is about 50 feet much of which is occupied by a flat floor (Ph 56 shows this distributary meltwater channel with channel No.11 in the background).

All the channels discharge eastwards into the same valley, that of the Lochar Water but at their eastern ends they become progressively less incised and the two highest channels do not penetrate down the valley side. Two other channels, 8 and 9, occur to the north as unconnected parts of this meltwater system. The most interesting feature of this channel system, however, is the parallelism of its three main members. This feature together with their low gradients and orientation along the slope contours recall the vexed question of ice marginal drainage. (Sissons 1961b p.15). Since several of the channels have up and down profiles a marginal origin in its strictest sense is in this case impossible. Their parallelism, however, does suggest control by, or the influence of, the ice edge/bedrock contact position in either a subglacial or a submarginal environment.

To the east of Lochar Water another channel system is found/

found. This one, however, has neither the uniformity of dimensions nor the parallelism of its predecessor. Again, however, some of the channels are long; both channels 5 and 6 are more than one mile in length. (Fig 40) They have several distinctive peculiarities. At several points along their length they have abrupt changes in direction. Such direction changes "seem to reflect control of the submarginal drainage in part by structures in the ice" (Sissons 1961b p.15). However, at several of the points where the main changes in direction occur the channels appear to have emerged from a position in which they had been running parallel to a drumlinoid ridge. This infers that the control, if there was any, may have been exerted by the underlying relief conditions rather than those within the ice. Channels 4,5,6 and 7 all show at some stage directional changes at the"lee end" of drumlinoid forms. (Fig 40) Channels 6 and 7 are at theirwestern ends eroded into till although they may occasionally penetrate to bedrock as at Exposure 6 (Fig 40). They are as much as 30 feet to 35 feet deep. At the point where their courses cross, however, they are little incised and have developed a flat floor as much as 35 yards wide.

Channel 7 (Fig 40) has an unusual course. Its change in direction in its upper course maintains it in a direction roughly parallel to the slope contours but when it eventually turns down slope it cuts through one of the drumlinoid ridges. This is a case where the underlying relief, far from affecting the course of the subglacial drainage network, has been superimposed on. Although now streamless and/

and the only example of this superimposition found during fieldwork channel 7 probably indicates the way in which many stream courses now dissecting drumlins and other upstanding landforms, might have been initiated (e.g. see Lochar Water at Exp.5 Fig 40). Price, (1960 p.487), has shown that in the Upper Tweed drainage basin supraglacial streams have often been let down onto and eroded themselves into upstanding spurs. This is certainly a possibility which could account for some of the features on Figure 40. It also raises the interesting question of an original continuity of the two meltwater systems; both have similar component members and both have a similar relationship to the surrounding landforms. The present break may have been caused by the intervention of the Lochar Valley which may have contained, a greater depth of ice or a temporarily dammed lake, both of which could have broken the continuity of the meltwater drainage pattern. (fuller discussed in Section 7). Price (1960 p.486) has also indicated that the meltwater streams of channels such as 9,10,11 and 12 could have flowed within or on the surface of the ice, thus leaving no trace in the Lochar Valley before continuing their incision on the following spur at 4,5,6 and 7 (Fig 40).

Channels 6 and 7 are the second examples in Area III of one channel cutting across the course of another (c.f. channels 10 and 11 Fig 43). If channel 6 is the later eroded of the two then it appears to have found a more convenient new course rather than utilising that of channel 7. There are two possible explanations for this crossing of the courses of meltwater streams. The path of channel 7, where it crosses the drumlinoid ridge, may originally have had a

pronounced/

pronounced up and down profile. When channel 6 was being cut this, perhaps quite slight, reversed gradient may have been sufficient to induce the meltwater stream, perhaps now with a much reduced pressure head, to take the more normal course around the relief obstacle. Alternatively the new course may have resulted from an ice block in the lower course of channel 7 and/or a more vigorous directional movement of meltwaters along, rather than down the slope contours.

The small meander in channel 5 (Fig 40) is probably an "in and out channel" as described by Sissons(1961b p.28/9). As in the development of normal river meanders, it was later abandoned for a more direct course. As Sissons suggests this again may indicate superimposition of supra or englacial meltwaters onto the underlying surface. The small channel system at 4, (Fig 40), is incised into till. None of the channels are more than 15 feet deep and their greatest width is about 50 yards.

Further to the east the channel systems at 1,2 and 3 (Fig 41) show the continuation of the meltwater drainage of the western, (Avon Valley), ice stream into the present drainage basin of the River Nethan. (It is important to note here that the altitudes of system 3 and the up and down profile of one of its members show that this occurred when ice occupied the Deadwaters Gap and therefore prior to the time when the lake overflow, as envisaged by Phemister (1925 p.114), (Fig 7), utilised this gap). Richey, (1930 p.332), has commented that some of the channels mapped by Phemister (Fig 7) "are rather vague". By the comparison of Figure 7 and Figures 40 and 41 it can be seen

that/

that there are several surprising omissions on Phemister's mapping of fluvioglacial channels. The present writer, however, had greatest difficulty in locating some of the "terrace features" rather than the "dry channels" shown by Phemister.

Some of the channels and channel systems in the Avon and Glengavel Valleys are "feeder" channels which lead down the valley sides to the main areas of fluvioglacial deposition (c.f. Area I). These channels normally occur outside the sand and gravel areas and are cut largely in till. (e.g. channel 5 Fig 38, Channel 7 Fig 39) and channels systems 4 and 5 Fig 44). Like their counter parts in Area I these channels rarely penetrate far into the area of fluvioglacial deposition and never reach the valley floor. Many of them pursue courses which parallel the valley slope contours before plunging more steeply downhill and it might therefore be suggested that along much of their courses they were in a sub-marginal position before occupying a sub-glacial chute position at a point where perhaps a weakness in the ice allowed a greater downhill penetration.

Most of the channels, however, in the Avon and Glengavel Valleys are within the areas of fluvioglacial deposition. In Area I most of the channels in this position were found to be rather indeterminate rather than sharply-defined channel forms. This is not true of those in the upper part of Avondale. Many of these channels have cross-profiles which are as well defined as those cut in till or solid rock. Photograph 58 shows one of these. This channel, (No.3 Fig 44), is cut entirely in fluvioglacial deposits and is three quarters of a mile long. It emerges from an enclosed circular depression/

depression and at its head is surrounded on three sides by upstanding ridges of sand and gravel. It follows a sinuous course to the north-north-east, being incised into a well-defined terrace of fluvioglacial deposits, and eventually emerges at a level which is graded to the broad "flood-plain" of the Glengavel Water. The other characteristics of channel 3 are almost uniform along its length. Its gradient, less than one percent, is even less than that of the parallel system of channels on Figure 40. Its depth is consistently 30 feet - 35 feet and its width from 80 - 120 yards. It normally has a flat floor but this varies from 35 yards at its broadest to negligible proportions elsewhere.

Another very long channel in a similar position is that occupied by the A 71 Strathaven to Kilmarnock road at Loudoun Hill. (Channel No. 1 Fig 44). Although not so long as the previous channel, channel No.1 is much the better known and is locally known as the "Windy Wizzen". Charlesworth, (1926 p.38), mentions this channel but mistakenly states that it falls eastward when in fact it has a very steep gradient to the west. Although the channel emerges very gradually from the flat-floored basin to the east, at its deepest part it is incised 80 feet into the adjacent fluvioglacial terraces (Fig 44). At its broadest the channel is fully 100 yards wide but it appears to be "V" shaped throughout its length. A similar channel in a comparable position is situated to the south-west (No.2 Fig 44).

The thick sand and gravel deposits extending back up to

the/

the headwaters of the Glengavel Water (Fig 39) also exhibit the scars of fluvioglacial action. The meltwater channels here are not as long as those in the floor of the Avon. Again, however, they are found to dissect terraces and moundy spreads of sand and gravel. The highest of the channels occur almost on the watershed where two channels, (8 Fig 39), divide three, probably formerly continuous, flat-topped sand and gravel spreads. At an exactly comparable height, (1,000 feet), on the opposite side of the valley at Brown Hill, (Fig 39), another channel, No.6, dissects a similar sand and gravel spread. This channel appears to have carried meltwaters from the Powbrone Valley northwards into the Glengavel Valley and indicates that the lower watershed to the south (970 feet) was at this time blocked by ice. It is suggested that these meltwater channels are incised in what are kame-terraces deposited in marginal lakes around a decaying ice mass which occupied the valley floor. The channels may have been cut by short-lived torrents which drained these lakes on the further break-up of the ice. Thus, the channels all have short but steep courses. The fact that they do not penetrate to the valley floor suggest that the channels are sub-glacial chutes (Sissons 1961b p.23). Channel 6 has a double exit. Elsewhere this would in the light of Sissons' publications, (1960 and 1961b), be regarded as an up and down sub-glacial channel, but in the local circumstances this channel may in fact be exceptional in that it could equally have been formed by simultaneous drainage in both directions. (Common 1957 p.96).

Numerous other channels to the north in the floor and

lower/

lower slopes of the Glengavel Valley also indicate the movement to the north of meltwaters in this valley during deglaciation. These were added to by the channels issuing from the west bank tributary valley of the Woollen Burn. (Nos. 6 and 7 Fig 38). The origins of many of these channels, also dissecting kame-terrace spreads of sand and gravel, may well be similar to that already suggested in the Glengavel/Powbrone area. They also appear to have often given rise to fluvioglacial deposits. For example the course of channel 6 (Fig 38) appears to give way to a fluvioglacial ridge which in the light of local circumstances would conform to the description of a "subglacial engorged esker" (Sissons 1961b p.24). The variety of channel types in Area III perhaps reflects the variety of circumstances possible during deglaciation even in quite limited areas, and certainly indicates the difficulty of making regional generalisations of conditions during ice wastage.

The overall pattern of fluvioglacial drainage in Area III implies a very strong west to east movement of meltwaters. This reflects the regional ice gradient which must also have declined in this direction and this in turn reflects the sources of the ice streams which invariably appear to have been to the west.

7. <u>Fluvioglacial Deposition</u>

As already stated Area III contains in upper Avondale one of the largest accumulations of fluvioglacial deposits to be found in Central Scotland (Phs 57 and 58). This has not gone unnoticed by commercial sand and gravel companies and whilst they are at present removing/

removing some of the finest samples of supposed lake terraces in Scotland, the exposures which their excavations reveal and the information which they proffer greatly facilitated the present investigation. The interest of the fluvioglacial deposits in Area III, however, is not only derived from their abundance but also from their variety of surface expression, distribution, orientation and significance to the regional pattern of deglaciation.

In general the Avon Valley contains not only the most extensive but the thickest of the fluvioglacial spreads. Its main tributaries also share in this distribution. Even within the southern hill area, however, considerable fluvioglacial deposition has taken place. In contrast the northern hill area, with one exception, is without fluvioglacial deposits. The exception is the well-marked narrow linear belt of sand and gravel which extends along the north, and the south, facing slopes of the Corse Hill/Ardochrig Hill watershed (Fig 36).

The Corse Hill/Ardochrig watershed is in its upper parts almost entirely devoid of fluvioglacial deposits. (Fig 36) On both its north and south flanks, however, it has areas covered by fluvioglacial deposits. On the north flank these deposits occur as a narrow and discontinuous belt from above 850 feet west of High Cleughearn, (Fig 42), to below 500 feet east of Glassford in the Avon Valley (Fig 43). This remarkable linear belt of deposits therefore extends for seven miles west to east and declines in the same distance through a height range of more than 300 feet. In the west the orientation shows a slight northerly component whilst to the east of the/

the point where it crosses the watershed, (Powmillon Valley), it generally shows a slight deflection to the south of east (Figs 42 and 43).

On the western boundary of the thesis area the deposits commence immediately to the east of several small meltwater channels (1 and 2 Fig 42). A series of elongated ridges composed of fluvioglacial deposits overlies a wider sheet of sand and gravel which, however, is rarely more than two feet thick. (Exp 6 Fig 42) The surrounding area is till-covered but at some exposures this is seen to contain lenses of gravel. (Exp 1 and 2 Fig 42) The first few linear ridges at High Cleughearn are 10feet to 15 feet in height and 50 feet broad and are smooth and rounded in appearance. Several smaller forms are also found and two of these are almost perfect cone shapes. To the east, however, the fluvioglacial forms increase in size at Exposure 9,(Fig 42), a spot appropriately, if mistakenly, called, "Kame-End", there is an elongated winding ridge 20 feet high and 80 feet broad with steep sides and a rounded undulating crest. This ridge is also composed of waterworn fluvioglacial deposits. To the north several detached sand and gravel masses exhibit flat-tops. To the east the elongated ridge becomes a bench of sand and gravel banked against the rising ground to the south and with a steep face to the north, a feature noticed also by Gregory (1925 p.416). It is suggested that the ridge to the west, its appearance and composition justify its being designated an esker, is superseded by what is in fact a kame-terrace deposited in a marginal or submarginal position. The steep north-face is in fact an ice contact face. There are many

additional/

additional reasons for suggesting an ice marginal position along this north-face of the Corse Hill/Ardochrig Watershed. Two miles immediately to the west of High Cleughearn there is a well known concentration of fluvioglacial deposits known as the "Eaglesham Sands and Gravels". (Richey et al 1930 p.333). The channels mapped at 1 (Fig 42) are only the easternmost of a series, which the present writer has mapped in the field, which directly connect the fluvioglacial deposits at Cleughearn with those at Eaglesham. The Eaglesham deposits are a series of terraces "which end off sharply down the valley (to the north-east) in a series of steps ... and must mark the successive positions of the ice-front showing the successive shrinkage of the ice filling the Clyde Valley along this its south-western side". (Richey et al 1930, p.333). Richey also observed "that much of the material was carried in laterally from the north-west" (1930 p.333). The present work shows that some of these waters also flowed out of the Eaglesham lakes along and under the declining ice margin, to the east, and may have been a major source of the meltwaters which cut the channels and deposited the kames and eskers of the fluvioglacial sequence as far east as Chapelton. (Fig 36)

James Geikie (1894) also examined the deposits at Eaglesham and concluded an origin almost identical to that later reiterated by Richey and quoted above. He also (1867 p.60 footnote) made the observation that the till cover to the west in the Paisley area below an altitude of 900 feet shows signs of having been eroded since its deposition whereas the till above that altitude appears to be/

be untouched. (This fact is extremely important in the light of the more recent conclusions by Dr. J.B. Sissons (1963/64)).

Sissons, (1963 p.153), also notes on the uplands south of Eaglesham, "a line above which meltwater features are poorly developed or quite absent and below which they abound". (The present work, (Figs 42 and 43), fully confirms this). He maintains that this line delimits the maximum stage of Simpson's Perth Re-advance in this part of Central Scotland (Simpson 1933). The present investigation of this area reveals no evidence to disprove this statement and indeed the circumstances suggested would help explain several of the anomalous features already mentioned. Firstly, whilst the directional landforms, drumlins and eskers, shown on Figures 42 and 43 suggest a west-east ice movement the striae (Fig 36) suggest a direction from north-east to south-west. These striae, notably outside the suggested Perth Re-advance limit could therefore be attributed to a previous period during which the ice cover was more extensive. Secondly the north-south orientation of till fabric (No 26c. Fig 15) compared with the more expected west-east orientation of Nos. 26 and 26b (Fig 15), could now be accounted for by the more marginal ice position of the former. (Flint 1956 Fig 5 - 2 p.59 shows that with the greater "splaying out" effect of glaciers in their marginal areas, directional features may be oriented at 90° to the general direction of ice movement.) In either event the fluvioglacial features on the north flank of Ardochrig Hill could not owe their existence "to the survival of a sheet of snow or ice on the sheltered north-eastern slopes/

slopes of the Ardochrig Hills", (Gregory 1925 p.416), for eastwards as can be seen on Figure43 the fluvioglacial forms penetrate a low point in the watershed and actually occur on the south-facing slopes.

To the east, as far as Chapelton, the esker ridges continue to increase in size and number and achieve their maximum development at the head of the Powmillon Burn (Fig 43). In this locality there are two distinct series of fluvioglacial deposits. The northern one consists mainly of a single linear ridge (Ph 59) which prolongs the orientation of channel No.2 (Fig 43). This ridge has steep sides and a sharp but undulating crest, is 20 feet - 25 feet high and 60 feet broad. At its eastern termination too it is continued by a meltwater channel which is incised into the rising rock surface.

To the south of this esker a second series of sand and gravel ridges, some with distinct flat-tops and one with a kettlehole depression in its surface, are found at the terminus of channel 1 (Fig 43). The ridge in which Exposure 3, (Fig 43), is located is about 200 yards long, 50 feet high and up to 100 yards broad.

Professor Gregory (1925 p.416) inspected several exposures in these ridges and concluded that because "the Highland material is very scarce" and because of the possibility of its being derived from the underlying boulder clay that "the ridges do not prove the presence of northern ice during the kame formation". Despite this statement he quotes four different types of Highland rocks which he found/

found and indicates at least four different exposures at which he observed Highland erratics. A rock type analysis of the gravels at Exposure 4 (Fig 43) was carried out. (site No.30 Fig 37). This reveals 6% Highland stones and 94% of Carboniferous pebbles, (80% of which were local basalts), a composition which would be expected from meltwaters derived from the north-west, rather than any other direction.

Immediately to the east of channel 4 at point D. (Fig 43) meltwater erosion gives way to a further phase of fluvioglacial deposition. The first landform in this series is to the south of the channel terminus and is an elongated mound of sand and gravel 20 feet high, To the west the ridges and mounds are lower and more elongated being from 3 feet to 15 feet in height. Like the isolated esker ridge to the south-west of Chapelton, (Ph. 59), there is no vegetational change on the ridges and they are difficult to photograph. Photograph 60, however, taken with a certain amount of snow-cover helps pick out some of the main features. In the middle foreground a ring-shaped ridge only a few feet in height almost completely encloses a flat bottomed depression. Beyond this numerous other ridges and depressions can be made out.

The character of this series of deposits with its numerous branching elongated ridges and enclosed depressions, and its continuous relationship with a subglacial meltwater drainage system to the west is strikingly comparable, in miniature, to the Carstairs sub-glacial esker system of Area II. On the skyline of Photograph 60 a basalt escarpment 15 feet - 20 feet high can be seen. At this point the ridges terminate abruptly and are succeeded once more by meltwater/

meltwater channels, some of which course their way through the escarpment itself. Both the depositional systems partly shown on Photographs 59 and 60 terminate to the west of localities where the surface gradient locally increases. This suggests that the deposition may occur as a result of ponding of water or a slackening of the velocity of the sub-glacial streams due to the locally reversed gradient. At each of these points meltwater channels, sometimes with an up and down profile are incised into the rock barrier and at both localities the channel systems eventually give way again to a further depositional cycle. Viewed as a whole the fluvioglacial features on the north-facing slopes and, after penetrating the low point in the watershed south of Chapelton, on the south-facing slopes of the Corse Hill/Ardochrig ridge, form a remarkable series of alternating fluvioglacial erosional and depositional features. The letters A - H, (Fig 43), mark the points at which each phase of either erosion or deposition gives way to the other.

In the locality of Exposure 17, (Fig 43), several low elongated ridges of fluvioglacial deposits 5 feet - 15 feet in height occur in a parallel sequence. In a sense they are a corollary of the parallel series of meltwater channels 10,11 and 12, (Fig. 40) for with ice contact slopes on both sides they probably indicate meltwater deposition in parallel tunnels within the ice. This parallel system of fluvioglacial erosion and the associated depositional forms may also prove Sissons' conclusion, (1961 p.16), that apparently marginal or submarginal channels may often be "formed subglacially". This fluvioglacial/

fluvioglacial system, which can be traced at least as far as the Glasgow to Kilmarnock road (A 77) two miles south of Newton Mearns, terminates to the east of Glassford, after a distance of more than 14 miles. The last fluvioglacial deposits in the system are several massive, sometimes flat-topped, mounds of sand and gravel. Their orientations are at 90° to the rest of the system and might be related to the edge of the ice mass which occupied the Avon Valley at this point. Several of these ridges have steep, frontal slopes towards the Avon, which are as much as 70 feet high. Their appearance suggests that they are kame terraces deposited in lakes marginal to the ice mass in the valley floor. The flat-topped mound in which Exposure 24 is located, was formerly worked by Kings and Co.Ltd. for sand and gravel and this firm supplied the following borehole records in and around the edge of this feature.

TABLE XXI

Bore No.1 (Ca 560')

Stratified sand and gravel	12'
Clayey sand and gravel	11'
Sandy clay	1'
	24'

Bore No.2 (ca. 520')

Sandy clay	8' 6"
Sand and gravel	3' 6"
Sandy clay	12' 6"
mostly clay with black gummy bands	
	24' 6"

Bore No.3 (ca 500')

Sandy clay	6'
Sand with some gravel and clay	10'
Firm Red clay and stones	4'
	20'

Bore No.4 (ca 500')

Clay and gravel	11' 9"
Sandy clay	1'
	12' 9"

In general the deposits are very fine. The hill

originally/

originally had a capping of sand and gravel and even in this overlying layer sand was dominant. At depth, however, the increasing percentage of silt and clay induced the closure of this pit. The occurrence of "firm red clay and stones" at the base of the deposits, (borehole No.3), suggests an underlying till stratum. Although this is no longer visible, it is the second site in Area III where red till occurs well to the north of the southern boundary of Carboniferous rocks.

The deposits at this locality recall those of Stonehouse on the opposite bank of the Avon less than one mile to the north-east (Fig 45). At several horizons in the borehole records clay layers and especially the black gummy bands are reminiscent of the lake clays of the Stonehouse section (Exps 33,34 Fig 43). The table below gives a reconstruction of the exposed section at Stonehouse.

TABLE XXII

Photographs		Strata	Thickness	Notes
	1	Coarse unsorted gravels	5'	(475' O.D.)
	2	Stratified sand and gravel	10'	
	3	Grey till	4'	
	4	Stratified comrse and fine sands with some gravel	6'	Iron Pan
	5	Reddish brown coarse/medium grained sands with some cobbles and occasional layers of brown clay. All parallel/ horizontal stratification.	3'	
62, 61	6	Stratified (varved) greyish blue,red,brown,greenish yellow clays and fine yellow sands. Coal layers. Upper surface of clays have flame structures penetrating into overlying looser sediments. Uppermost surface much disturbed by sands.	2'	
	7	Fine/medium gravels upper part much disturbed	2'6"	

TABLE XXII (contd)

		Strata	Thickness	Notes
63	8	Beige coloured silts bottom layers well stratified but upper layers contorted and penetrated upwards into overlying coarser stratum	1' 6"	
	9	Brown and grey horizontally stratified clays/silts/sands Dip 3^{o}, N.315^{o}	6'	Iron Pan
	10	Cross bedded sands and fine gravel. Dip of top 10^{o}, N.310^{o}	2'	Iron Pan
	11	Confused, often contorted assemblage of particles ranging in size from clay, silts, sands to coarse gravels Interdigitation of strata	8'	Iron Pan
	12	Grey till sometimes with silt lenses underlain by solid rock	15'	
			ca. 64'	

This magnificent exposure shows that prior to the ice readvance responsible for the deposition of the upper till a minimum of 31 feet of water-laid sediments had been allowed to accumulate. The lower section of the fluvioglacial sediments are exceedingly contorted and disturbed and their intermingling with the underlying till suggests the proximity of ice. Above this, however, the fine, very well sorted clay strata (Appendix IIIA) indicate a period of calm water, probably lacustrine, conditions. The occasional cobble in otherwise well-sorted sands (Ph 61) may indicate the former presence of floating ice which on melting dropped these fragments into the lake sediments below.

(Pettijohn/

(Pettijohn and Potter 1964 Plates 100A 107B 108A). The larger scale contortions may indicate glacial disruption but the smaller regular interdigitations(Phs 62 and 63) are almost certainly the result of load casting. The sediments themselves therefore do not necessarily indicate the complete withdrawal of the ice, from the area, indeed without ice blockage to the north this lake, perhaps also represented at a higher altitude in the deposits east of Glassford, could not have formed. This raises the question of the significance of the uppermost ironpan. Three others at lower depths might indicate that these may result from the aquiferous properties of the sand and gravels rather than distinct leaching/weathering periods. However one of the lower iron pans is much contorted and discontinuous, and suggests a formation prior to glacial disruption. This fact would indicate a succession of withdrawals and readvances of ice in this area. Since only two till horizons are present in this section it might be suggested that only two of the ice readvances represented were of more than local significance.

The deposits at Glassford terminating as they do in a position marginal to the ice stream in the Avon Valley suggest the contemporaneity of the ice streams from the north-west and south-west. (a conclusion already suggested by other evidence). The few orientation measurements carried out on the fluvioglacial strata at Stonehouse(Table XXII) indicate that whilst the main ice dam was to the north the main source of meltwaters was from the south-west. This fact together with the larger proportion of Old Red Sandstone and Southern Upland stones (8% compared with the 2% of Highland erratics in/

in the till (No 32 Fig 16), may again indicate the occurrence of a late glacial readvance of ice from the south in Central Lanarkshire. The stratigraphy at this site perfectly fits Dr. Sissons' suggested stratigraphy of areas overwhelmed by the Perth Readvance ice sheet (Sissons 1963 p.152).

(The writer is greatly indebted to Dr. L. Dutkiewicz of the Geographical Institute, University of Lodz, Poland for invaluable assistance in the investigation and recording of the stratigraphy at this site. Fig 45 is a copy of his work.)

The ponding of meltwaters and subsequent meltwater deposition at ice marginal positions in the Avon Valley can also be seen at the mouths of the Powmillon Burn and the Calder and Lochar Waters (Fig 36). At Strathaven these deposits cover a triangular area tapering off, both in thickness and extent, up the Powmillon Valley. (Field evidence and borehole records supplied by Lanark County Council and Henry Boot Group). East of Strathaven these fluvioglacial deposits have a steep face up to 130 feet high. This slope is topped by a level or undulating sand and gravel spread. An outstanding conical outlier, Kirk Hill, in Strathaven, (Ph 64), is again composed of sand and gravel and with ice contact faces surrounding it is probably a kame or perforation deposit. The evidence suggests that the frontal slope is an ice-contact face and that the fluvioglacial deposits were laid down after the manner of a kame-terrace against an ice mass in the Avon Valley by meltwaters derived from the important Powmillon meltwater channel (Fig 36).

A rock type analysis was carried out on gravels obtained from/

from this deposit (31 Fig 37). Their similarity, 4% Highland and 96% Carboniferous, with those at the head of the Powmillon Burn (No 30 Fig 20) supports the origin suggested above. Constructional problems have arisen from the great depths of "running sand", an apt, if not technical term and suggest an interesting geomorphological history. A retaining wall (Ph 64) has had to be built to arrest the downhill movement of the local graveyard. During a recent garage construction it was found impossible to sink the fuel tanks to the statutory depth of 15 feet and eventually the surface of the site was raised in order to comply with the regulations. The same problems, caused again by the infilling of excavations by running sand recently delayed the installation of a new sewerage system in the town. The county engineer had to resort to chemical impregnation to stabilise the sand before the pipes could be installed. A series of borehole records taken in connection with this sewerage scheme and made available by the County Engineer's Office in Hamilton shows that this sand deposit penetrates at least a further 30 feet below the present level of the Powmillon Burn to a level of 370 feet O.D. The present writer feels that this is evidence that these fluvioglacial deposits are infilling a "pre-glacial" course of the Avon Water at this point. To the south, the Avon where it has not rediscovered this course (from Queyholm to its confluence with the Powmillon Burn (Fig 36), flows in a restricted gorge-like course which contrasts with the more open, rediscovered courses to the east and west. The former course of the Avon Water leaves the present one at Queyholm to the south-west of Strathaven/

Strathaven. It follows a north-easterly course and at the surface is marked by an extensive flat-bottomed depression. Further east it has been partly re-excavated by the waters of the Powmillon Burn which follows its course back to the present Avon Valley. Immediately to the west of Queyholm an exactly similar circumstance is found and the post-glacial Avon course contains, at Avon Linn, the only waterfall on the Avon Water.

Further to the west similar fluvioglacial deposits occur near the confluence of the Calder and Avon Waters. Here vague terraces can be distinguished on the Calder Valley flanks (Fig 40). A good exposure (No.32 Fig 37), however, reveals only four feet of well-sorted fine stratified gravel and sand overlying at least ten feet of grey/black till. This suggests that the terraces here are more erosional than depositional. A rock type analysis of the gravels, (No 32 Fig 20), shows 96% Carboniferous and 4% Old Red Sandstone pebbles, again suggestive of a south-westerly origin. Two nearby lower exposures in the river bank show black/brown stratified clays at 600 feet O.D. and may again indicate the temporary ponding of meltwaters by ice in the main valley.

The Lochar Water valley,(Fig 40), shows similar fluvioglacial deposits. Exposure 9 (Fig 40) is in an extensive flat-topped terrace the upper exposed parts of which are composed of very coarse gravels (up to two feet in diameter). As at Strathaven this terrace extends to the north-east along the flank of the Avon Valley, being at this locality closely associated with the development of a meltwater/

meltwater channel system in the same direction.

At Deadwaters, (710 feet O.D.), Phemister (1925 p.114) maintained "a large lake whose level may be put at about 740 feet overflowed eastwards and flowed to join the Nethan Valley". All the depositional evidence for this large lake is confined to Upper Avondale or the detached areas described above. In the Deadwaters area (Fig 41) there is little indication of a lake. Numerous isolated kames and eskers, several as much as 35 feet high, occupy the valley floor and indicate the presence of stagnant ice. Their fresh, apparently unaltered appearance and superficial exposures of stratified gravel,(Exp 1 Fig 41), indicate neither erosional nor depositional features which might have been expected of a vigorous lake overflow in this locality. The recent construction of a new bridge over the Kype Water at Deadwaters involved the sinking of eight boreholes on both sides of the river immediately to the north of Deadwaters. These gave remarkably consistent results which were made available by the County Surveyor's Office, Hamilton. A representative bore, No.6, on the east bank of the Kype shows one foot six inches of sand overlying six feet of sand with large gravel, overlying ten feet nine inches of sand with small gravel all of which overlies 17 feet nine inches of red sandy clay and boulders. This lowest stratum is probably till. Less than two miles directly eastwards a further set of borehole records (Geol. Survey) reveals the following representative stratigraphy; two feet of surface material, seven feet of gravel, four feet of sand and 25 feet of boulder clay. Again it is suggested that the fluvioglacial/

fluvioglacial deposits indicate a flow of meltwaters through this important gap first noticed by Phemister (1925). Numerous meltwater channels falling eastward have already been shown to confirm the movement of meltwaters, rather than lakewaters, from the Avon drainage basin into that of the Nethan. Two of these, Nos. 1 and 2 (Fig 41) dissect what was formerly a more continuous sheet of stratified sand and gravel. A rock type analysis of the gravels, No 33 Fig 20, shows 60% Carboniferous, 18% Old Red Sandstone and 22% Southern Upland rocks and reflects their western origin.

Further upstream the Kype Water contains additional areas of fluvioglacial deposition. At Exposure No.15 (Fig 41) an elongated sinuous esker ridge overlies a well-defined terrace of "valley-fill" deposits. Photograph 65 is taken looking upstream at Exposure 15 and the associated land forms. Photograph 66 is taken from the summit of the fluvioglacial ridge looking downstream. The exposure shown in Photograph 65 has three to five feet of coarse gravels over 10 feet to 12 feet of stratified sands and gravels which in turn overlie 10 feet of red till. If the overlying ridge is, as it appears to be, an esker, then the stratigraphic relationships at Exp.15 imply one of two alternatives. Firstly, the esker may indicate a local readvance of ice which did not leave behind a till stratum but is solely represented by the fluvioglacial ridge. The second possibility is that the fluvioglacial deposits were all laid down subglacially and the esker later deposited on top of them.

A gravel sample was obtained from the upper gravels in

the/

the valley terrace (No 34 Figs 37 and 20). This contains 2% of Highland, 42% of Carboniferous, 2% Old Red Sandstone and 54% of the local, Southern Upland rocks.

In the northern upland area at High Alderstocks in the headwaters of the Calder Water there are a few small scattered patches of fluvioglacial deposits. These have no surface expression. A gravel sample of one (No 35 Fig 37), reveals 2% Highland, 84% Carboniferous and 14% of Old Red Sandstone pebbles. The high percentage of Old Red Sandstone fragments might well indicate a carry from the extensive outcrops of these rocks in Ayrshire to the south-west.

Lower in the course of the Calder at Browncastle (No 36 Fig 37) a further gravel deposit was analysed. At this exposure three feet of coarsely sorted gravels are seen to overlie at least three feet of grey till. (a fresh exposure of the till can be seen beside the spade in photograph 52). The material above the gravel is not so easy to designate. The photograph shows its depth to be from three to five feet. It consists of a brown clayey matrix with a few widely scattered pebbles. It is sometimes separated off from the underlying gravels by a layer of cobbles/pebbles. (as indicated in the photograph) It is tentatively suggested that this may be an ablation deposit which again, as in a previously described section (No 34 Fig 37), would suggest that the gravels may have been deposited subglacially or that the last ice cover did not deposit a true till.

The rock type analysis of the gravels, (No 36 Fig 20), showed 98% Carboniferous rocks and 2% Old Red Sandstone rocks. This

is/

is closely comparable to the underlying till, (No 21 Fig 37), which contains 100% Carboniferous pebbles. The almost complete exclusion of erratics suggests that the meltwaters have come from the extensive Carboniferous area to the north-west, a conclusion already indicated by the evidence of fluvioglacial erosion.

Despite the variety of features and the many different relationships shown by the fluvioglacial deposits described so far in Area III, they are far surpassed by those of Upper Avondale. Photographs 1 and 51 have already shown some indication of the well-developed terraces and the great depths of sand and gravel found in the area.

The deposits begin at the south and western watersheds of the Glengavel and Avon Waters and the Dipple and Woollen Burns. (Figs 38,39 and 44) They descend with increasing thickness into the main Irvine/Avon through valley.(Fig 36) At their upper limits the deposits are more likely to consist of isolated mounds and elongated ridges. The existence of several kame-like mounds of sand and gravel on the watershed at the head of the Woollen Burn, (Twopenny Knowe Fig 38), proves the overriding of these hills by ice during the glacial period. At a later period, during deglaciation, local relief differences exerted a greater influence over the distribution of fluvioglacial deposits and as already suggested the Kames of Avon (Ph 67) were probably deposited by meltwater streams flowing from east to west, whereas the main ice movement was from the south-west to the north-east. This elongated ridge with an undulating but well-defined ridge crest, and/

and steep sides is composed of sand and gravel. The underlying stratigraphy, (Exposure 2 Fig 38), shows ten feet of stratified sands and gravels over three feet of coarse gravels, over eight feet of red till. Both Smith (1898 p.67) and Gregory (1925 p.401) concluded that the "Kames" were "a moraine formed by ice from Distincthorn and Wedder Hill".(The hill shown on the horizon of photograph 67). Under the present theories of ice accumulation areas and morphological terminology the Kames of Avon would undoubtedly be interpreted as an esker. Its origin as an esker ridge related to the meltwaters from channel systems 9 and 10, (Fig 38), seems clear from field mapping. Phemister, (1925 p.114), came to a similar conclusion. Similar ridges of fluvioglacial deposits (Ph 67) extend down the Woollen Valley towards the Glengavel (Fig 38).

In the Upper Glengavel Valley, however, conditions during deglaciation were slightly different. The highest fluvioglacial deposits, terminate at Exposure 13 (Fig 39), at a height of 1,000 feet in the Powbrone Valley. At the maximum stange of glaciation ice overrode the col at the head of the Powbrone Valley and cut the meltwater channels (Phs 9 and 10) declining to the east. It has, however, already been shown in Chapter II that the Dungavel/Nutberry/Hagshaw Watershed eventually emerged through the ice as a nunatak area and presented a barrier to the west-east movement of meltwaters. At this stage the marginal drainage from the ice in the Glengavel/Powbrone Valleys must have either become ponded against this rising ground to the east or drained beneath the ice itself. In the absence of flat-topped temporary/

temporary-lake deposits it is suggested that the thin sheet of current bedded sands and fine gravels frequently found in the upper Powbrone Valley, (Exps 11,12,13 Fig 39), are the evidence of this subglacial drainage. Lower in the Powbrone Valley, however, and in the neighbouring parts of the Glengavel Valley, flat-topped spreads of sand and gravel become dominant. Phemister, (1925 p.112), noticed this and described them as follows. "Here, at the highest level, 1,000 feet, gravels were deposited among rotting ice-cakes and a flat terrace at about 950 feet was formed in a small lake fed by the Powbrone Burn. As the ice shrank northwards down the Glengavel Valley deposition of sand and gravel followed closely. In this way fluvioglacial spreads, in some places very moundy owing to the presence of detached ice cakes during deposition, were built up with a general surface fall down the valley". Phemister visualised the ice cover in Upper Avondale as downwasting, largely in situ, the ice remaining longest in the valleys and lastly in the main Avon Valley. Eventually even the ice in the Irvine/Avon through valley split into two lobes, "one lobe continuous with western ice occupying the Kilmarnock Platform, the other with eastern ice in the Clyde Basin". The water flowing into the intervening ice free area in Upper Avondale he visualised as forming an extensive imponded lake. These conclusions accord with those of Peach (1874 p.329) and J. Geikie (1894 p.178-9).

The flat-topped nature of the fluvioglacial deposits at the confluence of the Glengavel and Powbrone Valleys and their accordant/

accordant summit levels of 1,000 feet certainly indicate the ponding of water at this locality. The horizontal bedding, (Fig 7 Phemister 1925) and the 15 feet of laminated clays and sands well-displayed in Exp 1 (Fig 39), also indicate the existence of this lake. Some of the channels which dissect the surface of these deposits, (e.g. Channels 6 and 8 Fig 39), are almost certainly due to the final draining of this lake as the ice barrier disintegrated. This process probably took place suddenly and may account for the steep short descents of many of the channels.

To the north, as Phemister indicates, (Ph 51), the altitude of the terraces became increasingly lower. Their surfaces are mainly undulating but the relief of these undulations is normally less than ten feet and the intricacy and irregularity of the pattern they produce makes it impossible to map them in detail. Many of them are due to the melting (out) of small masses of buried ice whilst others show the courses of meltwater channels which are incised into the surface of the deposits (Fig 39). At the large exposure shown in Photograph 51, (Exp 5 Fig 39), 20 feet of stratified sands dipping towards the Avon Valley, (to the north), overlie 50 feet of stratified sand with layers of interbedded gravel and these in turn overlie 25 feet of till. The rock types of the gravels were analysed. The results, (No 37 Figs 37 and 20), show 2% Highland 34% Carboniferous, 30% Old Red Sandstone and 34% Southern Upland pebbles and emphatically suggest their southern derivation.

The deposits in the Glengavel Valley appear to have been greatly/

greatly added to by meltwaters emerging from the Woollen Valley to the west. (Fig 38) The meltwater channel systems 15,16 and 17 are succeeded downstream by a well-marked linear system of fluvioglacial ridges almost one mile long. At their western end the ridges are only 10 feet to 15 feet high but at the point where they first branch the steep-sided, sharp-crested ridges are as much as 60 feet high (Ph 68). Numerous large boulders are found dispersed over their surface, probably left stranded there by the downwasting ice, for these ridges too, like the Kames of Avon, appear to be of esker origin. Air photographs Nos 54 and 55 show the relationship of the deposits in the Woollen and Glengavel Valleys. On the western flank of the Glengavel Valley these linear ridge deposits gradually assume a more tabular shape. (see on either side of channels 6 and 7 Fig 38). Their flat-topped nature and relationship to the surrounding landforms suggests an origin similar to that proposed by Phemister for the terrace features in the Upper Glengavel Valley. They too are deeply incised by meltwaters (meltwater channels 6 and 7 Fig 38).

The exposures lower in the Glengavel Valley to the north of Exposure 5 exhibit fluvioglacial deposits both finer and coarser than those found at the former site. At Exp 1 20 feet of stratified sands and silts with coal layers overlie 15 feet of laminated clay (680' O.D. top of clays). These in turn overlie a further four feet of sandy silt, which rests on six feet of till. A further three feet of gravel and sand can be seen beneath the till. The surface form/

formsof the fluvioglacial deposits in the Glengavel as far north as Peelhill, (Fig 44), continue to consist of high, level or undulating banks of sand and gravel, linear ridges of sand and gravel and deep incisions caused by meltwater channels and present day stream erosion.

The broadest expanse of fluvioglacial deposits is found in the Avon Valley from south of Loudoun Hill to east of Drumclog. (Fig 44) (Phs 57 and 58). Here, however, there is a well pronounced division between the hummocky undulating deposits of the north-facing slopes and the smooth terraced deposits of the south-facing slopes and the valley floor. The absence of a large scale map with a contour interval of less than 100 feet and the necessity to establish the relationship, both geomorphological and commercial, of the landforms in this area suggested a detailed survey providing accurate height data. This was carried out in the summer of 1966 and together with two sections of the area surveyed by Alexandra Transport Co.Ltd., a map with a contour interval of ten feet was produced (Fig 46). This map clearly shows the contrasts between terraced and undulating areas. As a result of the accurate levelling several of the terraces could be grouped according to a similarity of surface altitudes. Terraces once continuous but now interrupted by erosion can also be distinguished. These terrace groups are shown by different letter and shading symbols on Figure 44.

The highest terraces are those marked B (Fig 44) and these decline/

decline smoothly from west to east. They achieve their maximum altitudes in the extreme west at Loudoun Hill where the break in slope at the front of the terrace occurs almost exactly at 700 feet. One mile to the east at Lochgate Farm (Fig 44) the terrace has lost its sharp form but its front break in slope is at less than 700 feet. One mile further east at Holms Farm (Fig 46) terrace B again retains its sharp definition, and the well-marked break in slope at its edge occurs at 671 feet. In a lateral distance of two miles, measured almost exactly west-east, the terrace flat falls from 700 - 671 feet i.e. the terrace has a gradient of 0.55. Photographs 69 - 71 afford a panoramic view of the terraces to the south and east of Loudoun Hill. On the left of the photographs is the terrace dissected by channels 1 and 2 (Fig 44). Below Loudoun Hill the remarkably smooth and well-developed level of the Leven can be seen. On the right (to the east) the sharpness of the terrace disappears. These features can also be distinguished in Photograph 57.

The composition of the terraces is well displayed in the four active sand and gravel pits at present engaged in their removal. At the Loudoun Hill Pit of Alexandra Transport Co.Ltd. a 65 foot exposure, (Exp 3 Fig 44), shows 15 feet of coarse but sorted gravels overlying at least 50 feet of sand, all of which is well stratified. Both the sands and the gravels dip at an angle of 25° to the east. Two rock type analyses were carried out on these gravels and the results are shown in Table XXIII. The average rock type content is 1% Highland, 47% Carboniferous, 39% Old Red Sandstone and 3% Southern Upland/

Upland pebbles.

TABLE XXIII

Site	No.	Highland	Carboniferous	Old Red Sandstone	Southern Upl.
Loudounhill	38	2	44	42	2
	39	-	50	36	4
Avonside	40	6	68	8	14
South Torfoot	41	8	86	6	-
	42	8	84	4	-
Snabe	43	-	42	40	18
	44	4	36	42	18

Alexandra Transport Co.Ltd. made available an excellent coverage of borehole records on the terrace section known as the Leven just to the south of Loudoun Hill (Fig 44). Of the seventeen bore journals inspected, average depth 75 feet, not one penetrated to the base of the fluvioglacial deposits. Four borehole records, Nos 43, 44, 45 and 49, the locations of which are shown as W, X, Y and Z respectively on Figure 44 give a representative picture of the drift stratigraphy and these are shown in Table XXIV. There is a tendency for the finer material to become increasingly dominant at depth as in the exposed pit face. (Exp 3 Fig 44). Boreholes 43 and 45 show this particularly well with 35 feet 6 inches and 40 feet of fine sand at their base.

Air/

Air photograph No 57 and photographs ,69 - 71 indicate the

TABLE XXIV

Borehole No 43 (701.1 O.D.)

1.	Soil and sandy clay	3'
2.	Fine Sand and Gravel	3' 6"
3.	Sharp Sand and Gravel	3' 6"
4.	Fine Sand	1"
5.	Coarse Sand and Gravel	3'
6.	Soft and Dead Sand	2' 6"
7.	Coarse Sand and Gravel	4' 6"
8.	Fine Sand	4'
9.	Sharp Sand and Gravel	14' 6"
10.	Fine Sand	35' 6"
		75'

Borehole No 44 (711.26 O.D.)

1.	Soil and Sandy Clay	2' 6"
2.	Sharp Sand and Gravel	17' 6"
3.	Fine Sand and Gravel	10'
4.	Sharp Sand and small Gravel	21'
5.	Fine Sand	5' 6"
6.	Sharp Sand andGravel	10' 6"
7.	Fine Sand	3'
		70'

Borehole No 45 (694.74 O.D.)

1.	Soil and Sandy Clay	2' 6"
2.	Fine Sand and Gravel	14' 6"
3.	Sharp Sand and Gravel	14'
5.	Fine Sand and Gravel	1'
6.	Fine Sand	40'
		72'

Borehole No 49 (691. O.D.)

1.	Soil and Sandy Clay	2'
2.	Fine Sand and Gravel	39'
3.	Sharp Sand	4' 6"
4.	Fine Sand and Gravel	6' 6"
5.	Sharp Sand	1'
9.	Fine Sand and Gravel	26'
		70'

relationships of these higher terraces, (700 feet - 730 feet), a lower one south-east of the Leven (670 feet) and the adjacent lowest flats at 660 feet - 670 feet. The upper terrace was almost certainly once continuous between Cairnsaigh and Loudoun Hills. The positions of the breaks in slope at the front of the upper two terraces and the accordant relationship of the lowest flat to the intake of channel 1, (Fig 44), indicate that the dissection of the highest terrace was the result of meltwater erosion during and subsequent to the drainage of the lake in which/

which it was formed. Although the internal structure and surface gradient of the highest terrace indicates deposition by eastward flowing streams, the lowest flat, in its western part, declines from east to west. The meltwater channels Nos 1 and 2 prove the westward flow of water at this later stage and accord with Phemister's conclusions of an ice dam to the west, formerly supplying the waters and deposits responsible for the higher terraces, but which eventually disintegrated and allowed the westward escape of the imponded waters.

The second sand and gravel pit at Avonside Farm, is on a lower terrace, the upper surface of which, now largely removed by excavations, was 20 feet - 30 feet below the level of its higher neighbour. It appears that again in the area of this pit subsequent meltwater/river erosion has almost entirely removed the higher terraces but in their place left behind several equally well-defined but lower examples. Only 15 foot exposures are available at this pit but again the material in entirely stratified sands and gravels most of which have a distinct eastward dip. The rock type analysis of these gravels, (No 40 Fig 37), shows 6% Highland, 68% Carboniferous, 8% Old Red Sandstone and 14% Southern Upland pebbles. (Table XXIII).

Two further sand and gravel pits are at present working the highest terrace, terrace B, at South Torfoot and Snabe (Fig 44). At South Torfoot the terrace although long and narrow has a well developed flat surface and steep sides normally about 30 feet high. (Ph 72). Although the main terrace gradient is, with its length, towards the north, the levelling survey revealed a consistent fall in/

in altitude of up to 9 feet west to east across the breadth of the terrace. At the exposed working face the uppermost five feet consists almost entirely of stratified gravels which have a 6° to 7° dip 80° to the east of north. The underlying, almost pure sand strata, (Ph 73), have consistently steeper dips of 10° in a direction 65° to the east of north. The rock type analysis of these gravels show 8% Highland pebbles, 85% Carboniferous, 5% Old Red Sandstone and no Southern Upland stones (Table XXIII).

At Snabe this terrace is still well preserved although now at a lower level of 620 feet and with an extensive peat cover normally about five feet in depth. (Phs. 74 and 75). All three photographs of exposures in this pit, (Phs.74,75 and 76), show evidence of the tendency for an upper coarser stratum consisting of sorted gravels to overlie consistently finer deposits of stratified sands, sometimes with ripple-bedded (left hand side of Ph 76) and silty/clay strata. Again as at South Torfoot the overlying gravels with dips as little as 1° or 2° to the east are exceeded in depth and steepness of dip by the underlying sands (25° dip in a direction 70° east of north). At two sites in the Snabe pit frost wedges were observed. Both of these commenced at the surface of the sands and gravels and penetrated four feet and eight feet respectively down through the stratified sands and gravels. The larger one was 15 inches wide at the top and the smaller one ten inches wide. Other frost wedges were recorded in this locality by Galloway (1961a). These fossil frost wedges, now peat covered, indicate a period of severe climatic conditions subsequent to/

to the deposition of the sands and gravels in Upper Avondale and during which this area was ice-free. The rock type contents of the gravels at this site, (Nos 43 and 44 Fig 37), differ mainly from those of the other pits in their high percentage of Southern Upland pebbles, a reflection perhaps of the effect of meltwaters issuing from theGlengavel Valley. As a whole, however, the variations in rock type content at the four pits are not easily explainable. Particularly perplexing are the high proportions of Old Red Sandstone fragments at Snabe and the much smaller totals at Avonside and South Torfoot, both of which are nearer the outcrops of these rocks than the former pit. The results at sites, Nos. 40,41 and 42, with the very high percentage of Carboniferous rocks imply a vigorous movement from the north-west. Together the results, as shown in Table XXIII, present strong evidence for the mingling, in Upper Avondale, of meltwaters from the south-west and from the north-west. This conclusion accords with the evidence of ice directions gained from the features of glacial erosion and deposition and fluvioglacial erosion.

The suggestions of Bailey (1930 p.321) and George (1958 p.56) on the patterns of ice movement in the Ayrshire Plain indicate that two confluent ice streams, one from the Highlands and one from the Western Southern Uplands moved into Central Lanarkshire from the west-south-west. This accords with the field observations made during the present investigation (e.g. the shell fragments in the till at site 22 (Fig 37) indicating the presence of/

of Highland Ice was nevertheless deposited by an ice stream moving from west-south-west to east-north-east).

The origin of the terrace deposits in Upper Avondale was almost certainly, as Phemister (1925) suggested, due to deposition in an extensive ice-dammed lake. The distinctive nature of the slightly dipping upper gravel stratum overlying the steeper dipping sands is consistent throughout the higher terraces.(This was also proved statistically by channel sampling and sieving the deposits at the Loudoun Hill and South Torfoot Pits. At both sites the upper strata are conspicuously similar whilst the lower strata have common characteristics quite dissimilar to the overlying beds. The results are shown in graph form in Appendix IIB). The depositional sequence appears to indicate the deposition of the steeply dipping (fore-set) beds of sand in a lake ponded in front of the ice margin i.e. as a delta deposit gradually extending further eastwards. With the filling up of this lake by the sands the water became shallower and the proglacial streams carried the meltwaters further to the east depositing en route the coarser, gravel (topset) beds. The terraces therefore are not true lake terraces. Their surface expression is mainly that of an extensive outwash sheet which has been dissected by later erosion. Its gradient of 0.55% accords with Flint's (1956 p.139) statement that "gradients of 0.5% to 1% in the headward parts of valley trains are common".

The smoothness and consistency of the terraces so far described implies the absence of ice. Occasionally, however, large

boulders/

boulders lying on the surface of the terraces and small enclosed kettlehole depressions, (Fig 44), indicate that small ice masses may have been washed into the lake or carried along in the subsequent outwash streams. In the area of fluvioglacial deposition covering the lower north-facing slopes of Mill Rig (Fig 44), however, this regularity and smooth appearance completely disappears. Instead numerous elongated ridges, conical and irregularly shaped mounds and enclosed depressions abound. Figures 44 and 46 illustrate how the terrace features extend up to the lower slopes of the northernmost of these mounds but do not penetrate into the undulating area even although the hollows may be below the level of the highest terrace. This is evidence of the occupation of this area by a remnant stagnant ice mass even while the lower valley was completely ice free. Many of the mounds are 50 feet high and more than 50 yards broad but others are only slight undulations less than ten feet high and scarcely more in breadth. Some of the more linear ridges may indicate deposition by meltwater streams in tunnels or channels in the decaying ice. The frequent kettlehole depressions show the locations of former buried ice masses. One of the most striking landform features of this area is the large meltwater channel, (Ph 58) No 3 Fig 44), which emerges from the stagnant ice-kame and kettle area and incises its way through the terrace area before joining the Glengavel "Flood-plain" at an accordant level. This channel indicates several interesting correlations. Firstly, it is incised into the terraces and therefore shows that meltwaters were still being produced from/

from the stagnant ice area after the draining of the lake. Secondly although the channel no longer contains an active stream, its exit is graded to the present level of the Glengavel "flood-plain". Not only therefore was channel 3 cut at a late period during deglaciation but also the Glengavel "flood-plain" has not been lowered since this period. This may indicate that the extensive gravel deposits of the lower Glengavel valley are in fact an outwash deposit almost unaffected by the effects of post-glacial erosion and deposition. It must be inferred from the evidence presented above that the stagnant ice-lobe at the head of channel 3 (Fig 44) existed even after the withdrawal of the ice dam at Loudoun Hill. The origin of the channel itself may be attributed to the final melting of the stagnant ice-mass but it is interesting to note that, like the kettle/channels of the Lanark area, (Area II), it too has a kettlehole depression at its head.

The well-marked fluvioglacial terraces do not extend east of Caldermill, at which point they have declined to an altitude of just over 600 feet. Although the smooth decline in altitude noticed in the terrace extending eastwards from the Leven, (Fig 44 Ph 70), implies only one phase of deposition/erosion, the terraces at Snabe and Caldermill to the east are too low in altitude to fit the related gradient. These lower terraces therefore must be the product of later deposition/erosion. The fact that there was not, as Phemister suggested, one lake extending from Loudoun Hill to Deadwaters, a distance of nine and a half miles, but rather several disconnected and probably non-contemporaneous lakes, is borne out by the differing heights/

heights at which lake clays are found. In the Glengavel Valley these are found at 680 feet, in the Calder Valley at 600 feet and as has been already shown in the Avon at 508 feet (Glassford) at 437 feet (Stonehouse). All these heights refer to the top of the lake clays at the present time. To the east of Caldermill (Fig 36) the Avon Valley narrows and the valley sides rise quickly to heights in excess of 650 feet and fluvioglacial deposits are generally absent. There is therefore no definite evidence of the lake(s) in Upper Avondale having as,envisaged by Phemister, extended to the east of Caldermill.

Extensive fluvioglacial deposits are found in Area III. These may occur as single isolated forms e.g the "Kames of Avon" or as vast assemblages of features such as in Upper Avondale. The variety of fluvioglacial landforms found in this area is greater than in the previous two regional divisions of Central Lanarkshire. The disposition of the landforms provides a picture of the deglaciation environment which accords with the conclusions of the glacial conditions formed in previous sections. The rock type contents show sometimes puzzling varieties but in general suggest a mingling of ice streams in Avondale, a conclusion already arrived at in sections 4 and 5.

8. <u>Glacial History</u>

Numerous exposures at which two tills, often separated by considerable thicknesses of water-laid deposits, can be observed, show that there has been more than one ice advance in Area III. The fragmentary evidence of the lower till does not allow a full picture of the earlier glaciation to be given. It might, however, be suggested/

suggested that Area III was overrun at this period by ice from the north. (Barren Red Erratics and striae). The existence of upland areas which remained ice-free and distinct upper limits to distribution of fresh features of fluvioglacial erosion and deposition induced Sissons (1963 p.30 and Fig 1 p.154) to delimit in Area III a late glacial re-advance which he correlates with that of Simpson (1933). The present field mapping programme fully substantiated this evidence and revealed stratigraphic evidence confirming an ice readvance. The existence of frost wedges in the deposits of Upper Avondale is also significant. These show that the melting of the ice sheet, responsible for the deposition of the fluvioglacial deposits in Upper Avondale, took place before a subsequent period of colder conditions during which ice did not reach this area. The attribution of these deposits to Zone I times (i.e. prior to the subsequent cold period of Zone III) therefore seems quite feasible and would again confirm the observations of Dr. Sissons.

The ice to the north of the Corse Hill/Ardochrig Hill watershed appears to have been derived from the Western Highlands. This ice stream overrode a low point in the watershed, now occupied by the Powmillon Burn, and east of this locality became confluent with another major ice stream, from the south-west, occupying the Avon Valley.

This latter ice stream was almost certainly composed of two confluent glaciers. One of these, the northernmost, although having a south-west to north-east movement had its origin in the south-west/

west Highlands. It was joined in the south by an ice stream with the same orientation whose origin, however, was in the Western Southern Uplands. Together these ice streams moved north-eastwards along the line of the Avon Valley. Richey's map (Fig 6), derived entirely from evidence in Ayrshire to the west shows the relationships of these ice streams. The overstepping nature of the distribution of different coloured tills in Area III has been taken as evidence of the fluctuating strengths of these ice streams. There is some evidence that the last _active_ ice stream may have been the southernmost one. A recent Radio-Carbon date, not yet published, of shells below the till at Kilmaurs, Ayrshire again confirms the late glacial readvance in Zone I times (Dr. J.B. Sissons personal communication) and indicates that ice moved from the Firth of Clyde into the Ayrshire Plain, and therefore by implication, into Central Lanarkshire, at this period.

During deglaciation vast volumes of meltwater were released. The evidence of the channels and deposits left behind indicates that a west-east ice gradient occurred throughout Area III. This again is proof of the western sources of the ice masses which invaded Central Lanarkshire. The melting and dissipation of this ice cover was associated with the blockage of the main drainage systems and there are several clear examples of the temporary existence of ice-ponded lakes. In other areas stagnant-ice masses left behind the chaotic assemblages of kames, eskers and kettleholes still in evidence to-day.

9. Summary of Conclusions

1. The evidence of glacial striae is confusing partly because they are related to different periods of ice advance. The earliest ones indicate that the direction of ice movement was from north-north-west to south-south-east. (Fig 4). The striae related to a later advance show that the main mass of ice in Area II came from the south-west.

2. The distribution of till in Area III is as much a reflection of relief configuration as of altitude. The altitudinal limits therefore are in many localities misleading. The highest till exposure is in the Powbrone Valley (Fig 39) at just over 1,200 feet. Numerous till-covered summits over 1,000 feet show that ice has at one time almost certainly completely inundated Area III.

3. The distribution and altitudes of the fluvioglacial landforms have much more significance. In the south-western hills these are found on watersheds at heights in excess of 1,000 feet. To the north and east they are generally only found below this altitude. A particularly well-marked continuous sequence of fluvioglacial deposits and meltwater channels is found in the northern hill area. This linear sequence declines from an altitude of 900 feet at High Cleughearn in the west to an altitude of 500 feet at Glassford in the east a distance of seven miles. At Chapelton it penetrates the west-east watershed and becomes marginal to an ice stream to the south thus proving the confluent and/

and contemporaneous nature of the two ice streams entering Area III.

The absence of meltwater features above this linear sequence was taken by Sissons as an indication of the altitudinal limit of ice advance during Zone I cold phase. No evidence was found during the field investigation which disproved this ice re-advance and its occurrence explains many otherwise anomalous features of the glacial geomorphology of Area III.

4. During the maximum stage of this late glacial re-advance three ice streams, one of Highland origin from the north-west, one of Highland origin from the south-west and one of Southern Upland origin also from the south-west must have been confluent in the eastern reaches of the Avon Valley.

5. During deglaciation the ice generally wasted in situ. The upland areas where the ice cover was thinner first became ice-free. The ice masses remained longest in the main valleys where they frequently disrupted drainage. Many of the tributary valleys thus became flooded and there is frequently evidence of temporarily ice-dammed lakes. There is evidence for a more extensive lake in Upper Avondale which may have stretched from the ice blocked restriction in this through valley at Loudoun Hill to the similarly restricted part of the valley at Caldermill. There is no evidence that this lake, as Phemister (1925) suggests, extended eastwards to Deadwaters. Even after the ice-dams of this lake were removed and the lake drained stagnant ice masses were still found in Upper Avondale.

CHAPTER V

THE GLACIATION AND DEGLACIATION OF CENTRAL LANARKSHIRE

The results of the field observation and borehole investigations indicate that there has certainly been more than one glacial period in Central Lanarkshire. Occasionally three distinct tills have been found in boreholes in "buried valley" deposits. Generally, however, only and upper and a lower till have been observed.

The lower till may not everywhere be contemporaneous but in the absence of other evidence it will be assumed that it represents an earlier glacial period. As already stated, this lower till is preserved most frequently in the "pre-glacial" or buried valleys. In the buried valley of the Nethan, near Blackwood, (Table IX) the stratigraphical relationships of the upper and lower tills can be most clearly seen. Till fabric and rock type analyses of the tills show that both tills are remarkably similar. The overlying gravel deposits, however, are markedly different. The gravel layer overlying the lower till has 18% of Highland erratics whilst the gravel overlying the upper till has only 2% . This is taken to indicate that the influence of Highland Ice was much greater during the earlier glaciation. It has been shown that this could account for the distribution of Highland stones in the gravels as far south as Carnwath.

The evidence of glacial erosion during this earlier period is also difficult to identify. The predominant trend of moulded/

moulded hill-slopes throughout the area is from south-west to north-east. In the Hagshaw Hills, however, in Area I, high level through cols indicate the penetration of a thicker and earlier ice stream from north-west to south-east. The anomalous orientations of some glacial striae may indicate that they are related to the earlier rather than the subsequent phase of glacial activity. The one on the north facing slopes of the Corse Hill/ Ardochrig Hill, ridge (Fig. 36) has been already cited. The writer has also shown that there are considerable grounds for reversing the directions indicated by some of the glacial striae recorded by the Geological Survey. Those on Cartland Muir (Area II) are particularly good examples. Nevertheless, by putting together this often indefinite and widely distributed information a reasonable picture of the main directions of ice movement during this earlier glaciation can be presented (Fig. 47).

The writer also concludes that there is sufficient evidence in Central Lanarkshire to confirm the occurrence of a major glacial readvance during Zone 1 times as suggested by Sissons (1963/64). As Sissons has pointed out, several hill masses remained as nunatak, ice free areas, even during the maximum extent of this ice cover. All the evidence of ice movements during this readvance points to ice moving out from the wetter, western upland districts where ice accumulation took place. Thus ice streams from the South-West Highlands and from the western Southern Uplands moved eastwards into Central Lanarkshire. It is hardly surprising therefore that the ice free areas become more predominant in the eastern districts of the thesis/

thesis area. Reasons have been indicated for suggesting that the huge Carstairs deposits were laid down prior to this period and were in fact untouched by the most recent ice advance. Even better evidence, in the form of the Crossford Moraine, has been presented which indicates that the Nemphlar Channel, protected from the advancing ice streams by the upstanding nunatak hill mass of the Black/Dillar/Darnfillan Hills, contains a distinct limit of late glacial ice penetration in Central Lanarkshire. Over the larger part of Central Lanarkshire, however, the drift topography and the surface deposits were left in their present condition by the advance and retreat of the Zone 1 ice cover.

The evidence of glacial erosion is particularly difficult to separate from that of the earlier period. Numerous striae, however, suggest that the Zone 1 or Perth Readvance ice streams, in contrast to their earlier counterparts, moved with, rather than against, the grain of the country. Thus in the nunatak hill mass of the Eaglesham Hills, the ice streams moved from west to east in two lobes, one to the north and one to the south of the upstanding hill district. To the south of the Avon and Clyde Valleys the striae almost invariably emphasise the uniform direction of a strong south-west to north-east ice movement. (Fig. 48).

Although the directions of these ice streams are well established by the evidence of directional landforms, their sources are not so easily distinguished. To the west in the Ayrshire Plain, Richey and others have shown (Fig. 6) that both Highland and Southern Upland Ice Streams were confluent and sometimes followed the same/

same south-west to north-east direction. By an examination of the limit of penetration of "shelly drift" and Highland erratics, Richey has distinguished a line, south of which the districts have never been overrun by Highland Ice (Figl 6). In a sense the map he has constructed is misleading for it gives an impression that the area north of the line has equally been free of Southern Upland Ice Streams. The present work and that of previous writers has shown that Southern Upland erratics are scattered throughout areas well to the north of the line. This emphasises the important conclusion that where confluent, the two ice streams waxed and waned, advanced and retreated, over what has aptly been termed a "debatable ground". Some evidence has been presented in the text which implies that the last push of ice, during this general readvance, was from the south.

The study of till fabrics has been more helpful in the dissected hill areas of the south where the landforms have perhaps been more conducive to the formation of good till fabrics. In the more open landscapes of the northern parts of Central Lanarkshire the evidence of the fabrics is less certain. The study of rock types, however, has been perhaps of greater help in indicating the routes followed by the main ice streams. Like the Southern Upland"Santuary Area" to the south-west, none of the tills in the Douglas Valley contain Highland erratics. In the tills of the north-facing slopes, of the Corse Hill/ Ardochrig Hill ridge, and most of those on the south-facing slopes, there is a similar absence of Southern Upland erratics. Throughout the remainder of Central Lanarkshire, however, the erratic contents are/

are mixed. The weight of the evidence of fabric and rock type content studies in this area favours an ice movement from the south-west. In the Clyde Valley this south-weatern ice stream appears to have reached to the northern boundary of the thesis area. Three localised exceptions to this northward penetration of "southern ice" are found. In the northern parts of the Glengavel Valley (Fig. 48) near its confluence with the Avon, an ice stream from the north-west appears to have penetrated to a limited extent. Immediately to the north of Stonehouse the presence of an ice dam to the north and the influx of ice from the west-north-west implies again a limited penetration of the northern ice streams into Central Lanarkshire.

The regional pattern of fluvioglacial erosion provides a remarkably close confirmation of the directions of ice movement as outlined above. Some of the channels must have been initiated at a period when the ice was still hundreds of feet thick. Some of these channels occur on valley slopes several hundred feet above the valley floor. Others penetrate cols at altitudes in excess of 1,000 feet and show that ice had previously overridden the surrounding land surface. Many other channels, however, are much more closely related to the present relief. These channels were cut when ice was downwasting and numerous areas stood up as nunataks above the ice surface. Important relationships between fluvioglacial erosion and fluvioglacial deposition have been established by an examination of some channel systems. The well-developed marginal/submarginal sequence of channels and deposits extending from High Cleughearn to Glassford/

Glassford (Figs. 42,43), show the close relationship between meltwater erosion, deposition and local relief. This lateral system, however, is particularly helpful in establishing the local limits of ice penetration during the Perth Readvance.

The last meltwater channels to be cut are those which course the surface of the valley floor fluvioglacial deposits. Their function may have in most cases been both erosional and depositional.

The distribution and characteristics of fluvioglacial deposits are equally helpful in interpreting the nature of deglaciation in Central Lanarkshire. The rock types present in the fluvioglacial deposits indicate that meltwaters laid down deposits which have generally been derived from much greater distances than those of the underlying glacial tills. As with the tills the greatest depths and accumulations of meltwater deposits are to be found in the valley floors. In the upland districts fluvioglacial deposits are rather sparsely distributed although locally quite spectacular concentrations are found. These consist of elongated ridges, often eskers, kames and less frequently kame terraces. All of these have ice-contact slopes and show that deposition took place in tunnels, crevasses and fissures within and at the margins of an ice mass which downwasted in situ. Their distributions show that ice remained longest in the valley floors. Occasionally remnant pockets of ice were completely covered by fluvioglacial debris. This protective mantle may account for the local existence of detached, stagnant ice masses/

masses long after the area had become generally ice free. A very good example of this was cited in the Upper Avondale district, (Area III Fig. 44) but others are particularly well displayed at Bonnington (Area II Fig. 26) and Sandilands Station (Area I Fig. 17).

Other areas have deposits which are more closely associated with ice-marginal positions. The Crossford Moraine is a good illustration. So also are the more complicated morainic districts at Blackwood and Brocketsbrae.. The marginal sand and gravel deposits in the Lower Clyde Valley seem to indicate that ice remained last in the valley floor. An exactly comparable situation is found in Avondale where marginal streams appear to have banked up thick deposits of sand and gravel against the edge of the ice lobe occupying the Avon Valley.

Some of the largest spreads of fluvioglacial materials were deposited in pro-glacial areas. True lake clays, deposited in lakes which were formed by the damming of the normal drainage lines by ice dams, are occasionally found. Those in the lower Avon Valley near Stonehouse (Area III), the Carstairs Basin (Area II), and the plateau surfaces of Areas II and III are the most notable. In other areas, however, perhaps as a result of greater proximity to the meltwater sources, coarser deposits - sand and gravel - are found. The two finest examples are at Bonnington (Area II) and Loudoun Hill (Area III) (Figs 26 and 44 respectively). In both cases a definite ice margin position can be distinguished immediately to the west. In front of this a proglacial lake was gradually infilled by deltaic sediments./

sediments. On the filling of this lake extensive outwash sheets with well-developed, smooth surfaces were formed by streams leading away from the ice edge. Later meltwater/river erosion has in some localities produced several sets of terraces which only in the broadest sense could be called lake terraces. The directions of movement of the ice streams during this late glacial readvance and some possible ice marginal positions are shown on Figure 48. It must be emphasised that there is generally at present insufficient evidence to indicate a definite maximum limit of ice penetration into Central Lanarkshire. The line shown in Figure 48 is tentative and not necessarily contemporaneous all along its length. With the disappearance of this Zone 1 ice sheet and the beginning of the succeeding Alleröd warmer phase approximately 12,000 years B.P. (Sissons 1965 p.480), Central Lanarkshire became, as it has since remained, ice free. During the Zone III cold phase (10,800 - 10,300 years B.P. Sissons 1965 p. 480) glaciers again occupied the South West Highlands and the Western Southern Uplands (Sissons 1965 p. 480 - 482) but none of these penetrated to Central Lanarkshire. The effect of this cold period in the thesis area appears to have been minimal. Frost wedges were formed in some of the fluvioglacial deposits, (Smbe, Area III) but there is very little evidence of other periglacial action. The sharpness and definition of many of the fluvioglacial features and the fresh appearance of eskers in particular suggests a negligible effect of slumping and soil creep.

Slope or head deposits are rare in Central Lanarkshire

and/

and exposures in such deposits were found in only three localities. At one of these, (Logan Area I), head deposits are covered by fluvioglacial deposits and therefore relate to a Zone I,or earlier cold period. At a second, Tinto Hill, (Area II), the periglacial deposits, probably because of the combination of suitable bedrock, steep slopes and altitude, are actively forming at present. At a third exposure in the upper reaches of the River Nethan, the slope deposits are not overlain by drift and could possibly be related to the Zone III cold period. The relative sparsity of periglacial deposits in Central Lanarkshire contrasts markedly with the areas of the Southern Uplands to the east and south. Bearing in mind the suggested limit of ice penetration at the Perth Readvance stage the reason for this seems clear. The Perth Readvance was a period of much more severe climatic conditions than the succeeding cold period. During this earlier glacial phase most of Central Lanarkshire was under a protective cover of ice, the areas to the east, however, were not. (Fig. 48) Sissons (1965 p.482), has indicated that the increasingly drier eastern Southern Uplands did not nourish glaciers during the last glacial phase in Scotland. It might therefore be concluded that the extensive development of periglacial deposits in the Central and Eastern Southern Uplands is the result of their exposure to the severe cold conditions of Zone I times.

As a whole, therefore, with the exception of the gorge courses cut by some of the rivers in the"post-glacial"period, the landforms of Central Lanarkshire have remained almost untouched since the end of the Perth Readvance. Its unique location, however, has given Central Lanarkshire a complicated glacial history. In earlier/

earlier glacial periods it was completely overrun by ice.
During the Perth Readvance ice streams from both the Highlands and the Southern Upland, although sometimes anomalously with the same direction of movement, invaded the area. These in places coalesced but even together were of insufficient dimensions to cover the entire area of Central Lanarkshire.

Foreword to Chapter VI

Chapter VI is concerned with Sand and Gravel deposits in Central Lanarkshire. This topic is of concern to, and indeed much of the information was made available by, people with varied interests:- geologists, geographers, businessmen, planners, administrators, engineers and many others. The writer has found that it is impossible to obtain comprehensive and contemporary literature on the physical aspects of sand and gravel and their economic significance. This deficiency provides the people enumerated above with many problems and it is hoped that this chapter will in some measure show how these may be overcome.

A questionnaire survey of all the operating pits in Central Lanarkshire, (pit owners listed below), was undertaken to gather as much information as possible on working practices, production techniques, production and the problems facing producers. Interviews were also conducted with the planning authorities and those concerned with the utilisation of sand and gravel. Since much of the information was gained at considerable expense to the individual companies concerned and in view of the highly competitive nature of the industry, specific information cannot in a few circumstances be revealed. Where this problem arises the name of the specific pit or pit owner cannot be mentioned and the point is raised in a more general manner. The writer must, however, again acknowledge the courtesy and valuable information which was accorded to him by all the pit owners and operators, not only in Central Lanarkshire but in all the areas from which information/

information was acquired.

Central Lanarkshire Sand and Gravel Companies

1. Alexander Russell & Co. (Glasgow) Ltd. 3 Clairmont Gardens, Glasgow C.3.
2. Alexandra Transport Co.Ltd. 250 Alexandra Parade, Glasgow E.1.
3. J. Anderson & King Ltd. 21 Old Castle Road, Glasgow S.4.
4. Auchinlea Sand and Gravel Co.Ltd. Cleland, Motherwell.
5. Auchlochan Estates Co.Ltd. Auchlochan Farm, Lesmahagow.
6. J.M. Filshie & Sons Ltd., Snabe, Drumclog.
7. Kings & Co.Ltd. 19 Woodside Crescent, Glasgow C.3.
8. Redland Quarries Ltd. Weighbridge, Carstairs.
9. Shanks and McEwan, Ltd. 22 Woodside Place, Glasgow, C.2.
10. Tinto Sand and Gravel Co.Ltd. Carlisle Road, Airdrie.

CHAPTER VI

SAND AND GRAVEL IN CENTRAL LANARKSHIRE

1. Distribution of Resources and Relevance of Glacial History

The only available literature on this subject are the Wartime Pamphlets. (H.M. Geol. Survey No.30 1942) and the separate publication of Professor J.G.C. Anderson (Scottish Sands and Gravels) who conducted the survey. The breadth of the subject, the extent of the ground to be surveyed and the limited resources available restricted the amount of detailed investigation possible during this wartime investigation and the resulting documents are more useful at a regional reconnaissance level than as a source of detailed information. Possibly the best informed and most helpful publications yet to appear on the wider implications of sand and gravel are the Reports of the Advisory Committees on Sand and Gravel (H.M.S.O. 1948 and 1955). These are unfortunately only concerned with England and Wales but they do examine the whole field of the sand and gravel industry. The committees' final conclusions and recommendations are outlined in Part 18 of these reports. One of their last statements is a warning. "It follows from this that any survey carried out by a body without intimate local knowledge of an area is likely to be of limited value and.....(may have) detrimental economic effects in the longrun". (H.M.S.O. 1955 p.26). This is exactly the point made in the Introductory Chapter of the present work. It is impossible to explain the distribution of sands and/

and gravels in Central Lanarkshire without having first described their origins, that is - the glacial history of the area.

In common with most of Scotland, (a fuller statement of conditions in Scotland as a whole is given in Appendix V), very little use is made of sand and gravel which is not of direct fluvioglacial origin. Only one pit in Central Lanarkshire utilises other material, in this case river gravels. Most of the attention therefore in this chapter will be focussed on fluvioglacial deposits.

A highly significant fact of the glacial history of Central Lanarkshire is that ice has invaded the area on several separate occasions. Of the earlier glacial periods there is less evidence but in some localities beneath the upper drifts, further deposits of sands and gravels can be found. The exposure at Blackwood (Area II), in the buried valley of the River Nethan, is fairly typical of "pre-glacial" valley deposits (Table IX). Here 25 feet of sands and gravels overlie in succession, 10 feet of till, 30 feet of sands and gravels, possibly 40 feet of till and 20 feet of sands and gravels. Sissons (1963 p.152) implies that thick deposits of stratified sediments, as seen in this exposure, indicate the melting of the ice which deposited the underlying till. This section therefore would indicate the melting of three ice sheets, the earliest of which is not now represented by a till stratum. The middle layer of stratified deposits appears to represent the period of ice wastage immediately prior to the readvance of ice during Zone I (Perth Readvance) times. This illustrates an important point - within the areas covered by ice during the Perth Readvance stage, all the remaining, earlier sand and gravel deposits/

deposits will normally be covered by an overburden of more recent drift deposits. Therefore in localities such as at Blackwood mentioned above, even although the buried fluvioglacial sediments have a greater thickness than those at the surface, their presence will not be obvious after a survey of superficial drift conditions alone.

A second point also emerges from the occurrence of the Perth Readvance in Central Lanarkshire. In the areas outside the limits of this ice advance, tentatively shown on Figure 48, the earlier deposits are less likely to be covered by the Perth Readvance drifts. Thus the Carstairs Esker system, although possibly of the same age as the middle fluvioglacial stratum at Blackwood is, if Figure 48 is substantially correct, not buried because of its extra-glacial location during Zone I times.

Although there are several possible situations whereby sands and gravels can be laid down during active glacial conditions either under the ice, (Carruthers 1953 p.14) or in lakes in front of the ice (Phemister 1925, Charlesworth 1926), there appears to be no doubt that the great quantities of sand and gravel relate to the period of ice wastage and decay. It is the depositional environment during this period of ice wastage which influences the depth, extent, morphology and composition of the sand and gravel deposits. In a sense there are only two main groups of fluvioglacial deposits - those laid down in a proglacial environment and those deposited in an ice-contact position. The proglacial sediments as a consequence of their location/

location tend to occur in smoother, more extensive sheets. These sands and gravels are usually both well-sorted and well-stratified but if local calm water conditions prevailed silt and even clay may occur. The so-called "lake terraces" consisting of topset and foreset beds and outwash sheets are the most frequently occurring landforms of this category.

Ice-contact deposits tend to contain a wider range of particle sizes and are not well-sorted with cobbles frequently being found in close juxtaposition with silt lenses (Ph 28). Although often stratified, the stratification is frequently discontinuous and faulted. Their surface expressions, in contrast to the deposits of the proglacial areas, are characterised by irregularity, with mounds, ridges and depressions frequently alternating in rapid succession. Kames, kame-terraces, eskers and kettleholes are the distinctive features of these ice-contact deposits. It is possible to distinguish two further types of ice-contact deposit. The morainic areas, whether true moraines, like that at Crossford, (Fig 30), or of less certain origin such as those at Blackwood and Brocketsbrae, (Fig 23), all contain sands and gravels. Again, however, the lack of sorting is a characteristic of these deposits, but more so in the morainic deposits for till lenses frequently occur. (Most of the other ice-contact features, eskers, kames and kame-terraces are remarkably free of till).

A third important group of ice contact deposits also occur - the valley-fill fluvioglacial deposits. These are important because/

because of their widespread distribution. They normally occur as a layer 5 feet - 20 feet thick overlying till. They are thickest in the valley floors and thin out on the valley sides. (Fig 10). Their surface expression may be moundy or undulating, coursed by meltwater channels or flat. Occasionally distinct esker ridges are found but these appear to lie on the surface of the deposit rather than to be an inherent part of the underlying stratum. (Phs 12,65 and 66). It therefore appears that these valley-fill fluvioglacial deposits were formed beneath the ice.

The thickness and extent of fluvioglacial deposits are inevitably related to the meltwaters that deposited them. The greatest thicknesses and most extensive deposits of sand and gravel are in localities where local conditions of relief and meltwater supply favoured their accumulation. In general therefore valley floors and lower valley slopes contain the greatest concentrations of sand and gravel. Areas where the ice margin remained for protracted periods were especially favourable. This explains both the deposits at Bonnington, (Fig 34), and those in Upper Avondale (Fig 44). The longer the period of meltwater deposition, the thicker and more extensive are the resulting deposits. In a dissected area, however, an ice stream has margins at its sidesas well as at its terminus and thus whole suites of kame terraces may be found in positions formerly located between the ice margin and the valley sides (e.g. Upper Glengavel (Fig 39) and the lower Clyde Valleys (Fig 33).

It must be concluded that a knowledge of the glacial

history/

history and in particular a knowledge of the conditions of fluvioglacial erosion and deposition, is a first essential of a survey of sand and gravel resources. This knowledge not only helps explain the distribution pattern of the deposits but also indicates the likelihood of adverse conditions such as thick overburden and the presence of till, clay and silt bodies within the deposit (Figure 49 shows the distribution of all the proven sand and gravel reserves in Central Lanarkshire as revealed during the present investigation. Note that the map shows all the sand and gravel deposits regardless of thickness, impurities and thickness of overburden).

2. Problems of Quantity

Even with a knowledge of the distribution of reserves the extractor still faces many problems. One of the biggest of these is to guage the volume of any particular deposit. "Before the second World War the winning of Sand and Gravel was mostly by hand digging and with the minimum of mechanical plant ... In 1939 there were less than ten companies (in Scotland) with mechanised plants". (Maclean 1960 p.99). Operators were therefore more flexible and could afford to utilise even quite small deposits. With the present circumstances of large capital investment on plant, (the most recent plant installed in Central Lanarkshire cost £60,000 for machinery alone), sand and gravel companies, not unnaturally, demand some assurance of longeivity. Apart from exceptional circumstances companies regard a minimum of ten years as an essential plant life period and since modern plants are expected to produce 200,000 - 250,000 tons of sand and gravel per annum, few companies/

companies are interested in deposits yielding less than two million tons of sand and gravel. There is, therefore in the industry a great demand for more accurate information on the volume of resources.

There are several prospecting methods whereby this information can be made available. The first is as outlined in the first part of this investigation - the application of the theories and laboratory and field techniques of glacial geomorphology. Air photograph coverage is available for the whole of Scotland on the scale of 1 : 10,000 and stereoscopic investigation of these photographs may allow likely source areas of sand and gravel to be located in the laboratory. Some workers have claimed that "the use of air photographs can eliminate as much as 90 per cent of the field work associated with materials exploration". (Bruce and Lundberg 1964 p.35). The same authors maintain that systematic observations and recordings of topography, drainage patterns, character of erosion , tone of photographs, vegetation etc. will enable the differentiation of areas covered by rock, till, moraine, sand and gravel. The present investigation revealed that these comments are justified only where there are very thick accumulations of sand and gravel, the landforms of which are distinctive from those of the surrounding areas (Phs 43, 46,47,57 and 58). Air photographs do, however, provide a very useful pre-field work guide to drift conditions and areas of concentrated meltwater activity.

Field survey will remain a necessary and invaluable guide to drift conditions. It is increasingly obvious that the mapping and identification of drift landforms and drift-free areas constitutes an/

an important part of delimiting potential resource areas. Natural exposures are often available especially in the vicinity of rivers and these allow more accurate investigation and recording of drift stratigraphy than any other source. This freely accessible information gives an indication of the thickness of fluvioglacial deposits, and by correlation with morphology and other exposures, an indication of the volume of the deposits. It also indicates the presence and the thickness, or the absence of, overburden, included till layers, clay and silt layers and other unwanted impurities.

The air photograph reconnaissance and the field survey together will indicate the localities in which the main sand and gravel resources are to be found. It is mainly on the basis of these two information sources that Figure 49 is constructed. In many areas, however, a lack of exposures does not allow an examination of subsurface conditions and to evaluate the potential of the deposits other prospecting techniques have to be employed. Boreholes when available can provide valuable information at little expense. As already stated, coalfield areas often have a good coverage of boreholes, although the recording of the overlying drift deposits may sometimes be haphazard. Their usefulness in recording the locations of the buried "pre-glacial" valleys of Central Lanarkshire has already been shown. Both the National Coal Board and the Geological Survey keep large borehole record collections. Outside the coal-bearing areas boreholes are only available where there has been recent development and these are normally only obtainable with the consent of the county or private authority/

authority concerned. Elsewhere if borehole records are not available and there are other indications of an economic deposit most sand and gravel companies commission a private consultant to put down bores. One company in Glasgow maintains its own drilling crew and rig. Frequently intensive drilling investigations are carried out but the intensity varies. At one thirty-acre site in Central Lanarkshire twenty boreholes were put down whereas at another site of similar dimensions only three were drilled. At the latter site and at several other sites opened up recently trial pits were dug to investigate the sub-surface drift. These trial pits up to 17 feet in depth, are a simple but effective method of checking the borehole information. The need for this was shown at a recent site investigation where rather puzzling and unhelpful borehole reports were obtained, viz. "soil and stones 1 foot, brown very sandy clay and stones 3 feet 6 inches, bound clayey sand and stones 17 feet 6 inches, occasional sandstone boulders 3 feet 6 inches, sandy clay and stones 4 feet 6 inches". From this information it was not possible to determine whether "the very sandy clay and stones" indicates a sand stratum which contains clay and stones or merely a gritty boulder clay. This is hardly the conclusive evidence for which pit owners are looking - and paying. It appears that even where boreholes are drilled with the express purpose of establishing the potential for sand and gravel extraction, the terminology varies with the drill operators and there is no accepted conventional use of terms. There appears to be an immediate need for standardisation of terminology perhaps along the lines suggested by Washburn and Sanders and Flint, (1963 p.478), who suggested a nomenclature system based on/

on the percentages of the various particle sizes present in the sediment. At the locality described above trial pits were dug adjacent to the borehole sites. These revealed in the upper fifteen feet no differentiation of material, all of it was of well-rounded gravel with fragments ranging from four inches in diameter downwards. There was a small amount of clay and sand in the interstices. The material was of exactly the same character and quality as that being worked in the nearby pit and it is therefore obvious that in this case borehole records were not only confusing but also misleading. Other borehole operations have produced accurate results which are of great value in obtaining some idea of the total volume, the proportions and grades of the different sands and gravels present and the qualities of these. For example in a fairly representative bore journal of the Upper Avondale deposits no less than thirteen separate strata are recorded in a 75 foot bore. Distinct layers of clay, "soft and dead sand" (sand with a high silt/clay content), fine sand, sharp sand, fine and coarse gravel are all recorded and the pit owner is therefore able to make an accurate assessment of the potential value of the deposit. In problem areas, where stratigraphic changes are likely, trial pits are not only a useful additional check but sometimes an essential one. These can very easily and very cheaply be dug to depths of 15 feet - 20 feet. One important point arises from the locating of borehole and trial pit sites. The field survey should be used to indicate the areas where this coverage should be concentrated. Where natural exposures are available no further investigation may be required but where there are indications of till penetration into the fluvioglacial deposits there is an/

an obvious need for more information. It is pointless, and at drilling rates of 12 - 30 shillings per foot dependent on the ease of penetration, expensive to establish a grid network of sites regardless of relief and the results of the field survey.

More recently, at least, three of the companies operating in Central Lanarkshire have made use of other exploration or prospecting methods - the geophysical methods. (Only two (of the geophysical techniques) have any relevance to the problems of the sand and gravel industry - the electrical resistivity and the shallow seismic methods" (Vann 1964 p.6).

The electrical resistivity method relies on the determination of the differing resistivities of different sub-surface materials. Four metal electrodes are generally stuck into the ground at measured intervals along a straight line. A measured current is introduced into the ground between the two outside electrodes and the resultant potentials measured between the two intermediate electrodes. The method can be expanded to cover wide areas in relatively short times and the costs are less than those of equivalent borehole coverage. (Vann 1964 p.7). However, the method is not without its disadvantages. It can only be used on dry land, cannot be used where misleading materials such as asphalt are present at the surface and is affected by the presence of metallic conductors, at or under the surface. Reasonably level topographic conditions are also essential and this is often impossible, especially where dealing with ice-contact sand and gravel deposits. Space is also a limiting factor for since "an electrode spread three times the depth of penetration is required" (Vann 1964 p.7)

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an investigation down to a 50 foot depth requires a lateral straight-line spread of the conductors over 150 feet. If the overburden is 30 feet thick the method is impracticable.

Refraction, rather than reflection, seismic techniques are of interest to sand and gravel prospectors. The method depends on the differing rates of transmission of shock waves through different materials. Although it is generally agreed that solid rock has higher transmission velocities than less dense material such as unconsolidated sediments, there is nevertheless considerable variation in the values recorded for different rocks, sands, gravels and tills and with such overlap problems "seismic velocities are not necessarily diagnostic of the materials involved". (Vann 1964 p.8). Other drawbacks to the successful use of this technique are dissected relief, man-made seismic disturbance, (traffic etc.), blustery weather conditions and clay or till overburdens. With both techniques there is considerable difficulty and skill involved in the interpretation of results. Similar materials under different local circumstances of water accumulation and type and thickness of overburden can give quite dissimilar readings. Regional variations in the character of the deposits must also be taken into account, boulder clays in Central Scotland need not necessarily yield the same results as boulder clays in the Highlands or in the South of England. No matter how excellent the equipment is, the success of the technique depends on the skill and experience of the operator.

The choice of the geophysical method used is partly determined by the local circumstances and partly by the facilities available. If a clay overburden is present and if speed and economy are/

are desirable then the resistivity method is preferable. If the sand and gravel rests on hard rock, however, there may be very little resistivity contrast and the seismic method may be preferable. In the United States these techniques have been longer used and more widely applied than in this country and even there tests are not always successful. One report (Bruce and Lundberg 1964 p.75) concludes that "seismic devices ... are, however, not of great use in glacial areas where many layers of varying velocities are encountered. It was found that resistivity measurements were more accurate, easier to accumulate, and easier to calculate". Another report, (Lum 1961 p.20), concludes that "the resistivity method used for depth (thickness) determinations of glacial outwash deposits ...has met with only limited success. The resistivity results are generally unreliable. This fact is believed to be caused by the unfavourable inhomogeneity and variability of the glacial deposits even over short distances. Any accurate and reliable depth interpretations from apparent resistivity curves must be accompanied by sufficient drill-like information to provide geologic correlation and control of the resistivity data".

This last sentence probably indicates the best method of investigation. Without borehole correlations the resistivity and seismic investigations should only be regarded as a reconnaissance survey, but with borehole information more precision can be achieved and it is possible to determine, with a reasonable margin of accuracy, not only the various types of material present but also their probable volumes. It seems sensible therefore to regard borehole and seismic/resistivity surveys/

surveys as essential complementary sources rather than as rival alternatives.

As already mentioned three companies made available the results of private resistivity investigations by different consultants at their pits. At one Upper Avondale pit considerable borehole information was already available and the company prospecting engineer was of the opinion that the resistivity investigation had contributed nothing that was not available from the borehole journals. At a second pit in Upper Avondale two resistivity investigations were carried out. The private consultant working without the advantage of borehole information was unable to give any details of a large part of the area which was peat covered. The remaining areas he divided into, (1) gravel bearing areas, in which average thicknesses never exceeding 16 feet were given, (2) an area of "predominantly sand, with very little coarse material or gravel" for which no thicknesses were suggested. Inconsistencies in the resistivity values were found. For example, although high readings indicate clean deep gravel", (consultant's report), the second highest reading was located in an area designated "shallow gravel". In the second investigation at this site, however, despite an absence of exposures and an indeterminate landform assemblage, the consultant was able to accurately delimit an area in which sand and gravel was absent (later proved by trial pits). Having studied the area in the field the writer feels that a series of trial pits dug speedily and at little expense at specially selected sites would have provided a clearer picture of the quantities and qualities of the material available. In this case the/

the company felt it imperative, for administrative purposes, to obtain a speedy estimate of the reserves available and a combination of trial pits and resistivity readings would have undoubtedly supplied a much more accurate inventory of resources.

The third resistivity survey was implemented in the Bonnington/Carstairs (Fig 23) sand and gravel deposits. The resistivity reports shows "productive areas" in which the sand and gravel is estimated to be 10 feet - 40 feet thick. Outside these areas the deposits are said to range from one to ten feet in thickness. The writer has paid especial attention to this site because of its great interest both academically and commercially. Information is available from the field survey, natural exposures, a sand and gravel pit now established at the site, seventeen trial pits and a line of ten very deep boreholes. Several conclusions emerge. The fluvioglacial landforms at the site, (Fig 34), make the delimitation of the potential sand and gravel bearing area a simple task. In the area characterised by deep kettleholes (Ph 40) as much as 100 feet deep, the resistivity survey indicates only small sand and gravel thickness of one to ten feet. All the other evidence emphatically indicates that the sand and gravel deposits in this locality are at least 100 feet thick and they are therefore misleadingly omitted from the classification of productive areas. The deep boreholes, immediately to the west of the area covered by the resistivity survey, show a thickness of fluvioglacial deposits varying from 35 feet 6 inches to 98 feet 6 inches and also indicate that the deposits are infilling two buried valleys which underlie the/

the area. The location of the boreholes and one of the buried valleys can be seen in Figure 31. Eastwards the landsurface rises to altitudes fully 100 feet above the borehole locality. Combining the borehole, landform and relief information there is no reason to suspect that the fluvioglacial deposits are less than 100 feet thick. Again in this area the resistivity survey provides a working set of figures which the company can use to plan its policy, an important consideration. Here again, however, there is some doubt as to the accuracy of a resistivity survey carried out without complementary and perhaps more helpful borehole/test pit information. This case is a further example of a recurrent situation where the company, had they been better informed, could have utilised at little or no expense several sources of information already available, - (1) the very distinctive evidence of the landforms depicted in Figures 26 and 34, (2) the evidence on the nature of the deposits readily accessible in the geological literature, (3) the borehole records obtainable from the Geological Survey.

The resistivity investigations in Central Lanarkshire have fully borne out the fact that,although useful, they should be used not as a substitute for, but in conjunction with field and borehole surveys. The problems of cost of equipment, its proper usage and the lack of trained personnel capable of interpreting the results, suggest little likelihood that sand and gravel companies will be able to undertake these exploratory techniques themselves. This means that the bulk of the information required by pit owners must continue to come from private consultants. In this light it would appear that

Government/

Government research establishments, the Universities and the Geological Survey have a valuable contribution to offer. A knowledge and understanding of the depositional environment and the sources of relevant information in the literature and borehole journals such as these institutions have, can greatly facilitate the delimitation and more efficient working of sand and gravel deposits.

The present investigation has allowed the collection of all the available information which is helpful in determining the volumes of sand and gravel in Central Lanarkshire. It was therefore possible to calculate the volume of reserves of sand and gravel in this area. All the information obtained from the field survey was first transferred from the 1 : 10,000 to the 1 : 25,000 O.S. maps. The sand and gravel bearing areas were than calculated using the kilometre square grid on the 1 : 25,000 maps. The thicknesses of the sand and gravel deposits were obtained from the field and borehole information and alterations made in respect of overburden and included till or clay strata. No consideration was made of differences in quality and only areas where a thickness of ten feet of sand and gravel was proven were included. Since no comprehensive survey of river-bed resources was undertaken these were excluded from the calculations. Sand and gravel reserves under present built-up areas were likewise excluded. Many other factors to be discussed later influence the actual economic workability and potential value of the deposits. The estimates are consistently conservative and include only proven reserves. The writer is aware of the many deficiencies of both the method and the information available. The justification for the exercise is the need for even such rough

estimates/

estimates by both planning authorities and extractors. Another justification may be that the writer can confidently say that, not only is this estimate the most accurate yet available, but also it is the only one which affords more than local coverage. Figure 50 shows the distribution and volume of sand and gravel reserves in Central Lanarkshire. The dominance of four areas Carstairs/Carnwath, Bonnington/Lanark, Upper Avondale and the lower reaches of the Clyde can readily be seen (approximately 56, 37,26 and 12 million tons of sand and gravel respectively). Between them they contain just over 70% of all the proven reserves (183 million tons). Carstairs/Carnwath and Upper Avondale have been the main sources of sand and gravel in Central Lanarkshire since the Second World War but the other two districts have only been exploited within the last three years. The Bonnington/Lanark source receives only a one sentence mention and the Clydeside deposits are not referred to in Anderson's book on "Scottish Sands and Gravels" (Anderson. British Limemaster).

3. Problems of Quality

This chapter has so far made very little reference to the qualities and characteristics of sand and gravel deposits and yet it is on these properties, rather than sheer volume, that the workability and economic potential of the deposits depend. The important qualities of sand and gravel are those which affect their working and the uses for which they are suitable. By far the largest quantities of sand and gravel are used in the construction industry. Here the demand is for grades of different sized particles ranging from fine sand to coarse gravel/

gravel. For each different size grading there are certain specific uses and in some cases no other size grading may be suitable, e.g. fine sands are used for plastering and coarse or "sharp" sands for concreting. Coarse gravel is used for road bottoming and drainage dtiches on embankments. Other special uses of sand, such as in glassmaking and foundry moulding, and gravel in decorative purposes use only small proportions of the total output. For most of these uses very strict specifications are laid down under the British Standards regulations.

One of the immediate problems of all fluvioglacial deposits is that they are of variable quality and contain inclusions of unwanted till and clay. Under present conditions where many good sand and gravel deposits are readily accessible, if the thicknesses of these till and clay layers are appreciable in comparison to the thicknesses of the sands and gravels, then the deposits will not be worked e.g. the Stonehouse deposits (Area III) (Fig 45).

A second problem also arises from the origin of the deposits. The ideal deposit for the most efficient working of plant equipment should contain 50% of sand and 50% of gravel. The results of the sand and gravel pit survey show that the actual production of gravel in Central Lanarkshire pits ranges from 5% to 65% with the average production being 36% of the total output. The deficiency of coarser deposits is a problem "throughout the Glasgow district" (A.Maclean Alexandra Transport Co. Ltd. Personal communication. Nov. 1965) and its seriousness has tended to increase in recent years. It arises from/

from the properties of the deposits themselves. Two pit owners have taken to importing gravel dredged from river beds up to eight miles distant in order to make good the deficiencies of coarser deposits being processed at the plant. Two others have utilised nearby isolated ridges, (eskers), which they have found to contain a high percentage of gravel. Thus a knowledge of the percentage composition of size gradings available from the different types of fluvioglacial landforms would greatly facilitate their most effective utilisation. This can be done by sieving representative samples of the different types of deposits available. This is an important line of research which may also illustrate factors indicative of the depositional origin of the sediments themselves. C.A.M. King, (1964 p.274 - 291), shows the academic relevance of size analysis studies, but geomorphologists have long known that different landforms have different particle size compositions and this fact has great significance to the present problem. During this investigation size analysis studies were undertaken of landforms/deposits which are utilised by sand and gravel excavators. The technique was based on British Standards 1377 p.17. Channel samples, approximately one foot wide and one foot deep were taken in columns four to ten feet in height. The vertical range of these samples, passing as they did through the various often well-defined and distinct strata is thought to give the most representative sample. The weight of the samples varies from 106 kilograms (small morainic sample) to 300 kilograms (esker sample). The coarse sediment was sieved in the field and the material/

material of less than three sixteenths of an inch diameter, (Sand), was retained and later sieved under laboratory conditions. The results are shown in Table XXV.

TABLE XXV

Particle Size Analysis of Certain Fluvioglacial Landforms

Locality	Description	Sample Size	Percentage Weight of Material Retained on Sieve									
			G R A V E L			S A N D						Clay/ Silt
			2ins.	$\frac{3}{4}$in.	3/16in.	No7	14	52	72	100	200	Passing
Linnhead (Lanark)	Esker	247kgs	15	12	33	13	5	6	10	1	1	2
Mause Blairgowrie	Esker	300kgs	9	9	10	29	13	22	6	-	-	2
Boncastle Hill (Douglas A74)	Kame	Private Consultant No Size Given	-	5	20	7	8	24	11	11	8	6
Loudoun Hill	Outwash Sheet	58kgs	3	19	32	10	16	20	-	-	-	-
S.Torfoot	Outwash Sheet	42kgs	1	14	23	7	4	32	9	2	6	2
Enochdhu (Blairgowrie)	Outwash Sheet	60kgs	12	20	26	39	2	1	-	-	-	-
Loudoun Hill	Deltaic Lake Sediments	12kgs	-	4	12	1	1	27	20	22	11	2
S. Torfoot	Deltaic Lake Sediments	17kgs	-	2	3	1	1	28	28	27	10	-
Brocketsbrae (Lesmahagow)	Morainic	106kgs	-	8	8	2	4	15	9	19	18	17

It can be seen that in terms of gravel content, (3/16 in. +), the/

the three outwash sheets yield consistently high results of 54%, 38% and 58% respectively. The difference in the first two figures can be equated with an increasing distance from the ice margin. (see description of Upper Avondale terraces Chapter IV Section 7). The esker results show 60% and 28% of gravel content respectively. This obviously indicates a certain variety of composition even within the same fluvioglacial landforms, a point which has already been noted. The channel sample of the second esker penetrated a silt/clay layer three feet thick. This variety of composition within the same fluvioglacial form was well illustrated in Chapter III by the trial pit excavated in one of the eskers of the Carstairs system which showed increasingly finer material in a distal direction. The kame analysis results (supplied by Jas. Anderson and King Ltd.) reveal the next highest gravel content. The deltaic lake sediments contain more finer material. The morainic deposit at Brocketsbrae has almost equal proportions, 16% and 17% of gravel and silt/clay respectively. This probably reflects the poor sorting of materials not carried any distance by meltwaters. The results will obviously vary depending on the proximity of the ice margin, degree of concentration of meltwaters and broad regional generalisations are therefore suspect. At individual localities, however, the implications are of vital significance to sand and gravel operators to whom this background knowledge is not readily available. The sand and gravel extractor can by judicious choice of his excavation site maintain a more even, and therefore more efficient, flow of material into the plant. A

greater/

greater appreciation by the extractor of compositional variations within his deposit will allow him to minimise the detrimental effect of "surges" (excessive concentrations of finer or coarser materials) (Maclean 1960 p.110).

Only a limited number of particle size analysis were undertaken but even the results of these are highly significant. It is felt that this technique could be developed on a more widespread scale and would provide valuable information on the origin of deposits, their extraction problems and their economic potential.

One of the great advantages of fluvioglacial outwash sheets is that the material is by nature already partially washed and graded. The three largest outwash sheets in Central Lanarkshire, all of which are being utilised, consist of gravel by far the larger proportion of which is less than three inches in diameter. This is important for although it is preferable to have at least 50% of gravel in a deposit all the pebbles greater than two inches in diameter normally have to be put through a crusher to be reduced to commercial aggregate sizes. With large quantities of material greater than this size crushers, (one of the most expensive items of plant machinery) have to be frequently replaced. Only a small proportion of Central Lanarkshire outwash sheet gravels are greater than two inches in diameter (Table XXV).

Perhaps the most publicised problems of sand and gravel concern the presence of impurities in the deposits. In Central Lanarkshire, roughly in order of significance these are, clay and silt material/

material, coal and soft stones, lignite and peat. Other vegetable and animal impurities, salts, limestones and shells are of negligible importance. (A.R. Roeder, lecture at Sand and Gravel Symposium Glasgow 23rd March 1966). The "iron compounds" cited as impurities in sands by Jordan (Jordan 1961 p.1543) were only mentioned as a mild problem at one Central Lanarkshire pit.

Clay and silt particles when present in significant proportions are thought to affect both the setting of cement and the strength of the concrete and may also give rise to "blows" in finished work. (S.A.G.A. Handbook 1962) p. 6 - 3). The British Standards specifications, (B.S. 882), lay down maximum permissable clay and silt contents. Clay and silt are also disadvantageous because although waste products they have to be put through the processing machinery and when removed can cause an appreciable loss in the total volume of material extracted. One Upper Avondale pit, working the "lake terraces" loses 12½% of the volume of material extracted due to the occurrence of large proportions of fine material. The defects of coal and soft stones are that they are thought to affect both the compressive strength and the durability of mortar and concrete (Knight 1935 p.195). They are also objected to because they spoil the appearance of the concrete. The most common soft stones in Central Lanarkshire sand and gravel deposits are brittle, sometimes weathered, sandstones and very soft, ochre-coloured, fossiliferous sandstones. Both of these, like the coal fragments, are found in Carboniferous sediments and it is in their outcrop areas that they are most prevalent. At some pits where these

fragments/

fragments are found, some of them are removed manually and others by mechanical devices known as "Jiggs" (remove light materials from gravels).

The main objections to peat and lignite are that their presence, (1) retards the hydration and setting of cements, (2) affects the compressive strengths and durability of mortars and conretes, (3) spoils the appearance of the concrete. Despite increasing investigation into factors affecting the strength of concrete some of these criticisms are unproven. (Jordan 1961 p.1543. Roeder 1963 p.48). One pit in Upper Avondale has to remove a considerable peat overburden before extracting the sand and gravel, (Phs 74 and 75), but this peat cover appears to have no recorded deleterious effect on the quality of the underlying material. The Loudoun Hill sand and gravel pit is known to have small proportions of lignite in its sands. This fact almost cost the loss of an important contract to supply the sands used in constructing the Hunterston Atomic Power Station. Extensive and thorough testing by Government departments, however, showed no harmful defects on the strength and durability of the concrete made with the sand and the materials were found to be perfectly acceptable.

Concrete bricks and blocks are being used in ever increasing quantities by the building industry. Reinforced concrete sections are now widely used in the construction of the increasingly common 10 - 30 storey domestic flats. Previously such faults and cracking that occurred were normally attributed to the settling of the building or poor workmanship. Latterly, however, and especially with the/

the advent of underfloor heating, reports of cracking and excessive deflections "in some cases greater than one inch in a span of 12 feet six inches", (Edwards 1963 p.57), became even more numerous. This prompted a series of investigations by the staff of the Building Research Station, Thorntonhall, Lanarkshire, which revealed disadvantages in certain Scottish Sands and Gravels which had been previously unsuspected. "The first important observation which was made was that many of the gravels and crushed rocks in common use in Scotland have a moisture movement ... - an increase in the water content produces a volumetric expansion and drying out again causes shrinkage" (Edwards 1963 p.54). It is to the drying out of these gravels and their consequent drying shrinkage within the concrete that much of the cracking, formerly attributed to shoddy workmanship and settling, can be attributed. Laboratory experiments revealed that different rock types had different drying shrinkage values and produced concretes of widely varying strengths and durability. Since different sand and gravel deposits are composed of varying proportions of different rock types, it is obvious that they too will also be subject to different rates of drying shrinkage. There are methods of "curing" the concrete by altering the proportions of cement, sand and gravel in the concrete mixes, by the use of entrained air and by using "rounded particles" (gravel) rather than "sharp-edged ones" (crushed rock). These precautions are outlined in an article by Snowdon and Edwards (1962 p.109 -116).

The main problem, however, rests with the quality of the coarse aggregate. Pure quartz and "Thames Valley Flint" are non-shrinkable/

shrinkable rocks, (0.000% shrinkage), dolerites (0.041% - 0.065%), and freestone (0.128%) are increasingly prone to shrinkage. The full implications of this work will not be realised until many more widespread and thorough tests have been performed. The fact that these tests are done on a private basis also restricts the assimilation of all the data. The following table shows the range of shrinkage values obtained in concretes using different gravel aggregates, (Edwards 1963 Table II), and shows the generally poorer shrinkage qualities of Central Scotland gravels.

TABLE XXVI

Gravel Source	Shrinkage of 1 : 2 : 4/0.6 concrete per cent
Thames Valley Flint	0.025
Central Scotland Gravel 1	0.030
2	0.058
3	0.058
4	0.061
5	0.091

The Building Research Station as a result of these enquiries has made certain specific recommendations on the restrictions of the use of gravels of different shrinkage qualities. These were first published in the Building Research Station Digest (2nd Series No.35 1963) and are reproduced below.

TABLE XXVII

Recommendations for using Concretes of Various Shrinkage Levels

Drying Shrinkage of Concrete %	Remarks	Use
0.000 - 0.025	Possible only with non-shrinkable aggregate of high elastic modulus such as quartzite gravel	Suitable for all concreting purposes, and essential for precast products where very low values of shrinkage are demanded by British Standard
0.025 - 0.04	Produced with hard, dense aggregate of non-shrinking or very low shrinking types, e.g. granite, mountain limestone, blast furnace slag and some dolerites	Suitable for all purposes except precast products of very low shrinkage unless these can be cured with high pressure steam
0.04 - 0.06	Produced with hard, dense aggregates of low shrinkage and softer non-shrinkable aggregates	Not suitable for precast products of low shrinkage and thin reinforced sections such as cladding panels and cast in-situ floors, particularly if heated, unless special precautions are taken in design. For concretes with this or greater shrinkage and extra allowance should be made for loss of prestress
0.06 - 0.08	Concretes at this and higher shrinkage levels can be produced with aggregates covering a wide geological range. At this and higher levels of shrinkage, durability is likely to become affected	Suitable for all general structural purposes except thin reinforced members as above plain concrete exposed to the weather unless air entrainment is used, and no-fines concrete

TABLE XXVII (Contd)

0.08 - 0.10	Severe warping and widespread deterioration has taken place in concretes of this shrinkage level	Suitable only in positions where complete drying out never occurs, for mass concrete provided the surface layers are air-entrained, and for heavy symmetrically reinforced members not exposed to the weather
Over 0.10		Suitable only for concrete kept in a permanently wet condition

The recommendations imply that it may be unsafe, without certain safeguards, to use concretes with shrinkages greater than 0.04% for precast products and thin reinforced sections. With the increasingly rigorous British Standards and architectural specifications the shrinkage factor has now taken an important place in the retailing of sand and gravel. Two of the largest construction projects to be commenced in the Glasgow area within the next few years are the building of the Kingston Bridge in Glasgow and the ErskineBridge at Old Kilpatrick. Tenders for these projects will only be considered from firms producing gravel of 0.05% and 0.06% shrinkage, or less, respectively. Of the eight operational sand and gravel pits in Central Lanarkshire, for which shrinkage values were made available, none has a shrinkage value of less than 0.45%, two are between 0.046% and 0.065%. five are between 0.066% and 0.085% and only one was in the poorest shrinkage category of 0.086% to 0.105% . As a result all but two of the active sand and gravel pits in

Central/

Central Lanarkshire will be debarred from tendering for the two contacts mentioned above. (It may be noted that these two pits are approximately thirty-five miles from Glasgow and to supply these two projects would involve round trips of 70 - 100 miles.)

The work of the Building Research Station is therefore vital in helping to overcome and suggesting remedies for these shrinkage disadvantages. The significance of the effect of variations in rock types has already been shown but a more thorough investigation of the rock type analyses studies, as shown in Chapters II,III and IV, in relation to shrinkage value would help clarify the physical factors affecting shrinkage qualities. Five examples collected during the present investigation illustrate this point.

TABLE XXVIII

Gravel	Percentage of Rock Types Present ($\frac{3}{4}$ in. Gravel Grading)				Shrinkage
	Highland	Carboniferous	Old Red Sandstone	Southern Upl.	%
A *	100	-	-	-	0.025
B	3	26	59	7	0.06
C	-	-	20	76	0.07
D	6	68	8	14	0.08
E	-	22	24	54	0.10

* In Central Scotland but not in Central Lanarkshire.

It would be unwise to make definite conclusions based on the few analyses so far completed, but in the light of Edwards' conclusions, (Edwards et al 1962,1963), certain trends emerge. (1)

A/

A high proportion of stones derived from the Highlands tends to improve the shrinkage qualities of the gravels. (2) Larger proportions of rocks of Old Red Sandstone age tend to produce medium shrinkage results. (3) Increasing quantities of rocks derived from Carboniferous and Southern Upland outcrops tend to inflate the shrinkage capacities of the gravels.

Since shrinkage tests are carried out by private consultants the results of the tests are not made public. Figure 51 shows the distribution of all the results made available and grades them into three categories: (1) best, shrinkage 0.045% or less, (2) medium, shrinkage 0.046% - 0.085%, (3) poorest, shrinkage 0.086 or greater. It is unfortunately not possible to separate crushed-rock quarries from sand and gravel pits. Several points emerge from this map. The general statements of the relationship of shrinkage qualities and rock types made above appear to be borne out by the distributions shown on the map. All the results in the Highland district fall in the "best" category. In the Southern Uplands and Central Lowlands, however, the results are more mixed. The majority are in the medium grade although there are noticeable examples of best and poorest qualities. There is a noticeable tendency for better results to be obtained along the Highland Boundary of the Central Lowlands and for the quality to decrease with the decrease of Highland material to the south. Some of the best results in Central Scotland and the Southern Uplands are derived from crushed-rock quarries which work one particularly suitable rock type e.g. Tinto/Cairngryffe felsite.

Having/

Having discussed the major physical factors which affect the qualities of sand and gravel, it is perhaps now appropriate to reassess the relative values of the sand and gravel resources shown on Figure 50. As far as possible the assessment is based on the other evidence of this investigation, since most of the defects e.g. coal, silt etc. are removed during processing the reassessment is of more relevance to extractors rather than to users of sand and gravel. The main defects are: (1) till and clay inclusions, (2) high percentage of "fines", sand/silt/clay greater than 75%, (3) presence of large quantities of coal and lignite, (4) poor shrinkage returns, i.e. greater than 0.086%. Thus a deposit with none of these defects would be classified as grade A, one with one of the defects outlined above would be classified as grade B, one with two as grade C etc. It can be seen from Figure 50 that all the sand and gravel deposits in Central Lanarkshire have disadvantages, for those included in the grade A category are invariably of small volume. This map presents again only a provisional guide but discussions with planning officers of Lanarkshire County Council have indicated the necessity and relevance of such a guide. Above all it should be remembered that sand and gravel are not inexhaustible natural resources. In England the "trend for the scarcer and /better deposits to become depleted" (Jordan 1961 p.1542) is already well established. In Central Lanarkshire with reserves of at least 183 million tons, and a present consumption level of above one million tons per year, absolute volumes of sand and gravel are not an immediate problem. There is, however, a definite shortage of/

of better quality easily worked deposits. There seems therefore to be an urgent need to conserve the better deposits and restrict their use to construction projects for which they are essential. Land use planning should as far as possible avoid alternative zoning or sterilisation of resource areas until they have been utilised. It may be concluded that although vast quantities of sand and gravel remain in Central Lanarkshire their qualities present problems to both extractor and user alike.

B. Economic Factors Affecting the Utilisation of Sand and Gravel

(1) Extraction Incentives and Marketing

In 1958, the first year for which accurate statistics are available for Scottish Sand and Gravel production (Ministry of Public Building and Works, Edinburgh), the six operational pits in Central Lanarkshire produced 392, 248 tons (Fig 52). In 1965, the most recent statistics yet available show that nine operational pits produced 1,177,705 cubic yards of sand and gravel (Fig 53). The change in the units used for measuring production was made to facilitate the collection and processing of statistics. The conversion factors conform to British Standards 648 and are for sand, 24 cwts = 1 cu. yard, and for gravel 22 cwts = 1 cu. yard. As a result of this change of units it is difficult to equate the two production totals exactly. There has, however, in this short period of seven years, been almost a four-fold increase in sand and gravel production. Despite this large production increase no firms reported difficulties in retailing thir supplies/

supplies. Since 1965 three new pits have commenced commercial production in Central Lanarkshire. This illustrates that the increase in production is related to a similar increase in market demand.

The sole reason for the large production in Central Lanarkshire is the incentive of the nearby/industrial market of the Clydesdale conurbation. The "current consumption of sand and gravel in the U.K. is nearly 2 tons per annum per head of population" (S.A.G.A. Handbook 1962 Chairman's foreword). At this rate the two million population of the conurbation, with its great demand for new housing, new industries, new roads etc. would be expected to consume nearly four million tons of sand and gravel. The Central Lanarkshire production, 1,177,705, cu. yards in 1965, only partly meets these requirements. Much of the remainder is derived from districts much further removed from the Conurbation than Central Lanarkshire. (Appendix V).

In common with most industries the sand and gravel industry is concerned with retailing goods at a profit. Thus if company policy and the physical factors are favourable and it is decided that a deposit can be worked and sold at a profit then it will probably be utilised. There are, however, many factors to consider before it is known whether a deposit will be profitable, but a ready market remains as a major incentive to production increases.

Economic sand and gravel production sites rely on good deposits, suitable locations, the availability of access roads and the presence/

presence of large, inexpensive water supplies for the processes of washing and silt and clay separation. There are clearly two great sand and gravel production localities in Central Lanarkshire where these requirements are satisfied (Figs 52 and 53). The first is centred on Carstairs/Carnwath and has an important outlier at Thankerton to the south. The second locality is to the west in Upper Avondale. Both localities had in 1966 four pits from which deliveries were made. For each of these pits the owners agreed to provide details of delivery volumes and destinations. By combining the total output totals of what the owners considered two or three average days, it is possible to obtain some idea of the average daily movement (May/June 1966 period) of sand and gravel from each of the two localities. The results are shown on Figures 54 and 55. There is considerable overlap of the two sales areas. The City of Glasgow itself with its huge consumption is normally the largest single market for the sand and gravel of both production localities. Glasgow takes 27% of the sales of the western production locality and 23% of those from the east. A large proportion of the sand and gravel from the eastern locality, 21%, goes to ready-made concrete plants and doubtless much of this also reaches Glasgow. The second most important market is the remainder of the Clydeside Conurbation. In the Upper Avondale locality, however, this is less dominant and much of the production is geared to supplying the larger markets in Ayrshire. For example, Kilmarnock, Ardeer (I.C.I. Works) and Irvine/Dreghorn together take more deliveries than Glasgow. Similarly the market area for the eastern locality extends farther to the east/

east, even as far as Edinburgh. Large scale construction projects such as the Hamilton stretch of the M 74 motorway can lead to temporary diversions, and often increases, in supplies. (Ph 77).

Since many other sand and gravel plants outside Central Lanarkshire are producing for the Glasgow Area,(see Appendix V), the market is highly competitive. Tables 29 and 30 show the figures on which the two marketing maps, (Figs 54 and 55) are based. Due to the confidential nature of the statistics, however, the writer is not at liberty to distinguish between the often very different and very interesting sales areas of individual pits.

TABLE XXIX Eastern Area

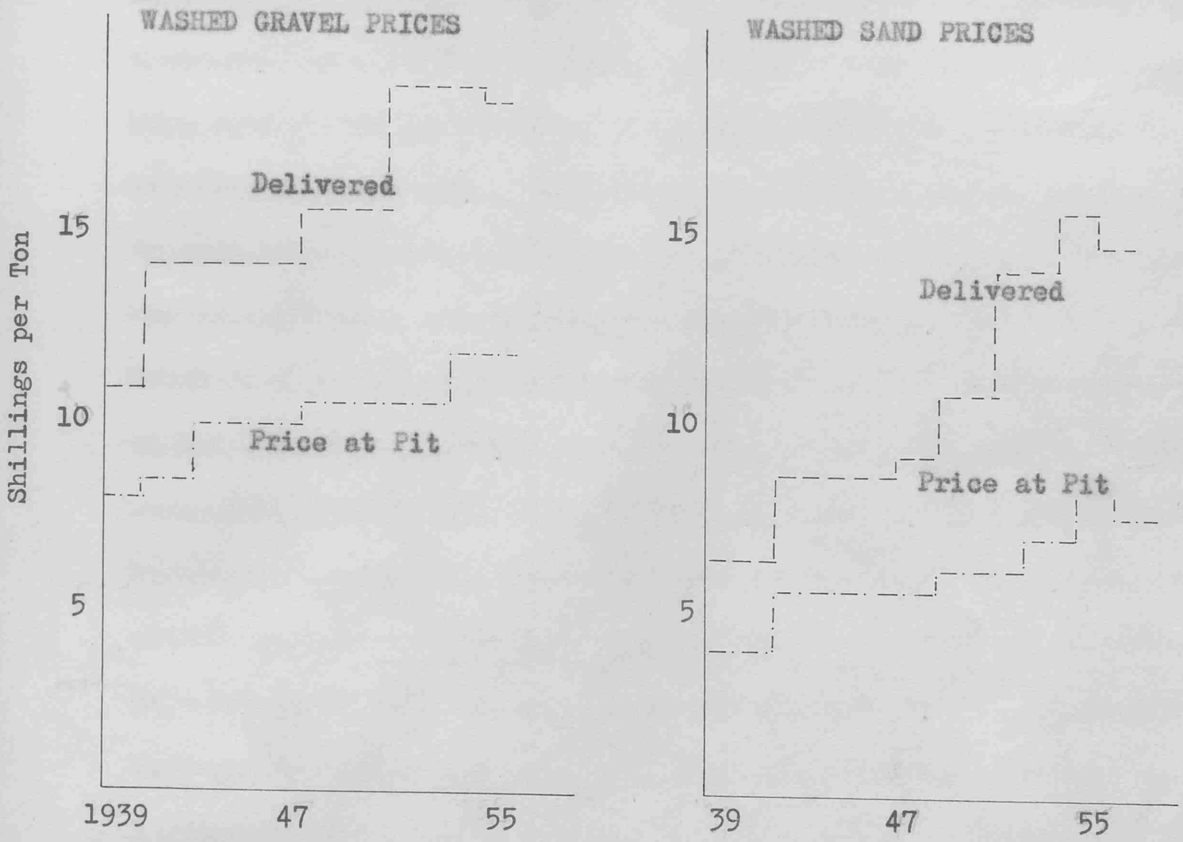
Hamilton Motorway	170
Glasgow	107
Hamilton/Motherwell/Wishaw	58
Paisley	57
Blackridge (W.Lothian)	36
Harthill	30
Airdrie	16
Whitburn	7
Edinburgh	7
Milngavie (Dunbarton)	7
Cumbernauld	6
East Kilbride	6
Bathgate	6
Clydebank	6
Bothwell	6
Dumbarton	4
Abbotsinch	4
Carluke	3
Stepps	2
Newmains	2
Livingston	1
Kilmacolm (Renfrew)	1
Penicuik (M.Lothian)	1
Killearn (Dunbarton)	1
Shotts	1
Crossford	1
Blackburn (W.Lothian)	1
Total	430

TABLE XXX Western Area

Glasgow	67
Ardeer	33
East Kilbride	30
Kilmarnock	23
Irvine/Dreghorn	17
Motherwell	10
Johnstone	10
Troon	8
Paisley	6
Airdrie	6
Uddingston	5
Hamilton Motorway	5
Eaglesham	4
Newton Mearns	4
Alloway	3
High Blantyre	3
Hamilton	3
Strathaven	2
Dunlop	2
Fenwick	1
Total	242

The extent of the sales areas covered and the long distances over which sand and gravelare delivered, illustrate that sales of sand and gravel are not merely a function of haulage distance. From Carstairs to Killearn (Table XXIX Fig 54), is a road journey of fifty miles and yet sand and gravel is supplied from Carstairs to Killearn. Even more significant is the fact that there is a sand and gravel pit only three miles from Killearn, the products of which are at least the equal of these at Carstairs. As many as eight other producing pits excluding those of Upper Avondale, are nearer to Killearn than Carstairs. Although transport costs therefore do not necessarily delimit the sales hinterlands of pits, they do present a major factor in the price structure of the two commodities, for both sand and gravel have great weight and bulk in relation to their value. Transport costs have risen continuously since 1940. A major factor in this increase is the greater haulage distances permitted by widespread and flexible use of trucks. Table XXXI shows the increase, both absolute and relative, of the transport costs involved in sand and gravel prices. In 1940 and 1956 transport constituted 23.5% and 39% of gravel prices in Central Scotland. The equivalent figures for sand were 41.7% and 48.3% (Report on the Supply of sand and Gravel in Central Scotland H.M.S.O. 1956). It is generally agreed that for every fifteen miles of haulage sand and gravel prices rise by an amount equivalent to the ex-pit price. Exact prices, however, are also a function of company policy and competition.

TABLE XXXI



This combination of, and sometimes conflict between, physical limitations and human decisions, so common to geographers, is well-displayed in the sand and gravel industry. At one pit, only five miles to the north of Glasgow, the value of the deposit, being one of the few remaining pits close to Glasgow, has led to its being worked despite a till overburden as much as fifteen feet thick. One of the biggest, recent construction projects in Central Lanarkshire was the construction of the nine mile section of the M 74 Hamilton Bypass. An interview with Mr. Kennett (Materials Manager for the construction company) revealed/

revealed several interesting facts about sand and gravel production in Central Lanarkshire. Despite the extensive use of sand and gravel substitutes , crushed rock, slag and blazes, often more suitable and necessary for a particular function, 420,000 tons of sand and gravel were used in the construction of this stretch of the motorway, its bridges, cuttings etc. This quantity of sand and gravel is equivalent to more than a third of Central Lanarkshire's total annual production The contract also had certain other specifications. Less than 30% of the total requirements were for sand, and gravel formed more than two thirds of the material required. A large proportion of the supplies, 220,000 tons, had to be delivered during the eight months peak working period. Two immediate problems faced the Central Lanarkshire sand and gravel producers. Firstly, most of them, as has already been shown, are producing more sand than gravel and would therefore face difficulties in supplying the volume of gravel required. Secondly, to fulfill such a large order, especially in the short interval over which it was required, would have meant curtailing supplies to regular customers, an unwelcome prospect at any time. In the light of these problems only one Central Lanarkshire producer tendered for the contract. The only serious rival bid was made by a producer outside Central Lanarkshire. who dredges a very high-gravel-yielding river bed. Eventually, based on price considerations, the contract was given to the Central Lanarkshire producer at Thankerton. This firm, to meet the contract commitments, had to install a second plant capable of producing 250 tons of sand and gravel per hour. At the peak of production, sixty trucks were making five/

five round trips per day and delivering 30,000 tons of sand and gravel daily. Even then alternative sources of supply were utilised. One crushed-rock quarry and five other sand and gravel pits provided additional gravel supplies. The construction engineers found the qualities of Central Lanarkshire gravels "more than adequate" for the specification.

Other factors of human decision can also affect the exploitation of sand and gravel resources. The siting of new developments, urban and industrial, involves a considerable reorientation of sand and gravel production and deliveries (e.g. the Motorway, Table XXIX). On the other hand, because of criticisms levelled at the industry valuable resources have often become unobtainable due to the restrictions of landowners and planners. In the light of all the numerous factors affecting the location of sand and gravel plants the Report of the Advisory Committee on Sand and Gravel (H.M.S.O. 1948 Chapter IV p.24-25) outlines the following main conclusions "The commercial workability of a deposit depends on physical conditions:

1) A gravel deposit extensive enough in volume to enable a fixed plant to work for at least 15 years.

2) An overburden shallow in relation to the thickness of the gravel beneath it and not too intractable for economic working (e.g. 10 feet overburden is unduly expensive unless the gravel is 40 feet thick).

3) A good proportion of the gradings of materials most in demand should be found in the working.

4) Ample water for washing.

5) Facilities for disposal of silt.

6)/

6) Accessibility from the broader point of view of road facilities and also the narrower one of working out an efficient scheme of quarrying and layout of plant".

These are certainly still the main considerations and are uppermost in the minds of all potential extractors. However, the preceding discussion has shown that numerous other factors are worthy of consideration at a more detailed local level.

2. Acquisition of Land and Planning Legislation

When all the factors previously mentioned in this chapter have been taken into account, it should be possible to assess accurately the value and potential of any sand and gravel deposit. Before the deposit can be utilised, however, two other major factors must be considered, the availability of the land and the restrictions imposed on its working by the local planning authority.

Extractors may purchase the land, buy the mineral rights or come to some other arrangement mutually agreed upon with the landowner. In practice, company policy and local circumstances determine the nature of the agreement. Some companies prefer to make a "lump" financial settlement and buy the land outright. In other cases this might not suit the landowner and payment may be made on a royalty per ton basis, with the landowner retaining ownership. In either event, tenant farmers may be in a particularly unfortunate position and may be relieved of their tenancy with only a minimum of compensation. The financial inducements offered by sand and gravel companies to landowners are normally great enough to overcome any prejudices or loss of amenity which may occur.

On a royalty basis of sixpence per ton and an annual plant output of 200,000 tons per year, neither figure being exceptional, a landowner would expect an annual income of £5,000. This is normally much greater than the income derived from the previous use of the land - usually farming. It is all the more rewarding when in fact only part of the land is at any one timeunavailable for farming purposes.

It is sometimes stated that sand and gravel bearing areas tend to provide only poor agricultural land. This is not necessarily so, (Report of the Advisory Committee on Sand and Gravel H.M.S.O. 1948 Part I Chapter I B), and in Scotland in particular areas of fluvioglacial deposits, often with a freerdrainage and lighter soils can frequently be distinguished by their richer, marsh-free vegetation. In Central Lanarkshire, however, the main sand and gravel bearing areas do not occupy high quality agricultural land. At Carstairs, (650 feet - 750 feet), the esker ridges with their peculiar topographic expression make ploughing difficult and provide only "unimproved" grazings which were formerly the common grazings of the Burgh of Lanark. In Upper Avondale, however, the smooth, level terraces, again at heights of 600 feet to 750 feet provide suitable arable land but many of the lower flats are liable to flooding and a large part of the area is covered by a peat layer up to fifteen feet thick. In neither of these areas has there been any serious competition between farming and sand and gravel extraction and in fact the sand and gravel companies can claim that the quality of the farmland on rehabilitation is in no way impaired and perhaps even improved.

Before sand and gravel companies can commence operations they have to submit detailed plans of their excavation procedures to the local planning authority for approval under the Town and Country Planning (Scotland) Act 1947. Recently, in fact, with the increased demand for sand and gravel workings, planning legislation has introduced further restrictions. In Lanarkshire potential producers now have to undertake the fulfillment of the conditions of eleven additional clauses. These attend mainly to the stripping and storing of soil overburden until such time as it can be restored, the phasing of development so as to produce as little interference to agriculture as possible, the communication to the planning authority of all plans for new developments and extensions and the removal of buildings and the suitable rehabilitation of the land on the cessation of working.

Even as early as 1948 the Report of the Advisory Committee on Sand and Gravel, (H.M.S.O. 1948 Chapter III p.23), noting the seriousness of the shortage of reserves in certain districts of England and Wales stated that "available reserves are so limited that it is important to ensure that no premature or inadvertant sterilisation of gravel results from ill-advised allocation of gravel bearing land to other uses". In Chapter VIII of the same report a graph showing the "Progressive Exhaustion of Reserves in the London Area", emphasises the seriousness of the situation.

TABLE XXXII

Progressive Exhaustion of Reserves in Greater London Area
(millions of cu.yds)

Region	1950	1970	1990
Vale of St. Albans	165	135	60
Western	130	50	-
Lea Valley	30	1	-
Eastern	18	1	-

The report, (H.M.S.O. 1948 p.23), concluded that "after a short period of very heavy demand, the demand for gravel is likely to remain at a level of about 25% above the pre-war level". Since the pre-was production of sand and gravel was about 30 million tons and the present production, after a continuous increase, is in excess of 90 million tons, this was a considerable underestimate. Both this report, and its successor, "The Waters Report" (H.M.S.O. 1955), prompted some of the planning authorities to give serious consideration to the problem of sand and gravel supplied. Cambridge County Planning Department, (Allocation of Land for the Working of Sand and Gravel Middle Anglia Gravel Region Oct. 1964), perhaps as a result of the problem of the Greater London Area, is one of those which had made a serious attempt to plan the utilisation of its sand and gravel resources. In Scotland with the much less extensive utilisation and perhaps with much greater resources of sand and gravel, these pressures have not yet been felt. Enough has already been said, however,/

however, to indicate that easily accessible, high quality deposits are already at a premium. Despite this background planning has until now been theoretical rather than practical. With the general lack of knowledge on the distribution of sand and gravel deposits, their qualities, volumes etc., and an absence of suitably trained staff, the planning authorities have not for example been able to allocate land for extractive purposes. Applications have been dealt with as they arise. The planner is often at a disadvantage of being unqualified to determine whether the qualities of a deposit merit the granting or refusal of planning permission. Nevertheless several producers "have found planning control a serious obstacle owing either to the refusal of permission to open new workings, (or to extend old ones), or to the imposition of conditions about such matters as to the restoration of land". (Monopolies Commission Report on the Supply of Sand and Gravel in Central Scotland 1956 p.16).

The planners' grounds for refusing applications are of several varieties. The main one is that mineral extraction involves the destruction of amenity. (1) where the ground is of great scenic attraction, (2) where the ground has scientific interest, (3) where the ground contains buildings or sites of historic interest. In Lanarkshire three such sites have been under dispute recently. The "Carstairs Kames" have been designated as a site of "Special Scientific Interest" by the Nature Conservancy and yet much of the area is now scheduled for mineral extraction. At Wilderness, Bishopbriggs, the Roman Wall of Antonine crosses an area of valuable sand and gravel resources and similarly at Hamilton/

Hamilton the Palace of Charelherault overlies a sand and gravel deposit. For all of these the planning authorities were not anxious to give planning permission. Secondly where land, after being worked, will not be available for some other productive use applications have been refused. One recent case in Central Lanarkshire involved a riverside farm steading which, after sand and gravel extraction, would have remained flooded. Thirdly, in order to maintain strict control over land allocation, planning authorities are not enthusiastic about granting permission to work areas which will "outlive" the contemporary twenty year Development Plan Period. Lastly if prospective users fail to comply with the planning legislation outlined earlier, or if the arrangements for the settling out of silt and discharge of water do not meet the requirements of the river purification boards, then planning permission would be refused or withdrawn. When permission is refused the decision may be taken to court where the case will be re-examined. The handicap of theplanning authorities is then most obvious for the extractors may claim that the deposit in question is the only one suitable for their purposes. The planner with a lack of knowledge is unable to counter this claim, with a suitable but perhaps less amenity-destructive alternative. A large number of these court cases have, as a result, been upheld in the extractors' favour. The publicity accorded to the recent court case on sand and gravel extraction on Loch Lomondside highlighted the arguments for and against mineral extraction in areas of great scenic and amenity value.

There is normally justification for the claims of the

planners,/

planners, the public and the sand and gravel producers. The Sand and Gravel Association (S.A.G.A.) of Great Britain, is fully aware of the adverse effect of bad publicity to the industry as a whole. "Refusal to answer the public's questions is a serious error. The Association now has its own Information Department ... The Information Department's main task is to tell people about sand and gravel before they have the opportunity to form their own misconceptions" (S.A.G.A. publication No.3 p.22). Thus the Association has published numerous pamphlets (see bibliography), to impress on their members; (1) the advantages of tidiness, tree planting and amenity preservation, (2) to publicise the essential nature of the industry to schools and the public, (3) to show the benefits the industry has provided in the fields of water sports, fishing, archaeology, nature study etc. This serious attempt at gaining the industry a responsible and priority reputation appears to be achieving results. Restoration of land to farming purposes after the removal of sand and gravel is now almost obiquitous. (Phs. 78 and 79). Where this is impossible the land may be built over or restored for other uses. (Ph 80). In some cases, even in wet pits, the restoration can appear quite natural and of scenic value (Ph. 81). Even before the exhaustion of the deposit the plant can be shielded by trees to offset the loss of amenity. Photograph 82 shows the effect of tree screening at a sand and gravel pit at Sevenoaks in 1948, upper photograph, and 1964, bottom photograph.

It appears that all too often neither the producers nor the planners have available all the relevant information. The most efficient and planned use of our sand and gravel reserves will only be

brought/

brought about by a wider and fuller investigation into the distribution and nature of the available resources and the problems their utilisation presents to all the interested parties.

3. <u>Present and Future Trends</u>

The sand and gravel industry in Central Lanarkshire has grown very rapidly since 1945. It utilises almost entirely fluvioglacial deposits. (5% river gravels). The mechanisation and modernisation of plant has been one of its most remarkable features. In 1956 only two of the pits in the area could supply washed sand and gravel, (The Monopolies Commission Report H.M.S.O. 1956 p.72), but by 1965 all the pits had installed washing plant. (The contrast in sand and gravel production since the early years of this century is partially illustrated by comparing photographs 83,84 and 73. The first photograph (Ph 83) is one of very few of its kind in existence and shows a sand and gravel pit at the time of the First World War. The second, (Ph 84), is of a pit during the Second World War. The third photograph (Ph 73) shows the almost completely mechanised industry of today).

One of the results of mechanisation is that the industry involves a large initial capital expenditure. The Monopolies Commission cited this and several other features as difficulties facing new producers coming into the industry. Another resulting effect is that the industry is gradually drifting away from its former "hit or miss" attitudes. Before installing plant, producers now want to know the volume of the deposit, its composition, its defects and the difficulties it/

it presents for working. They are hampered in this by a lack of basic knowledge about the depositional background of the materials and the techniques and methods of exploration available. The present investigation has tried to outline the various techniques and sources whereby relevant information can be accumulated. A more widespread investigation would allow a more realistic review of sand and gravel resources and help in their more efficient utilisation. This latter fact was realised as early as 1955 when the Waters Report, (H.M.S.O. 1955 Part 18 p.5), indicated that the "Ministry of Housing and Local Government and the Department of Health for Scotland are preparing a map of gravels and associated sands to show the distribution of the various types of deposit and the location of all gravel pits". After twelve years this has not yet materialised. A similar map for England and Wales did appear in 1965. This was the Ordnance Survey "Ten Mile" Sheet 2, "Gravel including Associated Sands". The map shows on a <u>ten mile to one inch</u> scale the distribution of production in <u>1959</u> and the location of sand and gravel pits producing 1 - 50,000, 50,000 - 100,000, and over 100,000 cu. yards of sand and gravel. In the light of the rapid recent growth of the sand and gravel industry, (almost 400% from 1958 - 1965 in Central Lanarkshire), this is an already outdated document. The other information that the map shows is the distribution, largely obtained from the Geological Survey one inch and one quarter inch maps and therefore already available in greater detail than shown on the ten inch map, of "Deposits of Economic Significance". These are classified as "Beach Shingle and Associated Sands", Valley Gravels/

Gravels and Alluvium", "High Level Gravels", "Bunker Pebble Beds and Blackheath Beds" and "Estuarine Alluvium". No estimates are given of quantities and qualities. In the light of some dubious drift classifications by the Geological Survey in Central Lanarkshire, the value of this even more generalised classification might be questioned. In fact the value of the whole map as anything more than an academic exercise is doubtful. Its justification as part of a series aimed at helping national planning is no more valid. All the information on the map sheet is readily available to county planning authorities in a more precise and up to date form.

Recently the industrial correspondent of the Scotsman, (The Scotsman, Edinburgh 2.2.66), reported that "the Government are to promote a survey of the Scottish sand and gravel industry in an attempt to ensure that their ambitious construction programme is not jeopardised through the lack of basic materials. The work is to be undertaken jointly by the trade itself, the Scottish Development Department and the Ministry of Public Building and Works. A meeting between those involved is to be held shortly to examine the situation. From that the committee that will conduct the study is expected to emerge and they will attempt to identify the reserves available and when they could be brought into use". This statement is reminiscent of that already quoted from the Waters Report in 1955 (H.M.S.O. 1955 p.5). The present investigation has shown that such information is already much sought after by planners and producers alike. However, it is perhaps appropriate to make the point that the criticism of the information on the corresponding map for England/

England and Wales indicates the senselessness of performing a similar exercise for Scotland. Planners and producers alike have their problems with sand and gravel; both could present numerous questions about these deposits which they would like to see answered, it is these answers which the proposed survey should be trying to provide. The enormity of the task and the limited resources made available for its completion will result in its being only of preliminary reconnaissance value. The bulk of the necessary investigation will remain untouched.

In the same newspaper report some sand and gravel producers are quoted as having found local authorities obstructive and unhelpful compelling "some merchants to bring in materials from 50 miles away although supplies exist locally". It has already been shown that such haulage distances are no longer abnormal in Central Lanarkshire and more important, that they do not necessarily reflect obstructions by the local authorities. (e.g. example already quoted of haulage between Carstairs and Killearn, Table XXIX). It is nevertheless true that local authorities do not have sufficient staff aware of the problems of sand and gravel resources and of those who would work them. Under these circumstances it must be difficult for local authorities to efficiently plan the utilisation of their sand and gravel resources. Whilst Government Departments can provide useful statistical information the real problems would be more adequately handled by technical and research institutions. The production of a map such as that already described is not the answer to the problem.

In the light of the Reports of the Advisory Committees, (H.M.S.O. 1948 and 1955), depletion of reserves appears to present the greatest/

greatest problem in certain districts of England and Wales. In Central Lanarkshire this is only true of the best quality deposits (Fig 50). The total volume of proven reserves, (183 million tons), at the present rate of working will last for more than a century. During that period no doubt new building practices and new building materials such as plastics will have eased the pressures on sand and gravel. However, at present new sand and gravel plants are being established only where very large resources, in excess of two million tons, are located. This immediately excludes ten of the twenty four resources deposits shown on Figure 50. Consideration of quality defects would certainly exclude several of the other deposits under present conditions. At present therefore the best deposits in terms of location, quality and ease of working have all been or are being utilised. The remaining deposits will provide increasingly difficult working conditions and less profitable returns.

The larger deposits, however, are not necessarily those of the best quality. This is particularly true in terms of gravel content. Many of the smaller deposits have a higher percentage of gravel material. For the more effective utilisation of these smaller deposits, many of which have been by-passed and are now located nearer the main markets than the present production localities, the re-introduction of smaller, temporary, mobile plants such as were formerly more common may be one answer. Undoubtedly some of the largest, untapped, high gravel content resources are to be found in the many suitable stretches of river beds. Only one plant, and that a small one, utilises river gravel/

gravels in Central Lanarkshire. This is on the Clyde at Thankerton, (Ph 85), Up until the present there has not been a great deal of "wet working", (dredging from water-covered sources), in Scotland, but in light of experience in the Greater London Area where wet workings, (Ph 86) sometimes even on a highly mechanised drag-line principle, (Ph 87), have long been the rule, this may be one of the most important future trends in Scottish sand and gravel production. Similarly beaches and estuaries have as yet been exploited on only a small scale (Phs 88 and 89). ("Nearly 90% of the sand and gravel used in Wales comes from dredging in the Bristol Channel" (H.M.S.O. 1955 Part XVI p.1).

It may be recalled that the shrinkage qualities of Central Lanarkshire are nowhere of the best quality. None of the deposits qualify to be included in the top two grades of Table XXVII. There is therefore a shortage of the highest quality gravels. In the light of investigations at the Building Research Station it appears that many of these defects can be overcome by suitable adaptations by architects and builders.

Lastly it may be appropriate to mention a topic which has only been touched upon in the present investigation - transport. Even the simple market survey carried out during this investigation revealed an unexpected complexity. The duplication of market areas and the supply of materials after expensive haulage distances of 50 miles, despite the local availability, at lower costs, of better quality products, inevitably involves a rise in sand and gravel prices and all new development projects. Whilst the benefits of competition and open markets/

markets in maintaining low costs and encouraging efficient production must be acknowledged, a certain amount of planning rationalisation of marketing appears to be called for. This, however, would call for a complete study by itself. The Monopolies and Restrictive Practices Commission, "Report on the Supply of Sand and Gravel in Central Scotland" (H.M.S.O. 1956) was mainly aimed at investigating the price control structure of the two marketing associations in Central Scotland. As a result of this report the price control system and the marketing association were abolished. This delicate question appears worthy of further study.

It must be concluded that the most characteristic trend in the sand and gravel industry of Central Lanarkshire has been and still is, one of change. The rapid development and modernisation of this industry since 1945 has fully met the needs and satisfied the demands of its market. The industry today, however, faces several increasingly important problems. Many of these problems can be eased by the research and help of public institutions and other research establishments. An increasing awareness of the problems and the background of sand and gravel production cannot but (help) benefit all the various authorities concerned with the utilisation of sands and gravels.

CHAPTER VII

CONCLUSION

As was first mentioned in the introduction this investigation can be regarded as having two distinct yet closely interrelated parts. The first part involves the study of the effects of the latest periods of glaciation on the landscape and the drift deposits of Central Lanarkshire. Particular attention is focussed on the determination of the direction of movement and the possible limits of penetration of the main ice streams. Much of the material left behind by these ice streams consists of fluvioglacial deposits. These consist largely of sands and gravels. The academic study of glaciation thus provides an insight into the origin and distribution of these two products. A third aspect of sands and gravels - their utilisation is the concern of the second part of this thesis. Here too an interesting and varied story is found but the investigation reveals that the story of sand and gravel utilisation is inseparably related to that of their origin and distribution.

The main conclusions are:

1) Central Lanarkshire has been overrun by ice on several separate occasions.

2) The latest of these ice invasions occurred during Zone I times and is, as suggested by Dr. J.B. Sissons, to be correlated with the stage elsewhere known as the Perth Readvance.

3) There is insufficient evidence to be able to definitely delimit the extent of penetration of this ice in Central Lanarkshire. There is, however, some evidence that the ice streams, derived from the west did not entirely cover the eastern districts of the thesis area. Other evidence, mentioned in the text, and from areas outside Central Lanarkshire may also confirm this theory.

4) A tentative limit of ice penetration during the Perth Readvance is suggested in Figure 48.

5) The wastage and withdrawal of the ice streams which formerly covered Central Lanarkshire led to the deposition of large areas of water-laid sediments. Most of these were of the type normally known as fluvioglacial deposits.

6) The processes of glaciation and deglaciation and the nature of the terrain in Central Lanarkshire together account for the origin and distribution of these fluvioglacial, sand and gravel deposits.

7) The sand and gravel deposits are at present being increasingly and profitably used in the construction industry.

8) The distribution of sand and gravel workings largely reflects the physical characteristics of the deposits imparted to them by their mode of origin and distribution.

9) Human decisions too play a major part in affecting the distribution of sand and gravel workings. Their influence is even more clearly shown in the complex issues of retailing sand and gravel.

10) Large deposits of sand and gravel, many of which are untouched, remain in Central Lanarkshire and at present rates of extraction/

extraction these will last for approximately 150 years.

11) None of the Central Lanarkshire sand and gravel deposits are of the very best quality. There is, however, great variation between the deposits. The effects of glaciation and deglaciation and the underlying geology again account for these variations.

12) The main defects to be found in some of the sand and gravel deposits of Central Lanarkshire are, coal, soft stones, clay and silt content, peat, lignite and only medium or low shrinkage qualities.

13) Most of these defects are removed or at least minimised by the processing methods. The Building Research Station is also carrying out investigations designed to improve the qualities of concretes made by using medium/low shrinkage gravels.

14) The most efficient utilisation of sand and gravel reserves depends on a more widespread distribution of the information, such as revealed during this study, of the "Distribution, Origin and Use of Sand and Gravel Deposits".

The object of this investigation was mirrored in a statement by Professor T.N. George in a report to the Scottish Council, (1961 p.28), "While it is highly unlikely that any large deposits of exceptionally valuable minerals remain to be discovered, there yet is widespread ignorance of the kind and quantity and distribution of each potentially useful mineral in Scotland; and a systematic survey, complementary to the work of the Geological Survey, is a major need to remedy this ignorance and to prelude further economic advance". Sands and gravels are at present Scotland's second most valuable mineral resource and their production is vital to the country's well-being/

being. This investigation, in a small area and in a small way, has shown how the application of academic research can contribute beneficially to practical problems.

APPENDIX I

Particle size analysis of deposits, by sieving and sedimentation techniques, proved to be a very useful research tool during the present investigation. It is felt that a more widespread use of these techniques could be very rewarding. There are, however, several problems involved.

The field and laboratory techniques are outlined in the British Standards (B.S.) publication No.1377. These are, however, of a generalised nature and were meant more specifically for soil investigations. During the laboratory till analyses it was found that it was not possible to follow the technique outlined without damaging the till sample and biasing the result. Especially with "Carboniferous" tills vigorous crushing is certain to break up individual particles of fine shale, coal and soft sandstone and the resulting particle size analysis result would be correspondingly altered. The addition of hydrochloric acid would likewise remove a large proportion of the limestone particles present. In the light of these problems and laboratory experience the following modified technique was used.

General Laboratory Procedure for Particle Size Analysis of Tills

1. Sample of till obtained in field.

2. Sample to be sieved is oven dried for 24 hours at a temperature of approximately 100°C. Size of sample 500 - 1,000 gms. (B.S. 1377 p.17)

(The/

(The size of sample is determined according to the largest size of sieve which will retain 20% of the total sample. For most Scottish tills this is somewhere in the region of No.7 size sieve).

3. Sample is now lightly crushed with a rubber headed pestle and mortar so that only discrete particles are retained on the No.7 sieve and the total weighed (It is advantageous to weigh out a round figure of the sample e.g. 500 - 600 gms. Great care must be taken to avoid crushing individual particles).

4. Sodium Hexametaphosphate is now added and the solution is stirred and left for 1 hour. (Only sufficient solution to cover the sample should be used).

5. The solution sample is now placed on the mechanical stirrer and stirred for 10 minutes, or until the sample is completely dispersed.

6. The whole sample is now transferred to a nest of sieves, e.g. Nos. 7,14,25,52,72,100 and 200 and placed on the mechanical shaker for 10 minutes.

7. Sieves and sample are again thoroughly dried. Sieve fractions retained are again recrushed (as in 3) making sure that all particles finer than the sieve size pass through.

8. The residue left on each sieve after hand sieving is removed, weighed and recorded.

9. On completion the sieves are thoroughly brushed and washed.

The above outline describes the method found most suitable for coarse sieving down to the 200 mesh size. It leaves a residue passing - usually between 30 and 50% for "Scottish Tills" i.e. 130 - 250 gms/

250 gms for a 500 gm sample. This residue can now be used to determine the percentage composition of the fine sand - clay material by the hydrometer or pipette methods.

Fine Analysis using the Hydrometer Method

1. The Hydrometers are calibrated (B.S. 1377 p.67) and graphs constructed.
2. Thirty gms. of material passing the 200 mesh sieve are weighed out.
3. One hundred mls. of sodium hexametaphosphate are added to the sample and the mixture is warmed and stirred for 10 minutes. Mixture is allowed to cool to room temperature.
4. The suspension is stirred on the mechanical stirrer for 15 minutes, or until suspension is complete.
5. The suspension is now transferred to a 1,000 ml. measuring cylinder and made up to 1,000 mls. with distilled water. (All the transferring should be done using distilled water in a washed bottle).
6. The suspension is shaken vigorously and the rubber stopper removed. The Stop Clock is started and readings are taken at suitable intervals. A record of the solution temperature at the times of these readings is taken simultaneously.
7. The hydrometer is washed in distilled water after each reading.
8. The shorter-stem hydrometer is used when the reading on the long-stem hydrometer approaches 1.008.

The reagents which are normally used in this laboratory experiment are Hydrogen Peroxide, Hydrochloric Acid and Sodium Hexametaphosphate/

Hexametaphosphate solution (see B.S. 1377 p.67 par.3).

The first two aid in removing impurities which may provide anomalous suspension results. If abundant plant remains are contained in the till the former may have to be used (see B.S. 1377 p.70 5a). It was thought however unwise to use Hydrochloric Acid as a reagent since it would obviously react with any limestone or carbon material included in the till (which may well be an important differentiating criterion) and provide a biased result. As a substitute procedure a small piece of the sample may be tested for reaction with these two substances and the results recorded as observed.

The tests on all samples should be as uniform as possible in order to ensure that the results are comparable.

The till analysis results are plotted on a Shepherd's triangle. The position of each till as shown in Figure I - A is a reflection of the percentage composition of that till in terms of 1) sand and gravel, all fragments retained on the 200 mesh or larger sieves, 2) silt and 3) clay size fractions. The latter two proportions were found by hydrometer techniques. The colours of the tills were determined whilst they were in solution. There is no distinct, observable segregation of any particular group of tills (Fig I - A). As was mentioned in the text it was originally thought that tills which were of distinct red and grey colours might have different particle size compositions. This was disproved by plotting the results of the particle size analysis of five red and five grey tills on the same graph (Fig I - B). This showed no segregation of tills on the basis of/

of colour. Further information of till characteristics using this technique would require a much more detailed investigation and closer correlation with the other factors involved.

APPENDIX II

Some of the results obtained by sieving representative samples of fluvioglacial landforms have already been presented in the text (Table XXV). Figure II A presents some of these in graph form. It can be seen that the graphs of the two esker samples decline quickest from right to left, this indicates the coarser nature of the sediments in these landforms. In contrast the kame and the morainic sample contain progressively greater quantities of finer materials.

A similar exercise was carried out on the upper Avondale "Lake Terraces" at two separate sites more than two miles apart. The lower strata of the terraces were deposited in a lake as deltaic spreads whilst the overlying strata were laid down as a more typical outwash sheet. The similar character of the deposits at the two sites can be seen in Figure II B. The underlying strata at both sites have more in common than the overlying outwash sheets which are also very similar. The graphs show that the South Torfoot deposits are consistently finer than the Loudoun Hill deposits. It has already been shown that this can readily be explained by the greater distance of the former site from the ice front to the west.

APPENDIX III

It was interesting to apply the particle size analysis technique to the investigation of the lake clays. At Stonehouse the rapid alternation of coarse and fine deposits (Fig 45) indicates that the lake was not always in a calm water environment. A representative sample of the clays shows that, while typically well-sorted and with an almost negligible fine sand proportion, the bulk of the "clays" consist in fact of silt-sized particles (68%). The "Stonehouse Clays" would be more properly termed the "Stonehouse silts".

The "brick clay" deposits, found in smaller pockets occupying depressions in the landsurface, normally consist entirely of clay. An analysis of these clays from the Auchenheath site indicates that they consist of almost 100% clay-sized particles (Fig III A). They appear therefore to represent a much calmer deposition environment than that at Stonehouse. The well-varved Auchenheath deposits (Phs 29 - 31) allowed the separation of the lighter and darker coloured varve samples. It was difficult, in hand specimen, to determine which of these represented the coarser and which represented the finer material. Size analysis by the hydrometer sedimentation method clearly distinguishes the two sections. The coarse light, coloured sample contains some silt-sized particles and when in suspension rapidly decreased from a hydrometer reading of

21 - 3/

21 • 3 after one minute to one of 9.0 after 24 hours. The fine - dark coloured sample, however, only decreased from 20.8 after one minute to 20.0 after 24 hours. After six days the hydrometer reading of the coarser sample had decreased to 4.25 whilst that of the fine sample remained as high as 16.0. This explains why only a small porportion of the graph of the fine sample is shown - the material largely remained in suspension and did not settle out during the course of the experiment.

APPENDI.

PRODUCTION OF SAND AND GRAVEL IN SCOTLAND
1958 - 1965

NORTH

	1958	1959	1960	1961	1962	1963	1964	1965
ABERDEEN	174,397	269,198	223,986	252,082	288,115	194,021	324,227	332,789
	57,586	44,435	63,181	94,125	87,816	163,904	148,850	198,497
	---	---	5,777	5,538	305	7,351	34,082	41,363
	231,983	313,633	292,944	351,745	376,236	365,276	507,159	572,639
ANGUS	141,790	164,660	185,685	126,539	165,509	193,696	179,322	168,455
	40,486	44,321	38,235	49,931	54,457	66,918	66,833	92,169
	---	---	7,207	2,976	2,424	1,120	12,477	1,155
	182,276	208,981	231,127	279,446	222,390	261,734	258,632	261,779
ARGYLL	291	13,042	40,603	150,690	70,494	180,303	130,532	70,975
	1,910	38,888	74,389	272,882	163,992	212,492	166,348	118,634
	---	500	25,600	72,390	3,056	30,400	17,664	40,482
	2,201	39,388	140,592	495,962	237,542	423,195	314,544	230,091
BANFF	4,114	6,032	2,751	7,098	8,550	13,682	7,940	18,892
	---	35	1,494	7,708	---	53,392	20,122	7,128
	---	---	2,091	---	---	---	---	---
	4,114	6,067	6,336	14,806	8,550	67,077	28,062	26,020
CAITHNESS	10,964	15,559	15,045	14,658	12,547	14,719	10,782	13,375
	21,358	23,381	18,543	21,934	17,885	20,594	17,467	17,463
	---	---	---	---	---	---	---	---
	32,322	38,940	33,588	36,592	30,432	35,313	28,249	30,838
INVERNESS	35,383	42,474	25,858	86,431	139,335	79,764	103,608	78,123
	26,678	56,166	45,535	216,503	166,302	57,726	145,686	108,260
	---	1,600	28,813	68,577	91,771	80,594	102,532	85,337
	62,051	100,240	100,206	371,511	397,408	218,084	351,826	271,270
KINCARDINE	4,130	4,503	798	3,582	2,781	2,897	1,556	2,981
	840	1,321	5,280	577	1,345	270	21,516	4,410
	---	---	1,916	4,163	---	4,815	---	---
	4,970	5,824	7,994	8,322	4,126	8,982	23,072	7,391

APPENDIX IV
(Continued)

	1958	1959	1960	1961	1962	1963	1964	1965
MORAY	23,592	27,227	31,653	37,610	69,617	65,002	64,164	78,041
	80,493	87,911	82,699	50,928	107,025	72,472	63,994	85,490
	—	—	—	—	—	3,200	—	—
	104,085	115,138	114,353	88,538	176,642	140,674	128,158	163,504
ORKNEY	820	4,370	4,350	12,309	11,200	3,357	3,591	1,976
	—	—	240	—	—	114	—	—
	—	—	—	—	—	—	1,090	—
	820	4,370	4,590	12,309	11,200	3,471	4,681	1,976
ROSS AND CROMARTY	17,708	80,123	43,768	58,931	61,981	30,188	19,999	23,218
	38,688	66,294	61,041	116,855	108,257	54,937	10,052	74,110
	—	3,210	8,258	5,382	19,358	14,497	12,701	24,272
	56,396	149,627	113,067	191,168	189,596	99,622	42,752	121,600
SHETLAND	—	—	—	—	909	4,999	6,255	5,260
	265	431	772	266	200	—	—	—
	—	—	—	56	—	—	—	—
	265	431	772	322	1,109	4,999	6,255	5,266
SUTHERLAND	48,181	31,156	18,428	31,004	48,111	29,925	25,076	19,673
	57,751	49,319	44,558	43,309	47,175	36,291	49,143	10,377
	—	—	—	6,261	2,548	1,843	2,680	1,051
	105,932	80,475	62,986	80,574	97,834	68,057	76,899	31,061

First figure refers to sand output, second to gravel, third to Hoggin and fourth to total.

SOUTH

	1958	1959	1960	1961	1962	1963	1964	1965
BERWICK	3,206	3,903	5,400	8,794	11,871	11,904	14,923	14,708
	---	---	690	7,118	11,132	8,096	12,691	11,961
	---	---	---	5,308	400	---	---	---
	3,206	3,903	6,090	21,220	23,403	20,000	27,614	26,669
DUMFRIES	57,432	75,825	94,798	97,065	100,998	87,873	78,524	100,776
	18,099	69,374	107,265	105,195	113,133	77,533	96,251	118,821
	---	---	---	156	2,168	8,442	10,633	5,591
	138,531	145,199	202,063	202,416	216,299	173,848	185,408	225,188
KIRCUDBRIGHT	8,167	9,143	7,788	10,233	13,299	9,140	6,606	6,975
	3,747	7,632	1,777	2,707	2,157	2,795	3,365	3,602
	---	---	5,087	24,169	12,507	15,720	9,238	18,736
	11,914	16,755	14,652	37,109	27,963	27,655	19,209	29,313
PEEBLES	45,310	89,761	132,313	193,808	192,820	228,525	356,835	194,226
	63,117	120,969	191,331	239,030	277,294	285,276	270,020	262,094
	---	1,337	---	1,248	52,030	39,215	32,008	7,015
	108,427	212,067	323,644	434,086	522,144	553,016	758,863	463,375
ROXBURGH	17,024	21,684	15,065	14,825	14,159	14,362	14,343	16,946
	---	501	532	278	12,839	339	117	---
	---	---	974	1,539	2,948	1,066	1, 388	171
	17,024	22,185	16,571	16,642	29,946	15,767	15,848	17,171
SELKIRK	2,760	4,495	3,653	912	14,159	4,423	28,723	28,665
	6,509	9,143	7,350	2,150	531	17,087	73,226	56,034
	---	---	---	3,062	1,651	---	---	---
	9,269	13,638	11,003	6,124	16,341	21,510	101,949	84,699
WIGTOWN	468	4,945	3,307	5,537	4,764	2,436	9,634	2,388
	269	525	3,939	2,011	2,811	8,247	27,334	3,915
	---	---	---	---	---	---	3,292	13,403
	637	5,470	7,246	7,548	7,575	10,683	40,260	19,706

EAST

	1958	1959	1960	1961	1962	1963	1964	1965
EAST LOTHIAN	10,444	10,199	11,146	10,992	9,413	7,058	8,839	7,897
	930	---	---	---	---	---	1,263	1,831
	---	---	---	---	---	---	---	---
	11,374	10,199	11,146	10,992	9,413	7,058	10,102	9,728
CLACKMANNAN	11,055	34,234	32,149	18,442	7,324	---	---	---
	6,364	18,054	15,548	9,545	4,688	---	---	---
	---	---	---	---	3,867	3,867	---	---
	17,419	52,288	47,697	27,987	12,012	3,867	---	---
FIFE	326,014	348,033	173,538	159,570	152,486	150,101	183,543	173,247
	45,282	47,177	38,198	44,927	56,051	71,225	43,950	88,228
	---	---	1,636	5,624	13,533	29,336	14,035	25,178
	371,296	395,210	213,372	210,121	222,070	250,662	281,538	286,653
MID LOTHIAN	139,672	168,867	163,138	169,749	181,241	174,466	214,654	189,933
	8,451	1,811	2,600	2,409	6,351	8,804	10,977	112,968
	---	---	---	---	---	---	---	26,696
	148,123	169,678	165,738	172,154	187,592	183,270	225,631	329,597
KINROSS	---	56,806	56,053	94,957	31,934	122,591	132,981	96,933
	---	48,253	49,006	128,425	119, 275	152,762	180,249	157,709
	---	---	3,411	1,461	---	---	---	---
	---	105,059	108,470	224,843	151,309	175,353	313,230	254,642
WEST LOTHIAN	23,155	46,171	59,938	65,207	40,278	33,852	45,760	61,901
	30	---	10,018	43,094	19,350	26,961	26,886	43,185
	---	---	11,691	3,286	---	4,000	25,063	4,241
	23,185	46,171	81,647	121,587	59,628	64,813	97,709	109,327

First figure refers to sand output, second to gravel, third to Hoggin and fourth to total.

CENTRAL

	1958	1959	1960	1961	1962	1963	1964	1965
AYR	242,682	259,874	286,969	264,923	260,214	305,216	304,944	344,302
	57,315	58,267	110,977	85,590	91,569	85,853	110,997	82,622
	---	---	---	---	7,947	2,915	5,626	70,750
	299,977	318,141	397,946	350,513	359,757	394,084	421,567	497,674
DUNBARTON	37,163	56,416	113,920	89,022	107,555	122,633	123,015	140,628
	54,765	49,318	100,667	81,438	70,149	95,101	88,099	72,026
	---	---	10,781	---	---	---	---	12,468
	91,928	105,734	225,368	170,460	177,704	217,734	211,114	225,122
LANARK	776,646	788,071	779,613	817,913	727,013	724,615	827,585	872,668
	249,065	259,810	251,504	291,614	301,211	325,279	663,280	527,233
	---	82,159	2,296	8,711	142,220	17,511	49,689	8,066
	1,025,711	1,130,049	1,033,413	1,118,238	1,170,464	1,067,405	1,540,554	1,407,967
PERTH	331,384	257,490	233,691	285,584	239,417	302,910	335,129	375,595
	332,484	251,196	231,997	255,213	256,976	286,423	459,826	378,346
	---	---	18,881	13,008	21,229	353,930	53,935	109,720
	663,868	508,686	484,569	553,805	517,622	943,263	848,890	863,661
RENFREW	103,312	78,231	95,665	121,970	102,771	160,018	149,547	160,359
	39,837	29,244	48,455	77,157	117,321	156,833	90,924	133,653
	---	---	---	---	---	15,563	---	---
	143,149	107,475	144,120	199,127	200,092	332,414	240,271	294,012
STIRLING	138,504	166,514	174,780	156,782	196,963	299,712	392,278	373,452
	76,646	72,104	147,796	63,317	67,768	182,863	187,676	314,208
	---	15,937	---	---	---	1,441	---	---
	215,150	254,555	322,576	220,099	264,731	484,016	697,954	687,660

First figure refers to sand output, second to gravel, third to Hoggin and fourth to total.

TOTALS

	1958	1959	1960	1961	1962	1963	1964	1965
Building & Lime Sand	1,382,444	1,509,866	1,334,481	1,482,906	1,547,024	1,662,655	1,718,092	1,542,900
Concreting Sand	1,366,964	1,615,651	1,700,900	1,914,283	1,841,617	1,978,452	2,387,637	2,868,476
Gravel	1,336,023	1,455,889	1,796,202	2,312,946	2,283,844	2,464,938	3,364,305	3,144,619
		104,743*	134,415*	229,853*	371,176*	620,643*	388,138*	490,520*
GRAND TOTAL	4,085,431	4,686,149	4,926,002	5,910,018	6,043,655	6,726,688	7,858,172	7,555,995

* Hoggin (not used as aggregate)

A P P E N D I X V

THE SCOTTISH SAND AND GRAVEL INDUSTRY

1. Past and Recent History

One of the greatest problems involved in studying the growth of the Sand and Gravel Industry in Scotland is the general absence of factual information. This was a difficulty also experienced by the Advisory Committee on Sand and Gravel (H.M.S.O. 1948 Chap.II p.18) who found that due to changes in the basis of compilation of statistics no comprehensive statistics were available for dates up to 1935, and that since that date "their failure to tally with the more accurate statistics of the Ministry of Works ... makes us hesitate to rely on them". In Scotland accurate statistics are only available from 1958 and it is not possible to give a complete statistical summary of production before that date. The Scottish Sand and Gravel Industry is, however, a very recent creation. "In 1939 there were less than ten companies with mechanised plants operating "(Maclean 1960 p.99). By 1958 there were one hundred and twenty one operators. Such production figures as are available also reflect this rapid and comparitively recent growth. In 1938 the Scottish sand and gravel production was 1,038,005 tons by 1964 it was more than 7¾ million cu. yards. (Min. Public Building and Works Statistics). Whilst the English and Welsh production increased more than four-fold in this period, Scottish production increased seven-fold. The extensive and traditional use of building stones was the main reason for the low output of sand and gravel/

gravel in Scotland prior to 1938. During the Second World War, however, an increasing demand and an influx of English contractors who had been accustomed to using sand and gravel prompted the greater utilisation of fluvioglacial deposits. Large amounts of crushed rock are still used and there are some uses for which it is used in preference to gravel e.g. where consistency in quality is essential as in "Blacktop" road surfacing. Crushed rock has the advantage over a fluvioglacial aggregate in that its composition, of only one rock type, precludes wide variations in characteristics. It is, however, now realised that rounded, sub-rounded gravel pebbles produce concretes whose strengths are at least the equal of crushed rock aggregates (Anderson p.6 H.M.S.O. 1948 p.18) and with this last objection removed sand and gravel began to be used in almost every construction project. By 1953 (H.M.S.O. 1956 p.18) the annual production of sand and gravel, 2,700,000 tons had surpassed that of crushed rock, 2,400,000 tons and the gap has continued to widen since.

Until quite recently the market for sand and gravel was confined to fairly local areas because of the difficulties and economics of transport. Even as late as the 1940s Anderson (Anderson p.36) stated that the reserves of the Mount Vernon area, a district now within the City of Glasgow, had not been exploited "owing to its slightly greater distance from Glasgow". The further development and improvement of haulage vehicles, however, together with the continually increasing demand has led to regular haulage distances which were unthought of only fifteen years ago. In the light of the evidence of the preceding

chapter,/

chapter, with the increasing exhaustion of nearby and suitable reserves haulage distances seem to be destined to even greater increases in the future.

2. Present and Future Conditions

Through the efforts of the officers of the Geological Survey the drift geology of a large part of Scotland is already recorded. Thus from the one inch and six inch Geol. Survey Drift Sheets, when available, many potential sand and gravel bearing areas can be located. It has already been shown, however, that sand and gravel deposits, in their fluvioglacial form have a highly variable character. Much more detailed research is required before the full value, the advantages and the disadvantages of Scottish reserves can be estimated. The distribution of present production, however, can be more accurately assessed from statistics provided by the Ministry of Public Building and Works and the following information is largely derived from this source.

Figure V A shows the increase of sand and gravel production in Scotland from 1931 to 1965. Since 1960, although the total output has increased by two and a half million tons, the number of producing pits has decreased by three. In general therefore the average pit size has been increasing. These features, however, are not evenly distributed. The Central Region (Ministry of Public Building and Works regional division) has always produced the largest output of sand and gravel (Fig V B). The northern group of counties is/

is next with slightly less than half the production of the Central Region. The East and the South (Fig V B) produce similar but smaller quantities of sand and gravel.

A closer examination of the annual county production statistics, (Appendix IV), reveals further interesting facts. Some of these are shown in the four maps of Figure V C. On the first of these maps the dominance of the Central Region can be seen. In comparison in 1965, adjoining map, the area of large scale production can be seen to have expanded. In the Central, Eastern and Southern Regions, the individual county production figures have generally increased steadily over this period. Only exceptionally does production fluctuate widely as a result of locally increased consumption e.g. Tay and Forth Road Bridges and the Hamilton Motorway. In the Highlands, however, county production of sand and gravel tends to vary widely. The most numerous pits are owned by the Forestry Commission and produce only small amounts of gravel for forestry, roads etc. In the past, however, occasional very large scale construction projects have created temporary "booms" in sand and gravel production. Some of these features can be seen on the third and fourth maps of Figure V C.

Argyll is typical of many Highland counties (Fig V - D). Here the distinction between the few , larger, temporary pits producing for hydro-electric construction schemes and the numerous, small, Forestry Commission and local pits can readily be seen. The upper quartile division for the Northern or Highland region is consistently

around/

around 10,000 tonsand the median producing pit about 5,000 tons or less. In contrast Lanarkshire exhibits the features of a county whose production is geared towards a consistently large market. The location, by size, of the producing pits on a vertical scale provides a much more even distribution. As a result the quartile divisions reflect much greater pit productions. The upper quartile divisionvaries between 100,000 and 200,000 tons/annum and the median pit size has increased from 40,000 tons per annum (1958) to 80,000 tons per annum (1964) (Fig V D). Lanarkshire therefore shows a rationalised picture of large scale and mechanised sand and gravel production for a reliable market. Argyll on the other hand, being farther removed from the Central Scotland markets, is an example of production for only local requirements which may occasionally be increased as a result of temporary large scale developments.

In the text, however, it was shown that there are distinct problems facing producers in Central Scotland. The best quality and easiest worked deposits are speedily being worked out. As a result there has been a recent tendency for production localities to become farther removed from the large urban markets. The production of counties such as Perth, 4 tons/inhabitant 1965, and Peebles 31 tons/ inhabitant 1965, (Min. of Public Building and Works Statistics) reflects this trend (Fig V C fourth map).

This trend can be shown in another way. The Clydeside Conurbation is the biggest single market for sand and gravel in Scotland. Much of this is derived from Central Lanarkshire, (Chapter VI),but the remainder/

remainder is derived from an even wider area. During the investigation the sand and gravel marketing survey was expanded to include numerous other pits in Central Scotland and overlapping into the Highlands and Southern Uplands. For each of these pits the percentage of an "average day's" production which was delivered to the Conurbation was calculated. These figures were plotted on a map (Fig V E) and lines drawn to delimit the zones in which 90%,50% and 30% of the total output was delivered to the Conurbation (shaded on map). The pits (triangle symbol) which only occasionally send sand and gravel are not numbered. The very wide source area of the Conurbation's sand and gravel supplies can readily be seen. Especially noticeable are its deep penetration into Perthshire and into Clydesdale as far as Southern Lanarkshire. The large Peeblesshire production already referred to appears to be aimed primarily at the Lothian markets.

In the light of past and present conditions there is no foreseeable reason for sand and gravel production to decrease in the future. Crushed rock is an expensive substitute and is only used where its special qualities are desired. Blaze, the refuse from two centuries of coal and oil shale extraction, presents problems but can be used for less demanding uses. This alternative, however, is restricted to the Carboniferous Central Lowlands and although cheaper at present prices, will, with the rapid exhaustion of suitable reserves, provide only a temporary source. Crushed slag is more expensive and limited to a few production centres and cannot become a major alternative. Sand and gravel therefore will remain the backbone of Scotland's construction industry for many years to come.

A P P E N D I X VI

SAND AND GRAVEL QUESTIONNAIRE

A. **Pit Details**

1. Name and address of firm:

2. Name and address of pit(s) in Lanarkshire and their dates of opening:

3. As above for solid rock quarries in Lanarkshire:

4. Other functioning pits or quarries outside Lanarkshire:

5. a) Total Annual Production of Lanarkshire Pit(s)

   b) Previous production figures:

   c) Future plans, expansion or contraction, life expectancy:

6. a) Volume of deposit worked up to present:

   b) Volume of deposit remaining to be worked:

   c) Total volume of this resource:

7. Nature of deposit being utilised, origin, consistent or variable composition, preference given to any one section or strata within excavation, reasons.

8. Qualities of sand and gravel:

   a) Percentage of various (BS) size grades produced:

   b) Shrinkability value:

   c) prevalence of impurities:

      i) clay and silt:

      ii) coal and lignite and timber:

      iii) others and importance of these: (if possible percentage)

   d) Percentage of waste products (by weight or volume)

      i) fine fraction

ii) coarse fraction

e) What tests have been carried out on deposit and by whom:

9. Problems of pit itself:

a) Water supply:

b) Access:

c) Ownership:

d) Expansion:

e) Distance to markets:

10. Markets for sand and gravel by percentage if possible:

a) Date:

b) Destination:

c) No of Loads:

11. Changes in market areas past and future:

B. <u>General Statements on Industry as a Whole</u>

12. a) Problems or otherwise due to resources themselves, lack of gravel, etc.

b) Planning permission and economics of pit:

c) Trends, larger units, technological advances, e.g. ready mix concrete, concentration on different qualities of deposits, etc.

APPENDIX VII

ROCK TYPE SAMPLING FORM

ROCK TYPE/ORIGIN ANALYSIS OF TILL

Rock Type	Highland			Central Lowlands									Old Red Sandstone				Southern Uplands					?
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Sample No.																						

Key to Table

1. Quartz Mica Schist) Dalradian
2. Lowgrade Metamorphosed Schist) Dalradian
3. Others) Dalradian
4. Limestone) Carboniferous
5. Sandstone) Carboniferous
6. Shale) Carboniferous
7. Coal) Carboniferous
8. Calcareous Siltstone) Carboniferous
9. Ironstone) Carboniferous
10. Whin) Carboniferous
11. Basalt) Carboniferous
12. Others) Carboniferous
13. Sandstone) Old Red Sandstone
14. Felsite and other Intrusive) Old Red Sandstone
15. Lavas) Old Red Sandstone
16. Others) Old Red Sandstone
17. Quartz Conglomerate) Ordovician Silurian
18. Greywacke) Ordovician Silurian
19. Haggis Stone) Ordovician Silurian
20. Chert) Ordovician Silurian
21. Others) Ordovician Silurian
22. Unidentified

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