THE ENGINEERING PROPERTIES OF GLACIAL TILLS IN THE TAFF VALLEY, SOUTH WALES

by

J.D. LEWIS B.Sc., F.G.S.

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Certification of Research

This is to certify that, except when specific reference to other investigations is made, the work described in this thesis is the result of the investigation of the author.

..John D. Lewis..
J.D. Lewis
(Author)

..24th September 1983..
(Date)

G.O. Rowlands....
Mr. G.O. Rowlands
(Director of Studies)

26th September 1983.
(Date)

B. Isaac........
Mr. B. Isaac
(Supervisor)

26 September 1983.
(Date)

Colin Harris........
Dr. C. Harris
(Supervisor)

7th October 1983.
(Date)

Declaration

This is to certify that neither this thesis, nor any part of it has been presented, or is being currently submitted, in candidature for any degree at any other University.

John D. Lewis

(Author)

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ABSTRACT

TITLE The Engineering Properties of Glacial Tills in the Taff Valley, South Wales.

Author J.D. Lewis

The present study assesses and examines the range of geotechnical properties that are to be experienced during an investigation of the glacial and periglacial soils of the Taff Valley.

The study procedures adopted and the techniques used were chosen from a review of the relatively limited literature relevant to the subject.

Detailed engineering geological and geomorphological mapping was carried out at a scale of 1:10000. Geological mapping has shown that the nature of lodgement tills is much more strongly dependant on local bedrock geology than that of melt-out tills and fluvioglacial deposits. Solifluction deposits closely resemble the soil types from which they are locally derived.

Geomorphological mapping has provided a suitable method of identifying and genetically classifying soils when related to models of glacial and periglacial processes. These models should be used to assist in the design of ground investigation programmes to ensure their efficiency in terms of data retrieval and cost.

Quantitative studies of soil mesofabric have been used effectively to interpret local and regional glacial regimes and also to delineate areas of past and present slope instability. Qualitative studies using the scanning electron microscope have demonstrated that glacigenic soil types may be genetically differentiated and classified upon the basis of microfabric characteristics.

Laboratory testing (classification, shear strength and permeability) has identified significant geotechnical differences between soils of differing modes of genesis and post-depositional history. The range of engineering properties attainable is directly attributable to textural heterogeneity within and between soils, particularly in terms of relative degrees of clast and matrix dominance.

An investigation of the permeability characteristics of these soils has enabled reliable estimates to be made of the permeability of gap and well graded glacial soils by relatively cheap indirect methods. Grading curves and the modified Kozeny-Carman equation with a suitably applied correction factor have been used.

The theories of soil genesis that are presented and the relationships that are drawn between soil types, landforms and geotechnical properties could provide a basis for the interpretation of site investigation data in other localities and regions that have undergone or are currently undergoing glaciation.

NOTATION

A	=	Soil cross-sectional area.
Ap	=	Surface area of irregularly shaped particles
Asp	=	Area of spherical particles
a/b/c	=	Clast morphometry axes
C	=	Pore shape factor
CH	=	Clay of high plasticity
CI	=	Clay of intermediate plasticity
CL	=	Clay of low plasticity
Cv	=	Coefficient of consolidation
c	=	Cohesion (total)
c'	=	Cohesion (effective)
c^1	=	Kozeny constant
$D_{'n'}$	=	Particle size by mass
dm	=	Particle mean surface diameter
dpi	=	Average grain diameter
H	=	Sample height
i	=	Hydraulic gradient
k	=	Coefficient of permeability
ke	=	Estimated permeability
km	=	Measured permeability
L	=	Clast vector magnitude
$M\phi$	=	Central tendency
m/c	=	Moisture content
NP	=	Non plastic soil
n	=	Porosity
'n'	=	Number
Q	=	Rate of discharge

R = Clast vector strength

S = Specific surface area

SD = Standard deviation

So = Specific surface area factor

T = Tortuosity factor

Vp = Volume of irregularly shaped particles

Vsp = Volume of spherical particles

WI = Plasticity index

WL = Liquid limit

WP = Plastic limit

Xi = Particle size fraction

$\bar{x}$ = Mean

η = Drainage path factor

θ = Azimuth of resultant clast vector

θd = Mean slope angle of proximal moraine face

θp = Mean slope angle of distal moraine face

μm = Microns

ρ = Bulk density

ρd = Dry density

σ_n = Normal stress (total)

σ'_n = Normal stress (effective)

σ_1 = Major principle stress

σ_3 = Minor principle stress

$\sigma\phi$ = Grading coefficient

τ = Shear stress (total)

τ' = Shear stress (effective)

ϕ = Angle of internal friction (total)

ϕ' = Angle of internal friction (effective)

ϕ_s = Particle shape factor

$\phi_{'n'}$ = Particle percentile diameter

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CHAPTER 1

LITERATURE REVIEW

1.0 Introduction

Within the past decade, significant advances have been made in the elucidation of the processes involved in the genesis of glacial till. Many workers, including Boulton and Derbyshire have recognised patterns of glacial sedimentation at the margins of modern glaciers. Boulton and Paul (1976) and Goldthwaite (1975) have shown that variations in the geotechnical properties between individual soil types can be directly related to the genetic modes of source, transportation and deposition. It is essential that these processes are fully appreciated before an appraisal is made of the textural, sedimentological and geotechnical properties of Pleistocene deposits encountered during site investigation.

Information gained from site investigations in the glaciated valleys of South Wales has been frequently found not to give a true indication of the expected behaviour of soils during construction. These materials show extreme variation in particle size, shape and grading and it is extremely difficult to obtain representative disturbed and undisturbed samples. They are also predominantly granular and their engineering properties are likely to be strongly influenced by their lithological heterogeneity.

It is hoped that this study will contribute to a deeper appreciation of the reasons for textural and geotechnical variability exhibited by glacigenic and associated soils. The results presented may also act as a guide for the improvement of site investigation planning and indicate the expected behaviour of soils in areas glaciated during the Pleistocene. Geotechnical properties are related to the glacial and periglacial land facets within the Taff Valley and to the inferred mode of deposition and post-depositional history of the characteristic compositional soil types. The construction of a genetic model will aid the assessment of problems likely to be encountered in these soils during excavation and construction. It will also assist in suggesting expected ranges of values and variability of soil properties and their spatial distribution and will provide a basis for choice of appropriate site investigation techniques.

1.0.1. Definitions

Whilst reviewing the available literature concerning all aspects of the genesis of glacial till and associated deposits and the development of their geotechnical properties, it became necessary to define many terms in common use at present. These terms, tabulated alphabetically, are defined and specified below in the context in which they are used within this research investigation.

Meetings held between British scientists interpreting modern and Pleistocene glacial deposits, reported by Boulton (1980), has crystallised definitions of some of the more loosely termed, process-related till types. These definitions in part have been used where applicable to the classification of tills in South Wales.

1. CLAST AND MATRIX

In a sedimentary deposit in which certain particles are much larger than the others, the larger particles (if fragments of pre-existing rock) are the clasts whilst the particles of smaller size comprise the matrix; (in part, after the American Association of Petroleum Geologists, 1949).

Unless stated to the contrary in this study, (for example, within fluvioglacial material), the matrix has been taken to include material of silt and clay size, whilst the clasts are the soil particles larger than silt size, (that is, sand, gravel, cobbles and boulders).

2. COLLUVIUM

A slope wash deposit, typically of silt and fine sand sized fragments. It is residual in, or flushed out from superficial deposits by water from melting snow, ice, rain or lines of springs or seepages; (in part after Rice, 1961).

3. DEBRIS

Supraglacially and subglacially derived clastic material that is disseminated in or on the ice as granular debris with an ice matrix; (Boulton, 1980).

4. FABRIC

The spatial orientation and dip of particulate matter within a soil or rock, or within an ice mass.

Derbyshire, McGown and Radwan (1976) recognise three classes of till fabric; a classification based upon features of both primary and secondary origin:

(i) the macrofabric; features including folds, thrusts and fissures;

(ii) the mesofabric; the disposition of clasts, and

(iii) the microfabric; the organisation of the till matrix.

5. FLUVIOGLACIAL

Of or pertaining to streams which are meltwaters from a body of ice; particularly for the material worked over and deposited by water within, beneath, or in the neighbourhood of a glacier or ice sheet; (after Challinor (1978)).

6. GLACIAL TILL (hereafter termed TILL)

A sediment whose components are brought into contact by the direct agency of glacier ice, and which, although it may suffer subsequent glacially induced flow, is not disaggregated; (Boulton, 1980).

Two approaches are adopted for the classification of till :-

(i) a genetic classification based upon the modes of formation and deposition, and

(ii) a classification according to textural properties.

(i) Genetic classification

(a) Lodgement till

An aggregated sediment accumulated subglacially by accretion from debris rich ice in the basal zone of a glacier, often suffering varying degrees of shear and stress relief; (in part after Derbyshire (1975)).

(a1) Comminution till

A lodgement till sub-type suggested by Elson (1961), containing a predominance of material that has undergone primary comminution by abrasion and interaction between particles in the subglacial environment.

(a2) Deformation till

A second lodgement till sub-type that is the result of penetrative deformation (brecciation, folding, plucking and thrusting) of subglacial sediment or bedrock. Glacially induced strain patterns have deformed the substrate to sufficient an extent that pre-existing sedimentary structures are overprinted; (in part after Elson (1961) and Banham (1977)).

(b) Melt-out till

An ice-free aggregate accumulated by slow surface or basal melting of a stagnant ice mass, often preserving an englacial and/or subglacial debris fabric. Described by Boulton (1970b).

(c) Flow till

Partially stratified, flow-textured till that has accumulated by downslope movement of a debris morass due to porewater pressures or particular gravity or imposed stresses when at or above the liquid limit. The debris has its source as an accumulation on the glacier surface or surface of ice-cored morainic units or by the melting out of material in subglacial cavities; (in part after Boulton (1971)).

(ii) Textural classification

The interplay between rock resistance and joint frequency, and glacial abrasion and quarring produces a range of till textures, three conditions of which are recognised by Derbyshire, McGown and Radwan (1976) :-

(a) Clast-dominant (granular)

The coarser particle sizes or modes predominate such that the material behaves as a granular mass with clasts coated in fines or aggregations.

(b) Well graded

Neither coarse nor fine modes dominate the texture, resulting in a complex interaction of all particles.

(c) Matrix-dominant

The fine mode or modes predominate such that the contained clasts behave as discrete particles within the matrix.

Derbyshire (1975) shows the spatial distribution of tills (texturally classified), within the United Kingdom as a whole, as shown in Figure 1.1.

7. HEAD DEPOSITS

An unconsolidated soil derived from underlying bedrock or partially indurated deposits transported in a saturated state by flow from higher to lower ground. It is usually associated with solifluction in a periglacial environment.

8. MORAINE

A morphological term used to describe facets of the landscape of which till is the compositional sediment.

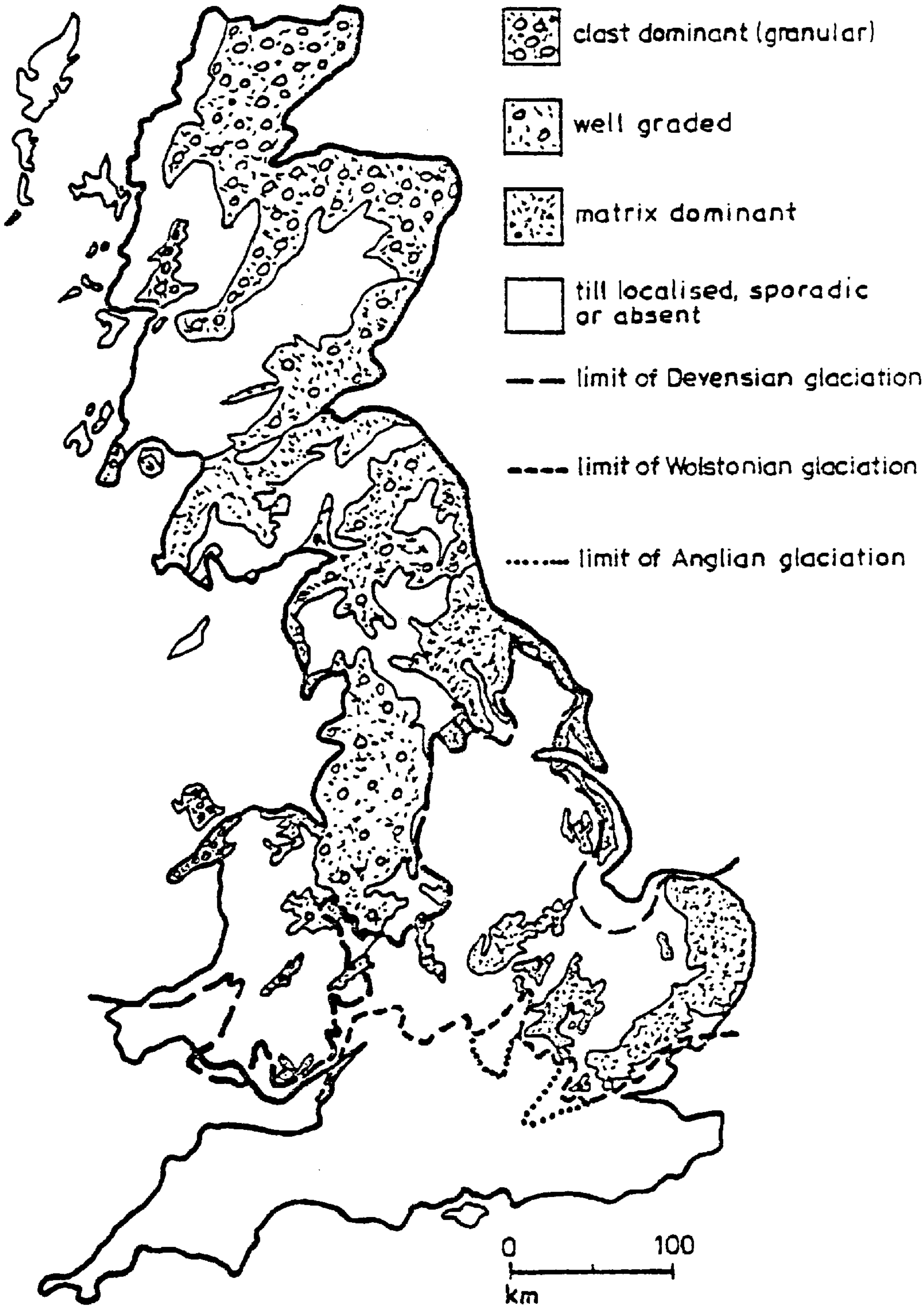


FIGURE 1.1

TILL TEXTURES: THEIR SPATIAL DISTRIBUTION IN THE UNITED KINGDOM

(partly after Derbyshire, 1975)

9. SOIL

Sediments and other accumulatons of solid particles produced by the mechanical and chemical disintegration of rocks regardless of whether or not they contain an admixture of organic constituents, (after Terzaghi (1943)).

10. SOLIFLUCTION

The process of gravitational mass movement on slopes in periglacial areas where saturated soils undergo slow downslope flow as a result of soil freezing and thawing.

11. TEXTURE

The character of a soil or rock determined by size, size-variation, shape, packing and orientation (fabric) of the component particles, and by any pore space between them; (after Challinor (1978)).

1.1 Review of Literature

1.1.1 Introduction

The wide and varied literature concerning glaciation, till genesis, characteristic landforms and the engineering properties of tills, stem from three main approaches to the acquisition of data:

(i) Subsequent to the advent of the glacial theory in the mid-nineteenth century, the development of glacial geology undertook the study of the textural characteristics of Pleistocene deposits. This initially began with the qualitative appraisal of the textural properties of glacigenic soils and was subsequently followed by quantitative methods of analysis, namely associated with study of till fabric.

(ii) Secondly, the study of glacial processes and sediments, modes of deposition and the character of the sediments produced beneath and at the margins of modern glaciers, is the approach that has been adopted notably within the past two decades.

Practical problems encountered during site investigation in Pleistocene and recent glacial deposits, for example, the assessment of areas of expected textural heterogeneity, has necessitated the description of modes of development of textural variability and has resulted in the genetic classification of glacial deposits.

(iii) A third approach has enabled the acquisition of a large bulk of the available data concerning the textural and geotechnical properties of tills and associated soils. This has been obtained as a product of site investigation in areas with a bedrock cover of Pleistocene deposits.

1.1.2 Early contributions to till textural analysis

The main topic of investigation prior to the late 1950's was the description of till texture. Early contributions were mainly in the form of critical observations on mesofabric clast orientation; for example, Miller (1884) describing pavement boulder clusters in till near Edinburgh, stated that :

"The longer axis of the stone is often directed in the line of glaciation, and the pointed end is frequently, but not always, toward the ice source."

Bell (1888b) described clast orientation in Swiss glaciers to determine whether such orientation existed in transit.

At that time, till was regarded as being :

"a confused and pell-mell mixture of stones" (Geikie,J.;(1895)).

This impression remained little changed for many years because the data collected tended to be largely qualitative and selective.

1.1.3 Till fabric analysis

The first well documented, mainly quantitative statistical approach to the analysis of data was undertaken by Richter (1936) in the investigation of clast long axis orientation. In addition to amplifying the results of Miller, he concluded that some clasts showed preferred orientation transverse to glacier flow and suggested that this may be due to readvance of glacial ice. (An alternative theory, however, was proposed by Donner and West (1957) who suggested that clast reorientation was related to strong ice shearing resulting in clast roll).

Some techniques now standard in the analysis of till fabric (including data representation as rose diagrams and contoured stereographic plots of poles to clast long axis dip), were originally highlighted by Holmes in 1941 to accompany his highly statistical approach to an investigation of till in New York State. In relating the degree of clast roundness to azimuthal orientation and to the directional variation of glacier flow, he hypothesised upon the probable nature of the transportational environment in response to the spatial relationships of clasts within till.

Holmes commented on the gradual accumulation of 'ground-moraine till' (lodgement till) beneath the moving glacier, producing fabric patterns in successive layers of till which recorded occasional shifts in the direction of glacier flow. Comparisons were drawn with directions exhibited by intersecting sets of striae on adjacent rock ledges.

Adoption of the latter environmental approach exemplified a changing trend in the analysis and description of till fabric, that is, in the interpretation of the modes of till genesis from observed textural variability. The analysis of till fabric following the work of Holmes has included many contributions, the most notable of which are briefly discussed below :-

(i) Employing the extensive use of rose diagrams, West and Donner (1956) produced a chronology of the glaciations of East Anglia and the East Midlands by the differention of the Cromer, Lowestoft, Gipping and Hunstanton tills in those areas.

Supplementary data concerning ice movement in the Cambridge area was provided by Perrin (1956). He used X-ray analysis and chemical treatment of the fine soil fraction to determine the percentage variability of chlorite, illite, vermiculite, kaolinite, montmorillonite and goethite in the local Lowestoft and Gipping tills. By comparison of the proportions of clay minerals present in the tills with the variable amounts in the local Jurassic and Cretaceous formations, ice flow directions within the locality were differentiated. Widescale till grading variability was also determined, undertaken by the mechanical analysis of material less than 4mm diameter.

(ii) By three-dimensional fabric analysis, Harrison (1957) describes long axis azimuth orientation and dip of clasts within matrix-dominant 'ground and end-moraine' (essentially lodgement and subglacial melt-out tills) south of the Great Lakes. He relates clast orientation to englacial debris fabric, mode of deposition and post-depositional fabric modification.

In samples of both till types, discoid and blade shaped clasts were preferentially imbricated upstream to the former ice-movement directions. In lodgement till alone, the long axis azimuth of blades tended to lie in the horizontal plane whilst that of rod shaped clasts exhibited maxima dipping upstream.

Combining kinematic analysis of the mesofabric with evidence from microfabric and englacial debris studies, Harrison suggests that the bulk of the till fabric has been inherited from the transportational environment. The long axis azimuth direction of discoid and blade shaped clasts represents a little altered, remnant englacial debris fabric defining the original slip planes of the basal, debris rich glacial zone.

Some of the 'end-moraine' material exhibits clast orientation related to post-depositional solifluction. By comparison of exhibited fabric with that of known mudflows, the downslope preferred orientation of clasts reflects slope control of post-depositional till movement.

(iii) Penny and Catt (1967) undertook meso and microfabric analyses of tills of Wolstonian and Devensian age in Yorkshire and discuss the orientation and possible mode of genesis of observed till fissuring. They conclude that the texture, in particular clast orientation in the Wolstonian (Basement) Till, was considerably modified during glacial advance of Devensian (Weichselian) age. They confirm the earlier conclusions of Holmes (1941) and Donner and West (1957) by stating that clast reorientation such that long axes became to lie at right angles to the direction of subsequent ice advance, may be related to ice shearing below the glacier sole.

Thin sections of the Drab and Hessle tills (Devensian age) showed that sand sized particles of the microfabric exhibited the same preferred orientation and ice movement directions suggested by the clasts of the mesofabric.

Fissuring within the Basement and Drab Tills, they conclude, was related to ice movement. Within the former, fissures are originated as a/c direction tension joints inherited from the parent ice, whilst in the latter they are suggested to be conjugate shear joints formed during post-depositional till deformation.

(iv) Andrews (1971b) provides a comprehensive review of the methods employed within the previous four decades in the analysis of till fabric. He suggests that these methods may also be applicable to the study of fabric of any soil, regardless of origin. The techniques that he suggests may be included in the analysis of till fabric, are highlighted below;

(a) 'Fixed' effect sampling design that will include 'typical elements' of the sample population.

(b) Sample sizes of 50-100 determinations are required.

(c) Field determination of the length of clasts of between 8mm and 100-200mm (axial ratio (a/b) to be between 1.2:1 and 2:1);

(d) Field determination of clast shape and roundness using the Zingg (1935) classification and Cailleux index, respectively.

(e) Field and laboratory analyses of particle orientation and dip. This covers the measurement of clast parameters at an exposure, laboratory study of mesofabrics taken from oriented blocks or cores and the measurement of orientations of the microfabric in thin section.

(f) Analysis of results by graphical display of data. The methods involved include;

(i) rose diagrams; to display the number or proportion of clasts in different azimuthal classes.

(ii) Polar stereonets; to display all essential information on the bearing and plunge of individual clasts, hence having advantages over the two-dimensional rose diagrams.

(iii) Vector trend analysis; which is well suited for regional fabric studies since the end product is a map of iso-azimuths with preferred vectors.

(g) Statistical methods for the analysis of till fabrics may provide an estimate of mean population; a point of balance of data when azimuth and plunge are measured; degree of data dispersal about the mean, and a parameter to test the distribution of the fabric against, for example, a random or uniform fabric. Andrews suggests that three methods may be used;

(i) Two-dimensional vector analysis, as suggested by Curray (1956), which will allow the calculation of resultant vector (θ) and vector strength (R) for either grouped or ungrouped data. This will enable determination of variance, standard deviation and standard error (by usual methods) for data groups, allowing significance testing against an appropriate hypothesis.

(ii) Three-dimensional vector analysis for use when dips are measured, plunging orientation data toward a specific bearing.

(iii) Chi-square analysis providing a test of data reliability against a uniformly distributed fabric.

Andrews comments that till fabric analysis is particularly useful for the determination of ice movement in areas of low relief as well as providing a method of determining flow vectors during deposition of moraines, drumlins or lodgement tills.

By reviewing the available literature it has been found that description of the textures of Pleistocene tills of differing modes of origin has principally revolved around the analysis of fabric. Some modes of till genesis have been discussed, (for example, Harrison 1957), however little attention had been paid to the description of the textural properties of the soils until the mid 1960's. Research in Scotland has supplemented the literature not only by the description of till fabric variability with ice flow directions, for example, Kirby (1968 and 1969), but also by discussing textural heterogeneity within the meso and microstructure of Pleistocene tills. In order that the reasons for this variability may be more fully appreciated, work was undertaken to intepret the modes of till genesis at the margins of modern glaciers. Workers, for example Boulton, McGown and Derbyshire, have provided an insight into the development of textural variability by their observations in areas where till deposition is currently taking place. If observations of till genesis were to be made within a specific area, the actual location of sites where this was likely to occur would essentially be based upon the interpretation of glacial depositional landforms. An investigation of the relationship between till types and the landforms of which they are the constituent components was thus found to be an important aspect of study in the glacial environment.

1.1.4 Landforms typical of an area of till deposition

The study of glacial landforms of depositon and interpretation of their modes of formation has provided a means by which the geological processes involved in till genesis may be more readily appreciated.

As early as the later part of the 1920's, research by Charlesworth (1929) related the textural properties of 'boulder clay' (till), 'kame deposits' (ice contact fluvioglacial material) and fluvioglacial outwash, to depositional landforms (drumlins, kame terraces and outwash plains respectively) around the perimeter of the

'South Wales End-Moraine'. This was further expanded, in 'The Glaciations of Wales and adjoining regions' edited by Lewis (1967), to include landforms of erosion, for example roche moutonnées and melt-water channels.

It has only been relatively recently however that the geomorphological land facets typical of a glacial environment have been adequately appraised. This has arisen through most work being undertaken at the margins of modern glaciers. Some of the most notable contributions have been made by Flint (1957) and Price (1973), whilst Embleton and King (1968) and Sugden and John (1976) comprehensively report the findings of other workers. Those facets that they describe and that are represented by a typical suite of till types, have been discussed and associated with till genesis by Fookes, Gordon and Higginbottom (1975) and Boulton and Paul (1976). By reviewing and summarising their findings, (undertaken below), an assessment of the relationships between soil types and glacial landforms may be produced.

Derbyshire, McGown and Radwan (1976) discuss the textural properties of till contained within small Norwegian push moraines (1-0.5m high) and Icelandic till flutes, drawing relationships with their modes of formation. These land facets however, prove extremely difficult to discern in Pleistocene deposits, particularly those at the margins of glaciation in South Wales, and hence here do not require further discussion. Silt coated, sub-horizontal fissures within well graded lodgement till of drumlinised form in West Scotland and North Wales, they state, is to be expected to control stability of the feature when in sympathy with slope direction.

1.1.4.1 Sediment/Landform models

The interrelationship between sediment type and landforms in areas of glacial deposition is extremely complex. Fookes, Gordon and Higginbottom (1975) have simplified the condition by introducing and distinguishing three sediment/landform models or systems, based upon the application of terrain analysis to glacial landscapes:-

(i) The till plain land system, comprising lodgement till which may have a drumlinised surface.

(ii) The glaciated valley land system composed of 'ablation till' (melt-out and flow tills) and morainic ridges composed of supraglacial morainic till; and,

(iii) the fluvioglacial and ice contact deposit land system, comprising those deposits laid down by glacial outwash in the lateral and proglacial zones of an ablating glacier.

Commonly recurring landforms include eskers, kames, kame terraces, delta moraines and ice stagnation features, for example, kettle holes and hummocky terrain.

The systematic appraisal presented above differs from that of the modified approach adopted by Boulton and Paul (1976), working in modern glacial environments. Here three land systems are described in a predominantly environmental manner based upon the supraglacial, subglacial or proglacial location of formation and deposition of till.

A classification of tills and their landforms, based upon the recently devised sediment/landform models of Boulton and Paul (1976), McGown and Derbyshire (1977) and Boulton (1980), and accepted current till terminology is exhibited in Table 1.1. The former workers relate the genetic model to the development of the geotechnical properties (consistency limits, particle size distribution and consolidation characteristics) of the more major till types. This may be further applied to Pleistocene deposits and is hence here adopted. Using these models as a guide, geomorphological mapping of areas glaciated during the Pleistocene may also be more readily approached.

1.1.4.2 Geomorphological mapping of Pleistocene deposits

Geomorphological studies in glacial terrain, achieved using stereo air photographs and field geomorphological mapping, can supply important data not only concerning the nature of the superficial deposits to be encountered but also enable the identification of geotechnical problem areas, for example, unstable slopes and areas of surface groundwater. This can be both time and cost effective when undertaken by experienced personnel.

Norman (1969) and Dumbleton and West (1970) have used air photograph interpretation of till landforms as an aid to the determination of expected soil lithologies constituting individual features. This provides a useful tool for an engineering geological site appraisal.

LAND SYSTEM	TYPICAL LANDFORMS	SOURCE OF GLACIAL DEBRIS	POSITION OF DEPOSITION	PRINCIPAL TILL TYPES (PRIMARY DEPOSITION)	TILL TYPES RESULTING FROM SECONDARY REWORKING
GLACIATED VALLEY LAND SYSTEM (MAY BE SUPER-IMPOSED ON (ii) and (iii)	(1) MEDIAL AND LATERAL MORAINES KAME TERRACES	(a) SUPRAGLACIAL (NUNATAKS AND VALLEY SIDES)	SUPRAGLACIAL (MAY BE SUPERIMPOSED ON (b))	(1) SUPRAGLACIAL MORAINIC TILL	
(ii) SUPRAGLACIAL LAND SYSTEM	(2) KAMES HUMMOCKY MELT-OUT MORAINE			(2) SUBLIMATION TILL MELT-OUT TILL FLOW TILL (ALLOCHTHONOUS / PARAUTOCHTHONOUS)	FLOW TILL
(iii) SUBGLACIAL/ PROGLACIAL LAND SYSTEM	(3) DRUMLINS FLUTED MORAINES PUSH MORAINES	(b) SUBGLACIAL PROGLACIAL SEDIMENT ASSOCIATION	SUBGLACIAL	(3) MELT-OUT TILL COMMINUTION TILL LODGEMENT TILL SUBLIMATION TILL DEFORMATION TILL	DEFORMED LODGEMENT TILL
	(4) OUTWASH PLAINS AND TERRACES		PROGLACIAL	(3) FLOW TILL (ALLOCHTHONOUS / PARAUTOCHTHONOUS) MELT-OUT TILL	

TABLE 1.1

TILL AND LANDFORM CLASSIFICATION (AFTER BOULTON AND PAUL (1976), McGOWN AND DERBYSHIRE (1977) AND BOULTON (1980))

Brunsden, Doornkamp, Fookes, Jones and Kelly (1975), discuss the techniques involved in geomorphological mapping, relating them to highway engineering along part of Section 4 of the Taff Vale Trunk Road, South Wales. The principles and products of geomorphological mapping are described, accompanied by examples of morphological, drift, morphogenetic and process maps. The authors are of the opinion that geomorphological mapping could be much more widely undertaken in the United Kingdom. This could enable site investigation to be designed so that it does not become so much a probing exercise aimed at identifying geotechnical problems, but more a confirmation and assessment of the problems that have already been diagnosed in principle by a geomorphological investigation.

1.1.5 The methods and results of classification of tills and associated soils

As more information became available concerning modes of deposition of till, corresponding variations in texture (including fabric), and the relationship to depositional landform types, it became clear that a comprehensive classification of tills was required.

As discussed in section 1.0.1, tills may be classified by two approaches :-

(i) genetically classified according to their modes of formation and deposition, and

(ii) classified according to the textural properties exhibited; that is, clast-dominant, matrix-dominant or well graded states.

McGown (1971) recognises seven criteria and data types necessary for the classification of unstratified till :-

(i) location,
(ii) mode of depositional history,
(iii) lithology and mineralogy,
(iv) particle size distribution,
(v) classification of the fine soil fraction,
(vi) range of mix proportions within the till,
(vii) variation of properties over the range.

To this classification system fabric analysis may be added as a useful criterion to aid in identifying and classifying tills.

1.1.5.1 Classification by the interpretation of textural properties

Following the work of Holmes which included determination of the mode of development of a till fabric, individual studies have been undertaken to describe the texture of Pleistocene tills and intimately associated deposits as an aid to interpretation of their modes of genesis. Notable contributions include those of; (i), Krumbein (1953); (ii), Elson and Peckover (1960); (iii), Reading (1973); (iv), Horton (1974 and 1975); (v), Dreimanis (1976), and (vi), Harris and Wright (1980). Their results are reviewed below :-

(i) Krumbein (1953) used the quantitative method of particle size distribution to determine the variation of till sedimentological properties with ice movement over an area in east-central Illinois. Textural properties, frequency distribution and clast lithologies remained reasonably constant within a given ice sheet, but modification of the former characteristics was a result of local variations in drainage conditions and reworking of hitherto deposited soils during ice readvance.

(ii) Elson and Peckover (1960) describe changes in clast azimuth orientation and dip, direction of striae, particle size distribution, and the mechanical properties of natural and optimum densities, as an aid to till description and recognition.

(iii) Reading (1973) attributes till textural heterogeneity, in particular flow till lenticularity, to the complex mechanisms of soil genesis in the glacial environment. Localised proglacial reworking by fluvioglacial and glacilacustrine agencies, he comments, plays a dominant role in the spatial variability of individual till units.

(iv) Horton (1974) describes the textural properties of till, glacilacustrine deposits and fluvioglacial outwash lying on the deeply dissected pre- glacial topography of parts of north and west Birmingham. Soil profiles exposed by boreholes sunk in association with construction of the M5 and M6 Motorways have been related to mode of genesis and have been stratigraphically differentiated using palynological evidence where possible.

In Horton (1975) the engineering properties of these deposits are described and related to localised depositional conditions; for example, development of glacilacustrine deposits in a proglacial environment.

(v) Dreimanis (1976) describes the textural properties of lodgement, melt-out, flow, comminution and deformation tills. Some of his till terminology does not conform with current classification, however he does compare the terms used above with his own. He reviews the available literature concerning current till classification based upon genetic processes, providing sedimentological examples from North America, (the Great Lakes region in particular).

In the description of melt-out and flow tills, he particularly emphasises that difficulties are to be expected in distinguishing the two varieties in deposits of Pleistocene age, and in specifying the subglacial or supraglacial melting out environment of the former.

(vi) With specific reference to the interpretation of mode of origin of tills and associated deposits in South Wales, Harris and Wright (1980) have used textural descriptions and mesofabric analysis as an aid to soil identification. They have recognised four main categories of superficial deposits. These are :-

(i) valley floor alluvium
(ii) glacial deposits (till and fluvioglacial outwash)
(iii) head (solifluction deposits), and

(iv) landslip deposits; recognised by disruption of superficial deposits by shear surfaces.

Till and head deposits proved the most difficult to distinguish by visual inspection alone since textural properties were extremely similar when heterogeneity within the units was taken into consideration. However, fabric analysis by measurement of clast long axis azimuth and dip, distinguished the two types. Their orientation characteristcs are :-

(a) within head, clasts were strongly preferentially orientated down the valley-side slope, perpendicular to the contours. This was imparted by gravitational shearing force as material flowed downslope in a saturated mass.

(b) Within till, clasts showed downvalley orientations roughly parallel to the contours. These were interpreted as being the result of the subglacial shearing force that accompanies lodgement till formation.

Some sorting of material within head, in the form of wet sandy, silty and gravelly layers and lenses (acting as zones of greater permeability than the soil mass), is described as being of importance when short term stability of cuts in such material is to be considered.

Harris and Wright (1980) conclude that slopes within the widescale solifluction deposits of South Wales require careful investigation to relate textural properties to mode of origin before engineering works are undertaken.

1.1.5.2 Investigations in modern glacial environments

The interpretation of modes and environments of till deposition during the Pleistocene and a subsequent genetic classification has been based upon descriptions of till textural properties and genesis beneath and at the margins of modern glaciers. The mechanics of glacier flow are somewhat better understood than the mechanisms of till deposition which have only been partially elucidated within the past decade. Observational studies have been undertaken by Boulton, McGown, Derbyshire and others at the margins of modern temperate glaciers (in Spitsbergen, Iceland, Norway and the Alps), whilst Price (1973), Menzies (1979), and others have worked on polar and sub-polar glaciers. Their findings have contributed greatly to knowledge of the processes involved in the genesis of the major till types and of their characteristic textural properties. The patterns of till genesis that are described and the sequences in which the soils lie are considered to be directly applicable to till sequences in lowland areas of North America and Europe glaciated during the Pleistocene.

1.1.5.3 The genetic classification of till

Most of the major till types are briefly defined in section 1.0.1., however, description of some of the characteristic textural properties developed during formation and deposition of these tills are here required. McGown (1974), Fookes, Gordon and Higginbottom (1975) and Boulton and Paul (1976) describe these as an aid to interpretation of their engineering behaviour. Figure 1.2 illustrates the nature and relative locations of the major till types developed in

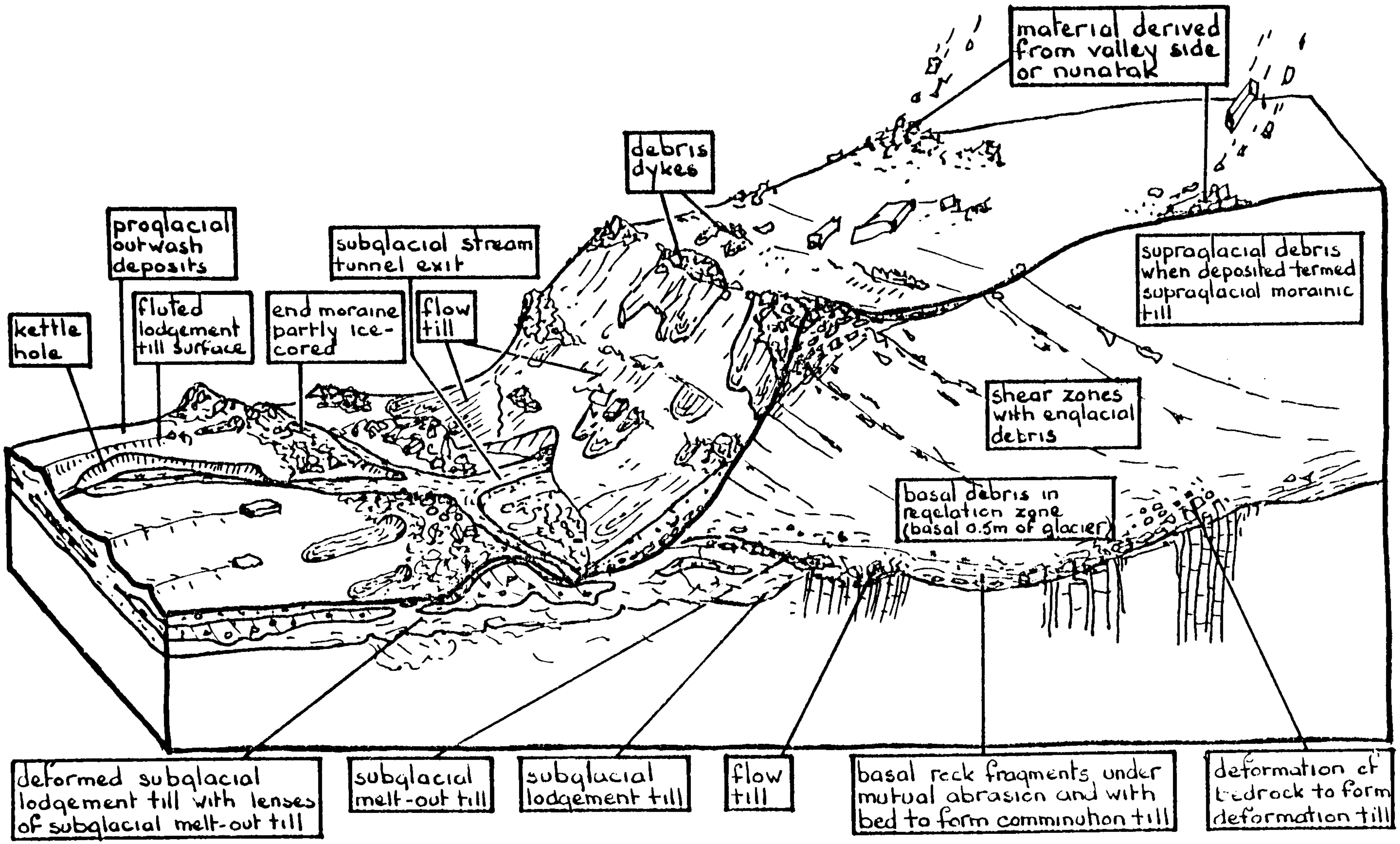


FIGURE 1.2

SCHEMATIC DIAGRAM TO ILLUSTRATE DEVELOPMENT OF TILL SEQUENCES AT SNOUT OF RETREATING GLACIER (partly after McGOWN and DERBYSHIRE, 1977) and around the snout of an active glacier, (partly after McGown and Derbyshire (1977)).

(i) Lodgement till

Debris has been described by Boulton (1970b) as being incorporated in the basal zone of polar and probably temperate glaciers by basal freezing mechanisms. In response to localised pressure differences in this basal zone of the glacier, resulting in pressure-melting of ice, subglacial debris is released from the sole during ice advance. This has been noted by Boulton to occur where obstructions lie in the ice flow path. Here the frictional resistance of debris particles against obstructions (for example, larger debris clasts) and the glacier bed, exceeds the tractional force exerted by the glacier resulting in till deposition. Boulton, Dent and Morris (1974) comment that the balance between lodgement of debris and reworking of hitherto deposited till depends upon the interplay of debris particle size and shape, irregularity of the glacier bed, local hydrostatic pressure and temperature of the glacier base, and the rate of ice flow.

Lodgement till is characteristically unsorted and contains a high percentage of silt and clay sized rock flour produced by attrition of underlying bedrock and interparticle contact at the glacier sole. Rock flour of silt size is the most common in Great Britain, however the matrix-dominant tills produced in areas of sedimentary bedrock tend to contain some in the clay size range accompanied by reworked clay minerals. McGown and

Derbyshire (1977) comment that the silt and clay sized particles of the microfabric tend to show a rather closed parallel arrangement (frequently coated around sand sized particles), with a sub- horizontal orientation somewhat parallel to the direction of ice movement.

Total stress within the till is dependant upon ice thickness whilst pore pressures that are developed are directly related to the efficiency of drainage with the till.

Following ice ablation the till is left in an overconsolidated state due to the removal of the surcharge load. Dessication after loss of the ice cover may further result in some degree of overconsolidation.

Within the major category of lodgement till, Derbyshire (1975) recognises two types of till classified by their formative processes :-

(a) In comminution till, abrasion and interaction between particles yields a distinctive grading curve reflecting the crushing characteristics of the dominant lithological and mineralogical components.

(b) Deformation Till

The plucking, thrusting, folding and brecciation of the glacier bed as it is overridden by ice, produces a till fabric reflecting the deformation of the underlying bedrock. A typical macro and mesofabric exhibited by deformation till shows a characteristic removal of stratal blocks in various stages of detachment from the substrate.

(ii) Melt-out till

Observations by Boulton (1976b) indicate that melting out is the main method of till accumulation. Debris that has collected supraglacially or subglacially and transported in an englacial position, may melt-out into a stable position. The till produced has been noted to frequently preserve structures derived from the englacial debris fabric. Boulton calls these 'melt-out tills'. He states that they can be produced by both melting of a debris rich ice mass from the surface downwards and by basal melting of buried, debris rich stagnant ice. The latter takes place at a very much slower rate, calculated by Mickelson (1971) to be at rates ranging from 0.5 to 2.8cm/yr.

McGown (1973) discusses the physical character and structural arrangement of the matrices of undisturbed specimens of silty and sandy 'ablation' (melt-out) tills. Samples obtained from modern glaciers in the Antarctic, Iceland and Norway and from Pleistocene deposits in the British Isles and Sweden, were studied under the scanning electron microscope. He highlights the variability exhibited by the microstructural arrangement of the matrices both within and between tills. Observations showed that an open arrangement of silt and sand sized particles coated in clay size material and flocculated cardhouse clay mineral arrangements were most widely apparent in Antarctic tills. Compact matrices with individual areas of clay size fraction and silt were typical of Norwegian tills, whilst those of Iceland exhibited an evenly spread matrix of silt and clay particles. Silt microclasts coated with clay size fragments (clay-silt buttresses) or clay-silt aggregations were the norm within Pleistocene tills.

The compactness of the matrix of melt-out tills it is suggested, was not entirely age dependant. It is more significantly controlled by local depositional conditions. Some breakdown of the more unstable structural arrangements was however noted. This has engineering significance when wetting of the till matrix and the imposition of increased stress is considered.

In relation to lodgement tills, melt-out tills tend to be more granular in nature as a consequence of the incorporation of material that has been washed and somewhat sorted by supraglacial streams or by debris that is derived from a supraglacial source. Vast accumulations of the latter on the glacier surface or as a covering to stagnant ice-cored morainic units will, upon deposition, produce the melt-out till sub-type described below.

(a) Supraglacial morainic till

Scree falling onto a glacier surface from the valley side may collect to form a supraglacially derived till. This is normally composed of angular cobble and boulder sized clasts that have not undergone a phase of tractional comminution. It therefore usually lacks the quantities of silt and clay that are produced in a subglacial environment by comminution. Such till is frequently deposited on valley sides during ice ablation as lateral moraine (often intimately associated with kame terrace deposits), although it may also develop along latero-frontal margins or occur as hummocky medial moraine on the valley floor.

(iii) Flow till

Melting out of material in the supraglacial or subglacial environment (the latter in ice or bedrock cavities) may increase local pore-water pressures if drainage is poor or permeability low. Tills in which this condition exists may undergo downslope movement when the liquid limit is reached. Fabric characteristics inherited from the parent ice will be destroyed and a flow till will result.

Boulton (1975) Boulton and Paul (1976) recognise two main horizons within flow tills which are developed in all glacial environments and which may be identified in Pleistocene deposits :-

(a) an upper allochthonous unit which has travelled from its source and which is particularly prone to flow under gravity. It has a low fines content due to subaerial winnowing

(b) a lower parautochthonous unit, little displaced from its source and which is less affected by surface processes of exposure. This tends to retain textural characteristics that are similar to those of the parental till source.

1.1.5.4 Discussion

A review of literature propounding methods of till classification has shown that two main approaches have been adopted :-

(i) Boulton and others have proposed a genetic classification as a result of studies conducted beneath and at the margins of modern glaciers. This has been based upon interpretation of the modes of till genesis, formation, transportation and deposition. Post-depositional influences upon the textural properties of the soils are also considered.

(ii) In the description of tills of Pleistocene age, McGown, Fookes and others have inferred modes of genesis from the sedimentological properties of individual deposits. This has been based essentially upon textural characteristics (including particle orientation and dip) of elements of the macro, meso and microstructure, and upon the degree of dominance of individual particle fractions.

Problems have, however, been encountered in using the genetic system of classification (which clearly defines individual modes of formation), to interpret the methods by which Pleistocene tills have formed. This has arisen because the genetic classes use a definitive categorisation (based upon field observations), which in some instances has proved difficult to apply to the interpretation of the evidence supplied by some textural properties. The genesis of till would appear to form a continuum between the extremes of, for example, deformation till in the subglacial environment and flow till in a supraglacial situation, rather than a set of clearly defined boundaries that may be inferred from some genetic classifications. A textural overlap has been noted to exist between different till types formed in a similar environment. Examples may be found when comparing the textural properties of subglacial melt-out till derived by basal melting of a debris rich regelation zone, with those of lodgement till deposited in the immediate neighbourhood.

In the interpretation of modes of formation of Pleistocene deposits, the genetic classifications highlighted earlier would appear to be best employed to essentially provide the guidelines by which to construct a genetic model. The latter is based upon interpretation of textural properties of the soils observed and may be aided by an appraisal of local geomorphological conditions.

1.1.6 The engineering properties of tills

Boulton (1976) assessed the influences of mode of genesis upon the engineering properties of tills, through its control on several important characteristics. These are principally :-

(i) particle size distribution

(ii) mineralogy and its spatial variation

(iii) the stress history of the till

(iv) the nature of the sequence in which the till lies

(v) the presence, frequency and orientation of joint planes within the till.

Post-depositional processes may affect these characteristics to a greater or lesser extent by wetting and drying, freeze- thawing, remoulding by solifluction and the downward washing of fines.

In engineering terms till is inherently highly variable and individual till units can behave quite distinctively. Elson (1961) recognised that this heterogeneity can be related to the wide range of differing geological histories of the deposits and to the influences of the various source materials from which till can be derived.

1.1.6.1 The properties of tills determined in early site investigations

Since the early 1950's much attention has been paid to the description of index properties, shear strength and compaction characteristics of a wide range of till types from localised areas within the western hemisphere. Investigations have principally been undertaken in association with engineering contracts, the objective being mainly to quantitatively express the variability of these properties within and between tills and sites.

Bernell (1957) describes a wide range of properties, from consistency limits to shear strength for tills excavated along proposed route-ways through the glacial terrain of northern Sweden. He states that at the time of writing, tills were often classified as belonging to a single soil group with similar geotechnical properties. Providing evidence to suggest otherwise, he establishes simple approximate relationships between the ranges of properties and the characteristics of the finest soil constituents. Interesting relationships are drawn between the maximum particle size of sieved material and the liquid limit determined according to the ASTM standard.

Figure 1.3 shows that the liquid limit of a clayey silt is independent of the particle size whilst that of typical 'morainic till' in envelopes (1) and (2) decreases with increased particle size. The relationship between liquid limit and size of particles is represented by a curve which approaches a vertical tangent as the particle size increases. Bernell used this curve to estimate the liquid limit of till for a given soil fraction determined by mechanical sieving. A true indication of the Atterberg limits of a soil however, depends upon the degree of disturbance and remoulding of the soil microstructure. Here Bernell has destroyed any interparticular bonding and structure by sieving the soil mass, hence his results may only be used to provide a guide for a more detailed appraisal and interpretation of the mechanical properties of the finer fractions of a till.

Adams (1961) described the physical properties and shear strength parameters of tills excavated in association with the St.Lawrence Seaway. He commented upon the problems experienced in excavation, the collection of samples and testing of the materials. High cobble contents frequently encountered within the tills made the collection of undisturbed samples virtually impossible. Problems also arose during the use of till for foundations and embankments due to the regular occurrence of highly permeable strata with high sand and gravel contents. They were interpreted as being of fluvioglacial origin.

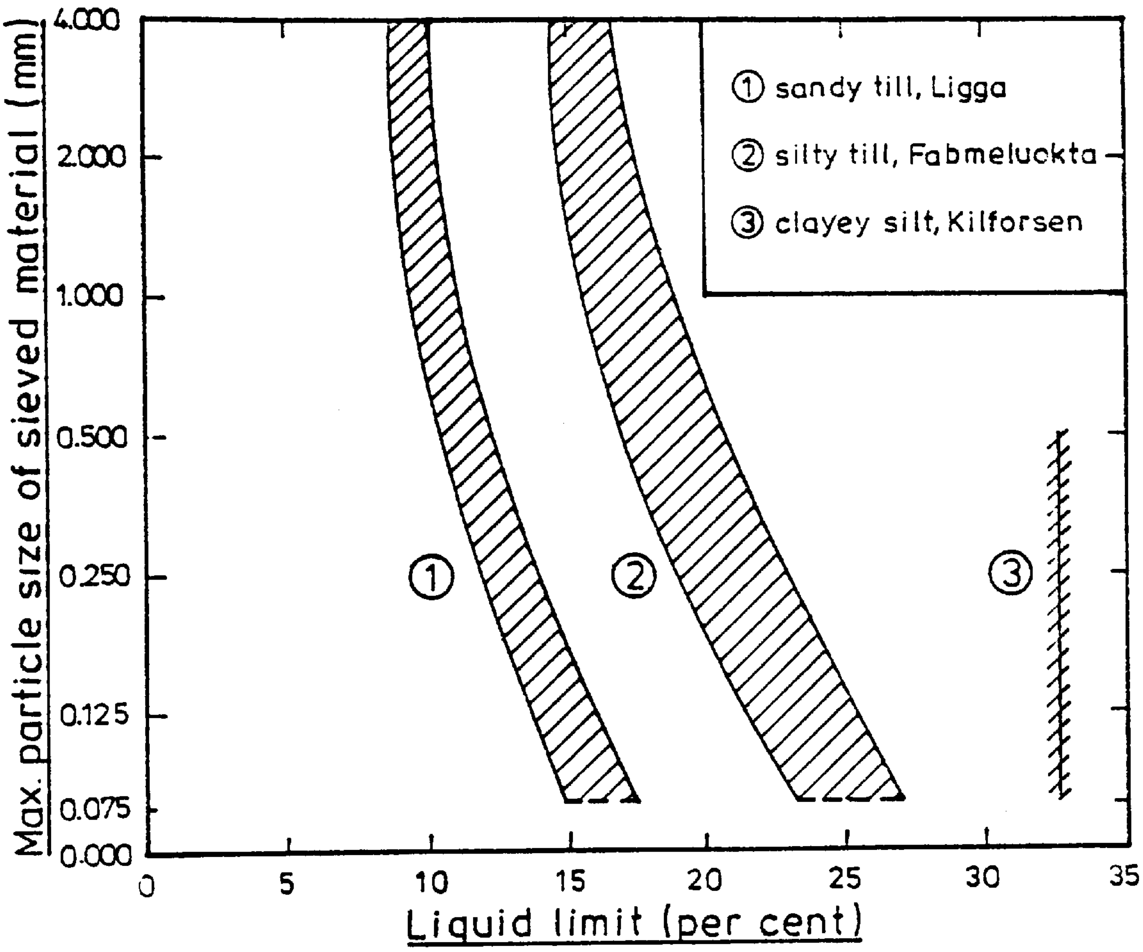


FIGURE 1.3

RELATIONSHIP BETWEEN LIQUID LIMIT AND MAXIMUM PARTICLE SIZE OF TYPICAL MORAINIC TILLS AND A CLAYEY SILT
(after BERNELL, 1957)

1.1.6.2 Methods involved in sample and data analysis

Beskow (1951) commented that :-

"the properties of tills depend in a rather complicated manner on the different fractions present within the soil."

For till identification and laboratory testing purposes McGown (1971) therefore recommends that the soil fraction either side of the split in a gap graded distribution should be separated, for example, see Figure 1.4. He concluded that greater variation in engineering properties is likely to be found when testing the fine soil fraction rather than the coarse. Therefore an engineering classification, he suggests, should essentially be based upon the fine soil fraction.

Statistical analyses of particle size distributions have been successfully used to differentiate between individual till sheets (and to recognise hitherto undescribed units), by workers including Chryssafopoulos (1963). He derived numerical values for each individual till formation pertaining to the following criteria :-

(i) D_{80} (the diameter at which 80 per cent of the sieved mass, by weight, is finer)

(ii) D_{60} (sixty per cent is finer)

(iii) D_{10} (effective size)

(iv) the percentages of sand, silt and clay present

(v) the percentage of material finer than 0.074mm diameter.

These values were then used to obtain the mean standard deviation of population and error of the mean. By the application of Student's 't' test, conclusions were subsequently drawn concerning the

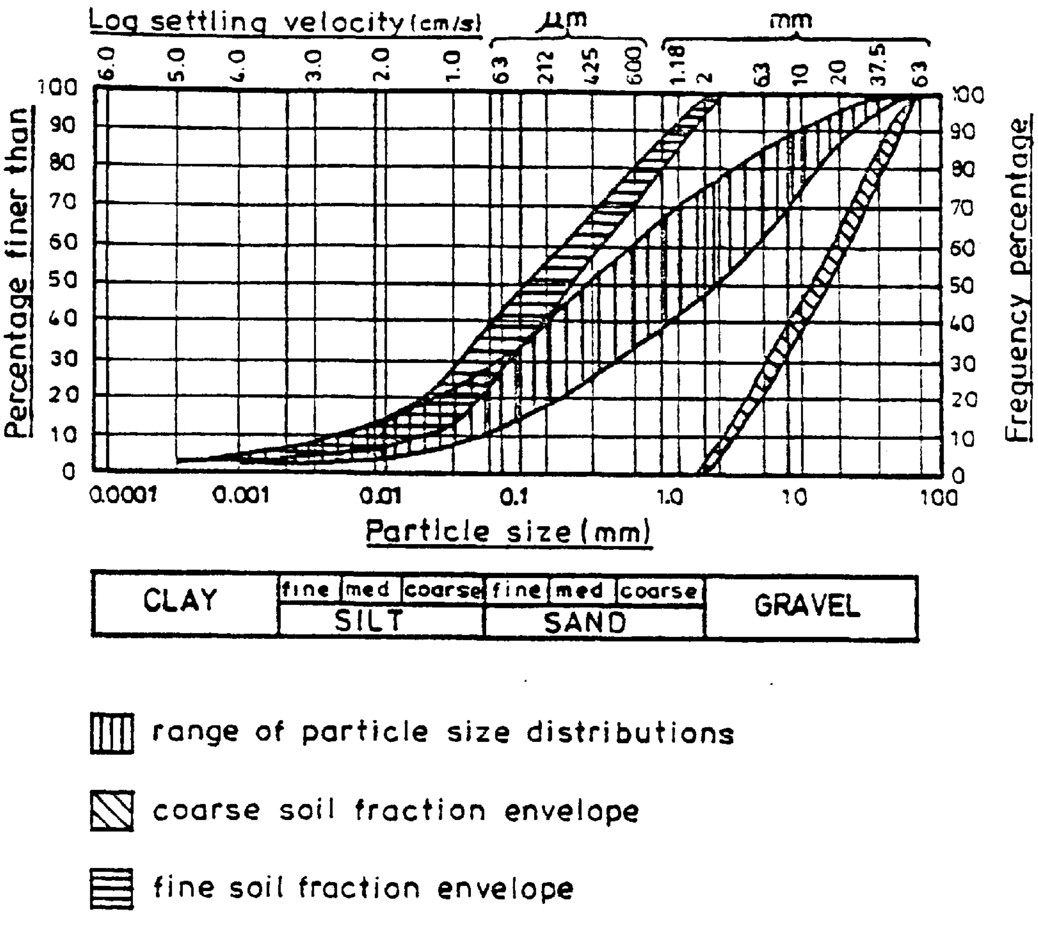


FIGURE 1.4

SEPARATION OF SCOTTISH MORAINIC SOILS INTO COARSE AND FINE FRACTIONS AT THE SPLIT IN A GAP GRADED PARTICLE SIZE DISTRIBUTION

(after McGOWN, 1971)

differentiation of individual populations, relating these to separate till formations.

Inman (1952) attributes lack of standardisation of descriptive measures obtained from the particle size distribution of soils, to the limited application of data from one locality to another. He recommends the use of five parameters that serve as approximate graphic analogies to the moment measures commonly employed in statistics :-

1(a) Phi median diameter

1(b) Phi mean diameter (Central Tendency)

2 Phi deviation measure (Dispersion)

3(a) Phi skewness measure

3(b) Second phi skewness measure

4 Phi kurtosis measure.

The second phi skewness measure is sensitive to the skew properties of the 'tails' of the sediment distribution. The parameters are computed from five percentile diameters, (ϕ_5, ϕ_{16}, ϕ_{50}, ϕ_{84}, ϕ_{95}) obtained from the cumulative size-frequency curve.

Parameters modified from those developed by Inman have been computed for use in the analysis of data for this current research investigation.

1.1.6.3 Specific aspects of the investigation of till properties

Specific facets of investigation of individual mechanical properties of tills and till-type soil mixes have been undertaken by several workers. For example, Holtz and Ellis (1961) investigated the shear strength characteristics of clayey gravel soil mixes in large scale triaxial equipment. They considered the relationship of shear strength to variable gravel contents, concluding that the effective angle of shearing resistance (ϕ') was 8 to 12 per cent lower for a clayey gravel soil than for a sandy gravel soil having an equal gravel content.

Gens and Hight (1979), in a discussion of the laboratory determination of design parameters for till in Cowden, Yorkshire, emphasise the problems of undisturbed sampling in cobbly till. Further to their investigation they discuss the dangers of reliance, for design purposes, upon strength parameters obtained from remoulded samples for which strengths tend to be significantly lower.

Rowe (1972) in the Rankine Lecture, discusses the necessity of thorough data availability concerning soil (including till) texture and its relevance to site investigation procedure.

Subsequent to the work of Boulton and others describing modes of till genesis, data concerning basic principles of till formation has been interwoven (out of necessity) with hypotheses propounding the development of the engineering properties of a soil mass.

The present morphological form of glacial deposits, their lithologies and their engineering characteristics are directly related to their modes of origin and deposition and to their subsequent histories. From the study of landforms in glaciated areas and using simplified glacial models, it may thus be possible to interpret the soil types comprising each land element present and to describe the ranges of engineering properties likely to be expected for each soil unit therein.

Adopting a similar approach, Fookes, Gordon and Higginbottom (1975), Boulton and Paul (1976), McGown and Derbyshire (1977) and others, have described the lithologies and engineering properties of a wide variety of glacial materials including most of the major till types. A discussion of these aspects is undertaken below.

1.1.6.4 <u>The properties of lodgement till</u>

(i) Particle size and index properties

Lodgement tills comprise the major soil type of the subglacial/proglacial land system. They exhibit a somewhat variable grading that is dependant upon the lithological and crushing characteristics of the underlying bedrock, and upon clast transportation distance and the nature of any reworked deposits incorporated during ice readvance. A wide range of plasticity is hence to be expected. These tills are typically bimodal in terms of distribution of particle size, usually having one mode in the clay/silt fraction and the other in the gravel/cobble range. Multimodal distributions are not uncommon, dependancy being placed upon the bedrock crushing characteristics. Differing crushing characteristics will, however, result in the production of varying percentages of silt/clay size rock flour and clay minerals. Very little data is available concerning the effects of proportions of these constituents upon the soil properties. High clay contents (often in excess of 30 per cent), dominating the behaviour of lodgement tills, determine that plasticity characteristics range throughout the CI to CH categories of Casagrande's classification.

(ii) Shear strength

The development of preferred clast orientation dominantly parallel to ice flow direction and of fissuring dependant upon stress relief and accumulation factors, will induce anisotropic strengths which directly influence the shear strength available along potential slip surfaces. The presence of fissures, accompanied by clasts in excess of medium gravel size, produce difficulties in obtaining undisturbed samples for shear strength determination. The scatter of results can be reduced by careful sample collection, selection and preparation.

Strength data obtained by McKinlay and Anderson (1974) for lodgement tills in the Glasgow area, has shown that the exclusion of the coarsest fraction (the cobble and boulder sized clasts) for triaxial testing in the laboratory, will usually result in strength values 3 to 4 per cent lower than those obtained by plate bearing tests. Results were 30 to 40 per cent lower than those derived when using a field pressuremeter, as shown below :-

Table 1.2 Comparison of the undrained strength of lodgement till using different methods of testing.

METHOD OF TESTING	UNDRAINED STRENGTH (kN/m^2)
FIELD PRESSUREMETER TESTS	200-245
IN SITU PLATE BEARING TESTS	145
LABORATORY TESTS	140

The grading, shape and mineralogy of clasts plays an important role in strength development within tills, with the accompanying effects upon plasticity. Particle to particle contact in the 30 to 35 per cent clast range, (as discussed by Holtz and Ellis (1961) working on artificial soil mixes similar in grading to some well graded lodgement tills), essentially results in the soil behaving as a cohesionless deposit. The effective angle of shearing resistance (ϕ') is greatly increased once this boundary is exceeded but compressibility becomes significantly decreased as a consequence of the bridging of particles in contact.

(iii) Permeability

As a product of their mode of origin the high fines contents of lodgement tills (the result of particle attrition at the glacier sole) accompanied by overconsolidation (increasing density and reducing pore spaces), reduces permeability below those of other tills. Fookes et al (1975) record values of as low as 2×10^{-8} cm/sec at the site of the Bradan Dam, Ayrshire. Local variations in grading, for example due to boulder clustering, pocketed development of comminution till, and more widespread changes as a result of variations in bedrock lithology, are however, likely to increase permeability to 1×10^{-4} cm/sec or more. This overlaps with values obtained for subglacial and supraglacial melt-out tills.

(iv) Behaviour

In terms of use as a fill material lodgement tills are generally good, but some having relatively high silt contents (typically derived from siltstone bedrock) are sensitive to moisture changes, problems especially arising in regions with high rainfall. Further, in these soils though to a lesser degree in those that are more clast-dominant, natural moisture content will often exceed the optimum moisture content for compaction purposes.

Linell and Shea (1960), discuss the characteristic texture, engineering properties and use of weathered lodgement till and unweathered till for dam construction in New England. The pronounced physical and mechanical variability of the former, and frequently higher clay contents, determines its restricted use in the dam shell, for use in the interior of embankments and for use in seepage control. Its lower strength necessitates, they suggest, flatter slopes for equal stability. Other applications may be found where shear strength is not critical. They further conclude that within lodgement tills where a complex intermixing of materials of various origins is common, it is possible that very small amounts of granular material may have a decisive influence upon the strength and compaction characteristics of the till. An example is given of the influence on Atterberg Limits of saturating illites with different cations. The effect of this would, however, be much less pronounced than effects induced by changes in particle sizes within the soil mass as a whole.

1.1.6.5 The properties of melt-out and flow tills

The engineering properties of melt-out and flow tills are strongly influenced by the properties of the till types from which they are derived. Release from ablating ice will result in collapse and slump structures in the former, and flow in the latter. This will allow reorientation of particles and a widescale destruction of fissuring and overconsolidation if reworking and melting out of lodgement till occurs.

(a) Melt-out till

These deposits are usually unsorted and well graded in an unweathered state and are more silt rich and generally coarser in grading than lodgement tills. They tend to be clast-dominant since they frequently include supraglacial and ice contact fluvioglacial materials with little fine fraction which have been deposited on the glacier surface or in ice marginal situations.

Copious amounts of free water present during ice ablation will also tend to flush out some proportion fines present within a debris mass during melt-out till formation, increasing clast predominance.

(i) Particle size and index properties

The bimodal and occasionally multimodal grading curves of lodgement tills are also exhibited by melt-out tills if directly derived from reworked units. Gap grading, as within lodgement till in this instance, is in the sand size mode. The fine fraction of melt-out tills (less than 425 μm) is described in the literature as falling into the ML - MI range of Casagrande's classification and hence tends to be sensitive to fluctuations in moisture content. The behaviour of the fine fraction may occasionally be dominated by the presence of clay minerals and to some degree clay sized rock flour, depending upon lithological variations within the glacially overridden bedrock. This tends to draw the tills up towards the 'A-Line' or on into the CL and CI categories.

Some preferred orientation of clasts may be retained from the englacial debris fabric but slump and shear structures developed as debris melts out, are frequently present.

(ii) Shear strength, consolidation, permeability and compressibility interrelationships.

Very little data is available in the literature reviewing the shear strength of melt-out tills. With low fines contents they tend to be regarded as being effectively cohesionless, whilst when larger percentages of the fine fraction exist, Fookes et al (1975) state, they are frequently classified as lodgement tills. Based essentially upon an engineering classification, this would suggest that the boundaries between tills of differing genetic modes are quite indistinct. An appraisal of the textural properties of the deposits would thus be required in these cases to enable a more detailed classification.

The anisotropic strength distribution characteristics of lodgement tills are usually absent within melt-out tills. However, exceptions occur when the melting out process results in retention of the shear fabric developed in the subglacial environment from which some melt-out till is derived via englacial shear planes. The presence of free water may remove varying amounts of fines, producing a more granular till with a higher friction angle and lower cohesion. This coarser grading is more typical of melt-out tills and tends to increase permeability to greater than 1 x 10^{-4} cm/sec.

Some difference is to be expected in the shear strength characteristics of melt-out tills deposited from within the glacier in relation to the supraglacial morainic till sub-type. The latter is commonly loosely consolidated whilst the former may have undergone some degree of consolidation by ice and debris surcharge loading and contain a higher percentage of fines, thereby increasing density. Slightly higher strengths result, accompanied by lower permeability and compressibility. The normally consolidated granular melt-out tills show little difference between peak and residual shear strengths, however, the overconsolidated nature of lodgement tills produces a much greater loss in strength in the residual condition.

The interaction between fines content and particles size and shape will dictate the consolidation and compaction behaviour of soils. The normally consolidated state of melt- out tills will allow greater compressibility than may be obtained for the overconsolidated lodgement tills. The compaction characteristics of the former are more strongly influenced by particle contact where their typically granular nature results in the achievement of lower degrees of compaction.

(b) Flow till

The two main flow till elements distinguished by Boulton (1975) and Boulton and Paul (1976) and discussed above in section 1.1.4.3., exhibit differing physical and mechanical properties as a result of minor differences in mode of origin and post-depositional textural modifications.

(bi) The upper, allochthonous element has undergone frequent failure and remoulding and usually lacks the fine soil fraction to varying degrees. This is due to weathering and the winnowing action of water released from active debris flows. Stratified sand and gravel lenses (due to stream action at the surface) may be interbedded with subsequent till flows. A wide range of index properties is thus to be expected.

(bii) The lower parautochthonous element has accumulated basally and has not been subjected to surface processes. It therefore retains the massive character, texture and hence particle size distribution of the melt-out till from which it is typically derived.

(i) Plasticity characteristics

Boulton and Paul (1976) relate mode of origin and formation of flow till and other till types to their plasticity. Their findings are shown in Figure 1.5. A T-line is produced running parallel to a similar line drawn by Skempton (1970) for a series of marine clays. The juxtaposition of the two lines reflects the poorer sorting of the tills. Winnowing-out of clay and silt from the

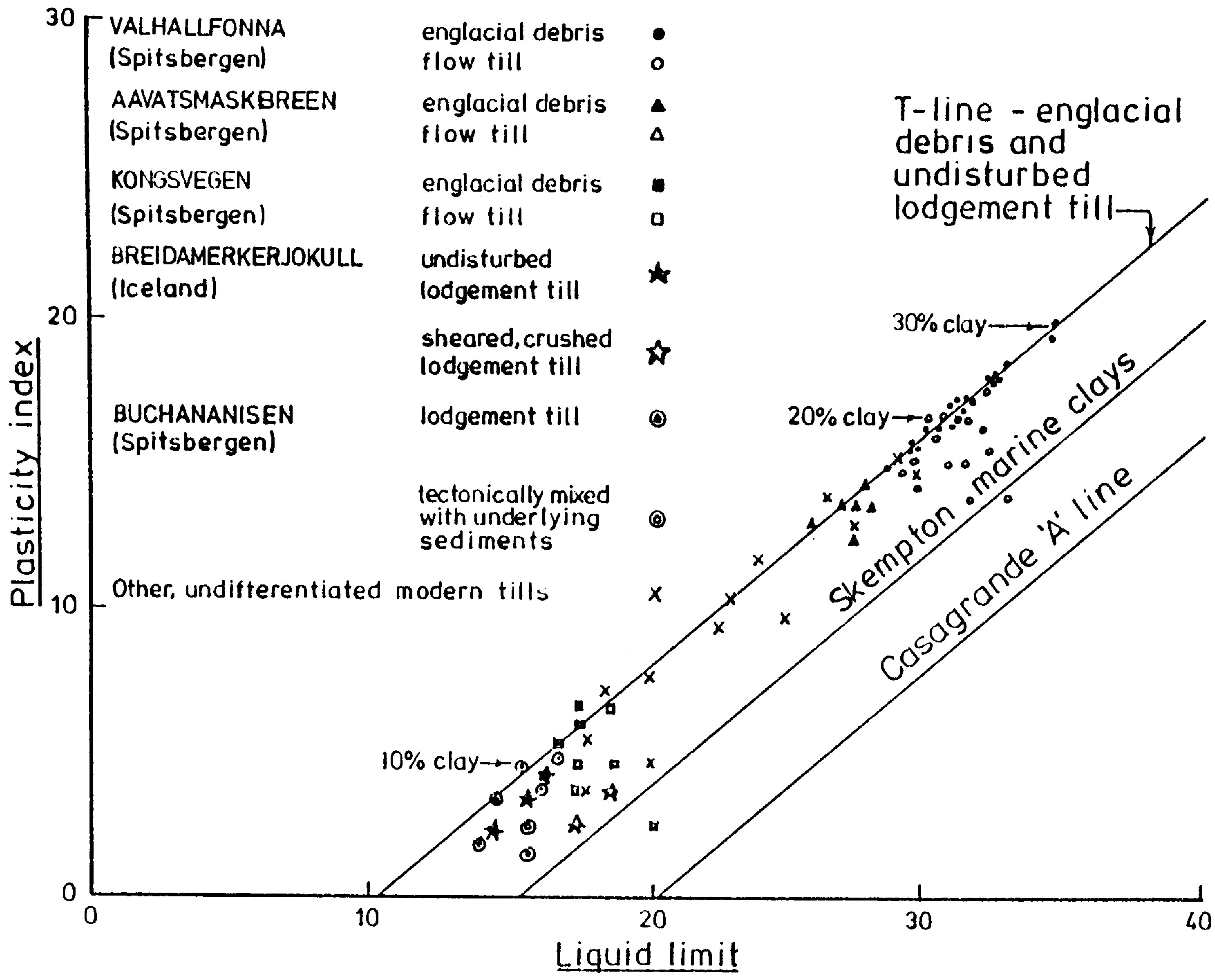


FIGURE 1.5

PLASTICITY PLOT FOR TILLS OF KNOWN ORIGIN AT THE MARGINS OF MODERN GLACIERS

(after BOULTON and PAUL, 1976)

uppermost surface of allochthonous flow till leaving a residual sand enriched unit, moves the sediment below the T-line and to the left. Enrichment in clay such that this dominates the distribution, moves points above the T-line and to the right; enrichment in silt at the expense of sand moves points below the T-line and to the right. Tills in which the silt mode is maintained but in which the clay content is increased at the expense of the sand fraction (thus retaining a more 'typical' bimodal till particle size distribution), merely move along the T-line to the right.

Interesting comparisons may be drawn between this work based upon modern tills and conclusions obtained from till of Pleistocene age in South Wales. These are discussed in section 4.3.2.5.

Boulton and Paul further comment upon the presence of voids in allochthonous flow till elements providing an apparently low density. The true voids ratio was calculated at 100 per cent saturation and a value of 0.65 was obtained which is essentially the same as for the lower element which is in the order of 0.6. The voids ratio for melt-out till at an adjacent location was determined to be significantly greater being in the region of 0.8 to 0.85. Differing degrees of particle packing as well as shear during flow were concluded to be responsible for the contrasting differences between the three units.

(ii) Shear strength

Again, very little data is available concerning shear strength parameters of flow tills. This is probably as a consequence of their highly variable nature which results in difficulties in the collection of undisturbed and statistically representative samples, and their generally localised distribution. The anisotropic strength distributions which are to be expected due to the stratified nature of allochthonous elements are not likely to be as marked in the parautochthonous flow till elements due to their more homogeneous nature.

The bulk physical and mechanical properties of flow till, as with other till types which are likely to contain laminated horizons or larger lensoid accumulations of sorted material, will be locally influenced by the presence of such horizons. Many of Rowe's (1972) remarks on thorough soil textural descriptions and data availability in relation to site investigation procedure are hence pertinent in these cases. He and other workers, including Barden (1972) and Collins and McGown (1974), further advocate that studies relating engineering properties to variations in soil texture should, wherever possible, be supplemented by a comprehensive microscopic examination of selected samples at medium and high magnifications.

1.1.6.6 Other studies in Pleistocene deposits

Further work describing some genetic influences on the physical and mechanical properties of Pleistocene tills has been undertaken by; (i), Fookes, Hinch, Huxley and Simons (1975); (ii), Milligan (1976), and (iii), Eyles and Sladen (1981).

(i) Fookes, Hinch, Huxley and Simons (1975) describe the physical and mechanical properties of tills and associated fluvioglacial and periglacial deposits along the line of Sections 4 and 5 of the A470 Taff Vale Trunk Road, South Wales.

Engineering geological mapping was undertaken to interpret soil and bedrock variability and to assist in the differentiation of components of the glacial landforms. This aided in the location of trial pits and boreholes so that an evaluation may be made of engineering problems concerning foundations, cuttings and embankments, slope stability and drainage. Engineering geomorphological mapping was undertaken to evaluate slope failure processes, sites of subsidence, and surface and sub-surface drainage characteristics relevant for design purposes.

Within the investigation no attempt was made to separate the granular tills encountered, but this, they suggest could probably be done by detailed study. They state that 'ablation' (melt-out) tills and possibly some lodgement tills are present.

Their grand average results of standard grading, index properties and shear strength tests performed on samples of till are summarised below :-

(a) Particle size distribution

The average grading of particles is shown below, however, wide variations were observed and were essentially typical of a glaciated valley containing an abundance of fluvioglacial deposits.

Boulders and Cobbles	:	25%
Gravel	:	31%
Sand	:	22%
Silt and Clay	:	21%

(b) Atterberg limits, mean values

Liquid Limit	:	24.1%
Plastic Limit	:	13.8%

(c) Natural and optimum moisture contents, mean values

Natural moisture content	:	12.9%
Optimum moisture content	:	7.1%

(d) Shear strength parameters

$c' = \text{zero}, \ \phi' = 34.6$ degrees.

Fookes et al also statistically examined the variation of soil properties along the section of the valley studied and drew comparisons between results obtained from samples recovered by pitting operations with those obtained from samples recovered by shell and auger techniques. Results have shown that material along the southern road section (Section 4) was generally coarser in grading that in Section 5. This is probably due to greater accumulation of relatively coarsely graded kame terrace material. Borehole data showed a coarser average grading than shown for samples collected in trial pits. The authors felt that this may be due to drop-tool methods of sample recovery, however, some flushing-out of fines from soils is to be expected when drilling is undertaken for sampling purposes. This suggests that trial pits may well be most profitably used for sample collection at shallower depths so that data scatter and unreliability can be limited.

(ii) In his review of geotechnical aspects of tills in Canada, Milligan (1976) describes some of the textural variations in till and in their properties as related to the aspects of design and construction of large structures. He states that the dense and impermeable nature of many Canadian tills makes them ideal for use as foundation materials for heavy structures and for rolled earth fill in embankment dams. However, their characteristically heterogeneous nature and their wide variations in engineering properties make till, on occasion, far from an ideal material.

Milligan relates till textural variability to recognised modes of genesis. The use of trial pits for identification of three-dimensional macro - structural variability within deposits is of utmost importance, he recommends. These can prove to be cost effective in relation to methods of obtaining core samples and will provide a better appreciation of textural heterogeneity. Depth limitations may however reduce the effectiveness of trial pits in site investigation schemes for large structures. This is particularly so where design requirements necessitate information on ground conditions at greater than 4 to 5 metres, the limit of effective, mechanically excavated trial pitting.

Whilst discussing till as a foundation stratum, Milligan states that examples have been cited (Adams, 1961) where end bearing piles have been driven into supposedly dense lodgement tills only to penetrate into the till for 3 to 6 metres more than the expected depth of refusal. The piles had initially penetrated granular till, (melted out material) that had reduced penetration to a degree suggesting the high densities of lodgement till.

He further states that the strength characteristics of intact till are normally high, however, low strength imperfections within the soil mass will strongly influence the stability of slopes and cuts. Examples are given were the presence of periglacial ice-wedge casts and fissures in matrix-dominant tills have influenced slope failure. He records thin zones of highly plastic slickensided clay (residual subglacial shear planes) within lodgement till of British Columbia. Their presence has resulted in instability of slopes cut to angles steeper than the 20 degrees of the slopes in their natural state.

In these examples a detailed site appraisal employing interpretation of textural variability based upon modes of till genesis would provide a guide to the expected engineering behaviour of till masses. It is thus of utmost importance.

(iii) Eyles and Sladen (1981) discuss the stratigraphy and some textural and geotechnical properties of weathered Devensian lodgement till in Northumberland. They relate till identification and a stratigraphic framework to recent depositional studies beneath and at the margins of modern glaciers.

Weathering of till, they report, has occurred to depths of between 3 and 8 metres. The oxidation of sulphides (eroded from local Coal Measure Series sulphide-bearing bedrock) and leaching of carbonates, has resulted in a colour change from grey in the unweathered till to a zoned, reddish brown weathering profile.

Fines fractions (silt and clay) and moisture contents increase with degree of weathering (zones III and IV) in response to disintegration of larger particles. This gives rise to systematic zonal changes in Atterberg indices and shear strength parameters.

(a) Atterberg Limits

Consistency limits are plotted on the Casagrande Plasticity chart differentiated into two data envelopes, one for Zones III and IV and a second for Zone I. These lie close to the T - line of Boulton and Paul (1976). Increasing clay and silt contents within the weathered zones increase the plasticity of lodgement tills from the CL range in an unweathered state to the CI category of Casagrande's classification.

Variations in plasticity index in unweathered lodgement tills, the authors state, are associated with changes in the lithology of the bedrock over which glacial ice moved and the distance of debris transportation.

(b) Shear Strength

Weathered lodgement till was noted to have higher undrained shear strengths than unweathered samples at any given moisture content.

Eyles and Sladen conclude that a model of glacial deposition derived from studies of sediment/landform associations in areas of modern glaciation, provides a good framework for a study of late Devensian deposits.

Interesting comparisons may be drawn between this work based upon lodgement till and the results of detailed textural and geotechnical interpretation of lodgement, melt-out and flow tills and associated fluvioglacial and periglacial deposits in the Taff Valley of South Wales.

1.2 The Relationship of Past Fields of Investigation to this Present Study

From a review of literature it has been noted that research and site investigation work has amassed a considerable amount of information and data concerning the engineering properties of a wide range of genetically differing till types. Data has been drawn from North America and western Europe, accompanied by isolated locations in Britain. In the latter case, work has been undertaken on tills in the Scottish Lowlands, Yorkshire, the Midlands and parts of Mid and South Wales.

It is felt however, that further investigation is required to describe the wide range of till lithologies, their respective landforms and the intimately associated fluvioglacial, periglacial and recent soil types present in areas of South Wales, notably in the Taff Valley. Relationships may be drawn between the genesis of these soils, their inherently variable engineering properties and their morphology. This will be based upon rationalised descriptions of till lithologies, engineering properties and characteristic landforms provided by studies undertaken beneath and at the margins of modern glaciers.

These points form the basis for this research investigation and from these a glacial model of till genesis within the Taff Valley, (between Merthyr Tydfil in the north and Tongwynlais in the south) is developed. This will be compared with a statistical model built from the data obtained as a result of laboratory tests and field observations on soils in that area.

TWO

CHAPTER 2

GLACIAL, FLUVIOGLACIAL AND PERIGLACIAL LANDFORMS OF THE TAFF VALLEY

2.0 Introduction

This chapter presents a summary of the methods and results of engineering geomorphological mapping undertaken as an initial phase of investigation within the Taff Valley.

In order to appreciate the reasons for textural variability within glacigenic soils, workers at the margins of modern glaciers have classified the deposits in terms of their mode of genesis. Methods of soil formation and deposition were observed and related to the textural properties of the deposits and were subsequently described in relation to the landforms of which they are the typical constitutional soil type. This procedure has been further applied to the description of periglacial landforms and soils in modern high latitude and altitude environments.

Within an area of Pleistocene deposits, here the Taff Valley, a similar methodology to that described above has been adopted as an initial stage of site and soil investigation.

Geological, engineering geological and pedological studies have been undertaken in the valley by such workers as Charlesworth, Anderson, Trigg, Blundell and Crampton. However, the findings of these workers have little bearing, if any, on the work undertaken in this investigation. The only works of any significance have been those produced by Fookes, Hinch, Huxley and Simons, and Brunsden, Doornkamp, Fookes, Jones and Kelly, which have acted as a foundation upon which to build this study.

As part of this study glacial landforms of erosion and deposition and land elements of periglacial mass wasting were delineated within the Taff Valley. Interpretation of these facets and elements of the topography by geomorphological mapping (employing field and stereo air-photographic techniques), permitted the development of a model of glacial and Postglacial activity within the locality. By relating this model to the sediment/landform models proposed by other workers, estimates of expected soil lithology within individual land elements have been made. These techniques have also enabled possible sites of interest to be located for detailed soil investigation. Subsequently, the engineering properties of the soils observed to constitute specific depositional land elements may be determined and relationships drawn with modes of soil and landform genesis.

2.1 Glacial and Late Glacial Background

At the climax of the last glaciation approximately 17,000 years b.p., ice of Devensian age (of the Margam Glaciation in South Wales), covered much of the British Isles, (see Figure 1.1). The Taff Valley is located at the southern limit of the area covered by ice advance during the Devensian glaciation. A peripheral periglacial zone would have been lying to the south of this line, retreating northwards at the close of the glacial phase.

Localised centres of ice dispersal are known to have existed within the glaciated area, one such centre being the uplands of the Brecon Beacons. This area probably acted as the source of much of the southward moving ice that produced the glacially moulded terrain of the Taff Valley.

Extensive modification of the pre-glacial landscape of the valley by glacial erosion and the deposition of sediments has resulted in the superimposition of new landform facets and elements upon the old. Since the Taff Valley is located towards the margins of Devensian ice coverage, much of the glacial soil present is associated with ice ablation and the production of fluvioglacial outwash. It therefore tends to be texturally clast-dominant. During the climatic amelioration of the Late Glacial at approximately 10,000 years b.p., much of this granular soil suffered periglacial reworking including solifluctual mass movement and the development of head deposits. These conditions produced their own landform modifications in the form of low relief elements, for example lobate solifluction elements.

2.2 Engineering Geomorphological Mapping

2.2.1 Methods employed

Land facet interpretation by detailed 'walk-over' field mapping has been aided by consultation of Ordnance Survey topographic and geological maps on a variety of scales, including 1:10560. The latter were used in conjunction with aerial photographs providing a full stereoscopic cover of the valley upto and over watershed limits. Viewing photographs stereoscopically enhances vertical relief and this has assisted in the identification of land facets of low relief that proved difficult to interpret in the field, for example, hummocky moraine and solifluction lobes and terraces.

2.2.2 Engineering geomorphological maps

Engineering geomorphological maps of specific areas within the region have been drawn to supplement site data describing the textural properties of the soils constituting individual elements of the land facet types. Three maps on the scale of 1:10000 (Maps 2.1, 2.2 and 2.3, in the appendix to this chapter) have been drawn of areas within the Taff Valley; these are of Taff's Well, Upper Boat and Aberfan/Troedyrhiw. The majority of soil textural and engineering data used in this investigation has been obtained from sites within these areas. The maps indicate :-

(i) morphogenetic features (forms defined by their modes of genesis), for example springs, landslips and solifluction lobes

(ii) morphological features, for example changes and breaks of slope.

They also show the distribution of the superficial "drift" deposits at the ground surface. The till covering is essentially one of melt-out and flow units which have been noted to overlie lodgement till at all sites. The latter is a typical component of the soil types present and is therefore included within the drift classes described in the legend of each map. Head deposits (a periglacial solifluction regolith) overlie all soil units, however this material is only indicated on the maps where it directly overlies bedrock.

2.3 Bedrock Geology

Study of local bedrock variability has revealed its importance in the location of glacial landforms of erosion and deposition and also as the source of the fractional constituents of the individual soil types present.

The valley of the River Taff runs north-north-west to south-south-east across the broad east to west synclinal structure of the South Wales Coalfield, (Figure 2.1). At the northern and southern limits of this syncline the river flows through gorges cut in the sandstones, grits and conglomerates of the Devonian Old Red Sandstone, the thick crystalline limestones and shales of the Carboniferous Limestone Series and the predominantly conglomeratic Millstone Grit. The major part of the Taff Valley traverses the core of the syncline, cutting cyclothemic sequences of tough, well cemented sandstones of varying thickness, (the Pennant Sandstones) and also thin micaceous, mudstones with coal and shale horizons. The overall effect of the varying degrees of hardness of the individual rock types and hence their resistance to erosion and weathering has resulted in a syncline with radially varying scenery. The heart of the syncline is a central plateau region of shallowly dipping beds of the Upper Carboniferous Series concentrically encompassed by the hog-back North and South Crops of the Lower Carboniferous units and by the Devonian Old Red Sandstone Series, quite rugged and stark to the north in the Brecon Beacons.

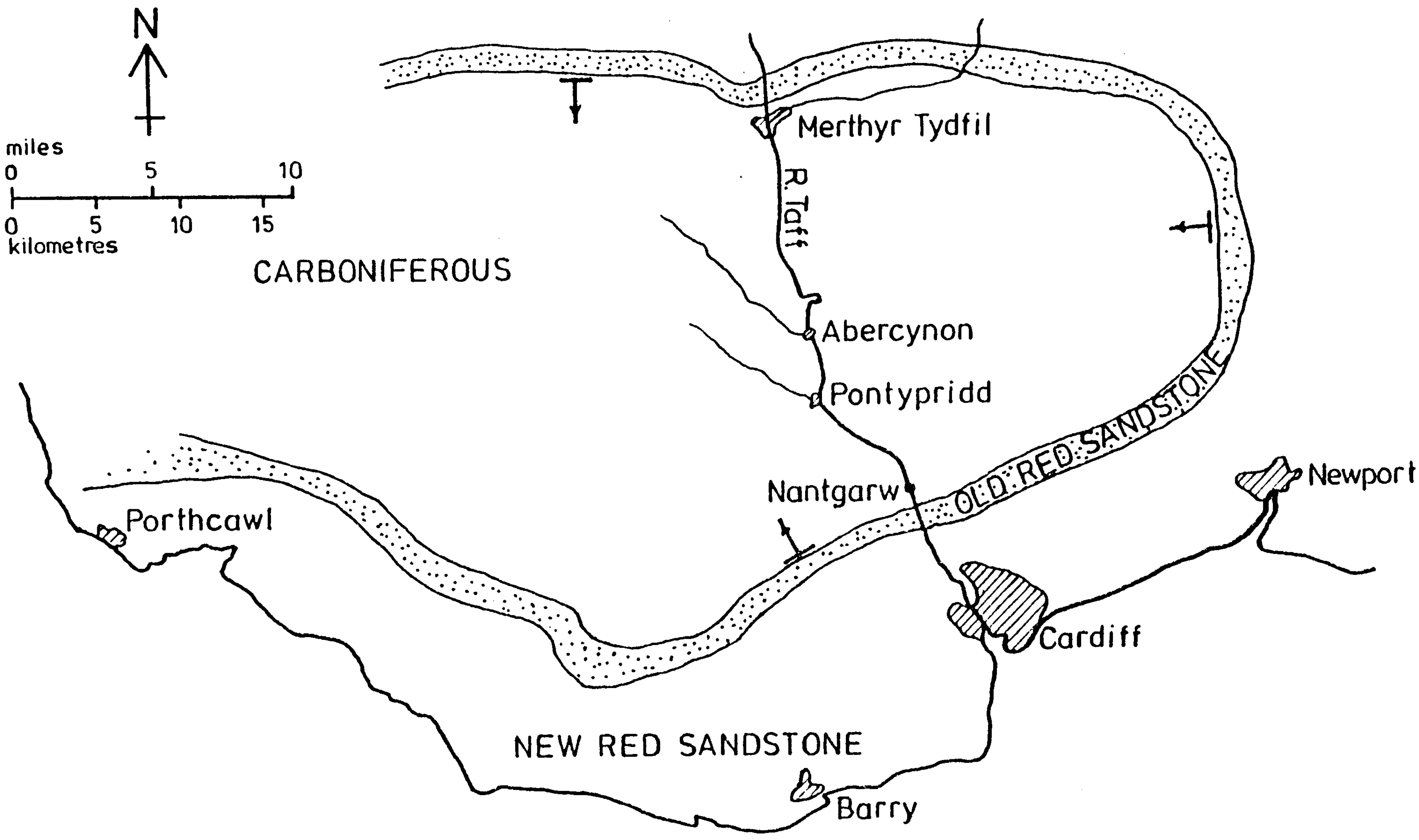


FIGURE 2.1

THE GEOLOGY AND STRUCTURE OF THE SOUTH WALES COALFIELD

The varying degrees of resistance to erosion exhibited by individual strata of the Productive and Barren Measures in the central area of syncline, were found to produce a characteristic topography when outcropping in the valley sides. The presence of hard sandstone units interbedded with softer mudstones, shales and coal seams has the effect of producing multi-stepped valley sides. These are particularly noticeable in the Taff Valley.

2.3.1 <u>The influence of bedrock lithology on the nature of the superficial deposits</u>

Interpretation of the textural properties of the glacial deposits in the valley, in particular the tills, has revealed that they are directly dependant upon local bedrock lithologies. The factor of utmost importance is the lateral and vertical extent of the lithological units present. The greatest thicknesses of till have been noted to develop where the softer bedrock units outcrop, (for example, the argillaceous strata, essentially mudstones, shales and coal seams). These units have been more readily incorporated into the basal zone of the glacier by plucking and have undergone greater degrees of comminution than the adjacent sandstone beds. Till tends therefore to be thickly developed in the predominantly argillaceous bedrock areas towards the north and south of the valley, in the localities of Aberfan and Nantgarw respectively.

Till thickness becomes generally reduced higher up the valley side due to a reduction in the erosional power of overriding ice and ice thickness and also post-depositional downslope movement of till by

Postglacial solifluction. Further complexities to this valley side pattern are induced by the 'terracing' of bedrock units. The cyclothemic Coal Measure Series sequences produce a stepped valley side profile. The basic pattern is one where bedrock terraces are developed as the uppermost surface of the arenaceous units where the overlying argillaceous sequences (including the coal-bearing horizons) have been readily eroded. The more matrix-dominant soils, that is, the lodgement tills, tend thus to be developed to greatest thicknesses on top of these terraces as derivatives of the argillaceous sequences above. Thinning of all superficial deposits tends to be a characteristic of the steeper slopes between terraces, (particularly on the terrace shoulders), probably as a consequence of solifluctual mass movement.

2.4 Glacial Landforms

2.4.1 The glacial valley

The characteristic form of a glaciated valley, a close approximation to the U-shaped valleys typical of heavily glaciated high altitude and latitude locations, is generally poorly developed within the Taff Valley. It would appear that this is the result of a combination of three factors:-

(i) the variable crushing characteristics of the local arenaceous and argillaceous sequences. Where the latter predominate, for example in the localities of Merthyr Tydfil, Abercynon and Upper Boat, the valley profile is wide with shallowly angled walls, the result of an essentially weak, easily eroded substrate.

(ii) the apparently low erosive power of a glacier or glaciers at the southern-most limits of the Devensian ice sheet. This would result in limited modification of the essentially V-shaped pre-glacial valley form, particularly in the lower reaches of the valley.

(iii) the high degree of till deposition and fluvioglacial infilling. This is accompanied by solifluction of unconsolidated material resulting in a rounded topography and the accumulation of material in the valley floor and low on the sides.

Some overdeepening of the original pre-glacial valley form, accompanied by oversteepening of valley sides is however noted in the north of the valley between Troedyrhiw (SO 068023) and Edwardsville (ST 086966) and to some extent locally to the north of Pontypridd (ST 072899). Within these areas the bedrock is predominantly arenaceous with a strong development of reticulate joint sets and faulting. These factors have inevitably resulted in the most effective erosion along these predetermined lines of weakness. The subsequent effect has been the development of a more typical U-shaped glaciated valley profile. The steep side walls typically slope at 30 to 40 degrees, whilst a flat floor infilled with fluvioglacial outwash overlies the soft Productive Measures of the Upper Carboniferous.

The interplay between local stratal dip and sediment depositional sites has resulted in a marked asymmetry of valley form in cross-section along its entire length. The dip of strata north of

Quaker's Yard (ST 097965) is predominantly to the south-east. This has resulted in the development of a valley form with the steep eastern walls approaching 45 degrees in places whilst the shallower slopes of the western side are developed to angles of between 10 and 35 degrees. To the south of Abercynon (ST 084951), the overall bedrock dip is to the south and south-west. Here, where dip is associated with the south-south-easterly running valley, somewhat shallower western walls of up to 38 degrees have resulted, whilst those of the east approach angles of up to 30 degrees. The presence of the Caerphilly Syncline which transversely cuts the lower regions of the valley to the east of Nantgarw (ST 121852), has the effect of producing local anomalies to this basic pattern.

2.4.2 Land facets of glacial origin

The glacial land facets of erosion and deposition encountered within the valley are here presented in accordance with the land systems categorisation of the glacial sediment/landform model developed by Boulton and Paul (1976) and discussed in section 1.1.4.1.

Three land systems are adopted :-

(i) the glaciated valley land system,
(ii) the supraglacial land system, and
(iii) the subglacial/proglacial land system.

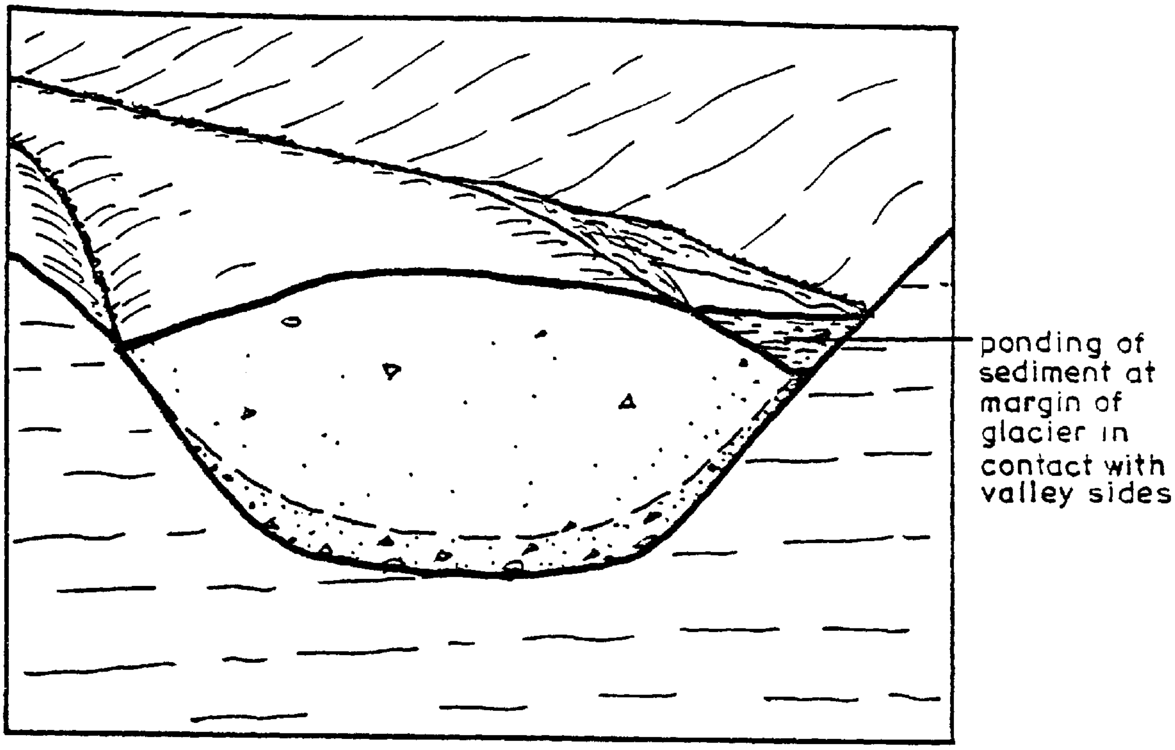
2.4.2.1. Land facets of the glaciated valley land system

(a) Kame terraces

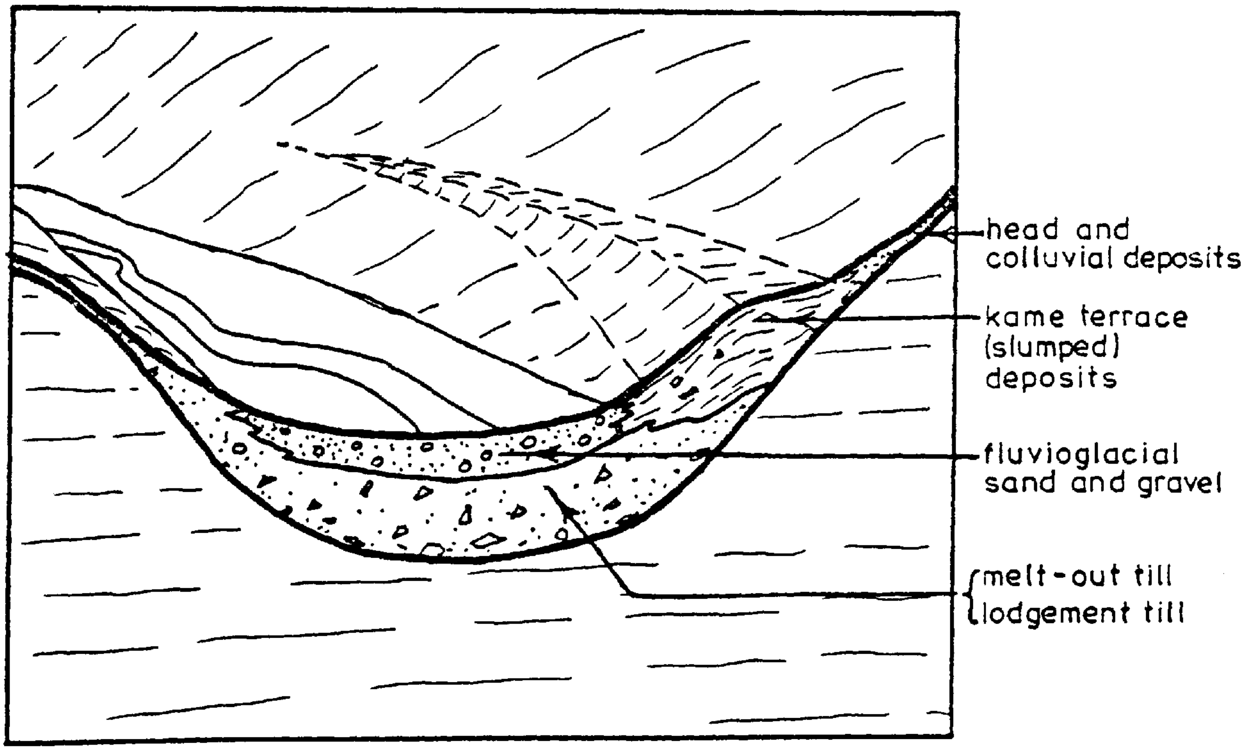
Amongst the most strikingly prominent land facets of glacial deposition within the Taff Valley are the ice contact kame terraces, located at varying heights above the river floodplain.

The development of these essentially valley-side terrace features is associated with lateral ice-marginal ponding of water, (Figure 2.2). Well graded and stratified granular fluvioglacial deposits accompanied by valley side scree collect in these elongate depressions. As ice ablates, the material immediately adjacent to the glacier tends to collapse and slump down the valley side until reaching the angle of repose. The original depositional fabric (clast long axis pointing downstream) will frequently become reorientated parallel to the bedrock profile where slumping has occurred. Accompanying collapse structures and loss of stratification are common.

Most widespread kame terrace development is in the wider, lower regions of the valley to the south of Pontypridd, (Map 2.2). Discontinuous remnants of terrace are however noted along much of the valley length. Development of these features towards the north of the valley is most apparent 0.5km. west of Edwardsville (north of Quaker's Yard) and at Aberfan, (Map 2.3).



(a) Glacial phase



(b) Postglacial phase

FIGURE 2.2

SCHEMATIC REPRESENTATION OF KAME TERRACE DEVELOPMENT ABOVE RHYDYFELIN (Taff Valley)

Top slope and side face angles are quite uniform within the valley. For example, above Rhydyfelin the kame terrace at ST 098892, shown in Plate 2.1, has a top slope angle of 4 to 7 degrees and a side face of 27 degrees maximum. On the opposite valley side to the west of Nantgarw (ST 115853) (Plates 2.2 and 2.3), the top slope has a 4 to 10 degree dip whilst the side face is developed to 26 degrees. The latter reflects the angle of repose of the predominantly granular deposits.

The kame terrace topography tends to become quite uneven with the development of hummocky elements (as shown at ST 109879 on Map 2.2) following post-depositional collapse. Some top slopes are noted to have reversed such that they shallowly dip in towards the valley sides at angles of up to 2 degrees, for example at location ST 10888787. Certain depressed elements of the hummocky topography may reflect kettle hole development by melting of sediment supported ice blocks.

Kame terraces within the valley vary in length from 0.5km to 4.1km and occur at a two main levels on the valley side reflecting the height to which glacial ice filled the valley at their time of formation. Marked similarities exist between the first and second terraces to the north and to the south of the valley. In the south of the valley between Pontypridd and Nantgarw, the terrace top slopes are at heights of approximately 20 to 30 metres and 105 to 120 metres above the present river level. To the north, in the region between Edwardsville and Troedyrhiw, the first and second kame terraces are at 20 to 35 metres and 90 to 110 metres above river level respectively.

PLATE 2.1

OBLIQUE VIEW OF A KAME TERRACE (KT) ABOVE RHYDYFELIN

PLATE 2.2

OBLIQUE VIEW OF A KAME TERRACE (KT) NEAR NANTGARW

PLATE 2.3

A STEREOPAIR OF AIR PHOTOGRAPHS OF THE YNYS-GAU AREA TO THE NORTH-WEST OF TAFFS WELL, AS SHOWN ON MAP 2.1. NOTE THE MORAINIC RIDGES (M1 TO M6). YNYS-GAU FARM (Y-G) IS ON THE LARGEST MOST NORTHERLY ELEMENT. NOTE ALSO THE KAME TERRACE (KT), ROCHE MOUTONNÉE (R), FIRST FLUVIOGLACIAL TERRACE (F1) AND THE RIVER FLOODPLAIN (FP). PLATES 2.2, 2.13, AND 2.14 WERE TAKEN FROM POINTS X, Y AND Z RESPECTIVELY; THE FIELDS OF VIEW ARE AS INDICATED.

This suggests that kame terrace development occurred in two main phases subsequent to till deposition and that ice thickness was correspondingly somewhat constant during both of these periods.

(b) Lateral moraine

Small, low relief ridges high upon the valley side have been interpreted as lateral moraine. They are less easily discernable in the Taff Valley than the kame terrace deposits due to their generally poorly developed profile. When present they frequently prove difficult to separate from rock benches unless soil information is available for that location. At a level of 150 metres above the river, 0.6 kilometres to the north east of Abercynon on the west side of the valley at ST 089957, (Plates 2.4 and 2.5), a lateral moraine is noted to have a terraced form horizontal to subhorizontal along the valley side. At this site soil exposure showed that this facet is composed of greater than 1.5 metres of very locally derived angular to subangular coarse sand and fine gravel with cobbles and boulders. The comparatively well sorted nature of the material and the much coarser grading than that of the overlying head deposits, suggests that the material may have collected as a talus cone or rampart of frost shattered scree along the glacier margin. Figure 2.3 (a) reconstructs the environment at the time of deposition when glacier ice was thin towards the close of the final glacial phase. Exposures of till less than 1.1 and 1.4 km to the north-east at Quaker's Yard, suggests that this glacier may have been an extension of ice flowing from the north to coalesce with ice of a glacier in the Cynon Valley.

PLATE 2.4

OBLIQUE VIEW OF LATERAL AND MEDIAL MORAINES (LM AND MM) NEAR ABERCYNON

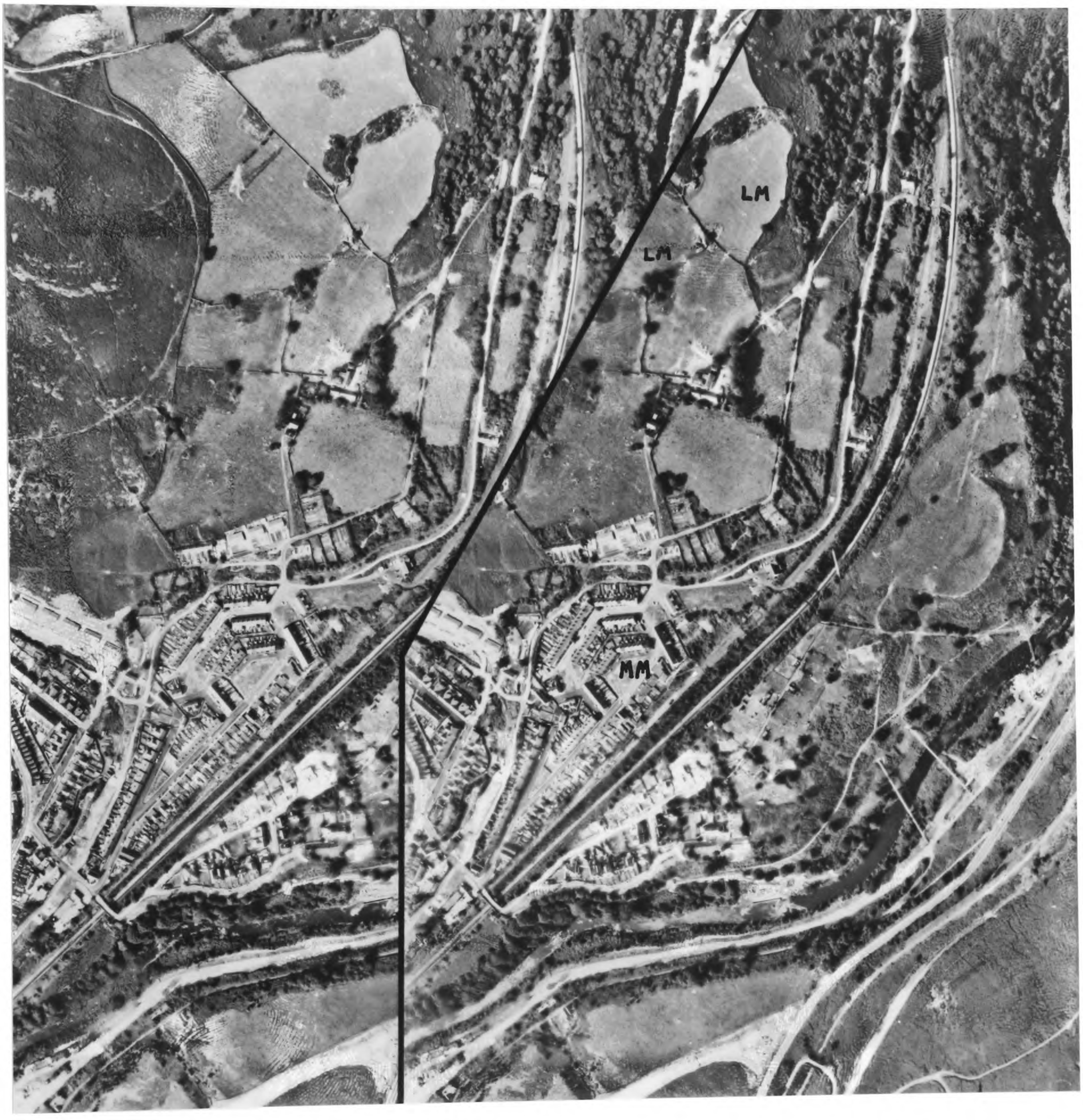
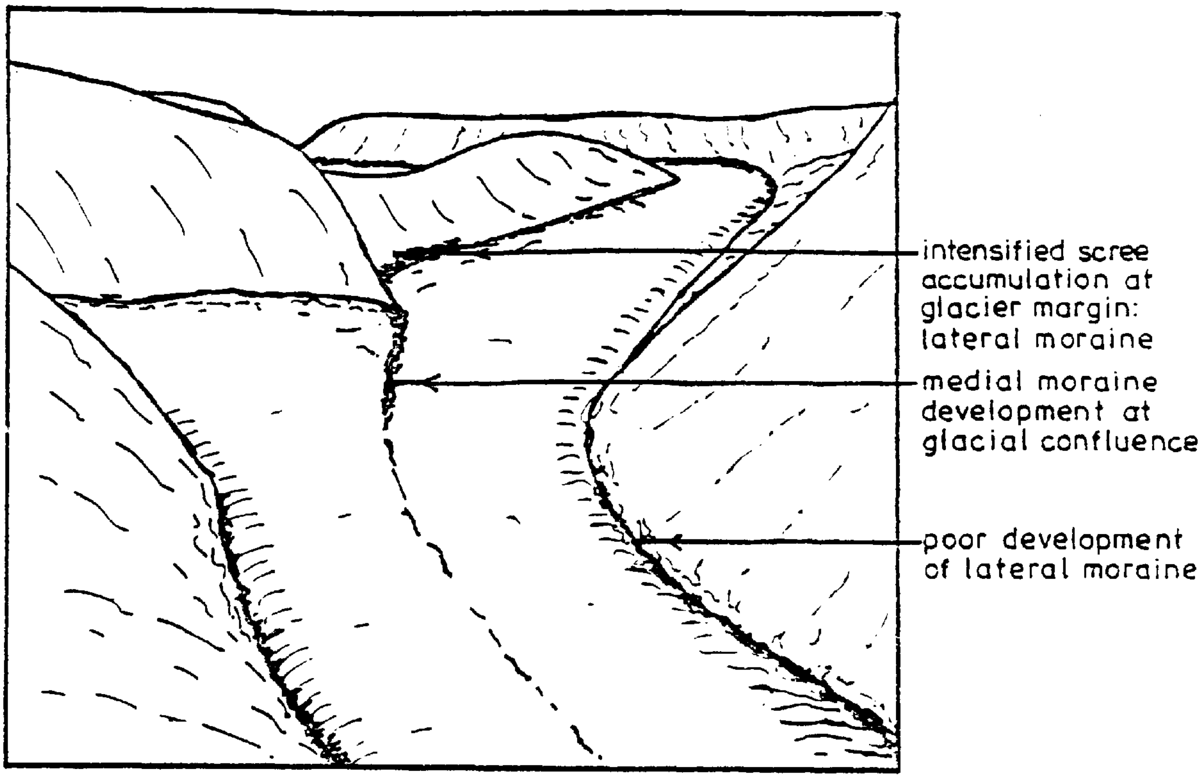
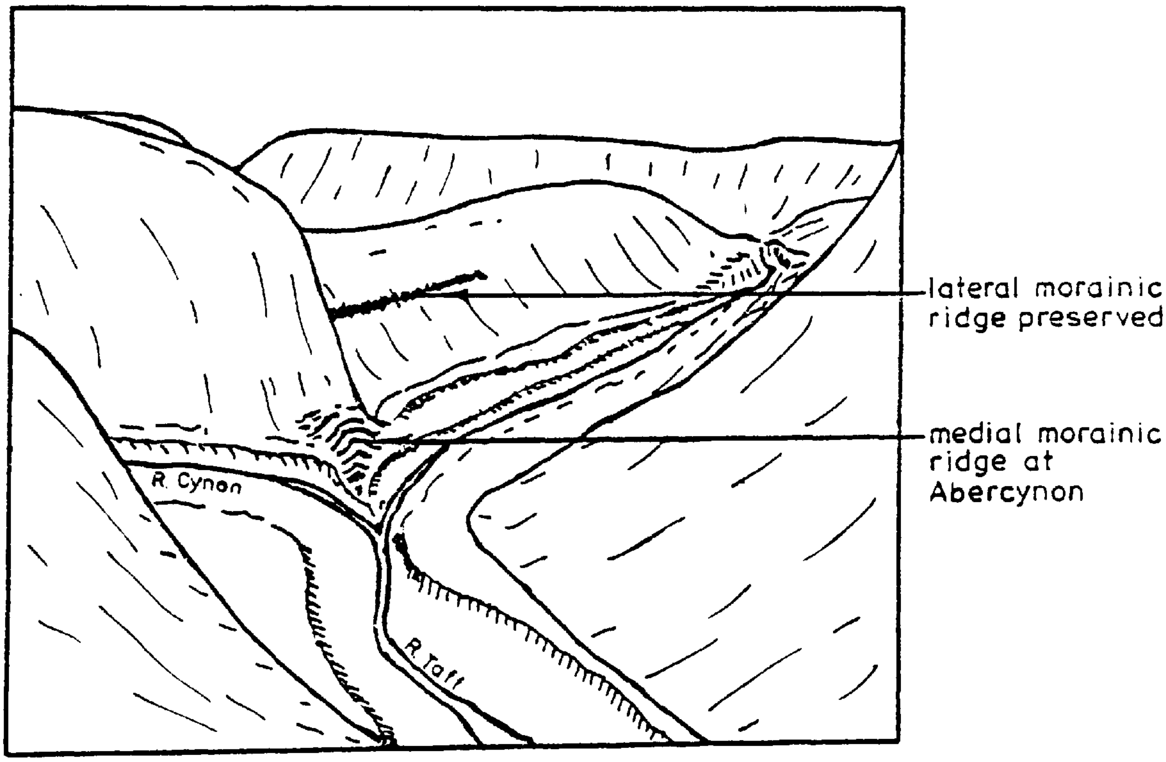


PLATE 2.5

A STEREOPAIR OF AIR PHOTOGRAPHS OF THE ABERCYNON AREA. LATERAL AND MEDIAL MORAINES (LM AND MM) ARE INDICATED



(a) Glacial phase



(b) Postglacial phase

FIGURE 2.3

DEVELOPMENT OF MEDIAL AND LATERAL MORAINIC RIDGES NEAR ABERCYNON

A second element with greater relief is developed to the east of Glyntaff (ST 088891), as shown in Plates 2.6 and 2.7. It lies on the downstream edge of a rock bench in the lee of which laterally transported debris collected, shielded by the relief of the bench. A talus cone of scree may also be seen 320 metres to the south-east of the moraine.

(c) Medial moraine

The mode of development of medial moraine is usually associated with the confluence of two valley glaciers.

Located at Abercynon, at the junction of the Cynon and Taff Valleys (ST 085952), is a wedge of coarsely graded clast-dominant morainic till tapering towards the south-south-east, as shown in Plates 2.4 and 2.5. The glacial model during the phase of moraine formation is reconstructed in Figure 2.3.

2.4.2.2 A land facet of the supraglacial land system

The high degree of ground coverage of melt-out till in the valley has resulted in the presence of hummocky melt-out moraine, as shown on Maps 2.1 and 2.2. In Map 2.3 (to the north of the valley) hummocky moraine is poorly developed.

Individual hummocks have not been found to exceed 10 metres in amplitude from base of trough to the hummock crest. The depressions between hummocks (of up to 3 metres deep and 15 metres in width near

PLATE 2.6

OBLIQUE VIEW OF A LATERAL MORAINE (LM) DOWNSTREAM OF A BEDROCK TERRACE (BT) NEAR GLYNTAFF

PLATE 2.7

A STEREOPAIR OF THE GLYNTAFF AREA, INDICATING THE SITE OF A LATERAL MORAINE (LM). THIS ELEMENT IS LOCATED ON THE LEEWARD (DOWNSTREAM) SIDE OF A BEDROCK TERRACE (BT). NOTE ALSO THE TALUS CONE (TC) WHERE A VALLEYSIDE STREAM REACHES THE VALLEY-FLOOR BREAK OF SLOPE.

Rhydyfelin) probably represent pockets where ice has melted and may be compared with kettle holes in their mode of formation. They typically contain a more disturbed englacially induced texture (including fabric) than exists in the hummocks between.

The example of a hummocky melt-out morainic element viewed obliquely in Plate 2.8 and shown in Plate 2.9 as a stereopair, lies 800 metres to the north-west of Edwardsville at ST 082970. Here a low mound 110 metres long and 45 metres wide, elongated parallel with the valley axis (towards 160/340 degrees), rises to a maximum of 7.5 metres above a mainly featureless terrace. The latter lies 22 to 24 metres above the present river level and slopes at between 3 and 6 degrees towards a series of fluvioglacial outwash terraces into which the present river has incised. No textural data could be obtained directly for the element, however, riverside exposures some 40 metres to the north provided evidence for the local sedimentary succession. The soil profiles exposed in the river bluff are part of a melt- out till sequence (here greater than 8 metres thick) overlain by an accumulation of kame terrace deposits of up to 3.6 metres thick. At the site of the morainic element topographic evidence suggests that the unit is composed of a greater thickness of melt-out till (possibly up to 6.5 to 7 metres more) around which the stratified kame terrace material has been deposited as a flat, featureless terrace.

The mode of genesis of the element is also suggested by topographic evidence. It would appear that till accumulated as hummocks of melt-out moraine towards what was originally the glacier margin. Around these elements of somewhat high relief, fluvioglacial deposits accumulated by ice-marginal ponding and outwash

PLATE 2.8

OBLIQUE VIEW OF MELT-OUT MORAINE IN AN AREA OF FLUVIOGLACIAL DEPOSITS
TO THE NORTH-WEST OF EDWARDSVILLE

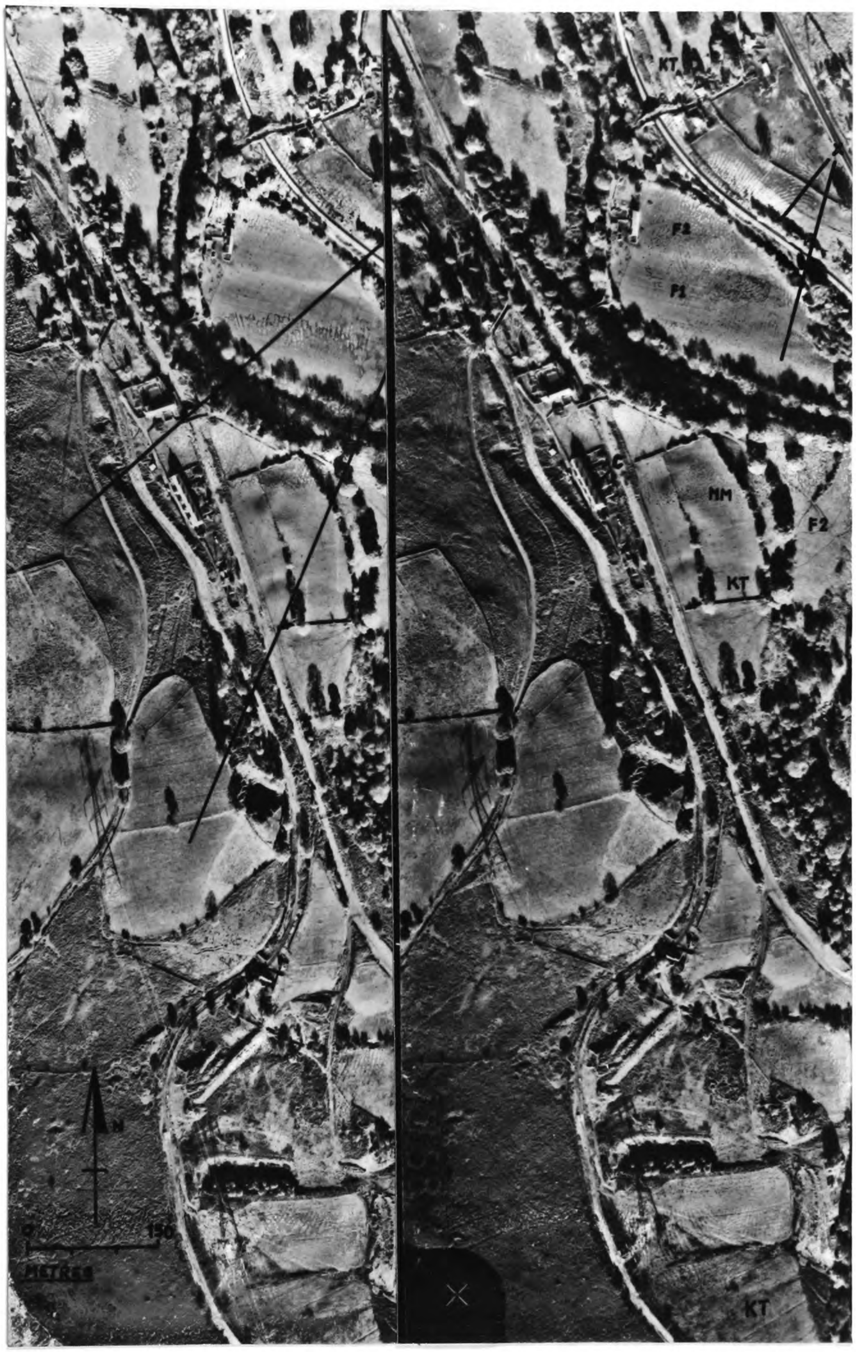


PLATE 2.9

A STEREOPAIR OF THE AREA TO THE NORTH-WEST OF EDWARDSVILLE. THE COTTAGES (C) ARE AT GRID REFERENCE ST 08029740. NOTE THE HUMMOCKY MELT-OUT MORAINE (MM) TO THE EAST OF THE COTTAGES. PLATE 2.8 WAS TAKEN FROM POINT X, WITH THE FIELD OF VIEW AS INDICATED. NOTE ALSO THE KAME TERRACE (KT), AND FIRST AND SECOND FLUVIOGLACIAL TERRACES (F1 AND F2).

transportation. This produced the shallowly sloping kame terrace feature predominant at the site. The downvalley flow of melt-water in this ice contact environment may have provided the mechanism by which the hummocky element became streamlined parallel to the axis of the valley.

2.4.2.3 Land facets of the subglacial/proglacial land system

(a) Drumlinoid features

Glacial moulding of till and shallowly dipping Coal Measure Series bedrock has resulted in the development of streamlined drumlinoid forms at one principle location within the valley.

At The Willowford (ST 104860), 500 metres to the west of Treforest Trading Estate, three bedrock-cored drumlin elements are arranged en échelon in a 'basket of eggs' formation orientated downvalley towards 150 degrees, (as shown in Figure 2.4 and Plates 2.10, 2.11 and 2.12). Each element has a well rounded stoss end (slope angle, 14 degrees) and a tapered leeward side with a maximum slope angle of 8 degrees. This is exhibited in Plate 2.10, showing the side profile, whilst the axial profile of the largest element is shown in Plate 2.11. Exposures within the largest element at ST 105858 show that the drumlin core is composed of current bedded, medium grained, Coal Measure series sandstone shallowly dipping at 4 degrees north-east. This is covered with a 0.4 to 0.5 metre thickness of melt-out till overlain by 0.1 metres of head deposit. The shallow covering of till has been attributed to

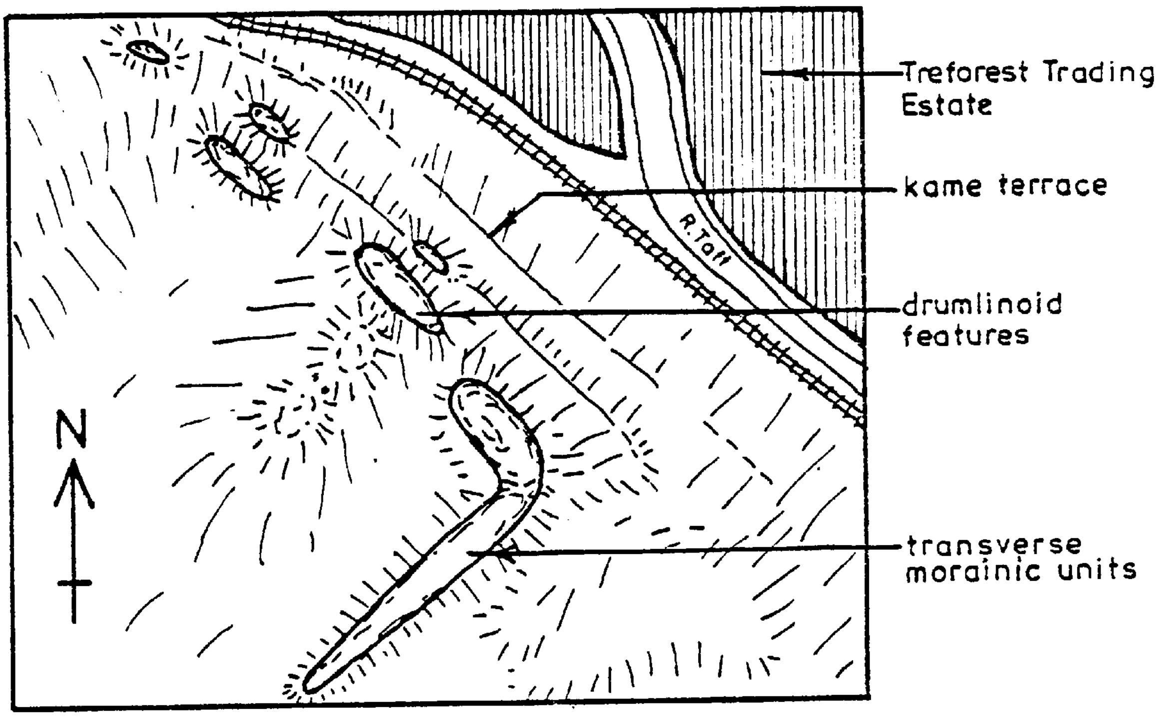


FIGURE 2.4

DRUMLIN FIELD WEST OF TREFOREST TRADING ESTATE

PLATE 2.10

OBLIQUE VIEW OF BEDROCK-CORED DRUMLINS (D1, D2 AND D3) AT THE WILLOWFORD, LOOKING DUE WEST

TREFOREST TRADING ESTATE IS IN THE MIDDLE DISTANCE

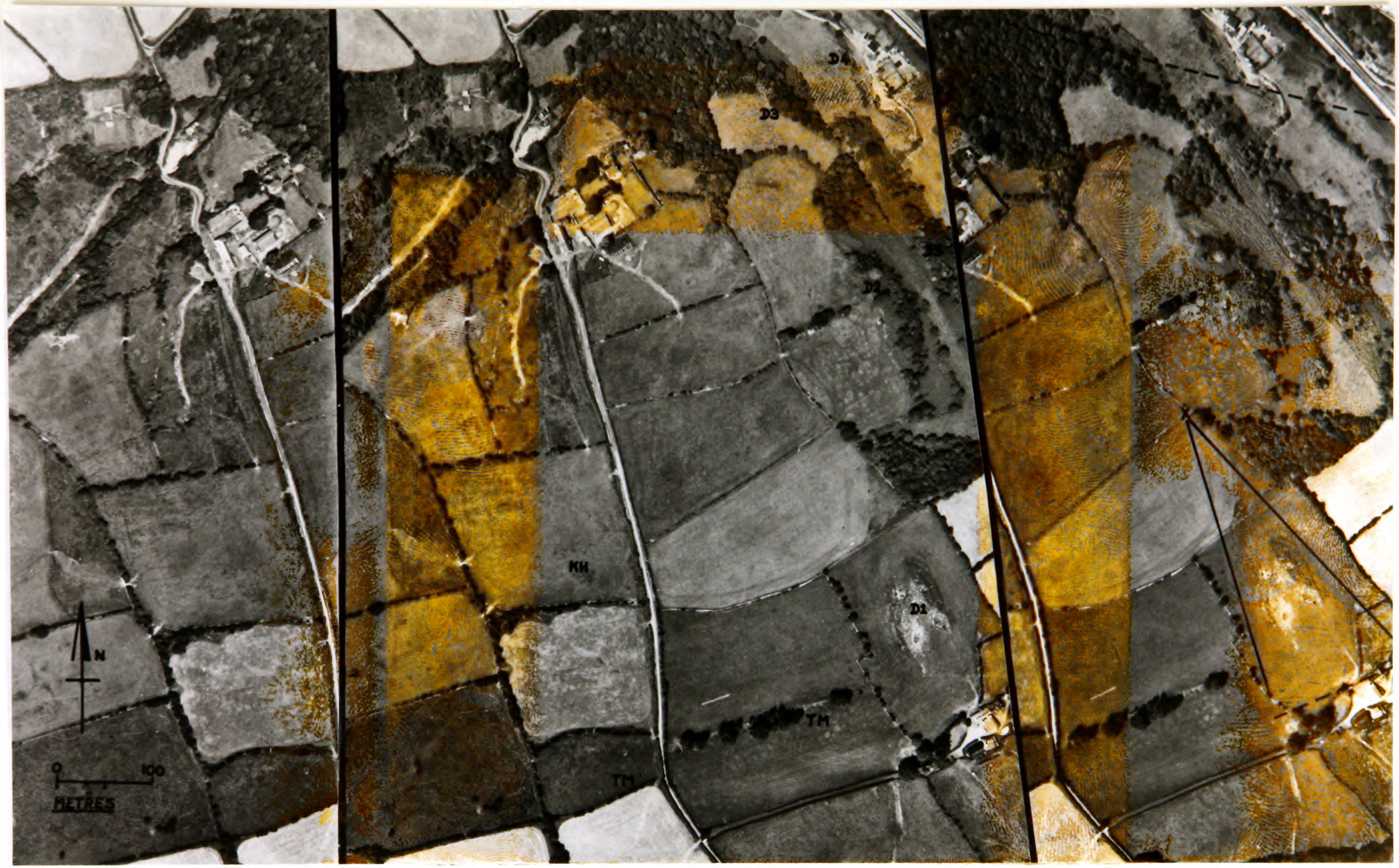


PLATE 2.11

A STEREOTRIPLET OF THE AREA TO THE WEST OF TREFOREST TRADING ESTATE, SHOWN IN MAP 2.2 AND PLATE 2.4. NOTE THE DRUMLINOID ELEMENTS (D1 TO D5). BUILDING STONE HAS BEEN QUARRIED FROM THE ROCK CORE OF ELEMENT D1, UPON WHICH IS SUPERIMPOSED A TRANSVERSE MORAINIC UNIT (TM). A KETTLE HOLED (KH) MELT-OUT MORAINE AREA LIES TO THE WEST. THE FIELD OF VIEW FOR PLATE 2.10 IS INDICATED BY THE DASHED LINE. PLATE 2.12 WAS TAKEN FROM POINT X WITH THE FIELD OF VIEW, AS INDICATED.

PLATE 2.12

OBLIQUE VIEW OF DRUMLINOID ELEMENT D1, LOOKING SOUTH post-depositional thinning by solifluction of material downslope away from the drumlin crest. The head deposits recorded at this site reflect the reworking of till by solifluctual mass wasting under periglacial conditions. This most westerly drumlin (the largest of the group, 185 metres long and 70 metres wide) has a transverse element orientated towards the west-south-west at right angles to the main body of the former. The feature has the appearance of a small terminal moraine superimposed upon the tail of the drumlinoid element, however it most probably owes its origin to a crevasse infilling as suggested by the gravelly sandy nature of the soil and its pronounced kamiform profile.

In conclusion, this latter group of drumlins have been formed by glacial moulding of bedrock mounds, upon which, as a result of ice ablation, has been the deposition of melt-out till. The till has subsequently been weathered and reworked by solifluction with the development of head deposits.

(b) Morainic ridges

Morainic ridges within the valley are well developed in the vicinity of Ynys-Gau Farm (ST 118848) between Gwaelod-y-garth to the south and Nantgarw to the north, (see Map 2.1). The presence of other similar elements is not apparent within the valley, however such features may well be preserved below the thick fluvioglacial and glacilacustrine deposits now occupying the valley floor.

In the fields around Ynys-Gau Farm between six and seven continuous and discontinuous morainic ridges are noted as shown in Figure 2.5, Plates 2.13, 2.14 and 2.3. Their orientation is transverse to the valley sides and they are truncated by the River Taff to the east. The most northerly ridge (marked M6 in Plate 2.3), is the most significantly developed of the group, its highest point lying at 28 metres above the river floodplain; typically the ridges are between 13 and 19 metres high. Postglacial breaching of the largest moraine by the River Taff, has left remnants of the ridge on the eastern side of the river, abutting the valley side. The granular, clast-dominant nature of this morainic remnant was proved during site investigation associated with the A470 Taff Vale Trunk Road at this location. The textural properties of the deposit are essentially similar to those of fluvioglacial deposits, being coarsely graded cobbly sandy gravels with boulders and less than 3 per cent silt present. The lowlying areas between individual morainic ridges are marshy with the present of abundant Juncus conglomeratus (as shown on Plate 2.14), a rush that thrives on predominantly silt and clay rich waterlogged ground. An accumulation of till rich in fines (possibly flow till) at the moraine base would provide the means by which these waterlogged areas developed.

The morainic ridges at Ynys-Gau have an predominant cross-sectional asymmetry. In seventy per cent of the examples, the upstream proximal faces slope (θp) at 7 to 11 degrees (mean of 8.7 degrees), whilst the distal slope angles (θd) range between 19 and 28 degrees (mean of 22.2 degrees); the other two ridges are virtually symmetrical. The slope angles of the

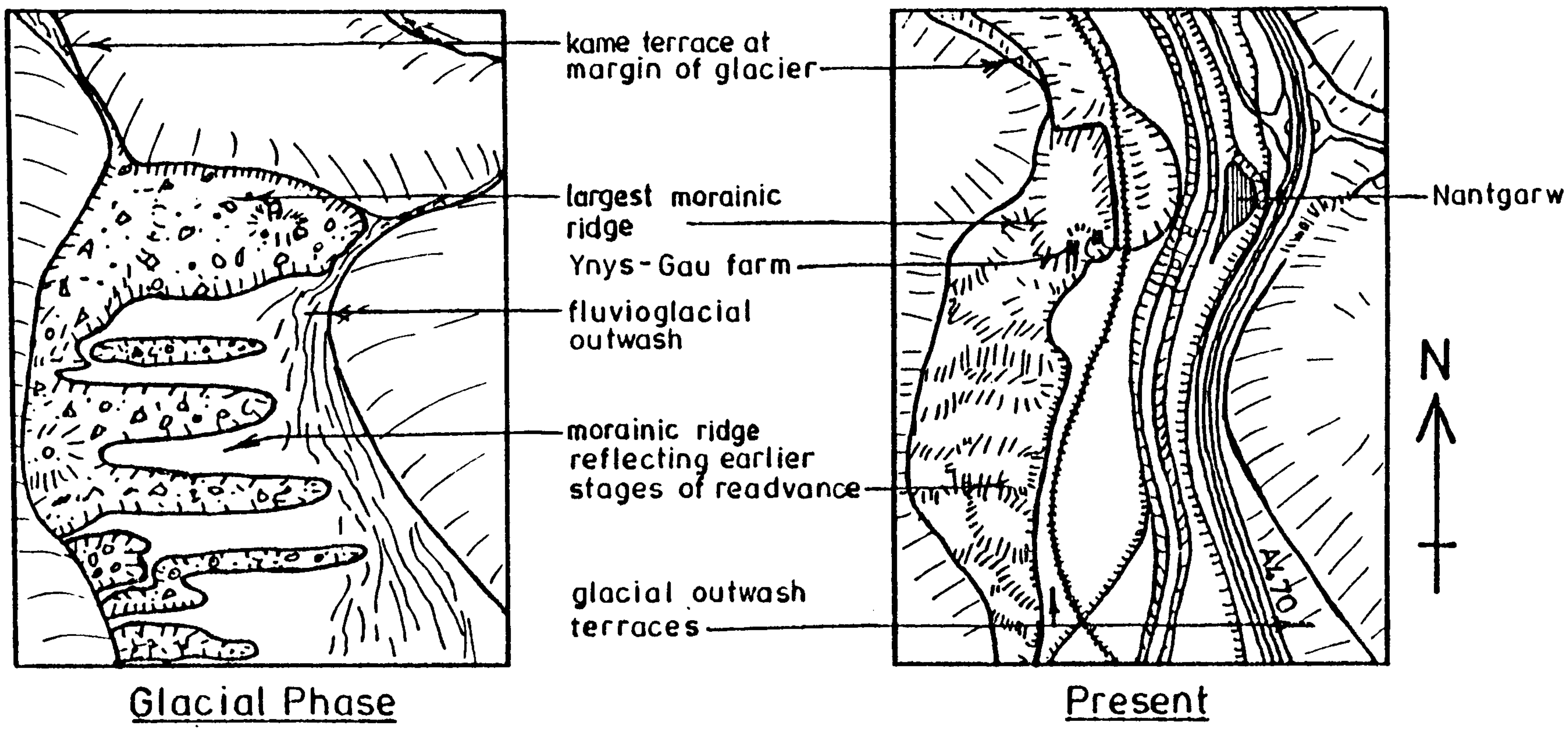


FIGURE 2.5

MORAINE DEVELOPMENT AT YNYS-GAU
POSSIBLY REFLECTING A PUSH MECHANISM

PLATE 2.13

OBLIQUE VIEW OF THE MORAINIC RIDGES (M1 TO M6) NEAR YNYS-GAU FARM, AS VIEWED FROM POSITION Y ON PLATE 2.3

PLATE 2.14

OBLIQUE VIEW OF MORAINIC RIDGE M3, (FROM POSITION Z ON PLATE 2.3)
TO SHOW CROSS-SECTIONAL ASYMMETRY
THE RUSH JUNCUS CONGLOMERATUS IS IN THE FOREGROUND

majority compare favourably with values for the proximal and distal slopes of "saw-tooth" push moraines described by Matthews, Cornish and Shakesby (1979) in the glacier foreland of Bødalsbreen in southern Norway. They describe the mean proximal and distal slope angles (θp and θd respectively) for the teeth and notches of the moraines. For the teeth, θp and θd were 8.4 degrees and 17.8 degrees respectively, whilst for the notches, values of 17.7 degrees and 21.2 degrees were recorded.

The asymmetry of the majority of the ridges observed in the fields adjacent to Ynys-Gau Farm, may be the result of the interrelationship of two main factors :-

(i) As a consequence of their mode of formation. Matthews et al (1979) describe two mechanisms for the development of an asymmetrical moraine cross-profile :-

(a) as the result of a push mechanism where material is "bulldozed" at the glacier frontal margin

(b) by glacial ice mounting the proximal morainic slope during its formation, resulting in a reduction of the slope angle.

Insufficient evidence, both in the form of in situ soil textural data (glacio-tectonic folds and thrusts, for example), and concerning the glacial environmental regime, exists to specifically allocate the development of the morainic ridges to one of these formational modes.

(ii) In response to the textural properties (degree of clast dominance) of the material composing the proximal and distal moraine portions. Exposure of material on the distal morainic slopes near Ynys-Gau Farm shows that it is strongly clast-dominant, composed of a high proportion of fluvioglacial sands and gravels. Here surface drainage tends to be somewhat better than on the proximal slopes. On the latter, poorer drainage characteristics, particularly on the lower slopes, may reflect a higher fines content which reduces the soil permeability. The higher fines contents within the material composing the proximal morainic slopes would therefore tend to reduce the angle of shearing resistance (ϕ) of the soil to lower than that of the distal slopes. This would subsequently result in a lower angle of repose and therefore lower final slope angles.

The moraine asymmetry in cross-section may therefore also be a consequence of the soil properties.

(c) Roches moutonnées

Ice-moulding of bedrock below the glacial sole has produced roches moutonnées within the valley. Their development low on valley sides and in the valley floor would have resulted in many of these land elements, wherever present, being covered by fluvioglacial outwash deposits and other products of ice ablation.

Two locations of roche moutonnée are noted within the valley, both to the south of Pontypridd :-

(i) 850 metres west of Treforest at ST 076893 (see Plate 2.15, feature R)

(ii) 550 metres to the north-west of Ynys-Gau Farm (ST 117849), marked R as shown in Plate 2.3.

Both features are developed in north to north-easterly dipping Pennant Sandstone Series strata of sufficient elevation to protrude above the blanket of superficial deposits. Each exhibits a typical morphology, that is, a smooth upstream face and a plucked downstream lee-side wall.

(d) Outwash plains and terraces

Elements of this land facet are abundant within the valley, as shown on Maps 2.1, 2.2 and 2.3. They are typically well drained due to their predominantly granular nature, characteristically a sandy gravel with a varying proportion of cobbles and boulders. The essentially horizontal, elongate form of the terraces and plains, accompanied by high permeability and high angles of repose for the deposits, have made them ideal locations for building purposes (especially ribbon development) within the valley and are developed to varying degrees. For example, five levels of outwash terraces are discernible immediately to the west of Edwardsville at ST 084966. They are probably the consequence of multiple phases of Postglacial

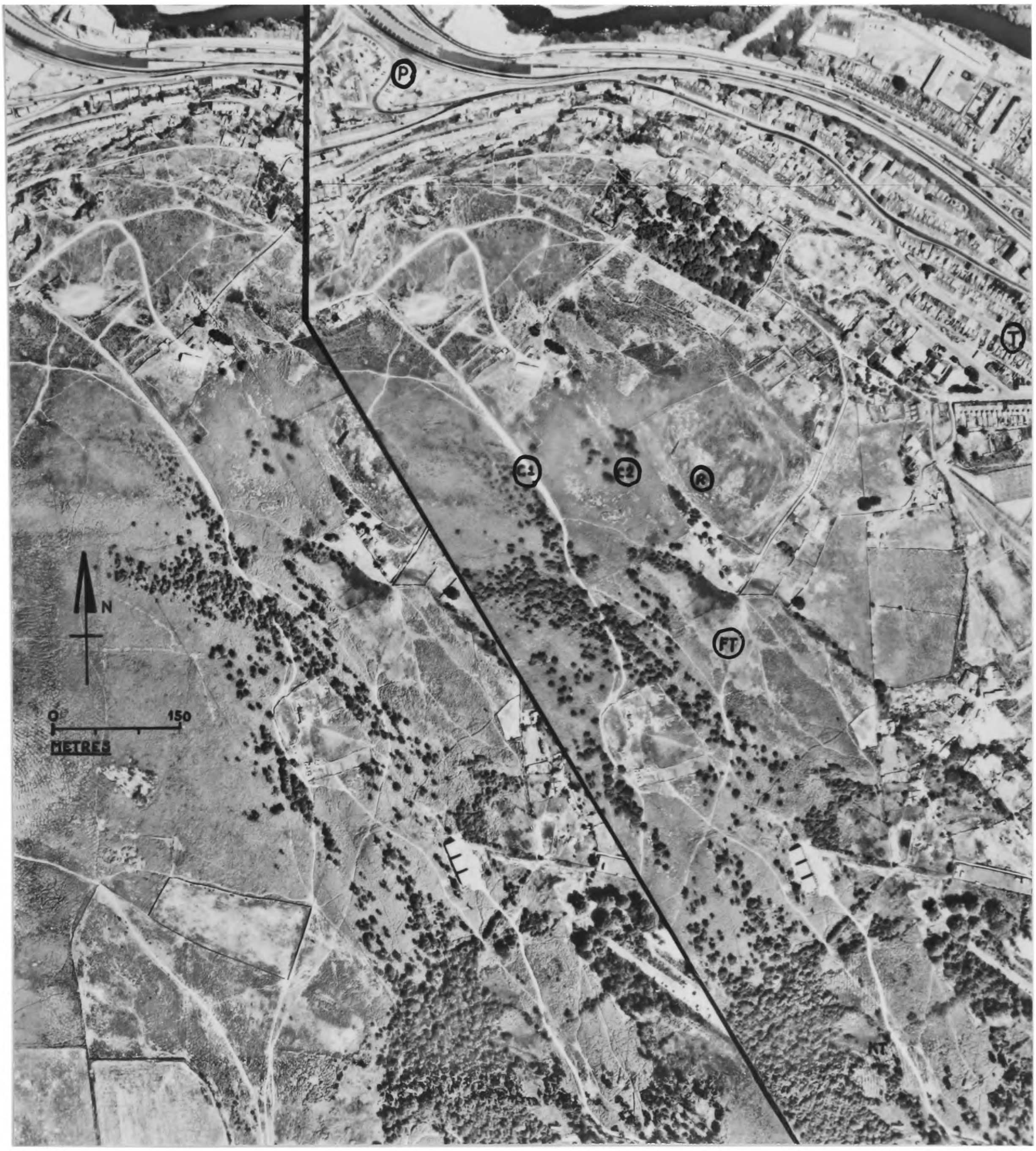


PLATE 2.15

A STEREOPAIR OF AIR PHOTOGRAPHS OF THE UPLAND AREA TO THE SOUTH OF PONTYPRIDD (P) AND TO THE WEST OF TREFOREST (T). NOTE THE MELT-WATER CHANNELS (C1 AND C2), POSSIBLY OF SUBGLACIAL ORIGIN, FOLLOWING TWO FAULT LINES; A TERRACE OF FLUVIOGLACIAL DEPOSITS (FT) IS LOCATED AT THEIR DISTAL (DOWNSTREAM) END. NOTE ALSO THE ROCHE MOUTONNEE (R) AND KAME TERRACE (KT).

fluviatile erosion that had downcut into a thickness of fluvioglacial deposits accumulated in the valley floor following ice ablation. The development of the gorge at Quaker's Yard 1.2 kilometres downstream, may also have been an important factor in the development of the terraces. The gorge is cut into a sequence of well stratified sandstones and siltstones, hence differing rates of bedrock erosion in the locality of the gorge may have effectively rejuvenated the river such that it sporadically terraced the deposits upstream.

Typically two main river terraces are apparent along the length of the Taff Valley. The lowermost terrace is elevated at heights of between 6 and 8 metres above the present river level, whilst the second terrace lies a further 11 to 16 metres above the lower.

Some fluvioglacial outwash deposits have proved difficult to fit into the model of ice ablation and glacio-fluviatile deposition in the Taff Valley. These deposits are labelled as undifferentiated fluvioglacial deposits in Maps 2.2 and 2.3. In some examples the characteristic terraced form is absent, hence recognition has been based essentially upon the textural properties exhibited. At other sites within the valley accumulations of this material lie at various elevations above the valley floor, beyond the typical extent of other fluvioglacial deposits. They therefore do not directly fit the model of glacio-fluviatile deposition following ice ablation at lower valley levels. Examples of the latter have been revealed during construction of the A468 Nantgarw to Caerphilly road, passing through the col between Mynydd Meio and Craig yr Allt. This material is shown in Map 2.2 at the lower eastern corner of grid square 1286. Site exposures and borehole data for the widening of this road have revealed an easterly dipping imbrocation of gravel and cobble sized clasts within fluvioglacial material, orientated from the Caerphilly Basin into the Taff Valley. A distinct lack of overlying till suggests that the deposit may represent sub-aerial overflow of glacial outwash from the ice dammed Caerphilly Basin into the Taff Valley via the low level col. This would have occurred during the closing stages of glaciation. These deposits have subsequently been terraced in their lower regions at Nantgarw by Postglacial fluviatile action and have become intermixed with other fluvioglacial deposits in the locality.

2.4.2.4. Other land facets of glacial origin and periglacial features

Other landforms not conforming to a glacial land systems categorisation but which are a direct consequence of glacial activity within the Taff Valley, are hereunder included.

(a) Meltwater channels

Only one group of meltwater channels further to the feature discussed near Nantgarw (section 2.2.1.3(d)), is readily identifiable within the valley. These elements are located at approximately 130 metres above the valley floor along the western margin of the roche moutonnée described above in section 2.2.1.3 (c) near Pontypridd and shown in Plate 2.15. The channels follow two north-south fault lines in the local Pennant Sandstone bedrock. They have a flattened base sloping at between 2 and 4 degrees to the south, relatively steep sides of between 22 and 31 degrees, and have a deltaic development of well drained, granular material (probably fluvioglacial sands and gravels), at their southern mouth in the proximity of ST 075892. The feature represents the location of a subglacial channel running beneath an ice sheet choking the Taff and neighbouring valleys at the climax of glaciation. The relationships of the roche moutonée, melt-water channels and sediment delta are shown in Plate 2.16.

(b) Buried river valleys

Anderson and Blundell (1965) record buried valleys for the River Taff, developed to depths of 42 metres below O.D. in the vicinity of the mouth of the present river, in the Cardiff district. Little data is however available concerning depth to rockhead below the present river level along the entire length of the valley northwards. The thickness of the superficial deposits above rockhead along the valley floor is extremely variable. This has been proved by shaft sections for currently operational and abandoned mines situated in the coal producing areas namely towards the north and south of the valley. The valley bottom profile is essentially a series of elongate basins eroded into a predominantly argillaceous substrate, with shallower regions between where the more arenaceous strata outcrop. The thickness of the superficial deposits from the north to the south of the valley, as shown in mining records, is

PLATE 2.16

OBLIQUE VIEW OF ROCHE MOUTONNÉE (R), MELT-WATER CHANNELS (C1 AND C2) AND DELTAIC FLUVIOGLACIAL TERRACE (FT) TO THE WEST OF TREFOREST given in Table 2.1.

Table 2.1 Thickness of superficial deposits in the Taff Valley

Coal Pit name	Grid Reference	Thickness(m)
Castle Pit	SO 06510261	2.1
Merthyr Vale No.1	SO 07370011	23.7
Merthyr Vale No.2	SO 07380000	19.9
Abercynon	ST 08289441	25.9
Albion	ST 08629263	17.1
Maritime	ST 05909088	3.7
Nantgarw	ST 11958574	13.7

(c) Glacilacustrine localities

The location of areas once occupied by glacial lakes has been ascertained by the interpretation of ground conditions in the flat, lowlying areas of the valley floor. The area now occupied by Treforest Trading Estate and also parts of the flat valley floor upvalley from Pontypridd and Merthyr Vale, are related to this genetic mode. The textural properties of the deposits exhibit pronounced within and between site heterogeneity as a direct consequence of the lacustrine kinetic regime existing at the time of sediment deposition. Examples have been observed and recorded within these areas (such as at Pontypridd; documented subsequently in section 3.3.1), where thickly laminated silts and clays (thicker but probably synonymous with varves), have been deposited in low energy proglacial areas, whilst sands of varying degrees of grading uniformity reflect higher energy environments.

The distribution of these deposits as a whole, as would be expected in the glacial environment, exhibits a spatial variability dependant upon the local morphology of previously deposited glacigenic soils. This is demonstrated by recreation of the local glacial environment that probably existed in the Merthyr Vale area towards the close of glaciation following ice ablation in the locality. Section records for Merthyr Vale Collieries Numbers 1 and 2 have revealed the lateral and vertical extent of the local soil types, as shown in Figure 2.6. Data shows that the glacilacustrine deposits thin in a southerly direction from 16.45 metres thick at Merthyr Vale No.1. Pit (at SO 07370011), to 1.9 metres thick at No.2 Pit (SO 0738000). This occurs over a distance of 90 metres. Where the melt-out till is relatively thin at the former site, (up to 1.8 metres thick), the glacilacustrine sands and silty sands have thickly accumulated. However, where there has been a large concentration of melt-out till (possibly originally a stagnant ice field), overlain by fluvioglacial gravels totalling 13.3 metres thickness at No.2 Pit, glacilacustrine deposition has been limited. The melt-out till would typically have had a hummocky topography (developed upon underlying lodgement till 0.3 to 2.1 metres thick), upon which fluvioglacial outwash gravels of variable extent had been deposited. In the somewhat lowerlying area to the north of the melt-out till field, glacilacustrine deposits in a proglacial situation had accumulated, probably in response to the former acting as a dam

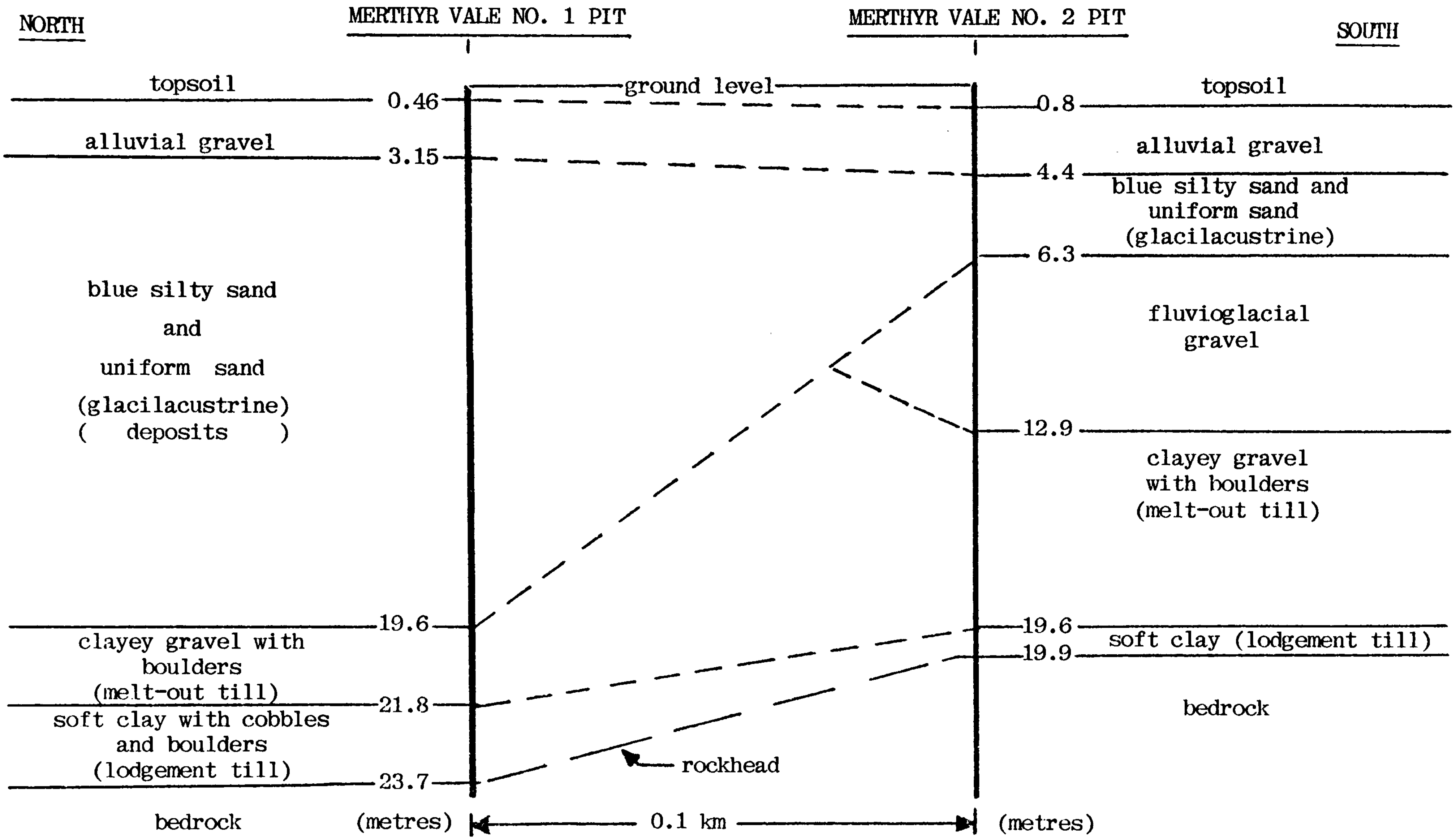


FIGURE 2.6

SECTION RECORDS FOR THE MERTHYR VALE COLLIERIES AS A GUIDE TO THE INTERPRETATION OF THE LOCAL GLACIAL MODEL reducing melt-water outflow. The combined effects of the till dam and glacilacustrine sediment influx resulted in a raised water level in the lake to a sufficient height to overtop the hummocky, outwash covered area now marked by Merthyr Vale No.2 Pit. Recent fluviatile gravels have subsequently covered the underlying glacigenic soils to a recorded thickness of up to 3.6 metres here. The resultant present day topography (as shown in Plate 2.17), is one of an almost features flat expanse of valley floor stretching northwards to Merthyr Tydfil.

(d) Periglacial landforms

Following the close of the final stages of ice advance within the Taff Valley periglacial conditions prevailed, providing mechanisms for modification of the local glacial deposits and bedrock by cycles of freeze and thaw. Frost shattering of bedrock exposures has resulted in the widespread development of scree-debris slopes. These have subsequently become overgrown to a large extent, however, soil textural evidence has proved their existence at several locations including upon the slopes above Gwaelod-y-garth (ST 114838), as shown in Map 2.2. This material is covered with finer periglacial soils, head deposits.

Geomorphological evidence within the valley has shown that a large proportion of the unconsolidated glacial deposits, mainly till, have undergone post-depositional mass movement by solifluction in the periglacial environment. In a saturated unstable condition the superficial deposits have flowed

PLATE 2.17

MERTHYR VALE NO.1 AND NO.2 PITS IN THE FLAT ALLUVIUM COVERED VALLEY FLOOR TO THE SOUTH OF MERTHYR TYDFIL downslope developing a lobate profile as individuals and a solifluction terrace when coalescencing. These elements are shown in Maps 2.1, 2.2 and 2.3.

Trial pits excavated to provide textural evidence for solifluction lobes in the vicinity of Aberfan, proved unsuccessful in revealing the layers of vegetable matter that are characteristically developed beneath the advancing snout of the feature. All elements at the ground surface were therefore identified solely upon morphological evidence. Where lobes and terraces have been recognised on aerial photographs (see Plate 2.18) and by field mapping (Plates 2.19 and 2.20), individual lobe widths have been noted to range between 18 and 105 metres. Frontal slopes (of varying dip according to soil type) are developed to heights greater than 4 metres above the standard local slope profile for the larger elements, whilst typically the lobes have a relief of little more than 1 to 2.5 metres.

2.5 Land Facet/Soil Lithology Relationships

By reference to the literature, for example to Boulton and Paul (1976), Fookes, Gordon and Higginbottom (1975), Fookes, Hinch, Huxley and Simons (1975), McGown (1971 and 1974), McGown and Derbyshire (1976) and Harris and Wright (1980) , it has been possible to ascertain the range of soil lithologies to be expected within each landform observed in the Taff Valley. The relationships between land facets and glacial and periglacial soil types are diagrammatically expressed in Table 2.2.

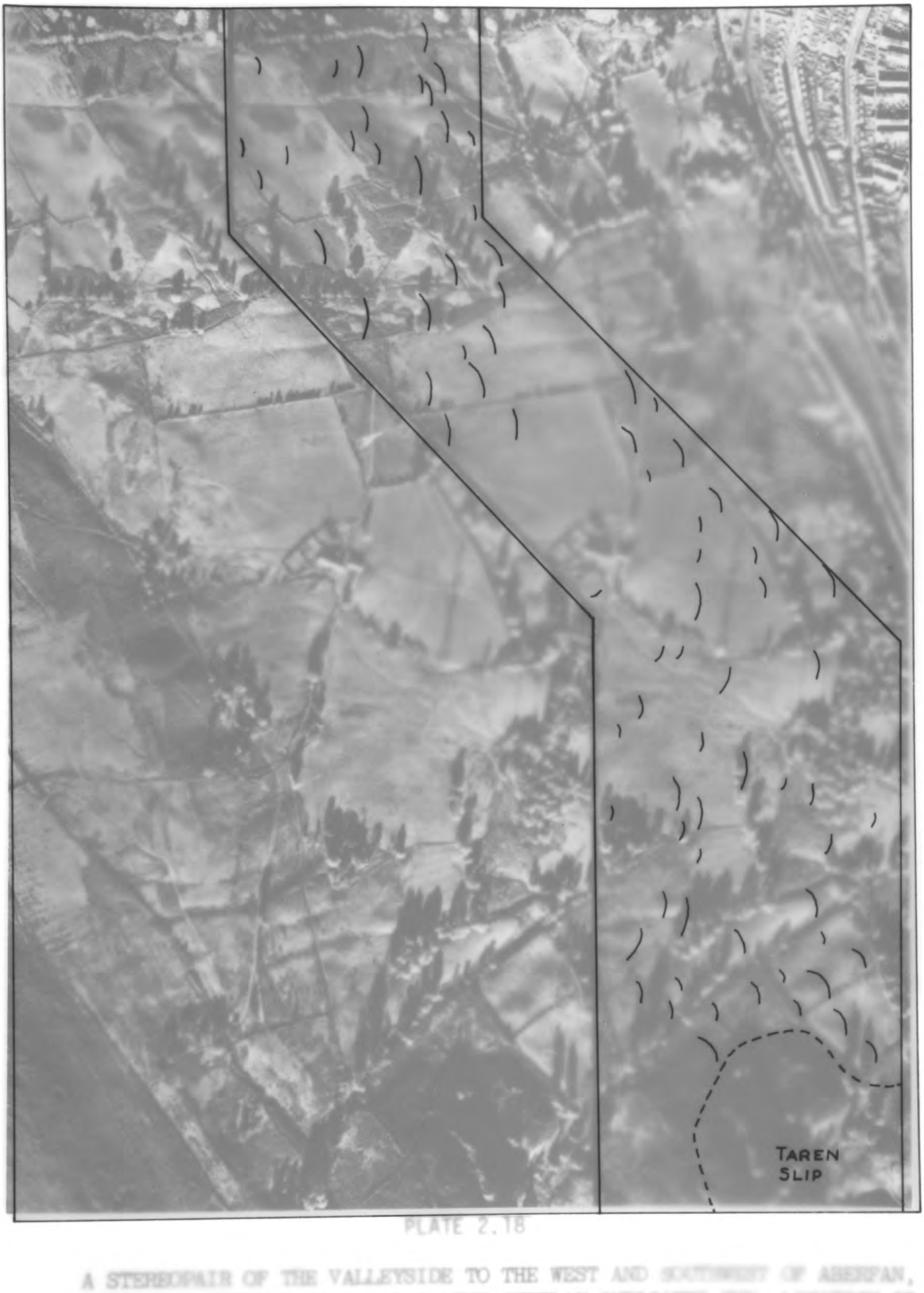


PLATE 2.18

A STEREOPAIR OF THE VALLEYSIDE TO THE WEST AND SOUTHWEST OF ABERFAN, PARTIALLY COVERED BY MAP 2.3. THE OVERLAY INDICATES THE LOCATION OF THE LARGER LOBES OF SOLIFLUCTED HEAD DEPOSITS AND TILLS DATING FROM THE LATE GLACIAL. THE TAREN LANDSLIP COMPLEX IS INDICATED IN THE SOUTH OF THE AREA.

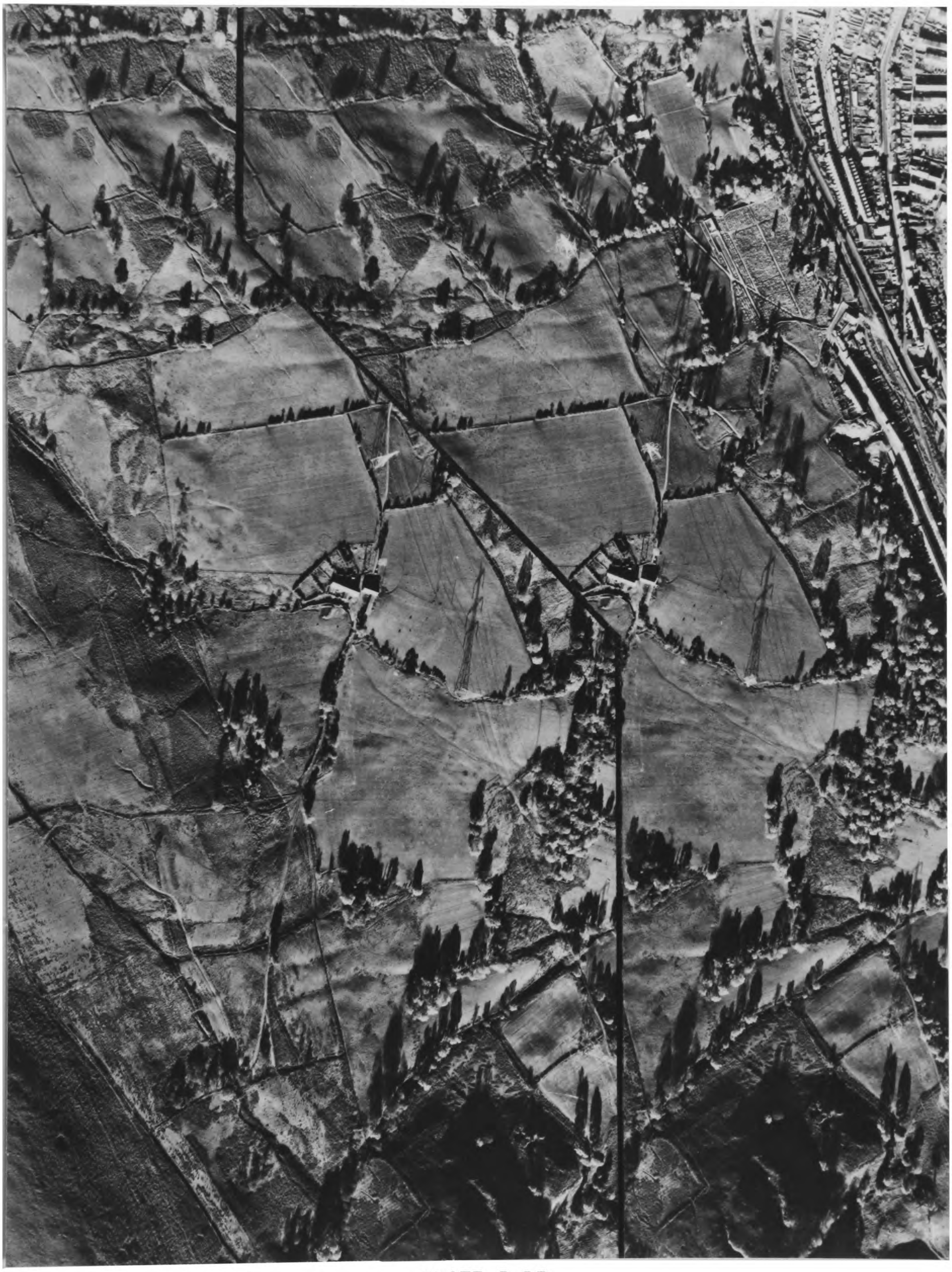


PLATE 2.18

A STEREOPAIR OF THE VALLEYSIDE TO THE WEST AND SOUTHWEST OF ABERFAN, PARTIALLY COVERED BY MAP 2.3. THE OVERLAY INDICATES THE LOCATION OF THE LARGER LOBES OF SOLIFLUCTED HEAD DEPOSITS AND TILLS DATING FROM THE LATE GLACIAL. THE TAREN LANDSLIP COMPLEX IS INDICATED IN THE SOUTH OF THE AREA.

PLATE 2.19

OBLIQUE VIEW OF SOLIFLUCTION LOBES (SL)
ON THE HILLSIDE TO THE WEST OF ABERFAN

PLATE 2.20

OBLIQUE VIEW OF SOLIFLUCTION LOBES (SL)
TO THE EAST OF MERTHYR VALE

LAND FACET	SOIL TYPE						
	LODGEMENT TILL (INCLUDING SUBTYPES)	MELT-OUT TILL	SUPRAGLACIAL MORAINIC TILL	FLOWTILL	FLUVIOGLACIAL DEPOSITS	HEAD AND SOLIFLUCTED TILL	FROST SHATTERED SCREES
Kame terrace		2	2		1		
Lateral and Medial Moraines		2	1	2	2		
Hummocky Melt-out moraines	R	1	1	1	1		
Drumlins	1	2					
Morainic Ridges	R	1	1	1	1		
Outwash Plains and terraces					1		
Solifluction lobes and terraces						1	1
Scree/Talus Slopes						1	1

1. Primary Importance | 2. Secondary importance | R. Reworked

TABLE 2.2

LAND FACET/SOIL TYPE RELATIONSHIPS IN THE GLACIAL AND PERIGLACIAL ENVIRONMENTS AS A GUIDE FOR AN ENGINEERING INVESTIGATION

In response to the above discussion of the land facets observed and of their varying genetic modes, the following chapter of this investigation presents a detailed description of the textural properties of the soil types within the Taff Valley. This will provide the basis for an assessment of the variability of the deposits in the light of a subsequent engineering investigation.

THREE

CHAPTER 3

FIELD DESCRIPTION AND INFERRED MODES OF ORIGIN

3.0 Introduction

The retreat of ice from the Taff Valley at the close of the Devensian (Margam) Glaciation left much of the local bedrock covered with superficial deposits, at present up to 25 metres in thickness. These deposits include tills, fluvioglacial sands and gravels and ice contact deposits on the lower valley slopes and valley floor, and sporadic kame terrace deposits higher on the valley sides. The soils subsequently became covered by Late Glacial products of mass wasting and Postglacial head deposits.

This chapter is concerned primarily with qualitative description of these soils, both in the field and on aerial photographs. Detailed field descriptions of typical examples of each major soil type are given. Particular emphasis has been placed on clast orientation measurements. They have been found to be particularly valuable in assisting in the interpretation of modes of genesis and distinguishing genetic mechanisms of some of the more texturally similar soil types. Data is supplemented by a description of the morphological and textural characteristics of the soils as observed in aerial photographs.

The second aim of this chapter is to discuss the origin of each soil in the context of a model of glaciation within the Taff Valley as a whole. The model, based upon a study of land facets as described in Chapter 2 and on field and aerial photograph observations, is intended to assist in data extrapolation from localities with an abundance of data to other more sparsely represented areas.

It is most convenient in this chapter to initially deal with the interpretation of aerial photographs and subsequently to provide the field descriptions and discussions of the origins of the soils.

3.1 Aerial Photographic Interpretation of Glacigenic and Periglacial Soils

It has been shown by Norman (1969) that aerial photographs, in addition to their use in delineating landform patterns, may provide an initial appraisal of the soil types to be expected within an area. He states that ranges of soil lithologies may be assessed by the study of four principle characteristics :-

1. drainage features, including gulley form
2. drainage densities as a factor of soil permeability and particle grading
3. tonal variations of the ground surface produced by changes in vegetation type

4. land use.

From these features Norman suggests that relationships may be drawn between the soil types observed and some characteristic landforms.

Norman provides a guide to the assessment of expected textural properties of a series of glacial soils. Specific examples of these soils, obtained from other literature, are included to supplement his findings.

- The granular, permeable sandy and gravelly soils (mainly of fluvioglacial origin and also the granular, clast-dominant melt-out tills) have a very low drainage density. Where gulleys are present, they are characteristically sharply incised and V-shaped. Light tones are typical of these soils as a consequence of their well drained nature, but sharp contacts between highly contrasting tones are frequent.

- Cohesive, impermeable clay soils (for example, the matrix-dominant and well graded subglacial melt-out and lodgement tills), develop a very high drainage density of shallow dendritic to disordered gulley patterns. A wide variety of tonal variations are typical of these soil types, the boundaries between tones tending to be diffused and softly edged.

- Non-cohesive, permeable silty soils (for example, some well graded melt-out tills and glacilacustrine deposits), have a varied degree of drainage (and drainage patterns) depending upon the origin of the soil. Ground tones and cross-sectional gulley form tend to remain uniform. The latter is usually U-shaped and often deeply incised.

Norman states that vegetation assemblages, both natural and cultivated, frequently show distinct contrasts between waterlogged fines rich areas and adjacent well drained granular sand or gravel accumulations.

Norman based his work on a study of the characteristics of tills and did not take into consideration the effect of a thickness of Late or Postglacial mantle (soliflucted head deposits) overlying the glacigenic soils and which may mask their typical features. The thickness of head and colluvial soils in the Taff Valley ranges between 0.9 and 3.2 metres. It is of sufficient depth in many cases to influence the drainage characteristics and densities, tonal variations and typical land use of the soils at greater depth. The highly permeable fluvioglacial outwash deposits (typically having a terraced form towards the valley floor), usually remain well drained with a very low drainage density, even when head deposits are developed to greater than 2 metres. However, the characteristic drainage and tonal contrasts that are typical of areas of melt-out tills tend to become subdued in the presence of an overlying head deposit. Where this occurs, the interpretation of soil types present is based more predominantly upon the landforms developed, here typically hummocky melt-out moraine.

In several localities, particularly near Aberfan, coarsely graded deposits of the second kame terrace have become masked by a silt rich head deposits derived from argillaceous bedrock outcrops upslope. The drainage density developed for the underlying soil does not give a true indication of its essentially well drained clast-dominant nature. The low profile and insignificant relief of the terraces, especially near Aberfan, has proved difficult to differentiate from the local bedrock terraces. Interpretation of the physical properties of the soils consequently require study in situ and could not be based upon Norman's criteria or landform morphology. Predictions of ground conditions using these factors alone usually prove inaccurate and always require supplementation by study of soil profiles and textural properties in situ.

Where head deposits have thicknesses of less than one metre it is possible to interpet the characteristics of the underlying soil types using aerial photographic techniques, particularly on the basis of drainage density. Examples are cited in the subsequent sections where waterlogged depressions between well drained (low density) coarsely graded hummocks of melt-out till and morainic ridges indicate the presence of silt and clay rich accumulations of flow till and reworked till lenses.

Seasonal conditions strongly influence the effective drainage of the soils present in the valley. The aerial photographs used in this investigation were mostly taken in the spring to late summer months when shadows were short and the weather good. The photographs taken in the late spring, particularly those taken after long periods of wet weather (reference being made to rainfall records for South Wales), provided high drainage densities on the less permeable matrix-dominant soils. This characteristic tended to decrease through the summer months as wet ground dried out. Aerial photographs taken in the spring and early summer therefore became the most useful for interpretation of soil types present and the determination of their spatial variability. The photographs taken in the later summer months were best employed in delineation of landforms of low relief, for example solifluction lobes and terraces, when longer shadows emphasised the form of individual land elements.

From this initial appraisal of the ground conditions within the valley, using Norman's work as a basic guide, the sites of greatest interest (including suitable excavations and stream-side exposures) were located and study routes between sites were plotted. This was essentially based upon the relationships drawn between landforms of known morphogenesis and the interpretation of the type and spatial arrangements of the soils to be expected therein.

3.2 Quantitative Data Presentation

In the late nineteenth and early twentieth centuries, the identification of glacial sediments and investigation of their modes of genesis was based upon qualitative methods of study. Subsequently, in the 1930's methods progressed to essentially quantitative procedures that were adopted principally for the analysis of till fabric. The study of clast orientations was employed as a means of interpreting local and widescale ice-flow directions within Pleistocene deposits. Notable contributions have been made by Holmes (1941), West and Donner (1956), Ostry and Deane (1963) and Penny and Catt (1967); their contributions have been discussed in section 1.1. The conclusions drawn by these workers were based essentially upon the graphic representation of clast orientation data in the form of rose diagrams. This method of description allows the rapid production of a readily recognisable picture of the spatial arrangement of clasts in situ, however, the method has shortcomings in that it is impossible to graphically represent the dip of individual clasts.

Further evidence to support conclusions drawn concerning the mode of origin, deposition or post-depositional transportation of a soil mass are provided here by the inclusion of quantitative rather than purely qualitative data, describing clast dip and azimuth.

In this investigation, dip and axial orientation data for bladed clasts larger than fine gravel size has been rapidly processed and represented graphically by employing a package computer program designed for the construction of Schmidt equal area stereonets. The deposits studied had an imbricate texture in which the axes of greatest elongation of the clasts generally corresponded with the direction of maximum dip. The dip and dip direction of the bladed clasts were measured and plotted as poles to planes on a lower hemisphere Schmidt equal area projection. Subsequently the data was statistically contoured employing Dennes counting nets and a modified Dennes net. This has provided a three-dimensional representation of clasts in situ for a variety of glacigenic and soliflucted soils in the valley.

The two dimensional rose diagram in also used here since it still has an application as a rapidly interpreted representation of clast orientation data. The vector strength and statistical significance of data represented by the rose diagrams are discussed.

3.3 Characteristic Textural Properties of Tills

Three principle till types are present within the Taff Valley :-

1. Lodgement till, (including comminution and deformation tills)

2. Melt-out till,constituting much of the total till present

3. Flow till,accumulated by flow of melted-out debris.

3.3.1 Lodgement till

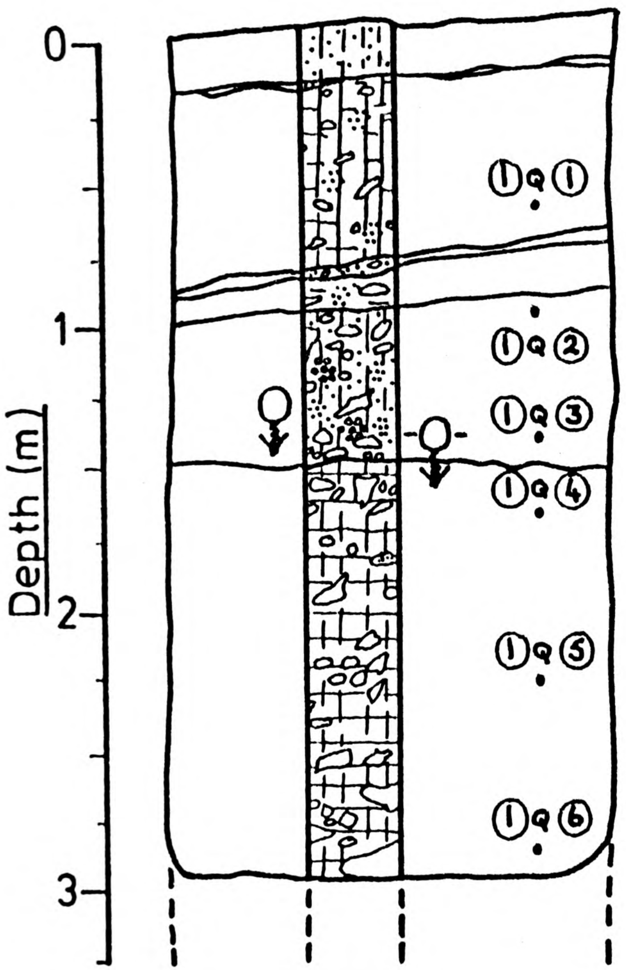
As a result of formation and deposition in the subglacial environment lodgement till tends to reflect the nature of the local bedrock over which glacial ice has passed. It is the attritional derivative of the substrate, reflecting the rock lithology and its crushing characteristics. Areas within the valley having a high percentage of argillaceous strata, for example those of the Productive Coal Measure Series located mainly to the north of Merthyr Vale and to the south of Cilfynydd, tend to develop a superficial cover of clayey silty lodgement till. With increasing elevation on the valley sides basic pattern changes in accordance with vertical variability in lithology of the locally shallowly dipping bedrock.

3.3.1.1 Textural properties in the areas with an argillaceous bedrock

In the predominantly argillaceous areas discussed above, lodgement till has developed to thicknesses of typically between 2 and 5 metres. The typical textural properties of the soil are shown in Figure 3.1. The mid to dark grey colouration of the deposit, as shown in Plate 3.1, would appear to reflect the presence of carbonaceous horizons within the lithologically argillaceous units. It invariably has the appearance of a firm to hard, compact, occasionally fissured, cobbly silty clay with frequently striated gravel sized clasts of siltstone and mudstone, (see Plate 3.2). Little or no sand sized fraction has been noted within the till, probably reflecting the bimodal crushing characteristics of the bedrock. The larger clasts of cobble and boulder size are subrounded to angular and bladed in shape and are composed of very locally derived Pennant sandstone and occasionally siltstone.

Some erratics of Devonian Old Red Sandstone (derived predominatly from the Brecon Beacons) and more abundantly Carboniferous Limestone and Millstone Grit quartzites, are present in lodgement till at the northern end of the valley. The relatively high strength of Carboniferous Limestone under attrition, has resulted in their preponderance as striated and polished clasts to the north of Abercanaid. Crushing and grinding of the weathered Devonian Old Red Sandstone clasts is common and is represented by the presence of small

Slope: 9°/116°



Topsoil	Dark greyish-brown silty SAND with rootlets Light grey (leached) silty SAND washouts at top of HEAD.
Head with colluvium	Mottled brownish-orange and light grey sandy clayey SILT (mod. firm to soft, moderately weathered) with gravel and some subrounded sandstone cobbles. Light grey cobbly SAND washouts. 40-70mm mottled brownish-orange sandy SILT at base of HEAD.
Melt-out till	Brown, weakly cemented, dense, slightly weathered gravelly silty SAND and angular to subangular GRAVEL with clustered subangular to subrounded cobbles and boulders of Pennant Sandstone and occasional Old Red Sandstone. Patches of iron-stained crushed Old Red Sandstone. Seepage (♀) at 1.25 and 1.5m depth, in gravel accumulations.
Lodgement till	Dark brownish-grey, indurated, stiff to hard, fresh (unweathered) angular to subangular cobbly silty CLAY (up to 35% cobbles) with iron-rich sand (crushed ORS) in patches, and angular to subangular cobble clusters with boulders. Lensoid cobble clusters at top of lodgement till Cobbles of flaggy Pennant Sandstone and some ORS. Size and percentage of cobbles and boulders increases with depth. No seepage.

FIGURE 3.1

DIAGRAMMATIC REPRESENTATION OF SOIL PROFILE NEAR ABERFAN (SO 0689 0083)

PLATE 3.1

A TRIAL PIT THROUGH GLACIAL AND PERIGLACIAL SOILS NEAR ABERFAN

PLATE 3.2

EXPOSURE OF LODGEMENT TILL NEAR TROEDYRHIW ferruginous sand lenses of extremely localised extent. These lenses, when continuous, act as conduits for water seepage through the till.

Localised jamming of groups of large clasts during till deposition has resulted in the development of gravel and cobble clusters (see Plate 3.3), occasionally with boulders up to 0.5 metres in length. These are commonly present as elongate assemblages (pavements) at numerous horizons; an example is shown in Figure 3.1.

As a facet of the till macrofabric, discontinuous vertical and subhorizontal shear and stress relief fissures have been noted within lodgement till samples from boreholes at Abercanaid and Nantgarw. Subhorizontal stress relief fissures at Troedyrhiw are shown in Plate 3.4. These however tend to be quite rare, developed only within localised pockets of clay and silt between clasts.

At the microfabric level, the presence of microfissures is recorded at depths in excess of 2.5 to 2.7 metres in lodgement till on the valley side above Aberfan. At depths of less than 2.5 metres the soil tends to be too granular and disturbed for the development or recognition of fissures. Within accumulations of platey, silt sized particles observed using a scanning electron microscope, microfissure sets were noted to have developed with an attitude normal and subnormal to the preferred particle orientation (see Plate 3.5). Other fissures have developed as a conjugate set at 45 to 50 degrees to the former, (see Plate 3.6). These microfissure sets are likely to be developed by shear stress during till deposition in the subglacial environment and stress relief mechanisms during ice ablation.

PLATE 3.3

A CLUSTER OF STRIATED GRAVEL AND COBBLE SIZED CLASTS
WITHIN LODGEMENT TILL NEAR TROEDYRHIW

PLATE 3.4

SUBHORIZONTAL STRESS RELIEF FISSURES (AT POINT OF TROWEL)
IN LODGEMENT TILL NEAR TROEDYRHIW

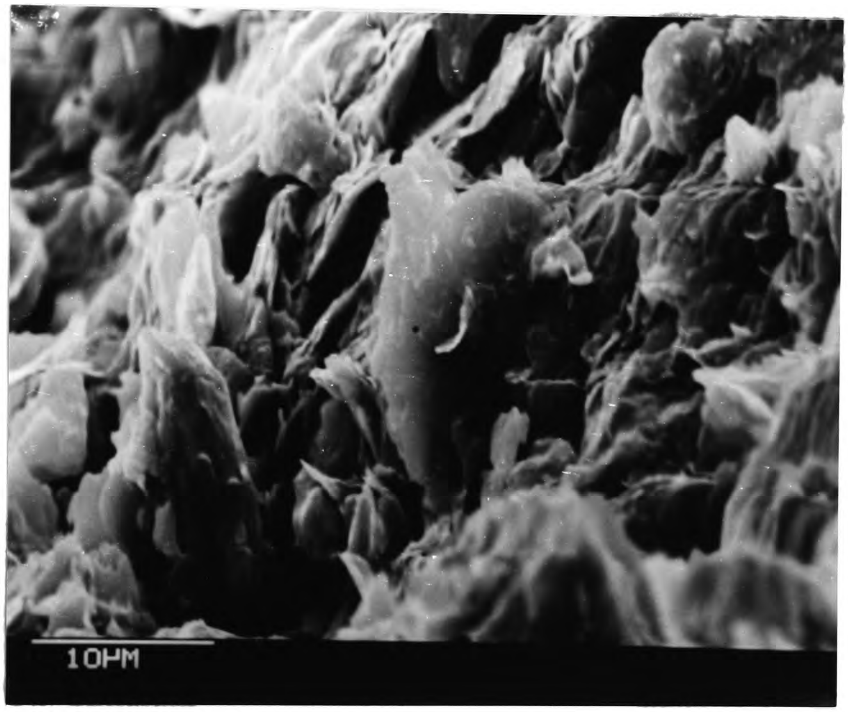


PLATE 3.5

PHOTOMIGROGRAPH SHOWING PARALLEL MICROFISSURE SETS APPROXIMATELY NORMAL TO PREFERRED PARTICLE ORIENTATION WITHIN LODGEMENT TILL FROM ABERFAN

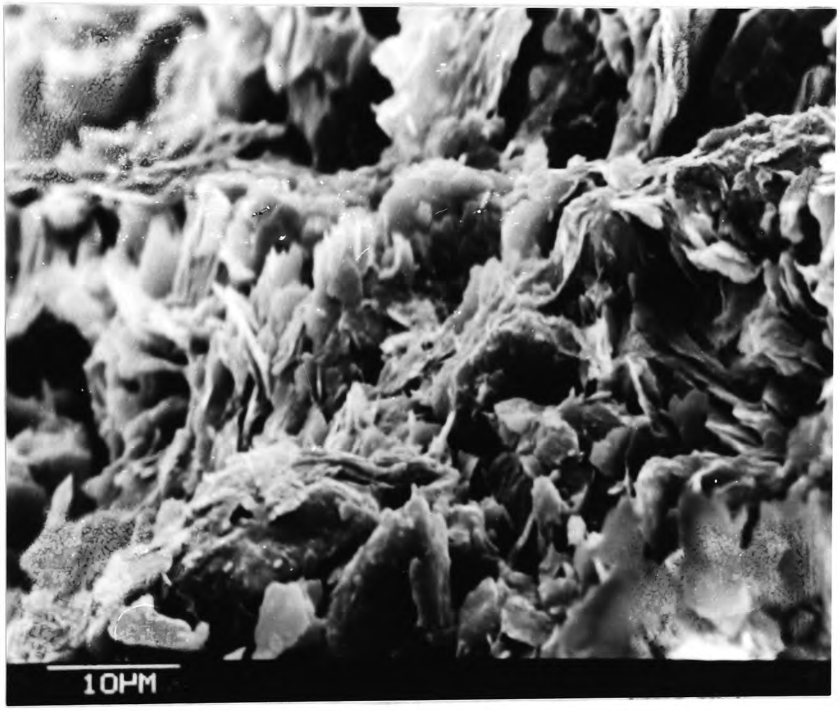


PLATE 3.6

PHOTOMICROGRAPH SHOWING CONJUGATE MICROFISSURES IN LODGEMENT TILL
FROM ABERFAN

Within the matrix-dominant tills, fluctuations in the direction of preferred orientation of platey clay and silt sized particles (shown in the photomicrograph, Plate 3.7), has developed as local conditions of formation dictated. These particles have a strongly developed flow structure around larger, more equidimensional silt sized fragments acting as microclasts. The bladed particles are orientated such that their long axes lie approximately parallel to one another. This appearance suggests a mode of formation where a 'plastering' effect has existed as particles reorientate themselves to a lineation approximately parallel to the local ice flow direction and the depositional shearing force. A subsequent phase of microfaulting normal to the preferred particle orientation has resulted in a localised rotation of particles immediately adjacent to the faults so that they lie approximately parallel to the plane of movement (refer to Plate 3.6). The throw of the faults appears to be in the order of 1-2 microns.

The dense to very dense nature of these well graded, occasionally matrix-dominant tills in a well drained and undisturbed state, accompanied by stress relief microfissuring, reflects overconsolidation during deposition beneath the glacier sole. Some accumulations of lodgement till, for example on the valley side north-west of Aberfan, exhibit a very localised heterogeneity, tending towards a clast-dominant condition where cobble/boulder percentages lie in the range of 40 to 50 per cent of the soil mass by weight. At this concentration contact between cobble sized clasts usually exists, hence the matrix tends to fill voids between adjacent clasts and has little effect on load transmission within the till as a whole.

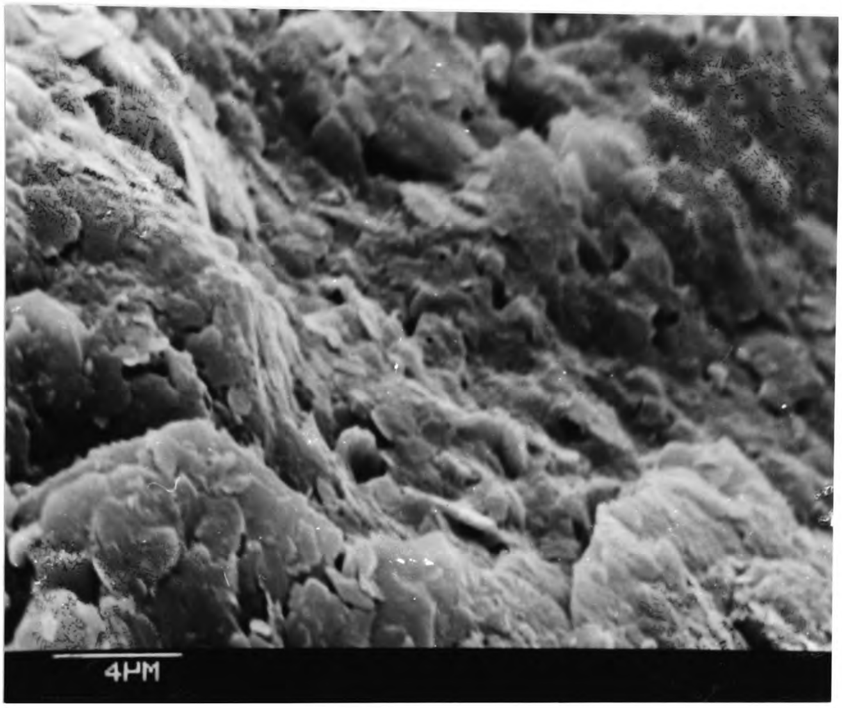


PLATE 3.7

PHOTOMICROGRAPH OF LODGEMENT TILL SHOWING PREFERRED ORIENTATION OF CLAY AND SILT SIZED PARTICLES

INDUCED BY 'PLASTERING' DURING DEPOSITION

3.3.1.2 Textural properties in areas with an arenaceous bedrock

In the area between Aberfan and Abercynon for a length of approximately 6 kilometres a high proportion of the bedrock is arenaceous. The Brithdir and Hughes Beds of the Pennant Sandstone Series are the major stratigraphic formations present. Lodgement till in this area of the valley is less well developed than in the argillaceous areas to the north and south, probably due to the greater strength of the underlying bedrock resulting in increased resistance to subglacial attrition. It is typically developed to thicknesses of between 3 and 5 metres, however, local exceptions in excess of this figure occur. Silt and clay contents are typically between 12 and 15 per cent lower in this area than in those with an essentially argillaceous substrate. This reflects the influence of bedrock lithology on the grading and textural properties of the soil. The clay sized fraction is composed of a greater proportion of rock flour than clay minerals. This has been observed in photomicrographs where there is an abundance of chipped, somewhat equidimensional shards of quartz in comparison with the more platey, well formed aggregations of clay minerals. This is a reverse of the situation within the tills derived from the argillaceous substrates. The generally coarser grading of these tills results in a more open texture than that developed for the tills of an argillaceous source. This is attributed to the greater equidimensional nature of the sandstone derived particles. Larger amounts of sand and sandstone gravel present result in a greyish-brown colouration when damp, whilst when dry a colour change to mid and light brown is observed. Relatively high sand percentages within these tills (10 to 25 per cent) are similar to that of the fines rich melt-out tills towards which the arenaceous lodgement tills form a transition zone from the argillaceous types. Particle size alone is therefore insufficient to differentiate modes of origin. Textural characteristics typical of a subglacial mode of origin, for example boulder clusters and the presence of comminution till and also a general state of overconsolidation, are thus diagnostic in the genetic interpretation of this soil type. All have been found to be well developed.

3.3.1.3 Deformation till

At sites throughout the valley where the predominant bedrock lithology is one of sandstone, site investigation using rotary drilled boreholes and limited exposures has shown that the basal 2 to 3.5 metre zone of lodgement till is frequently composed of angular Pennant sandstone cobbles and boulders up to 1.5 metres thick. At Abercynon these till macroclasts are firmly set in a fine silt and clay matrix which is layered parallel to the clast faces filling joints and fissures. The matrix, derived in part by attrition as comminution till, appears to have been forced into and between clasts in a fluid state, possibly as a result of pressure melting during subglacial transportation. Interpretation of the preferred orientation of the macroclasts, accompanied by the presence of the original lithological sedimentary characteristics, suggests that they are almost in an original in situ state, differing little from the local bedrock; they are, however, underlain in part, by till. Where dislocation from the substrate is involved, clast reorientation is parallel with local glacier flow directions, ascertained by striations on the underlying ice-scoured bedrock.

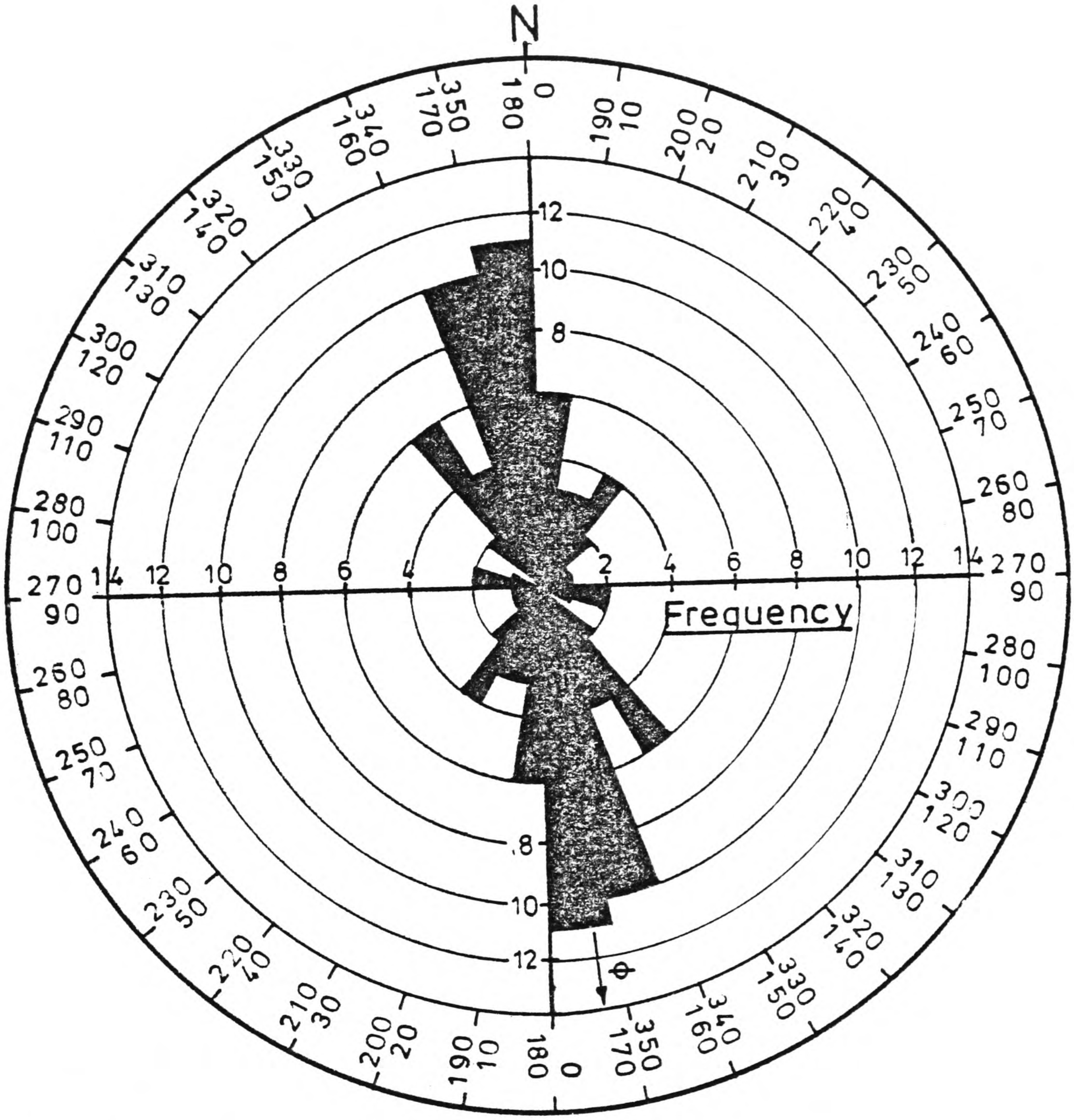
Many of the larger cobbles and boulders show lithological similarities to the local substrate. For example, borehole data for till beneath the Abercynon spoil tip has revealed boulders up to 0.7 metres thick that have been plucked from the Striped Beds (limited to thickness and outcrop) within the Hughes Sandstone, but which are underlain by lodgement till. These have been traced back to their source within the bedrock below and immediately upvalley.

Where the bedrock lithology is predominantly argillaceous, resulting in the production of generally well graded to matrix-dominant lodgement till, deformation till only occasionally exceeds 2 metres in thickness. Clasts of mudstone up to coarse gravel size, and deformed siltstone boulders up to 0.5 metres thick, set in a silty clay and clayey silt matrix, are dislocated from the heavily sheared and fissured bedrock. Fissures and shear planes have been recorded within highly to completely weathered siltstone bedrock to depths of 1.5 metres below rockhead immediately to the south of Aberfan. The shear planes were observed to be dipping at between 35 and 68 degrees towards 160 to 170 degrees. Boreholes sunk to the west of Aberfan have located the presence of a buried preglacial valley up to 20 metres below the present river level. The position of this feature and the presence and orientation of fissures and shear planes in the immediate locality at rockhead, suggests that local downstream ice-flow may have occurred from a source in a pre-glacial depression on the valley side immediately north-west of Aberfan, which acted as a nivation hollow lateral to the main valley.

The texture and fabric of these clast-dominant, heterogeneous till units, located at the base of principally matrix-dominant lodgement tills, compares closely with the textural properties of deformation till described by Elson (1961) in Pleistocene deposits. Derbyshire (1975) and Banham (1977) also describe these in recent tills deposited at the margins of modern glaciers. The clasts within the Taff Valley tills are in positions of varying degrees of extraction by plucking from the underlying highly to completely weathered, jointed and fissured bedrock. Localised basal pressure-melting and refreezing of the glacier sole is the probable mechanism by which sections of bedrock have become incorporated into the basal glacier zone and are subsequently deposited within the lodgement till.

3.3.1.4 <u>The results of quantitative mesofabric analysis</u>

Clast dip and orientation data for lodgement till was obtained from material exposed in a series of adjacent stream cut exposures located on the west side of the valley near the village of Troedyrhiw, (see Map 2.3, grid reference SO 065020). The textural properties of the soil are described in detail in section 3.3.1.1. Interpretation of fabric data is based upon the quantitative expression of results in the form of a rose diagram (Figure 3.2) and a plot of poles to direction and magnitude of clast dip (Figure 3.3). The poles have been contoured at regular percentage intervals as exhibited in Figure 3.4.



⊕ Azimuth of resultant vector

FIGURE 3.2

CLAST ORIENTATIONS IN LODGEMENT TILL
NEAR TROEDYRHIW
(Sample number-60)

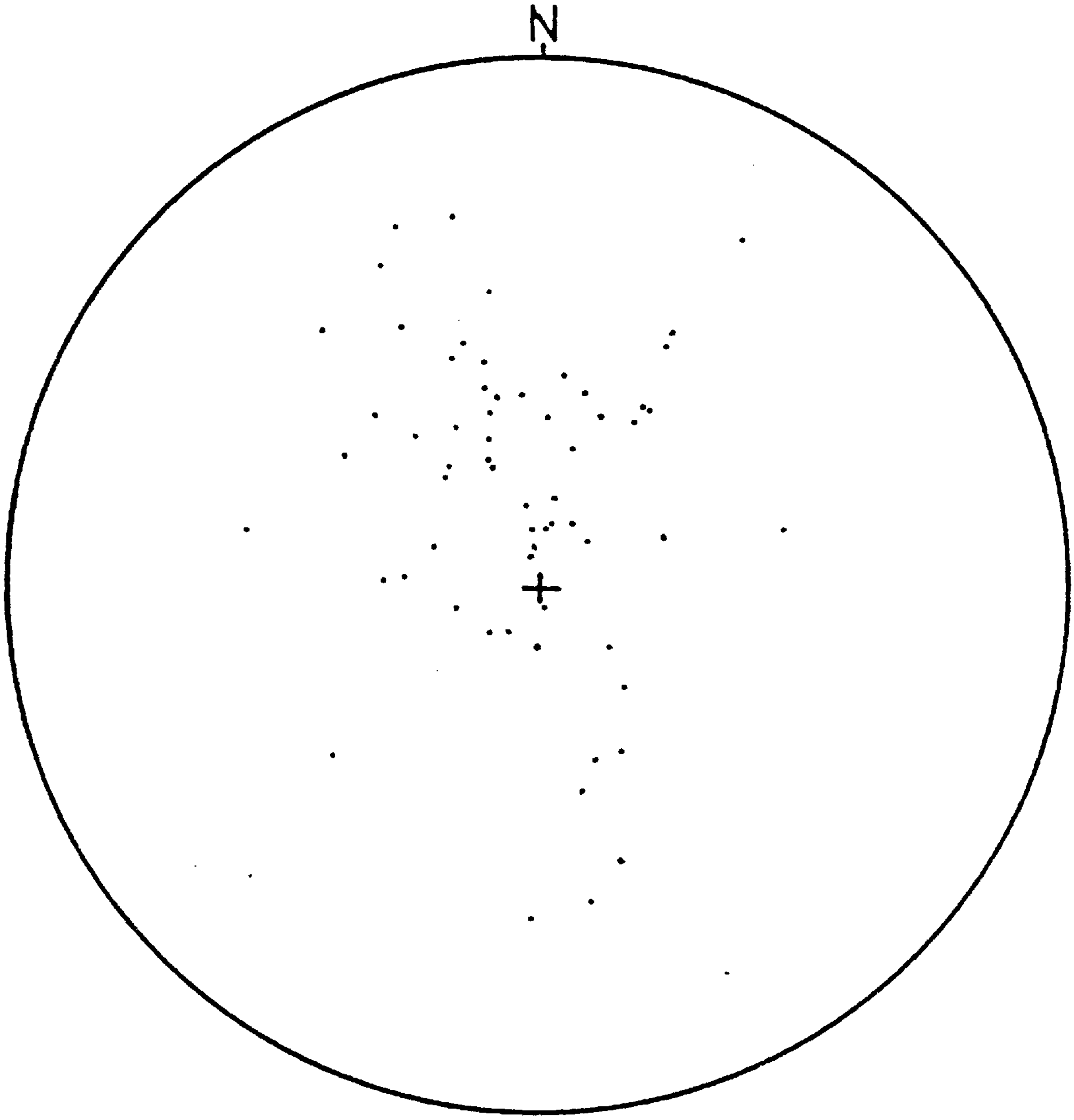


FIGURE 3.3

SCHMIDT EQUAL AREA STEREONET
SOUTHERN HEMISPHERE PROJECTION
PLOT OF POLES FOR CLAST DIP ORIENTATIONS
IN LODGEMENT TILL NEAR TROEDYRHIW

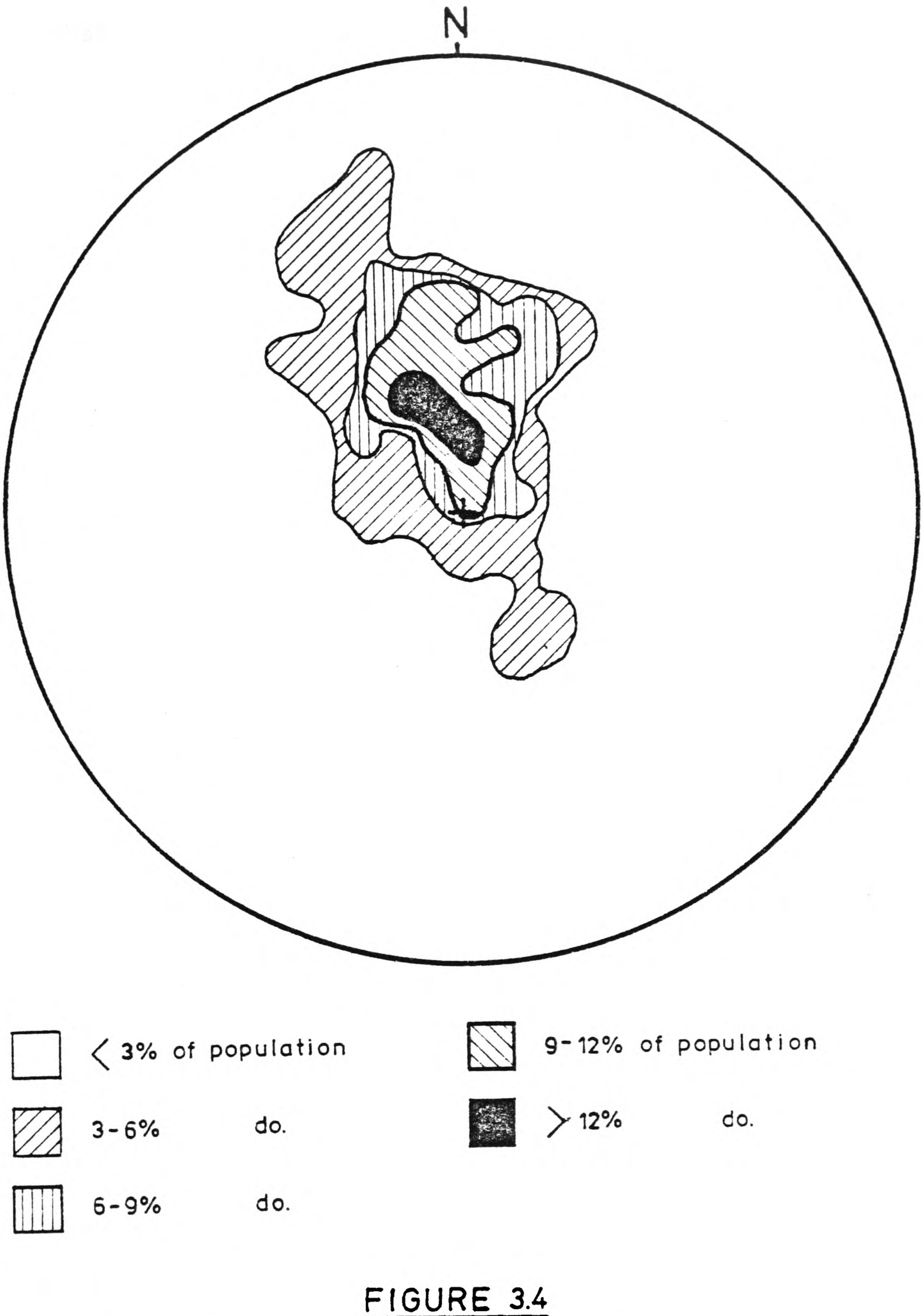


FIGURE 3.4

CONTOURED SCHMIDT EQUAL AREA STEREONET SOUTHERN HEMISPHERE PROJECTION FOR CLAST DIP ORIENTATIONS IN LODGEMENT TILL NEAR TROEDYRHIW

Clast orientation data in Figure 3.2 shows that more than 18 per cent of the coarse gravel to cobble sized clasts are aligned with long axes along a bearing of 170°-180°/350°-360°. The latter values closely correspond with the north-south alignment of the Taff Valley and hence principle ice flow direction.

Employing the Rayleigh test as described in Doornkamp and King (1979) and graphically represented in Curray (1956), a vector magnitude (L) of 54.6 per cent shows that the parallel arrangement of only greater than 18 per cent of the total clast population is highly significant at a level greater than 99.9 per cent. The azimuth of the resultant vector (θ) lies at 173.7°.

A small percentage of clasts (3 to 6 per cent) are aligned approximately normal to the major axis of orientation, at 090°-110°/270°-290°. This may be explained when one considers the mechanisms of ice flow and the corresponding transportation of debris within the basal ice zones. The major axis of individual clasts will become aligned with least frictional resistance to the flow of ice, that is, with their long axes parallel and subparallel to local ice flow directions. During transportation, rolling clasts may occur accompanied by ice shearing, resulting in 'flip' of individual particles so that they lie with their long axes at right angles to the ice-flow direction.

Interpretation of lodgement till clast dip data, stereographically presented and contoured on a Schmidt equal area net, lower hemisphere projection, (Figures 3.3 and 3.4), has revealed that 12 to 15 per cent of all clasts dip towards 170°-180° at between 15 degrees and 30 degrees from the horizontal. Some scatter of data is noted around this orientation. Occasionally clasts dip at up to 66 degrees whilst others dip upstream towards 350°-360°.

Further mechanisms of lodgement till deposition are inferred by interpretation of clast dip data from Troedyrhiw supplemented by microfabric evidence described in section 3.3.1.1 (refer also to Plate 3.4). Under high stress and as a product of subglacial pressure melting, clasts belonging to the meso and microfabric (microclasts) have been forced away from the basal debris rich zone of ice. Subsequently, a subhorizontal shearing stress at the glacier sole has orientated the clasts such that they dip shallowly downstream. This shear fabric appears to be a definitive characteristic of the lodgement tills of the Taff Valley. It has been found to very closely resemble the orientation of shear planes in highly weathered siltstone bedrock recorded near Aberfan (section 3.3.1.3).

It may thus be seen that interpretation of orientational properties of fabric at all levels, micro, meso and macrofabric are particularly useful in the interpretation and appreciation of the mode of genesis of lodgement tills. These characteristics may be used to separate undisturbed soils from those that have been reworked or undergone post-depositional transportation. The latter is further discussed in subsequent sections.

3.3.2 Melt-out till

The melting of debris rich stagnant ice en masse results in the release of melt-out till. In the proglacial terminal area, melt-out till deposition is usually the result of melting-out of debris from hummocky, ice-cored moraine. In the subglacial environment, the collection of stagnant ice on the lee-side of roche mountonees, substrate retardation of debris rich ice beneath overriding active ice, or the bedrock heat flux, will result in melt-out till deposition.

The texture and fabric of melt-out tills depositied in both subglacial and proglacial/terminal locations, reflects the nature of the debris source. Boulton (1970b) suggests that basal melting of ice will retain the fabric of ice-supported material present in the lowermost debris-bearing horizons of the glacier. This material has accumulated most typically as lodgement till and deformation till, becoming incorporated in the ice by basal pressure-melting and refreezing and by transportation along englacial shear planes. The texture of this lower unit will thus vary from one bearing striking similarities to lodgement till, to a second containing lensoid accumulations of deformation till. Examples of this have been found within the Taff Valley near Nantgarw, where local reworking of matrix-dominant and well graded lodgement till has resulted in the incorporation of elongate accumulations of the former at the base of granular melt-out till. Local reworking of basal melt-out till has also occurred. Meltwater in subglacial channels has modified the bimodal particle size distribution of the till by the addition of fluvioglacial sand and gravel to varying degrees particularly as lensoid channel infill deposits. Within the Taff Valley it is thus apparent that the interplay of surface and basal melting out processes has resulted in the development and retention of englacial and subglacial fabrics and textures to varying degrees. This has produced a complex intermixing of different till types and is a characteristic of this glacial process.

3.3.2.1 Thickness of till

The greatest thicknesses of melt-out till are noted to have been deposited in the lower reaches of the valley, south of Abercynon. This is towards the terminal area of ice extension, which at its maximum was probably in what is now the Bristol Channel. Melt-out till towards the south of the valley reaches a thickness in excess of 15 metres whilst to the north the thickness seldom exceeds 10 metres. Localised embayments in the rockhead occur at several sites within the valley. These effectively increase the till thickness by up to 7 metres. Major embayments are recorded at :-

- Nantgarw, below the south-eastern portion of the southern spoil tip extension

- Abercynon, below the north-western edge of the spoil tip known as Abercynon Tip 159

- the eastern side of the Taff Valley to the south of Merthyr Vale

- below the Merthyr Vale Tip immediately north-west of Aberfan.

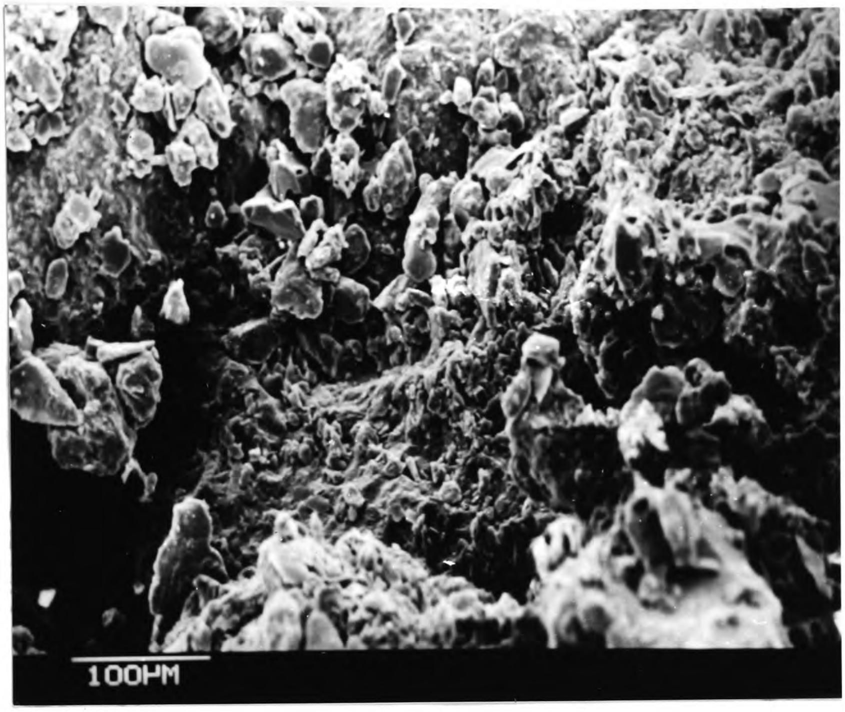
In most cases bedrock embayment accompanied by extensive till accumulation is associated with structural control, for example, on the eastern side of the valley near Merthyr Vale at the location of the Llanfabon Fault.

3.3.2.2 Textural properties

The texture of the melt-out tills in the valley (as shown in Plate 3.1 and diagrammatically expressed in Figure 3.1), is typically one of a mid to dark brown, compact, silty gravelly sand and sandy gravel with localised clusters of bladed and tabular subrounded to subangular cobbles and boulders, (see Plate 3.1). Cobbles are frequently present and are of locally derived Pennant Sandstone. Old Red Sandstone, Millstone Grit and some Carboniferous Limestone erratics are also present. Cobbles and boulders usually constitute 20 to 30 per cent of the total till bulk, the overall texture becoming well graded commonly clast-dominant.

The noticably heterogeneous, poorly sorted nature of the matrix of these tills in the valley is shown in Plate 3.8, where extremely localised heterogeneity from sand to silt sized particle assemblages is clearly demonstrated.

The moderate permeability of these tills with the frequent development of weep issues, results in modification of the original texture by the flushing out of fines. Seepage points coincide with discontinuous lensoid cobble clusters of up to 0.5 metres in length. These acts as drainage conduits within the till, whilst frequent lensoid gravel accumulations (possibly of fluvioglacial origin), play a secondary role in seepage due to their more disseminated nature. Concentrations of coarse sand and gravel fractions in the basal 0.1 to 0.2 metres of melt-out till at its contact with underlying lodgement till, act as the main aquifer for downslope drainage. Clay and silt sized fractions present within the zone have been removed, altering



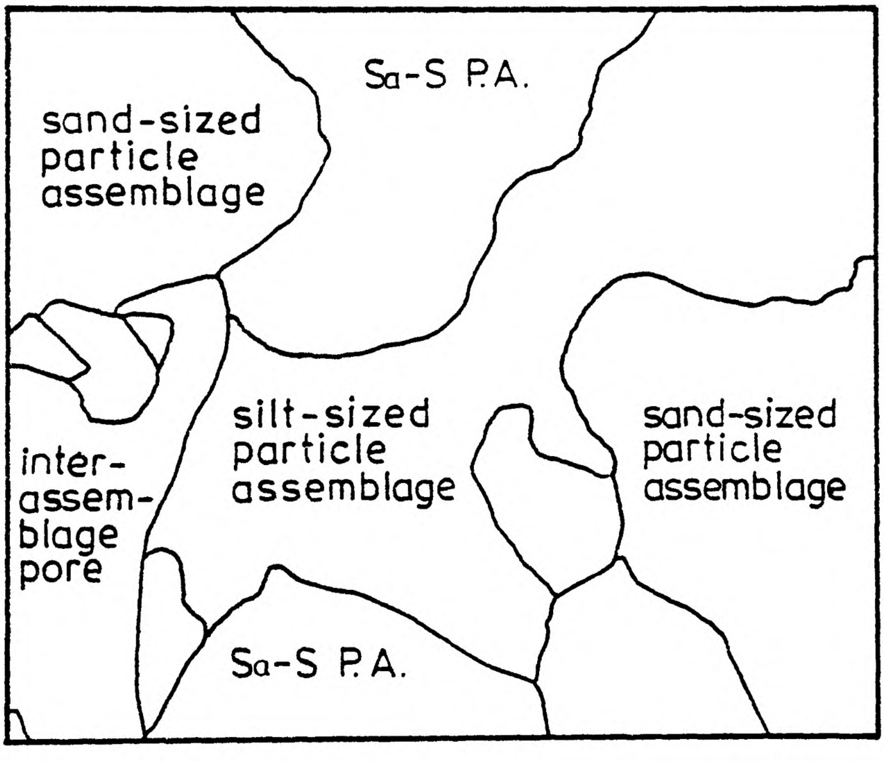


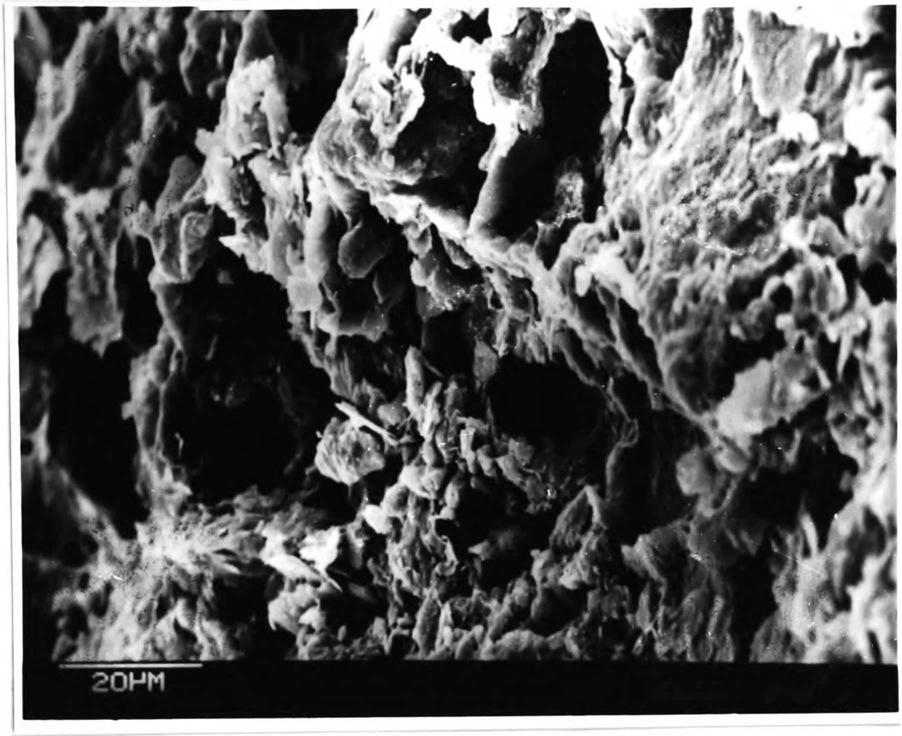
PLATE 3.8

THE HETEROGENEITY OF MELT-OUT TILL IN THE VALLEY, EXHIBITED BY LOCALISED ASSEMBLAGES OF SILT AND SAND SIZED PARTICLES (PORTION OF SAMPLE (1) & (2) SHOWN IN FIGURE 3.1) the particle size distribution such that the mean particle size ($M\phi$) is increased to lie within the coarse sand range. The angularity of clasts of all sizes, is less than for the overlying melt-out till in general. Downslope water flow at the top of the underlying, almost impermeable, fines rich lodgement till provides a mechanism for the depletion of fines and for the loose, openwork appearance of the zone. The typical fenestrate texture of this portion of the microfabric is exhibited in Plate 3.9. It shows a partially discontinuous system of pores (15 to 20 microns in diameter) passing through the till, resulting in an increase in the overall in situ soil permeability.

Further disruption of the till texture has been noted to have occurred as a consequence of the relative influence of two major factors :-

1. Weathering of the subsurface layers of melt-out till to a depth of between 0.9 and 2.5 metres which plays an important role in the further modification of the soil structure by depletion of fines due to downward leaching. A purple-black indurated horizon 5 to 32mm thick, containing an abundance of manganous nitrate salts marks the B_{2mn} illuviated horizon towards the base of the weathered zone. The discontinuous stratified concentration of fines in this basal zone would appear to be the result of enrichment by downward flushing of sediment in suspension.

2. Downslope movement of soil under gravity following ice ablation and till deposition which has distrupted the original textural properties. Evidence in the form of downslope slump and shear fabrics orientated downslope near the base of lodgement till at Nantgarw and other sites,suggests that all till types were prone,



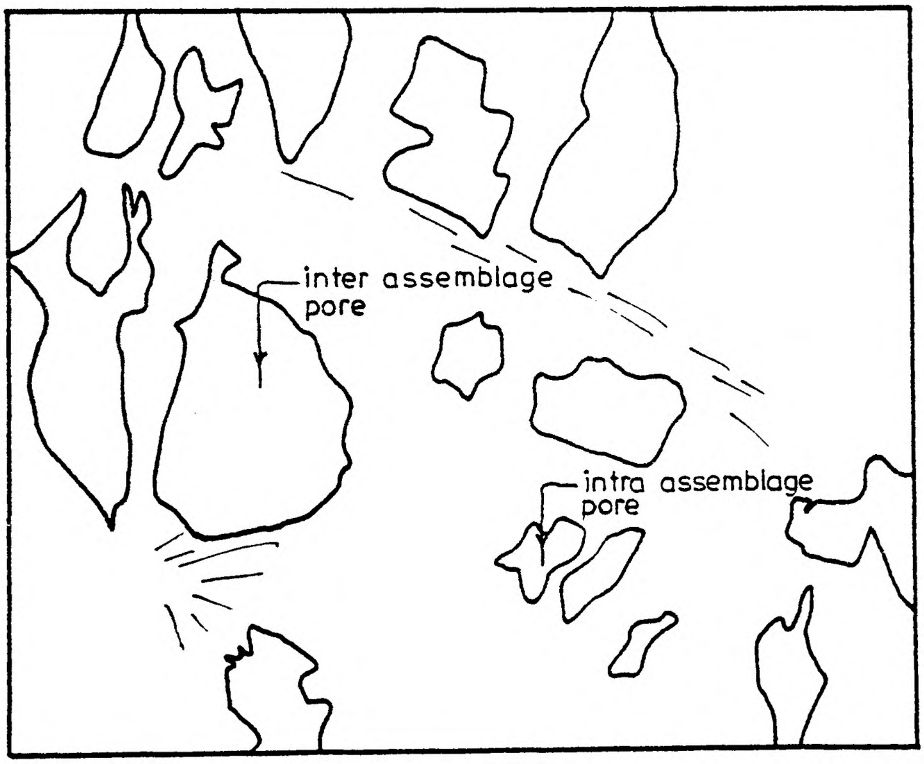


PLATE 3.9

THE POROUS, OPENWORK TEXTURE TYPICAL
OF MELT-OUT TILL IN THE VALLEY.

in part, to periglacial gravitational transportation in gelifluctate states. Discussion of some of the mechanisms of solifluction and its effect upon till fabric modification within the valley are discussed below in section 3.4.2.

3.3.2.3 The results of quantitative mesofabric analysis

Clast orientation data for melt-out till near Treforest Trading Estate (see Map 2.1, grid reference 110853) is quantitatively expressed as a rose diagram in Figure 3.5. A stereographic representation of clast azimuth orientation and dip, plotted as poles to planes, is shown in Figures 3.6 and 3.7. By comparison with soil specimens obtained from other sites the till sampled is regarded as being texturally and sedimentologically characteristic of typical melt-out till within the valley as a whole.

Orientation data in Figure 3.5 shows that a high percentage of clasts (greater than 40 per cent), of medium gravel to cobble size, have become orientated approximately parallel to the valley axis at this location, aligned 170°-180°/350°-360°. A weighting of data lying east of north draws the azimuth of the resultant vector (θ) to 010.9°. With a vector magnitude (L) of 58.07 per cent, the data is significantly different from a uniform distribution at a level of well in excess of 99.9 per cent.

In Figure 3.7 contouring of clast dip data (represented as poles to planes in Figure 3.6) at regular percentage intervals has further shown that for the sample of seventy clasts measured on the western

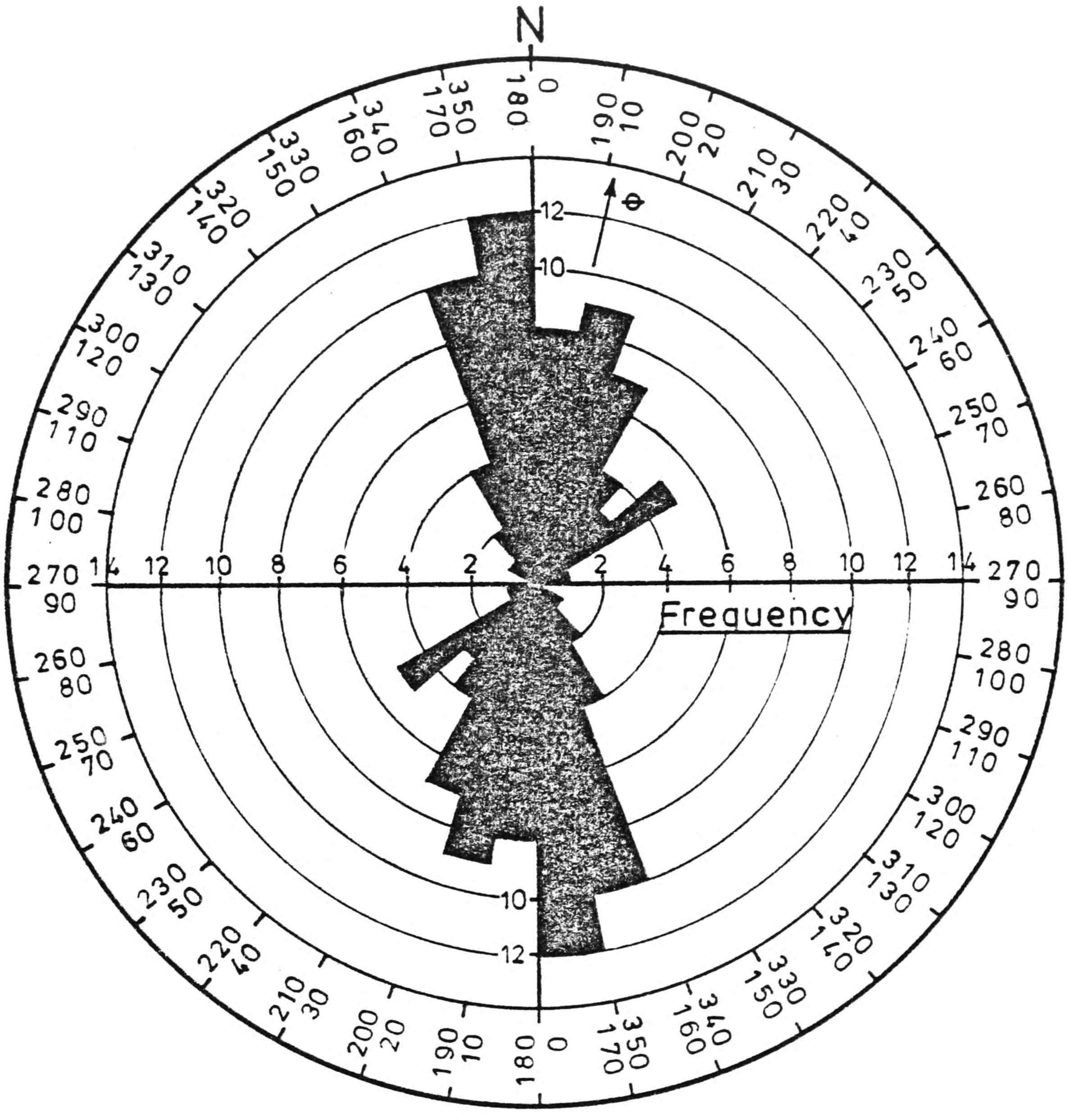


FIGURE 3.5

CLAST ORIENTATIONS IN MELT-OUT TILL
NEAR TREFOREST TRADING ESTATE
(sample number=70)

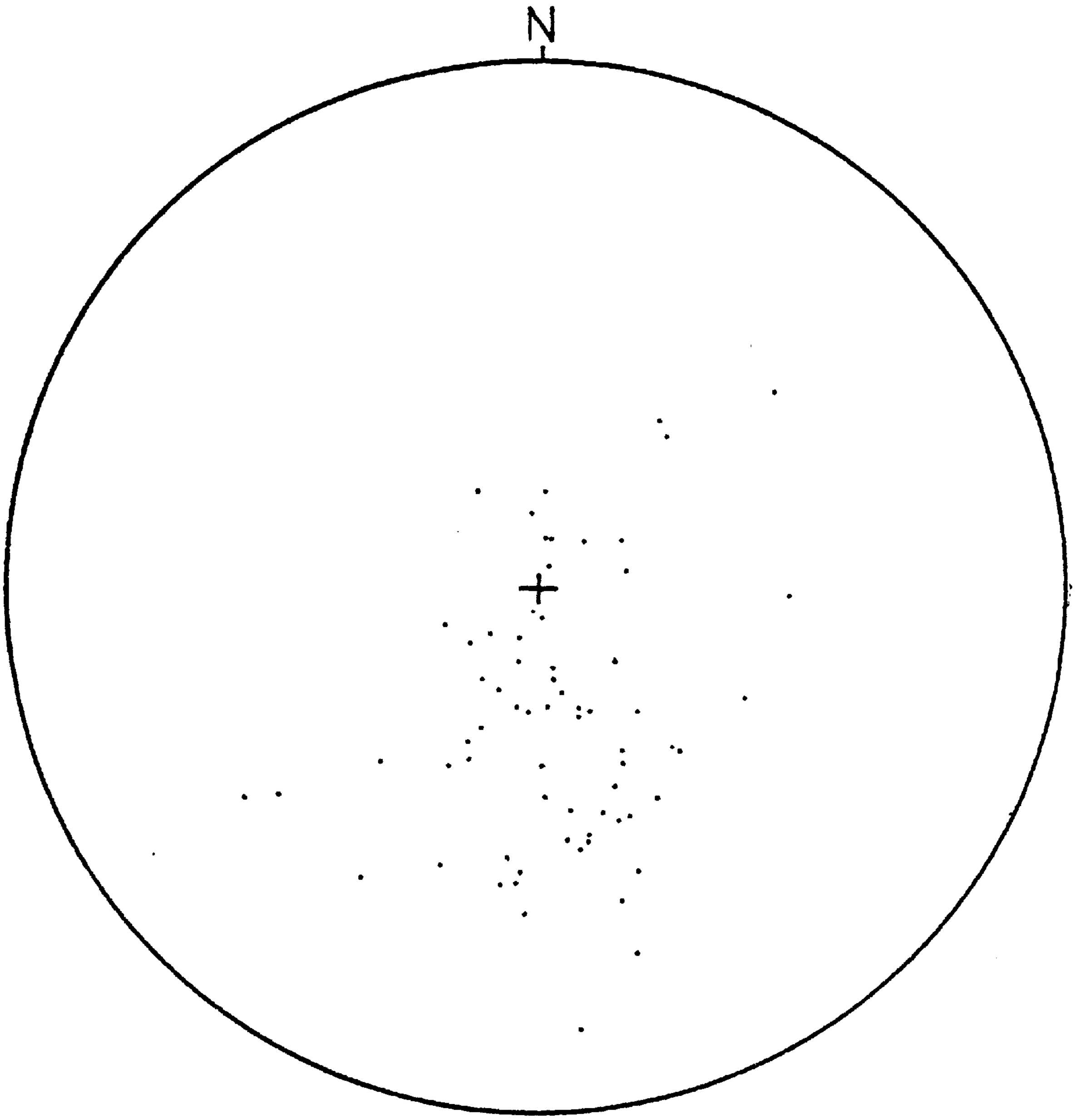


FIGURE 3.6

STEREOGRAPHIC PLOT OF POLES FOR MELT-OUT TILL NEAR TREFOREST TRADING ESTATE

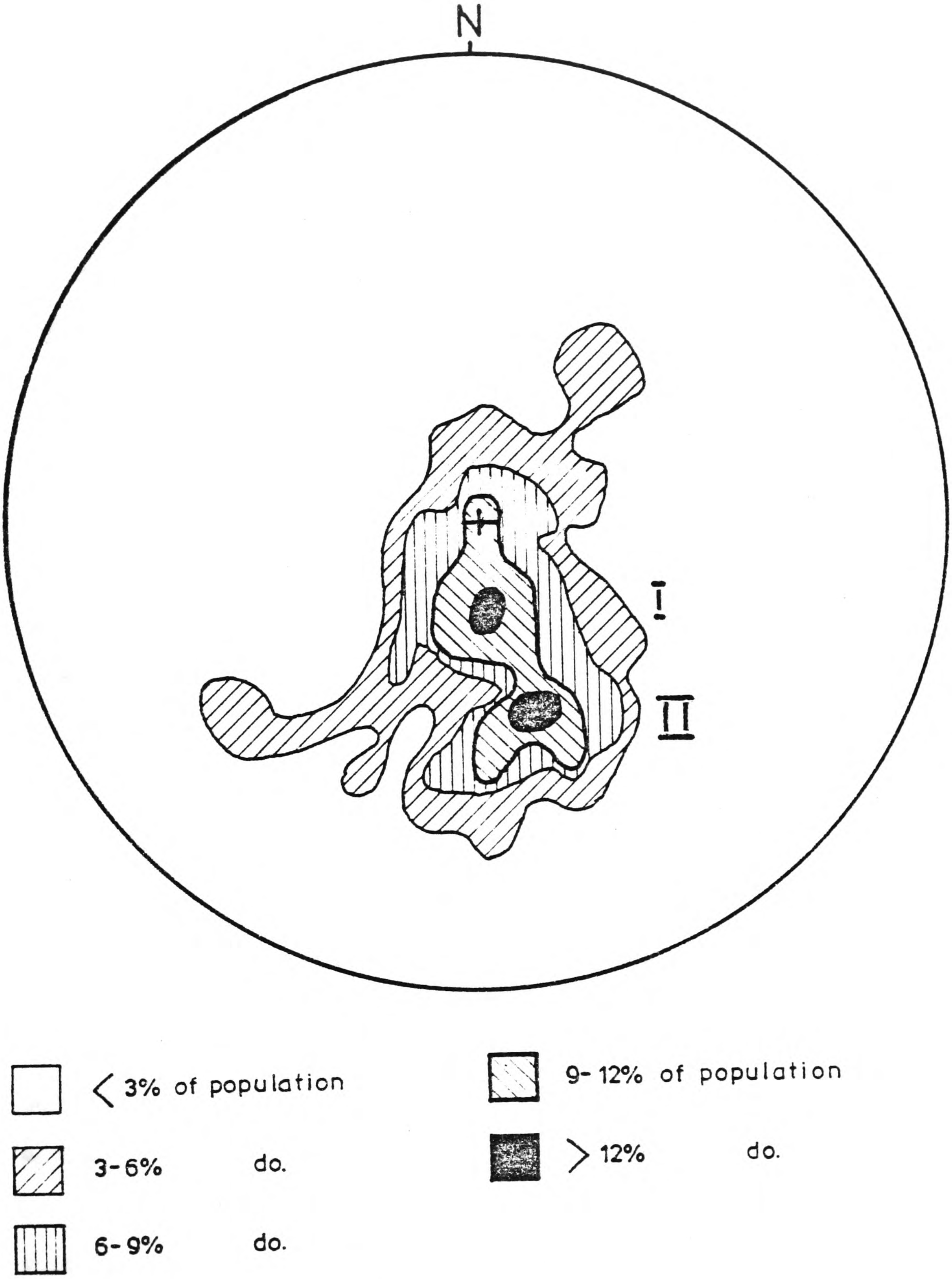


FIGURE 3.7

CONTOURED STEREONET FOR MELT-OUT TILL
NEAR TREFOREST TRADING ESTATE

side of the valley in the vicinity of Nantgarw, two centres of data population may be differentiated. The most dominant centre (I), with greater than 18 per cent of the total population, contains clasts with dips of 20 - 25 degrees towards 358°. A second centre, (II), of up to 15 per cent of all clasts has a dip range of 40-45 degrees towards 345°.

Interpretation of mean clast dip at each exposure where data was collected has shown that this fluctuates only between 27.7 degrees and 29.0 degrees, however, as previously discussed, two principle dip centres have become apparent by the stereographic presentation of data. In relation to the direction of clast dip in lodgement till at Troedyrhiw, dip of melt-out till clasts is shown to be a reversal of the former with dip trending upstream (or upglacier). The magnitude of dip is predominantly greater than for lodgement till.

An appreciation of the stages involved in the genesis of melt-out till may provide explanations both for, (i) the upstream dip of clasts, and (ii) the two centres of dip population.

The local geomorphological land facet at the site of exposure is one of hummocky moraine, located some 800 metres upstream from a series of large morainic ridges shown in Plate 2.3. Upon the elements of the former facet are built a kame terrace feature, soil profiles of which are exposed at more than 15 metres above the existing melt-out till deposits. Using geomorphological mapping as a tool in the explanation of the local glacial geology, hypotheses may be proposed concerning the development of the upstream, upglacier clast dip exhibited in Figure 3.7. The intimate association of melt-out till with flow till material at one exposure substantiates the evidence that clast dip and orientation is a result of the melting out of debris from glacial ice, the latter probably in the form of ice-cored morainic units.

Local changes in slope angles and the spatial variation of stagnant glacial ice and ice-cored morainic units, would impart localised modification of clast dip and orientation. This may account for the scatter of data abouth the azimuth of the resultant vector. The principally northern dip and orientation of clasts would appear to be the result of in situ melting of ice-supported debris such that the englacial arrangement of clasts, possibly reflecting englacial shear planes, was retained with the minimum of disturbance.

The more shallowly dipping data centre I in Figure 3.7 may reflect flow of unstable melted out debris down the upstream face of a transverse ice-cored moraine. The results of fabric analysis therefore suggest that data for flow till units has become incorporated during sampling for melt-out till. Some of the textural properties of the two types are essentially very similar (as discussed in the subsequent section), and thus a quantitative analysis of data may provide the only means by which some of the more similar and intermixed types may be differentiated.

3.3.3 Flow till

The recognition of flow till within Pleistocene tills as a whole, is somewhat problematic; this is the consequence of two principle criteria :-

1. their very localised development in areas of ice ablation and melt-out till deposition

2. the difficulties of textural interpretation of what are essentially two dimensional features.

The lateral extent of the deposits tends to be greater than vertical providing problems in distinguishing flow till in vertical exposure sections.

3.3.3.1 Textural properties

To the west of Treforest Trading Estate and in an area of hummocky melt-out moraine, the textural properties of till in a stream-side exposure reflect the repeated flow of a saturated debris rich morass. Two main units have been differentiated within the deposits, with two distinct horizons in the second (shown in Plate 3.10) :-

1. a lowermost, relatively homogeneous unit of brownish-grey sandy silt with occasional subrounded gravel sized clasts and bladed, subangular to subrounded sandstone cobbles and boulders up to 0.3 x 0.3 x 0.2 metres thick. A sub-horizontal stratification is exhibited by the preferential orientation of subrounded boulders in a predominantly silt rich area in the western portion of the exposure. This unit texturally resembles well graded melt-out till noted at other sites within the valley and discussed above in the latter part of section 3.3.2.3.

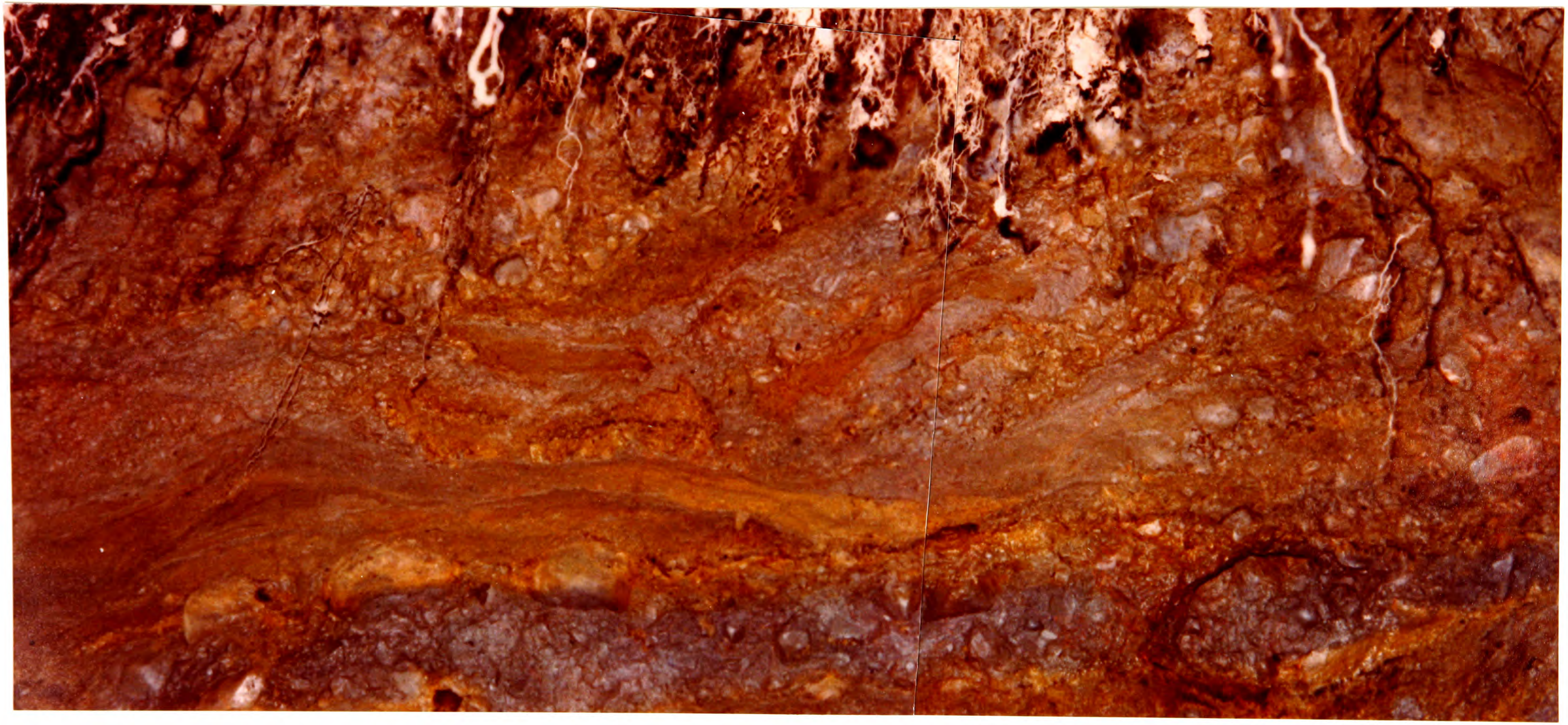


PLATE 3.10

EXPOSURE OF FLOW TILL NEAR TREFOREST TRADING ESTATE SHOWING LOWER BROWNISH GREY UNIT TEXTURALLY SIMILAR TO MELT-OUT TILL AND UPPER YELLOWISH BROWN AND BLUE GREY HETEROGENEOUS FLOW BANDED UNIT

2. an upper, noticeably heterogeneous unit exhibiting a marked difference from the lower in its development of a well defined flow structure. Alternating horizons of relatively uniformly graded yellowish brown fine to medium sand (between 10 and 30mm thick) and bluish grey sandy gravelly silt accumulations developed to thicknesses of between 85 and 100mm, are apparent. Flow of material is noted to have been in a northerly direction across the exposure. This corresponds very closely with the orientation of particles in population centre I in Figure 3.7, discussed above. Transportation of particles appears to be from a predominantly unsorted source of well graded silty sandy gravel (melt-out till) in the western portion of the exposure. The flow elements present attain a maximum dip of 37 degrees as they move away from the melted out mass, subsequently exhibiting slump structures and finally levelling out and thinning in an easterly direction on top of a melt-out till substrate.

The textural characteristics of the predominatly sandy units suggests an environment of greater energy, probably associated with large amounts of water providing a sorting agency for the material. The gravelly silt horizons are more dense (probably due to their more well graded nature) and closely resemble the melt-out till source immediately to the west. They reflect little displacement from this source or disturbance during their deposition.

By comparison of the textural properties of the sand and gravelly silt horizons in the second soil unit with the descriptions of tills forming at the margins of modern glaciers, interpretation of their modes of genesis has been made. The properties exhibited by the horizons compare favourably with the descriptions of allochthonous (far travelled) and parautochthonous (little travelled) flow till elements respectively, as described by Boulton (1971) in Spitsbergen. Using the latter as a guide to provide evidence that the two elements represent one flow till unit, a series of seven or possibly eight units (of two horizons each) have been interpreted at the till exposure. This shows repeated flow of the material during its formation.

3.4 Other Associated Soil Types

The close spatial association of the till types discussed above with material of fluvioglacial origin, accompanied by soil that has undergone solifluction in a periglacial environment, necessitates description of their textural properties at this stage.

3.4.1 Fluvioglacial deposits

Outwash deposits of fluvioglacial origin fill much of the valley floor along its entire length and are present at numerous levels on the lower valley sides. It is the compositional material of the outwash terraces discussed in Chapter 2, located above the present level of the River Taff.

The soil is characteristically a well sorted, current bedded, sandy gravel and gravelly sand with varying percentages of well rounded cobbles and boulders. Differing amounts of sand and gravel present reflect local fluviatile energy levels at the time of deposition. Low energy pockets associated with glacilacustrine deposition are present amongst the fluvioglacial materials in localised areas, for example, between Pontypridd and Cilfynydd and at the present site of Treforest Trading Estate. These pockets are marked by the presence of fine grained, uniformly graded sand and silt units of individual thickness up to 3 metres. Some thinner sand and silt bands of between 40 and 130mm thick are interbedded. The latter probably represent a sequential sediment influx loosely synonymous with varve formation in proglacial lakes. To the north of Pontypridd glacilacustrine deposits of silt and sand abruptly grade into sandy gravels with large cobbles and boulders via a change in energy interface, (as shown in Figure 3.8 and Plate 3.11). The fluvioglacial macroclasts exhibit an imbrication dipping upstream, which is associated with a high degree of rounding indicative of a high energy depositional mode. This is as a consequence of rapid influx of outwash deposits associated with heavy ice ablation upstream. These conditions existed after formation of the glacial lake (probably proglacial in this situation), towards the close of the Margam glacial phase and heralding commencement of the Late glacial.

Borehole data obtained in association with site investigation low on the valley side near Nantgarw (see Map 2.2), have revealed the presence of fluvioglacial deposits with a waterlain appearance at the contact between melt-out and lodgement tills. Texturally the deposit is a light to mid brown sand with rounded to subrounded gravel and cobbles and a small proportion of silt, (less than 4 per cent). This material is developed to a maximum thickness of 5.7 metres and appears to represent the sediment load carried and deposited by a subglacial stream flowing beneath the glacial ice at this location; melt-out

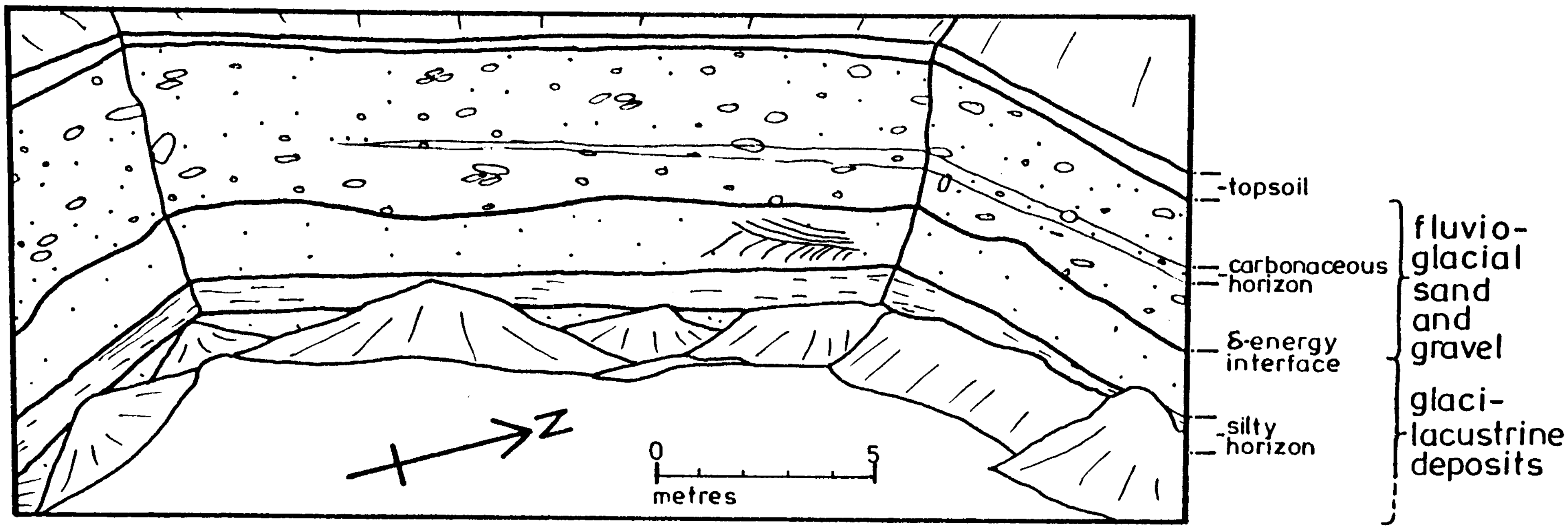


FIGURE 3.8

SPATIAL RELATIONSHIPS OF FLUVIOGLACIAL SAND AND GRAVEL AND GLACILACUSTRINE DEPOSITS AT PONTYPRIDD

PLATE 3.11

CONTACT BETWEEN GLACILACUSTRINE (LOWER UNIT) AND FLUVIOGLACIAL (UPPER UNIT) DEPOSITS AT PONTYPRIDD till was subsequently deposited on top.

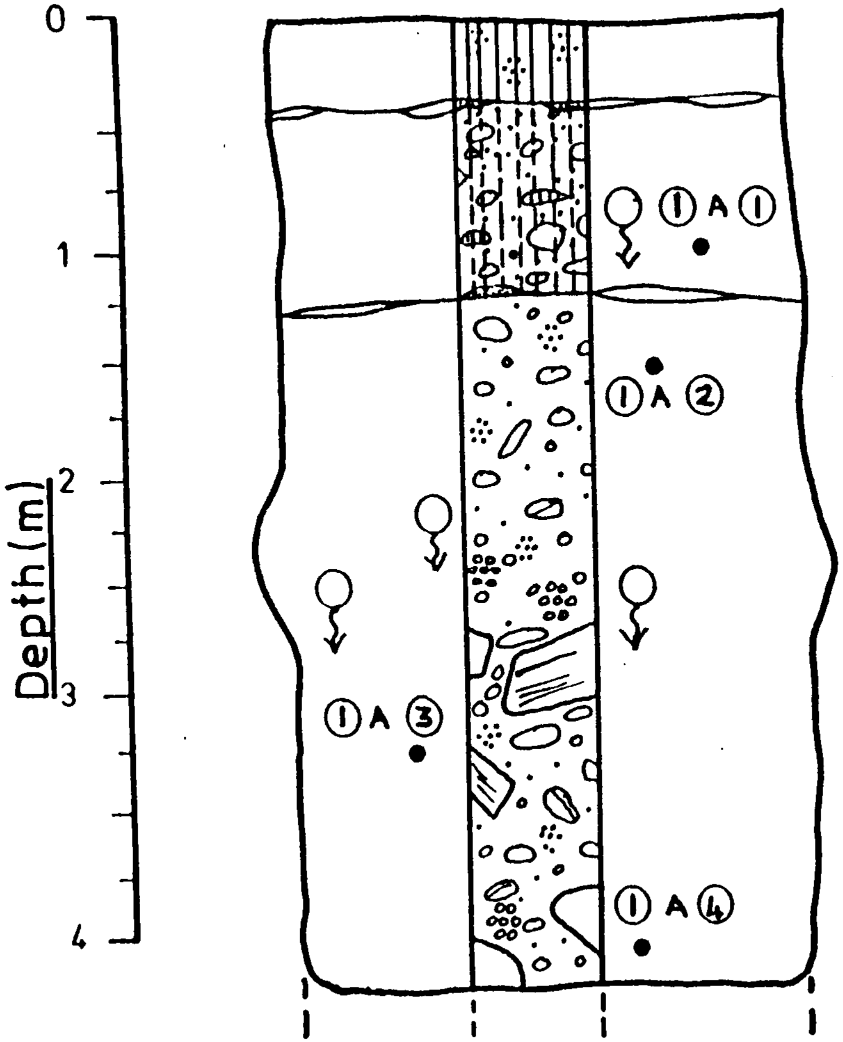
3.4.1.1 Ice contact deposits

Other clast-dominant soils within the valley are those that have been deposited in the ice contact kame terrace environment. A typical profile through these deposits is shown in Figure 3.9 and Plate 3.12.

The characteristic texture of the soil is one here described at an exposure low on the valley side in a kame terrace near Aberfan (ST 07129925, see Map 2.3). The deposit is a greyish brown, dense, poorly graded, angular to subangular sandy gravel with lenses of somewhat locally derived cobbles and boulders up to 0.7 x 0.7 x 0.4 metres in size. Lensoid accumulations of sandy gravel and a crude stratification are common, developed as depositional conditions dictate. These features are exhibited in Plate 3.13. The fine silt and clay sized fractions are absent within the material as a result of their removal by high water contents along the glacier margin where the material was deposited. Coarser silt and sand sized aggregations acting as discrete particles are commonly developed, as shown in Plate 3.14.

The decreased abundance of boulders towards the top of the deposit would appear to reflect the waning of flow energy towards the close of sediment deposition and kame terrace formation in the ice contact environment. The low altitude valleyside location of this deposit and the spatial relationships of other topographic units downstream from Aberfan, (for example other kame terraces and a drumlin near Edwardsville), suggest that the decrease in flow energy

Slope: 14°/073°



Topsoil	Brownish - black organic sandy SILT
Head with colluvium	Fairly dense mottled orange-brown and light grey silty fine SAND with sub-angular coarse gravel and cobbles of grey sandstone; greater percentage of cobbles with depth. Colluvial lenses at top and base.
Kame terrace deposits	Partially weathered in patches, slightly indurated, fairly dense to dense, dark grey-brown, subangular to angular sandy GRAVEL with lenses of angular to sub-rounded cobbles and boulders of blue-grey and brown Coal Measure Series sandstone. Cobbly and bouldery lenses are fairly dense to dense, whilst gravel lenses are loose to fairly dense. Boulders up to 0.7 × 0.7 × 0.4 m. Seepage as weep issues (♀) frequent in gravel and cobble lenses.

FIGURE 3.9

DIAGRAMMATIC REPRESENTATION OF KAME TERRACE DEPOSITS NEAR ABERFAN (ST 0712 9925)

PLATE 3.12

TRIAL PIT THROUGH ICE CONTACT KAME TERRACE DEPOSITS (GREYISH BROWN) OVERLAIN BY PERIGLACIAL HEAD DEPOSITS (BROWNISH ORANGE) NEAR ABERFAN

A CRUDE STRATIFICATION AND LENSOID ACCUMULATIONS OF SANDY GRAVEL IN KAME TERRACE DEPOSITS NEAR ABERFAN

PLATE 3.13

A CRUDE STRATIFICATION AND LENSOID ACCUMULATIONS OF SANDY GRAVEL IN KAME TERRACE DEPOSITS NEAR ABERFAN

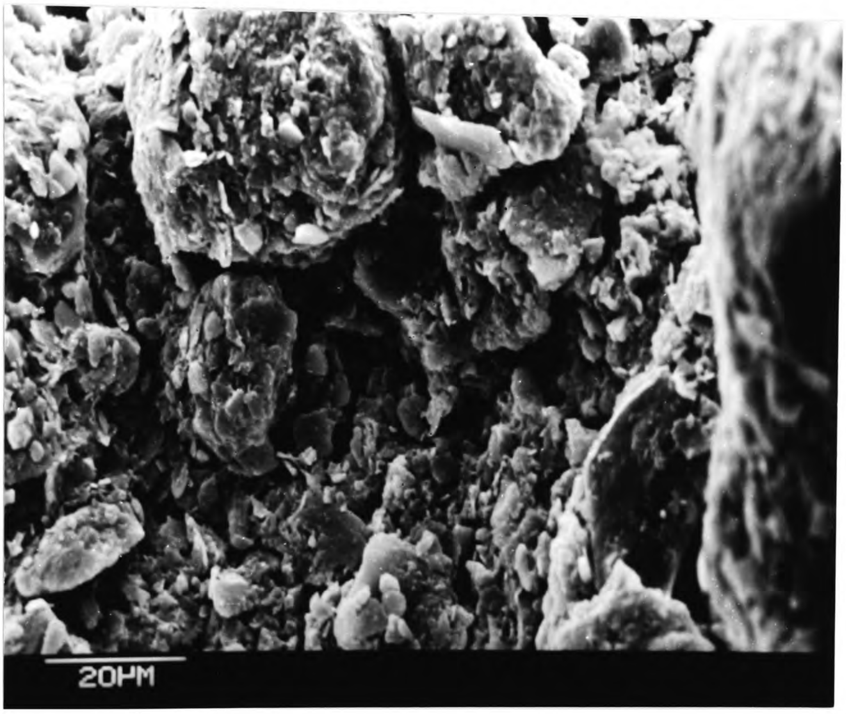


PLATE 3.14

SAND AND SILT SIZED AGGREGATIONS ACTING AS DISCRETE PARTICLES WITHIN KAME TERRACE DEPOSITS NEAR ABERFAN occurred during the final stages of glaciation within the valley.

The highly porous nature of these soils, as with weathered melt-out till, has assisted leaching, further resulting in the development of the B_{2mn} illuviated horizon containing manganous salts, here at depths of between 1.8 and 2.4 metres below the ground surface.

3.4.2 The reworking of till by solifluction and other mechanisms of post-depositional disturbance

As a consequence of ablation within the Taff Valley, much of the ice supported englacial debris was deposited essentially as a melt-out till in an unstable state on the oversteepened and overdeepened valley sides. Under periglacial conditions high moisture contents and subsequently enhanced pore pressures within this material, (the result of melting of interstitial ice and refreezing of interparticulate water) lowered the effective shearing resistance of the soils. This resulted in their subsequent downslope transportation as soliflucted till. The mechanism appears to have been enhanced, in part at least, by the build up of piezometric head of water entrapped in the local well jointed water bearing Pennant Measures bedrock by the almost impervious lodgement till cover.

This reworked deposit has been recorded as an upper layer of soliflucted soil of similar texture to the source material (with the exception of particle orientation), overlying more stable till units, notably lodgement till. Large masses of angular locally derived cobbles and boulders of scree and talus debris, also having moved downslope en masse, are typically incorporated at lower levels within the reworked till accumulations.

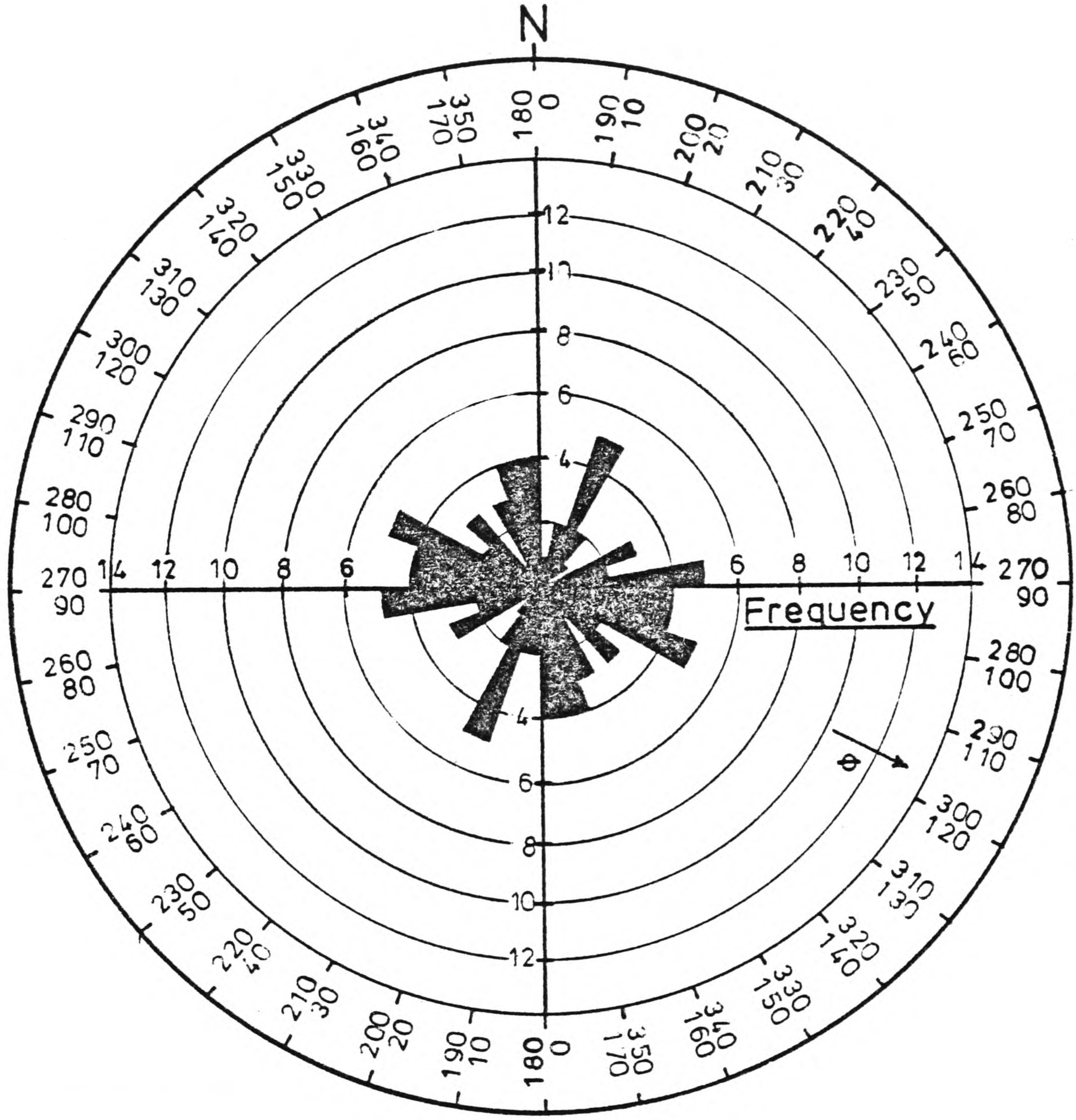
Interpretation of borehole data for superficial deposits near Nantgarw has revealed that slump structures and shear fabrics orientated downslope at the base of melt-out till in contact with lodgement till, record movement along this contact. This is probably associated with mass movement under gravity at some time subsequent to till deposition and whilst the tills were still in a sufficiently plastic state to retain these features. Data therefore suggests that failure took place quite soon after till deposition, probably during the early stages of the Late glacial. Similar modes of failure may have resulted in the development of the large landslip complexes locally observed in the Taff Valley, for example, the Rhydyfelin and Taren Slips, and the large complex to the north-west of Troedyrhiw.

It would appear that post-depositional slumping of the unstable superficial deposits at varying scales is a common occurrence within the valley and that much of the melt-out till cover as a whole has undergone at least some downslope transportation. The assessement of the degree of post-depositional transportation of the soil mass has here been based upon quantitative study of features of the mesofabric, that is, clast azimuth orientation and dip.

3.4.2.1 The results of quantitative mesofabric analysis of reworked till

Some clastic soils exposed at shallow depth in trial pits and exposures within the valley exhibit textural properties that are very similar to those of melt-out till. However, when clast dip and orientation are statistically examined the prevalent fabric characteristics of melt-out and lodgement tills are virtually absent. Figures 3.10, 3.11 and 3.12 show that a wide scatter of orientations are present within these soils, typical examples of which were sampled near Troedyrhiw (see Map 2.3). Two main clast azimuth orientations predominate, one east-west and one approximately north-south. Using the orientation data in Figure 3.10, the azimuth of the resultant vector(θ) is towards 117° with a low vector magnitude(L) of 17.66 per cent The wide scatter of data, only significant at the 90 per cent level, may reflect some degree of cryoturbation which has resulted in modification of the orientation of clasts induced during mass movement.

The contouring of data plotted stereographically, (Figures 3.11 and 3.12), has shown that two main centres of population (Ia and Ib) and two subordinate centres (II and III) are apparent. Centre Ia shows that between 9 per cent and 12 per cent of all clasts are orientated at 240° to 250° and dip very shallowly at between 5 degrees and 10 degrees into the valley side (the latter running 350°/170°). These clasts lie at between 1.0m and 1.2m depth below the ground surface. A second, somewhat smaller group of clasts (centre Ib belonging to the 6 to 9 per cent interval), dip at 35 degrees to 40



φ Azimuth of resultant vector

FIGURE 3.10

CLAST ORIENTATIONS IN REWORKED TILL
NEAR TROEDYRHIW
(Sample number=50)

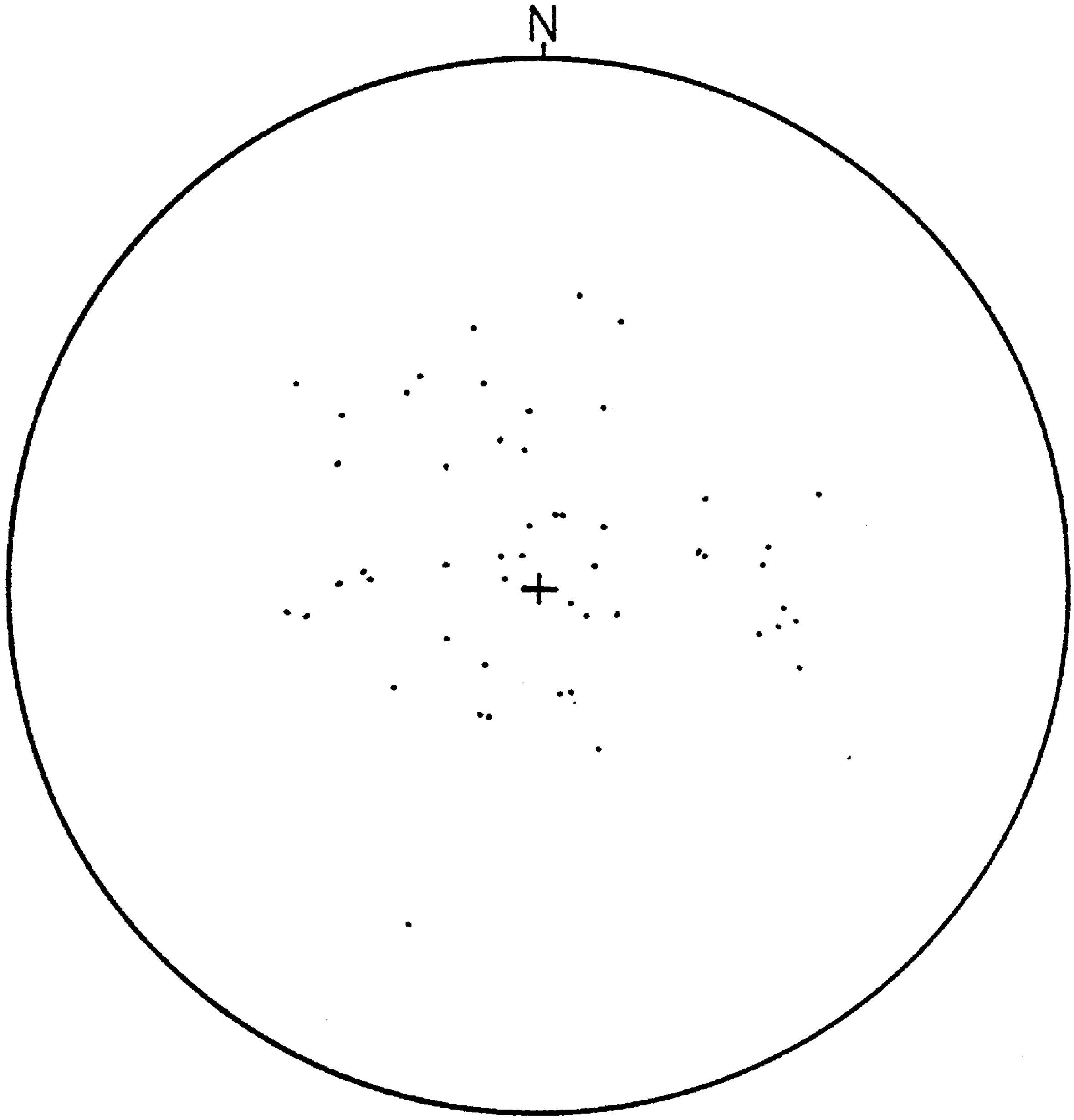
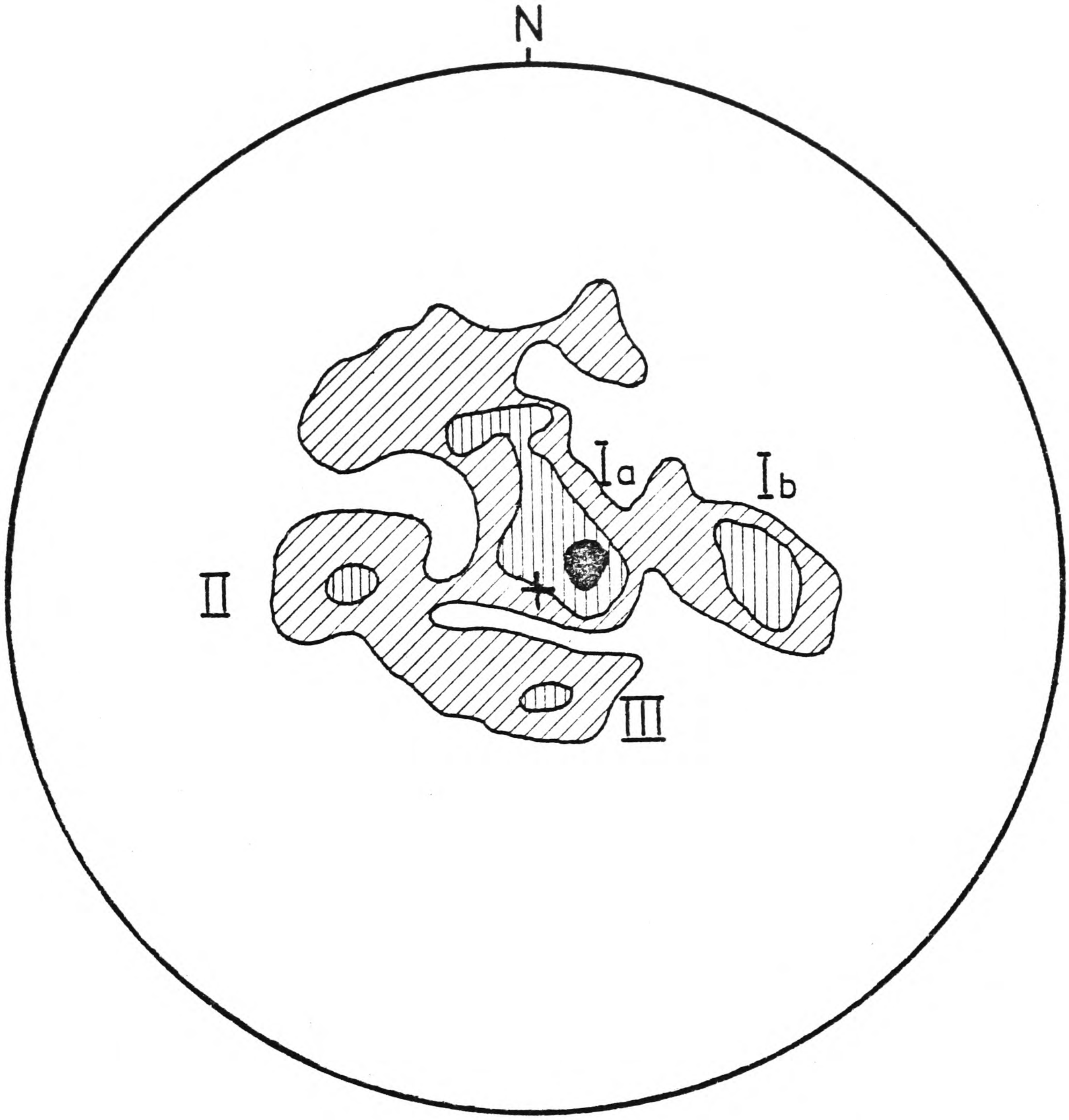


FIGURE 3.11

STEREOGRAPHIC PLOT OF POLES
FOR REWORKED TILL NEAR TROEDYRHIW



< 3% of population	6-9% of population
3-6% do.	> 9% do.

FIGURE 3.12

CONTOURED STEREONET FOR REWORKED TILL NEAR TROEDYRHIW degrees along the same orientation, that is, into the valley side. This group, however, lies at greater depth below ground level, at between 1.4m and 1.9m.

Clasts of centre II at the 6 to 9 per cent interval lie at similar depth to those of population centre Ia, however, clast dip is towards 100° typically at around 40 degrees from the horizontal.

Clasts of centre III dip at up to 25 degrees towards 340° to 360°.

Explanation of the results obtained and which are described above, is based upon intepretation of the mode of soil genesis. The clast populations shown as Ia, Ib, II and III in Figure 3.12 would appear to reflect post-depositional transportation of melt-out and lodgement tills in the vicinity of Troedyrhiw. Geomorphological mapping has located the presence of several lobate structures up to 55 metres in diameter, interpreted as being solifluction lobes which are the principle elements of the surface morphology in the proximity of the soil exposures. They are located at grid reference SO 066021 in Map 2.3. The imbricate dip of clasts into the valley side in population centres Ia and Ib is a typical fabric developed within solifluction deposits. However, it may also reflect small scale circular failures of till eastwards, down the valley side, imparting a shear fabric of clast rotation and dip reorientation in a due westerly direction. The influence of gravitational movement of overlying head deposits under planar flow appears to have had its influences in decreasing the amount of dip at depths shallower than 1.2m below ground level. This is being reflected by clasts of population centre Ia. Clast dip and orientation for centre II very closely resembles that of the head deposits represented in Figures 3.14 and 3.15, the data of which is discussed subsequently in section 3.4.3.

The fabric exhibited by clasts within population centre III bears striking similarities to that of melt-out till exhibited in Figure 3.7 and may represent the residual fabric of the original melt-out till from which it appears to have been derived.

In conclusion, the quantative data above therefore suggests that the soil sampled at the exposures near Troedyrhiw has been affected by two principle post-depositional mechanisms of disturbance :-

1. Initially, subsequent to melt-out till deposition, the deposit appears to have undergone highly localised slip failure (predominantly circular), producing reorientation of clasts. However, a small proportion of the original melt-out till fabric has been retained. Evidence for this has been obtained from towards the base of the disturbed till zone.

2. The subsequent wide scale solifluction of till at shallower depths under periglacial conditions appears to have produced mass reworking of the deposit and the realignment of clasts during saturated flow.

3.4.3 Head deposits and colluvial soils

3.4.3.1 Head deposits

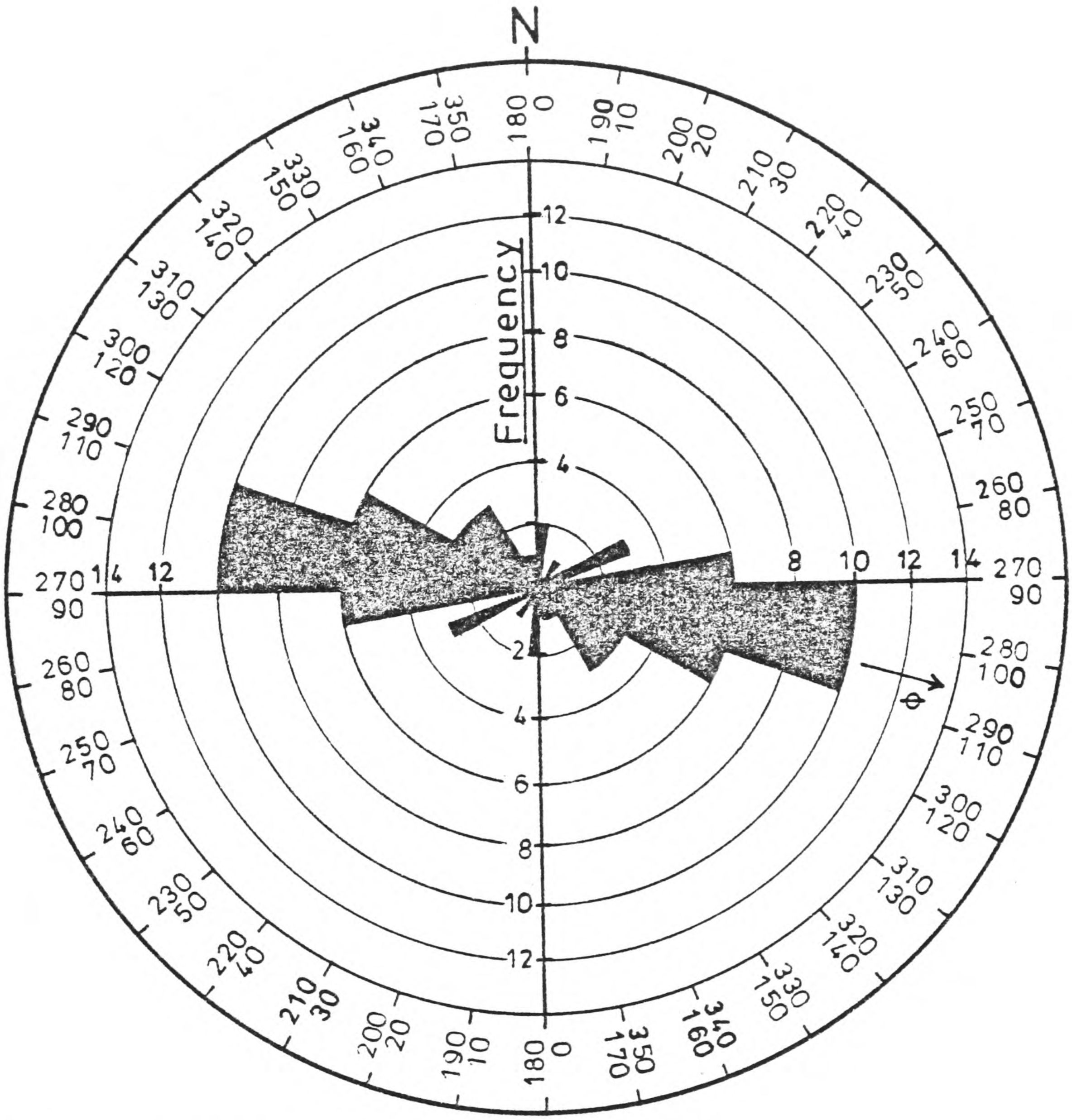
Soliflucted material of local upslope origin, the head deposits, commonly overlies glacial sediments (tills and fluvioglacial materials), from which much of the soil has been derived. Its typical morphological representation is one of solifluction lobes and terraces, revealed at the ground surface by detailed geomorphological mapping. The widespread occurrence of the facets, particularly on the lower valley slopes where the superficial deposits are thickest, is shown in Maps 2.1, 2.2 and 2.3. Thicknesses of head of between 0.9 and 3.2 metres have been recorded. In localised positions towards slope base, for example at Aberfan, the thicker accumulations are developed in glacially eroded rockhead depressions.

The typical appearance and textural properties of the head deposits are shown in Plate 3.1 and Figure 3.1 respectively. The vast majority of the deposits observed are a loose to medium dense, mottled orange-brown and light grey silty fine sand with bladed and oblate, angular to subrounded coarse gravel and cobble sized clasts. The latter are very locally derived from outcrops of sandstone and siltstone. Locally high clay and silt percentages were recorded in head deposits derived from mudstone rich outcrops upslope, providing textural properties more similar to that shown in Figure 3.1. Cobble percentages are usually noted to increase with depth. This is probably as a consequence of :-

1. greater exposure of the surface layers of superficial material to weathering agencies, reducing particle size.

2. Larger amounts of angular frost shattered scree and talus debris at depth. This would have been gravitationally derived from bedrock exposures upslope, introduced immediately subsequent to glacial retreat and prior to development of the other head horizons during the Postglacial.

The larger gravel, cobble and boulder sized clasts present within the head deposits have been noted to have a preferred orientation approximately parallel to the original Post glacial ground surface. A quantitative expression of clast dip and orientation data is provided in Figures 3.13, 3.14 and 3.15, showing the spatial arrangement of coarse gravel and cobble sized clasts within head deposits exposed on the western valley side in the locality of Troedyrhiw, (see Map 2.3). The majority of clasts dip down the valley side in an easterly direction whilst less than 10 per cent dip to the west. Data plotted as a rose diagram in Figure 3.13 shows that more than 40 per cent of all clasts dip towards 090°-110° at between 1 degree and 56 degrees (mean of 29 degrees) from the horizontal. The azimuth of the resultant orientation vector (θ) is towards 105.8° with a vector magnitude (L) of 63 per cent. This data shows a high significance of difference from a uniform distribution of clasts at greater than the 99.9 per cent level. Precisely 50 per cent of the clasts in the 090°-110° zone lie within the greater than 14 per cent contour of population shown in Figure 3.15, with dips of between 15 degrees and 25 degrees exhibited. The remainder of clasts are scattered more



ϕ Azimuth of resultant vector

FIGURE 3.13

CLAST ORIENTATIONS IN HEAD DEPOSITS
NEAR TROEDYRHIW
(sample number=50)

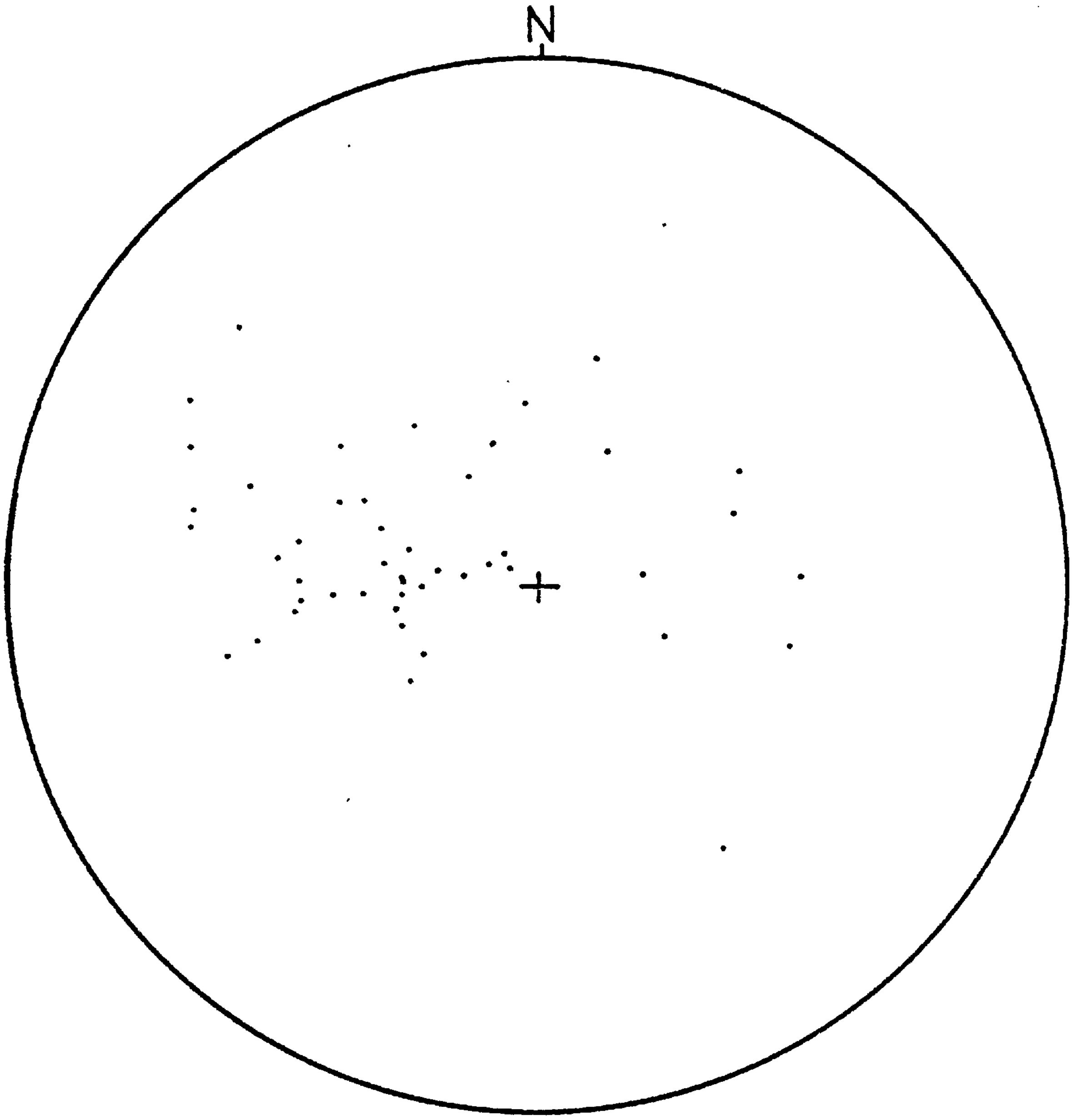


FIGURE 3.14

STEREOGRAPHIC PLOT OF POLES
FOR HEAD DEPOSITS NEAR TROEDYRHIW

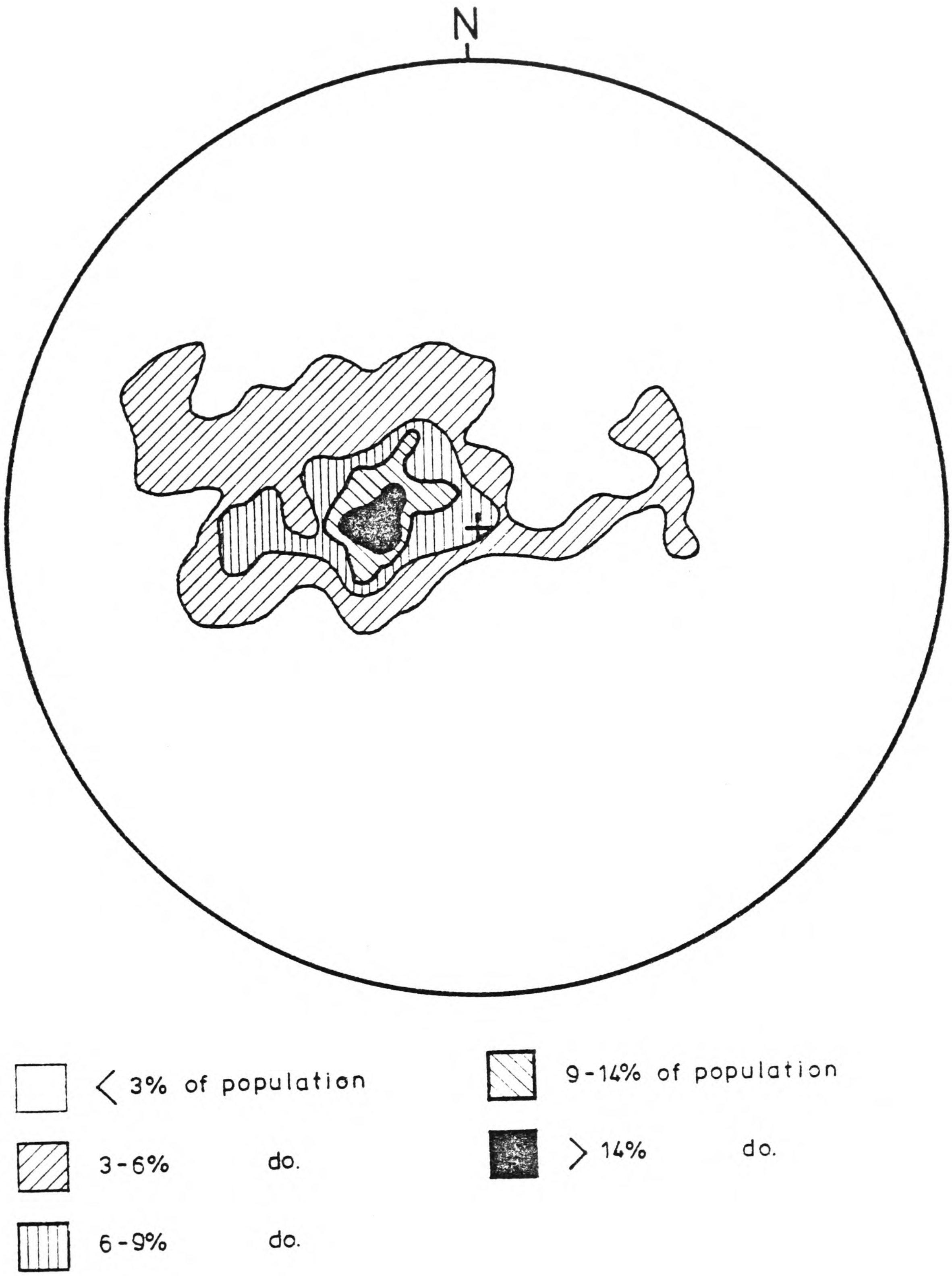


FIGURE 3.15

CONTOURED STEREONET FOR HEAD DEPOSITS NEAR TROEDYRHIW widely about these values. The mean clast dip closely corresponds with the local slope angles of between 24 degrees and 27 degrees towards 090° in the proximity of the exposures where this data was collected.

It may thus be seen that within typical head deposits, clast orientation is approximatelyparallel to the ground surface. The development of this orientation has been a result of the reworking of till and weathering and soil formation during widespread solifluction on the valley sides. This has produced the present slope morphology.

3.4.3.2 Colluvial soils

At numerous levels within the head deposits, at its base and also at the top below the upper 0.15 to 0.2 metres of topsoil, extremely localised heterogeneity has been observed by the presence of lenses of light grey, somewhat uniformly graded fine to medium sand. Individual lenses of sand up to 60mm in length have been observed at many sites, as shown in Figures 3.1 and 3.9.

These colluvial concentrations record the flushing out of silt and clay sized soil fractions as a result of channelled water seepage along the top of fines rich horizons within the head material. Washouts observed in the process of formation from small issues at the soil surface adjacent to trail pits at Aberfan have developed extremely similar textural characteristics to those observed within the head deposits which are genetically of periglacial origin.

3.5 Discussion

The textural properties and mesofabric characteristics of the variety of glacigenic and soliflucted soils within the Taff Valley, discussed above, show that all the soil types present exhibit some degree of inherent heterogeneity. This is as a result of deposition in glacial and periglacial environments. There are frequently a variety of lithologies present within soil types of similar genetic modes and local glacial environments.

The lodgement tills observed show the greatest degree of homogeneity. They are the result of bedrock attrition and a complex intermixing of attritional derivatives deposited subglacially. Of those tills produced in the argillaceous and arenaceous bedrock areas, the former exhibits more uniformity than the latter which tends to contain a greater abundance of sandstone and siltstone clasts set in an arenaceous till matrix. Some silt and clay size (principally rock flour) is also present. The clasts exhibit an imbrication dipping downstream. Larger scale variability has been observed by the presence of blocks of bedrock (incorporated by substrate deformation) within the lower lodgement till levels. This has been genetically interpreted as deformation till.

Melt-out tills exhibit a predominantly random textural variability as a characteristic of their mode of formation. Accumulated by the melting out of essentially englacial and subglacial ice-supported debris, its heterogeneity is a direct consequence of the local juxtaposition and variability of englacially carried debris and the flow of meltwater through the deposited till. Lensoid accumulations of outwash deposits are frequently apparent, accompanied by flow till formation as supraglacial ablation conditions dictate. Clasts within the till are imbricately dipped upstream, possibly reflecting the original englacial shear fabric.

The deposition of fluvioglacial deposits, both as outwash from the glacier snout and also in the ice contact valley side situation, produce their own suite of sedimentary structures and textural properties. The ice contact type tends to be the more heterogeneous as a consequence of :-

1. ponding of water in a low energy situation at the glacier margin

2. the sporadic influx of outwash sands and gravels

3. the incorporation of screes and other talus debris under gravity from frost shattered valleyside exposures.

The incorporation of scree and talus also accounts for some of the variability observed within periglacially soliflucted tills and head deposits. The washing out of fines from within the head deposits has taken place at numerous stages during its Post glacial formation and is also occurring in isolated sites at present. This induces extremely localised heterogeneity in the form of fine sand and silt accumulations. Local bedrock lithology upslope greatly contributes to the argillaceous or arenaceous nature of the head deposits.

Local substrate variability is, more widely, a significant factor in determining the textural variability of all soils present within the valley as highlighted throughout this chapter. This variability subsequently plays a prominent role in the engineering properties of each soil type observed and hence in the behaviour of the total soil as a mass. Discussion of the variability of engineering properties within and between individual glacigenic sediments of the Taff Valley is undertaken below.

FOUR

CHAPTER 4

SAMPLING, GRADING CHARACTERISTICS AND INDEX PROPERTIES

4.0 Introduction

This section presents a description of the methods of soil sampling adopted in this study, the methods of sample preparation and testing where they differed from those described in BS 1377:1975, and presents the results of standard tests performed on soil samples.

A comprehensive soil testing program covering the determination of particle size distribution, moisture contents and index properties was undertaken. The shear strength and permeability characteristics of the soils are discussed in the subsequent chapters. In addition to these test data, results of tests undertaken in conjunction with highway engineering and spoil tip stability assessment within the Taff Valley have been collected.

4.1 Soil sampling

The individual soil types present in the region of study have been described and qualitatively classified as well as quantitatively analysed by studies in trial pits and exposures. A qualitative differentiation based solely upon appearance is insufficiently precise as a consequence of operator subjectivity. Hence, statistical procedures were adopted for soil sampling in this investigation so that such influences were reduced and results made more representative of the total soil mass.

4.1.1 Technique

From a review of sampling techniques (Lumb 1974), it was concluded that for the sampling of predominatly heterogeneous soils in exposures and trial pits two procedures should be applied :-

1. A two-dimensional stratified random method using a random 'pin-pointing' principle which would prove a more efficient procedure than a two-dimensional systematic pattern based on an equally spaced matrix of sampling points.

2. In order to sample the whole range of soil lithologies present at exposures, for example where small lensoid accumulations are observed and which may be missed during random sampling, a subjective procedure based upon the experience of a skilled operator in these soils, should also be adopted.

4.1.2 Collection

During soil sampling account was taken of any stratification present within the soil. For example, finely stratified flow till units observed at Nant y Gedrys (grid reference 853110, Map 2.1) were carefully separated from the soil mass so that fabric disturbance and mixing of individual horizons would be minimised. The granular nature of all the soils studied made undisturbed sampling virtually impossible.

A visual description of the in situ properties of individual soil units at the sampling location was made sufficiently precise for it to be practicable to collect disturbed samples for the determination of particle size distributions and index properties. Visual properties and a textural classification could subsequently be directly related to an engineering classification.

The sizes of samples collected varied according to the size of particles contained within the soil mass. For soils containing greater than approximately 30 per cent of clasts larger than medium gravel size, in excess of 15kg of samples was collected. Where the percentage of sand sized fraction exceeded approximately 30 per cent, between 5 and 10 kg of soil was taken for testing, whilst up to 5 kg of soil was collected where particles of the fine mode (silt and clay) strongly predominated.

In order to obtain a sufficient number of samples to be statistically significant and representative of tills at depth, advantage was taken of site investigation work in progress within the valley. Bulk samples (including kame terrace deposits, melt-out and lodgement tills) were obtained from trial puts in the Aberfan and Nantgarw areas independant of the site investigation contractor.

4.1.3 Preparation and testing techniques

Prior to laboratory testing soil samples were prepared in accordance with the procedures for preparation set out in BS 1377:1975. However, from a review of standard testing techniques it was found that the procedure for preparation of disturbed samples for the determination of index properties could be suitably improved. The nature of the microfabric and the arrangement of its component particles strongly influences the engineering characteristics of a soil, therefore it was felt that microfabric disturbance could be reduced by improving the preparation technique. In samples where the fines content was in excess of approximately fifteen per cent, particles of less than 425 microns diameter were separated from the soil mass by manual extraction and light sieving to remove the coarser fractions. This reduced the disturbing influences of mechanical sieving. It was not feasible to make use of samples in which the fine fraction was less than ten per cent as a consequence of the limitations of the technique. With the latter case the fraction less than 425 microns required separation by wet sieving techniques.

It was felt that the manual removal of the fine fraction of less than 425 microns is only a suitable technique for adoption in a research environment and would not be cost effective in an industrial laboratory testing situation due to the extra preparation time involved.

During the soil testing programme the techniques used were constantly reviewed to ensure that the test results obtained reflected the true nature of the materials. For example, fabric and sample disturbance was constantly limited by careful handling and placement in testing apparatus. In situ conditions, including orientation, were recreated wherever possible.

The standard methods of soil testing described in BS 1377:1975 were adopted in full. It must be stated that the liquid limit of air dried soil was determined by using the cone penetrometer method. Wet sieving techniques were adopted for determining particle size distributions, with the pipette method being employed for analysis of soil fractions less than 63 microns diameter.

4.2 Methods Involved in the Analysis of Data

The total number of samples of till, head and fluvioglacial deposits for which data were obtained amounted to 248. This comprised specimens that were collected during the fieldwork phase of investigation and supplementary batches of data obtained from local site investigation schemes.

During the analysis of the latter data, it was found that little attempt had been made to correlate soil properties with the modes of genesis of the glacial materials sampled. Hence in the reports of investigations undertaken before 1974 the correlation of test results with soil descriptions and classifications has proved somewhat problematic. This is a consequence of limited and incomplete sample descriptions and poor description of soil texture and other features, for example striations of rockhead, which may have provided a more positive subdivisioning of the tills in terms of their modes of genesis. Only approximately 20 per cent of the data obtained before 1974 was therefore used in this investigation, in comparison with a 95 per cent usage of data from reports dated later than 1974.

For the statistical analysis of particle size distribution curves it was deemed necessary to modify some of the soil parameter equations that Inman (1952) derived from the percentile diameters ϕ_5, ϕ_{16}, ϕ_{50},

$\phi_{84}$and ϕ_{95}. His values, as discussed in section 1.1.6.2., directly relate the physical properties of a soil to the moment measures commonly employed in statistics. The measures were derived for the type of cumulative size frequency curves commonly in use on the continent and in the United States. Some, however, for example grading coefficient and phi kurtosis, were not directly suitable in their existing format for use with the type of particle size distribution curve that is produced in accordance with BS 1377:1975. Hence, the juxtaposition of some of the expressions used in the parameters below has been modified accordingly. In the case of bimodal and multimodal particle size distributions, where two or more concentrations of a certain particle size exist, the effectiveness of the phi kurtosis measure is severely reduced and hence this has not been computed.

The modified parameters are :-

1. (a) Phi median diameter $Md_{\phi} = \phi 50$

   (b) Phi mean diameter (Central tendency) $M_{\phi} = \frac{1}{2}(\phi_{16} + \phi_{84})$

2. Phi deviation measure (Grading Coefficient) $\sigma_{\phi} = \frac{1}{2}(\phi_{16} - \phi_{84})$

3. (a) Phi skewness measure $\alpha_{\phi} = \dfrac{M_{\phi} - Md_{\phi}}{\sigma\phi}$

   (b) Second phi skewness measure $\alpha_{2\phi} = \frac{1}{2}\dfrac{(\phi_5 + \phi_{95}) - Md\phi}{\sigma\phi}$

4. Phi kurtosis measure $B_{\phi} = \frac{1}{2}\dfrac{(\phi_5 - \phi_{95}) - \sigma_{\phi}}{\sigma\phi}$

Equations 1(b) and 2 are computed to cover the range and the spread of particle sizes with the frequency curve. Equations 3(a) and 3(b) are a measure of the frequency curve, whilst equation 4 is a measure of curve peakedness.

A logarithmic diameter has more significance in the analysis of statistical relationships of sediments, hence the phi notation was used in computation, where :-

$$\phi = -\log_2 \frac{d}{d_o}$$

d - diameter in mm.

d_o - standard grain diameter of 1mm.

4.3 Grading characteristics

4.3.1 Particle size

The characteristic grading curves and envelopes of 204 specimens of glacigenic, post glacial and Recent soils are summarised in Figures 4.1, 4.2 and 4.3.

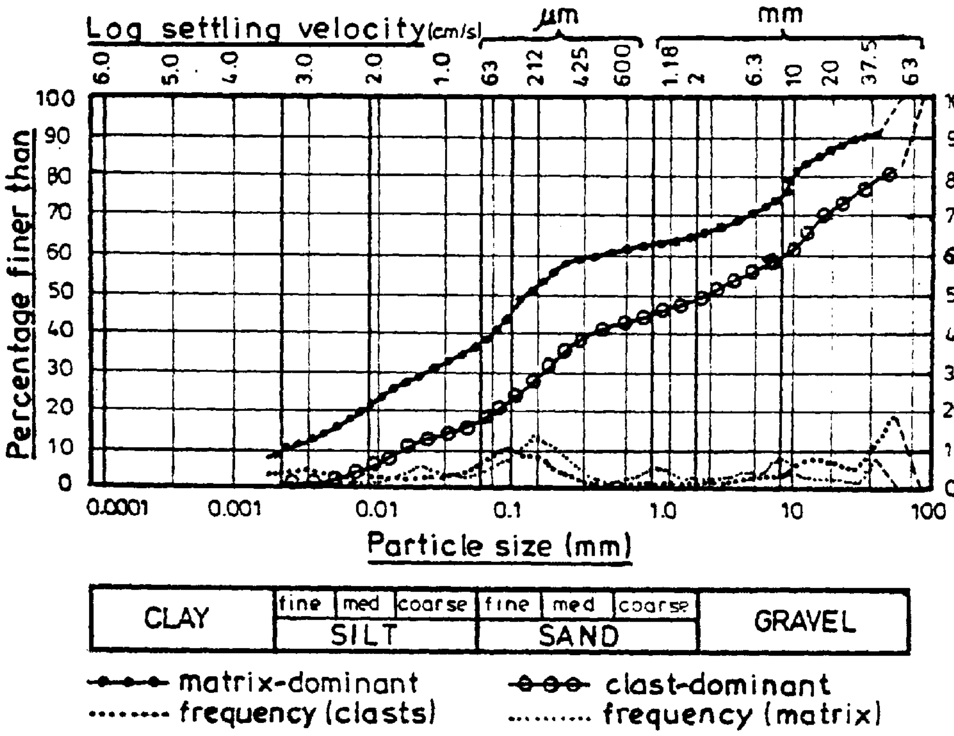
108 specimens of melt-out and lodgement tills have been differentiated on the basis of in situ and borehole sample descriptions, soil profiling (the melt-out tills overlie the lodgement tills), index properties and grading characteristics. Typical particle size and frequency distribution curves for these soils are shown in Figure 4.1. Important differences are exhibited by the curves of each till type.

1. Melt-out tills were the most well graded of the till types sampled. A noticeably coarser grading than that for lodgement till is quite apparent with clay content usually less than 10 per

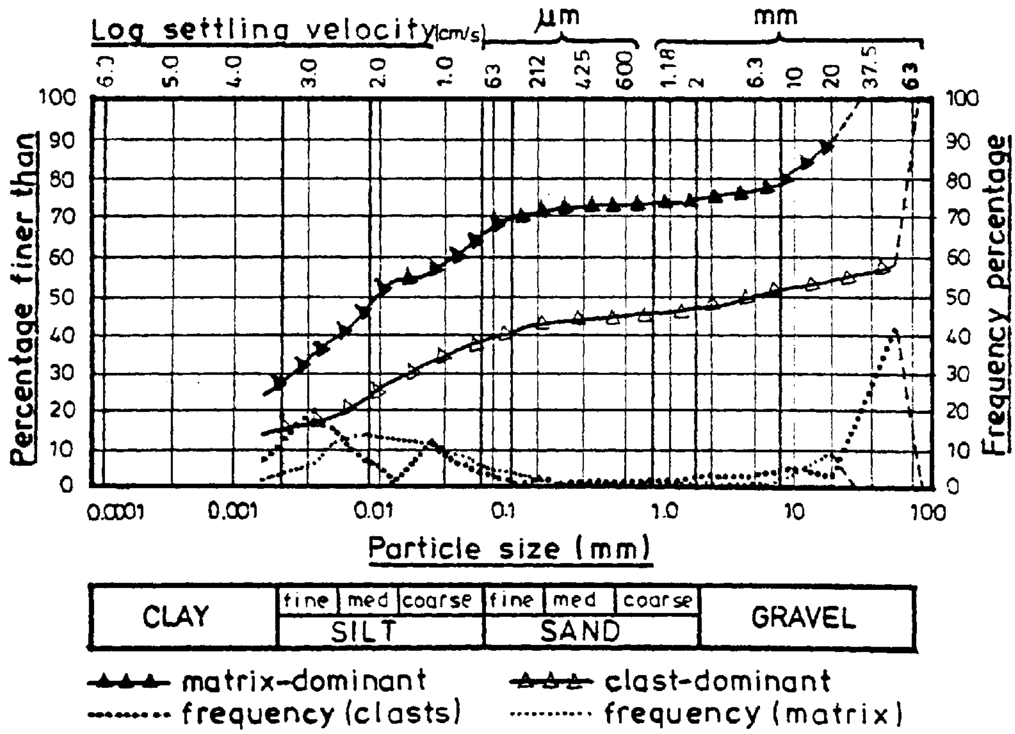
cent. A large proportion of the particles present within the soil are of fine to medium sand size and also coarse gravel and cobbles. This is reflected by the corresponding peaks in the frequency distribution curves for both clast and matrix-dominant sub-types. These peaks exhibit a lower degree of kurtosis than those shown for lodgement till as a consequence of a better graded particle distribution.

The coarser grading and more multimodal frequency distributions of the melt-out till sub-types would appear to reflect the mode of genesis of the soils. During transportation a wide variety of particles of differing lithologies have become included, both from sub-glacial and supraglacial sources, however, during deposition some degree of sorting and reworking by the process of melting-out has occurred. This has resulted in the removal of some of the finer fractions with the result that the most dominant modes lie in the finer sand and gravel/cobbles range.

2. Lodgement tills within the Taff Valley are characteristically gap graded in the particle range 0.1mm to 10mm, that is, in the medium sand to medium gravel range. This is clearly illustrated by the frequency distribution curves (lower graph, Figure 4.1) which show a strongly developed bimodal kurtosis in the silt and coarse gravel to cobble sizes. Within the matrix the lodgement tills have clay contents which are significantly in excess of those for melt-out tills. Quantities of greater than 20 per cent of the total bulk are typical with contents greater than 30 per cent having been obtained for some matrix-dominant sub-types.



MELT-OUT TILL



LODGEMENT TILL

FIGURE 4.1

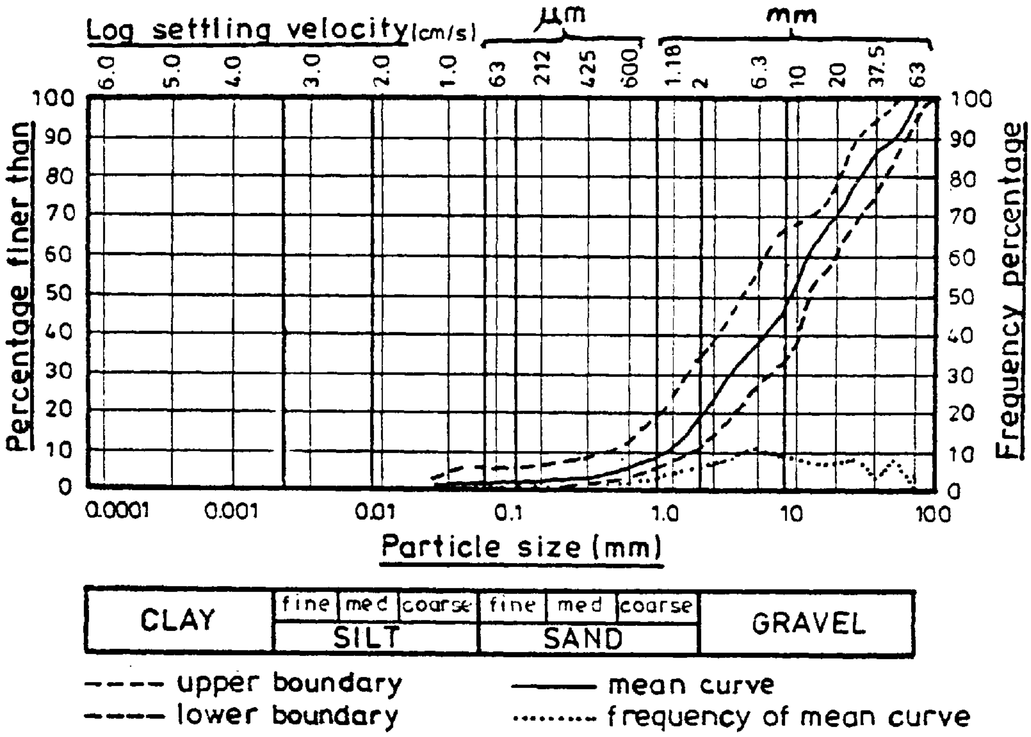
TYPICAL PARTICLE SIZE DISTRIBUTION CURVES FOR MELT-OUT AND LODGEMENT TILLS

Comparable matrix-dominant melt-out tills seldom have a clay content exceeding 12 per cent. The greatest proportion of particles within the matrix-dominant lodgement tills, greater than 45 per cent in some specimens, lie in the silt size range, predominantly medium silt. This is essentially a consequence of the large amounts of siltstone included by attrition of the argillaceous substrates common in the sampling areas.

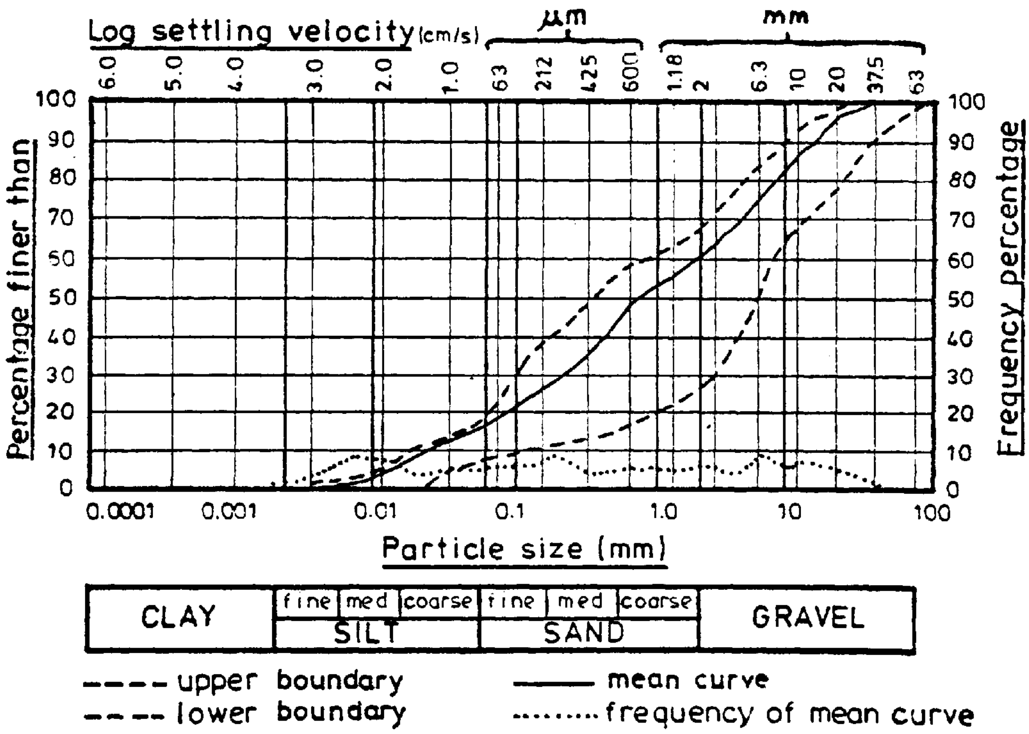
The clast-dominant sub-types exhibit the characteristic gap graded particle distributions and bimodal frequency curves common within all the lodgement tills tested. A shallower silt sized particle gradient is typical, accompanied by in excess of 40 per cent coarse gravel and cobbles.

Borehole and in situ field evidence suggests that an argillaceous bedrock type is more readily worked to produce a matrix-dominant lodgement till than is the harder, more resistant arenaceous bedrock. The latter tends to be eroded and deposited as a clast-dominant till with a relatively low clay/silt content.

Fluvioglacial deposits have been differentiated into two genetic classes on the basis of geomorphological mapping and in situ textural properties. Grading envelopes for 31 specimens of openwork outwash sands and gravels and ice-contact kame terrace deposits are shown in Figure 4.2. The former are relatively uniformly graded, lying within a narrow well defined zone which is readily recognisable by its very steep gradient in the coarse sand to gravel range. The frequency distribution of the mean grading curve is monomodal, rising sharply in the coarse gravel to cobble size. It peaks at approximately the 6.3mm



FLUVIOGLACIAL SAND AND GRAVEL OUTWASH



FLUVIOGLACIAL ICE-CONTACT

(KAME TERRACE) MATERIAL

FIGURE 4.2

PARTICLE SIZE DISTRIBUTION ENVELOPES FOR FLUVIOGLACIAL DEPOSITS particle size and gradually tails away to zero in the coarse silt zone.

Ice contact fluvioglacial materials deposited in the kame terrace environment are less well sorted than the outwash deposits and contain a greater mixture of constituents of differing particle sizes. The latter is reflected in the multimodal form of the frequency distribution for the mean curve, three main modes being noted, one in each of the silt, sand and gravel ranges . The wider variety of particle sizes is a direct consequence of the origin of the deposits. Greater silt and sand contents than have been noted for outwash materials suggest the following :-

1. a lower energy depositional environment, probably in an ice-marginal ponding situation

2. the modal peaks in the medium silt and fine to medium sand ranges may reflect the reworking and supraglacial transportation of the fine constituents of melt-out tills.

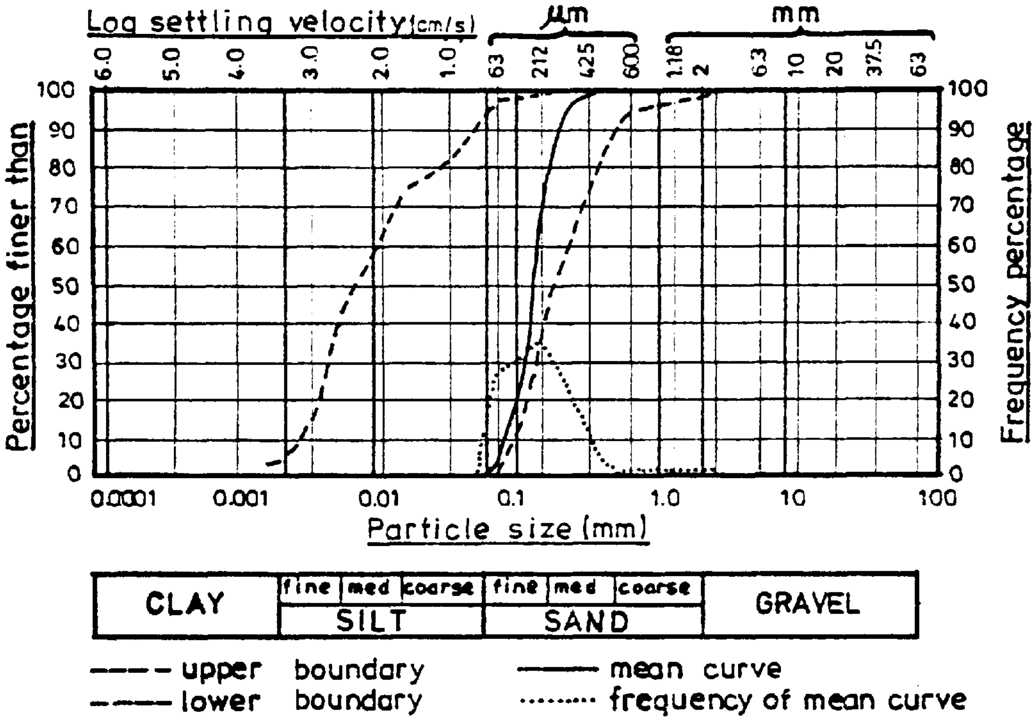
The coarse fractions are not readily distinguishable from others of differing modes of genesis.

An equally pronounced peak at approximately the 6.3mm particle size corresponds with a similar peak in the outwash deposits. It suggests that some of the latter is also deposited in this environment, probably derived via high energy supraglacial streams.

It would be reasonable to assume that some frost shattered screes would become included within the kame terrace materials deposited at the lateral ice margin. Field observations have shown that the angular clasts typical of these materials principally lie in the coarse sand to cobble and boulder range, with some degree of breakdown of siltstones also producing some coarse silt and fine sand sized clasts. These consituents and their localised variability as bedrock lithology dictates, produce the minor modal fluctuations in the frequency distribution curve over the particle range.

It is to be noted that the mean particle size distribution curve is close to the upper margin of the grading envelope for most of its length. Many of the specimens tested therefore fell into this area of the distributions; a small proportion of samples tested, however, fell below the mean line, the lowermost of which is shown as the lower boundary. The latter line closely coincides with the upper boundary for the fluvioglacial outwash, reflecting the transient characteristics of the two soil types of similar genetic modes. The two types have been separated at this grading interface principally upon the basis of geomorphological mapping which has distinguished kame terraces from fluvioglacial outwash terraces in the sampling areas. The interpretation of in situ textural characteristics and soil spatial variability has also aided in this differentiation.

The particle size distribution characteristics for 11 specimens of glacilacustrine deposits are shown in Figure 4.3. The specimens varied from an abundance of almost uniformly graded fine and medium sands through to the occasional specimen almost entirely composed of



GLACILACUSTRINE SAND AND SILT

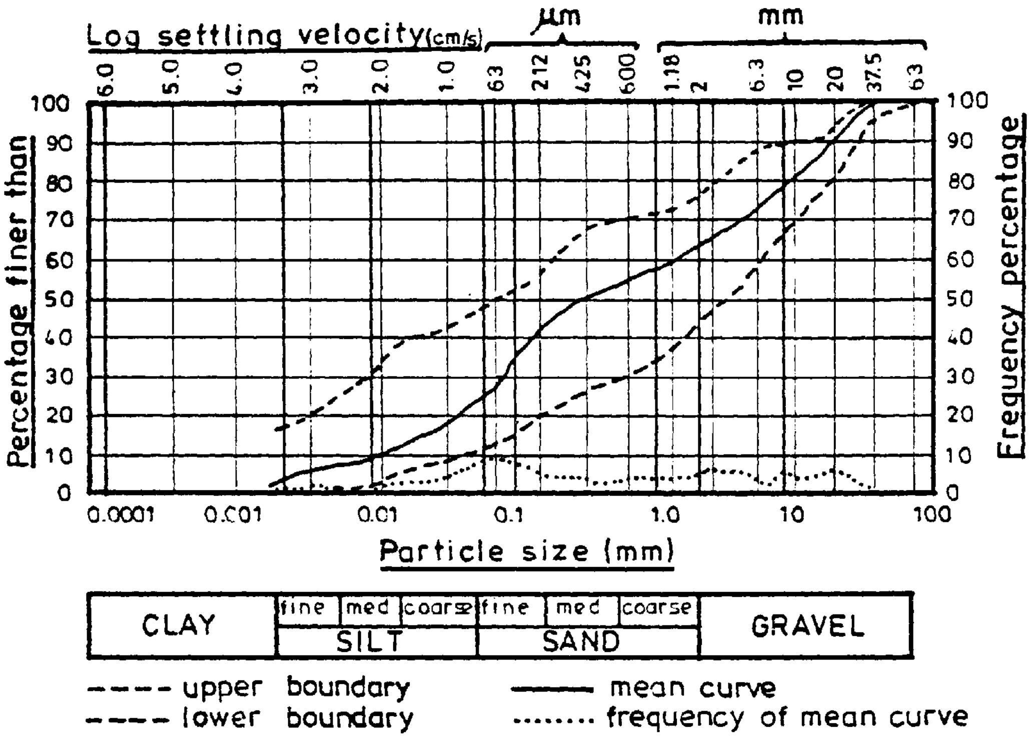
FIGURE 4.3

PARTICLE SIZE DISTRIBUTION ENVELOPE FOR GLACILACUSTRINE DEPOSITS silt, predominantly in the fine to medium silt range. This characteristic degree of uniformity in the range of particle sizes is reflected in the monomodal nature of the frequency distribution for the mean grading curve.

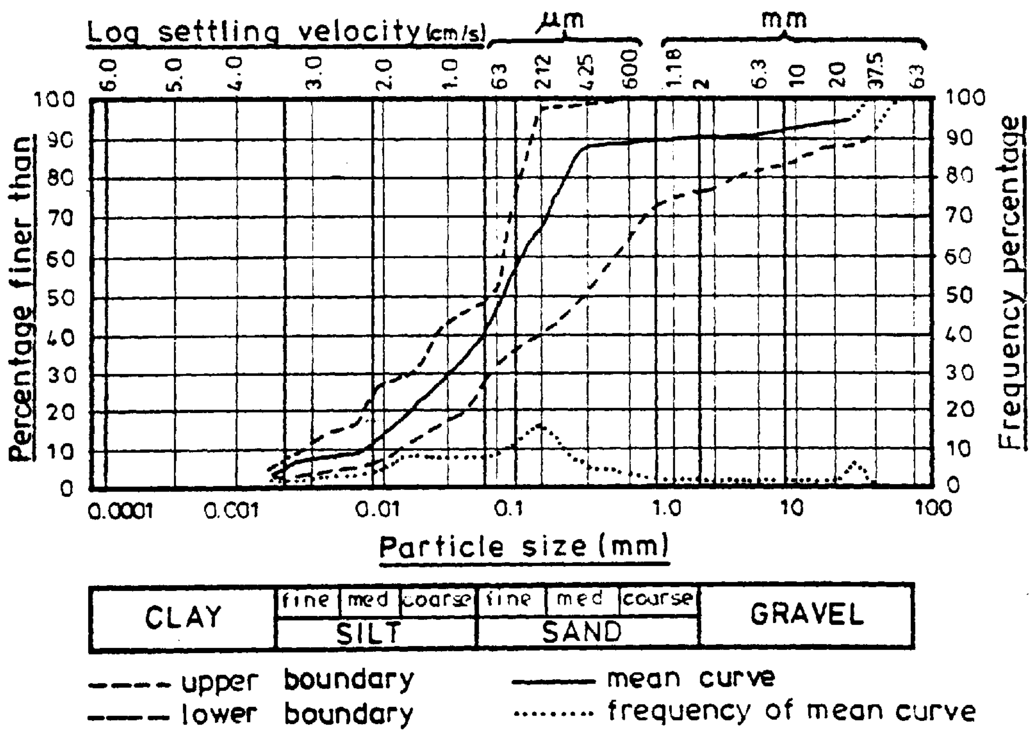
The range of uniformly graded specimens from sand to silt size records changes in energy within the depositional environment, as highlighted in section 3.4.1 for a typical case example. The silt sized fractions have been found interbedded with the sand sized elements, representing changes in flow energy, possibly associated with seasonal patterns of transportation and deposition synonymous with varve formation.

The grading characteristics of 54 samples of head deposits and colluvium are shown in Figure 4.4. The former typically exhibit multimodal frequency distributions reflecting the wide range of compositional materials of differing genetic modes that are present. The range of particle sizes and hence width of grading envelope for these soils therefore varies from site to site according to the source material immediately upslope from the site of deposition. The thicker deposits of head, often greater than 2 metres usually lie low on the valley side. They therefore tend to have a range of particle sizes close to that for melt-out tills and kame terrace deposits which provide the source constituents for these thicknesses to be developed. The grading envelope for head deposits, as shown in the figure, thus closely resembles that if the said sources, that is, well graded from the coarse gravel to clay sizes. The clay is usually present in greater percentages than in the source materials, probably as a consequence of the interplay of mechanical and chemical weathering agencies in the periglacial environment. The high silt and clay contents observed (approaching 50 per cent in come cases as shown by the upper envelope), reflect the slow chemical disintegration of argillaceous bedrock in the periglacial environment and are typical for the type of head deposits produced in these areas of the valley. More frequently the bedrock is arenaceous and when commonly accompanied by high fine to medium sand contents in the glacial source materials, the head deposits plot such that they lie close to the mean grading and frequency distribution curves. Kame terrace deposits tend to produce a particle size distribution for head deposits that lies close to the lower boundary.

Concentrations of colluvial deposits are abundantly recorded within and overlying the head deposits, as shown in Figures 3.1 and 3.3. They represent a washing mechanism whereby silts and fine to medium sands are either flushed out of the head deposits by percollating groundwater or remain as a residual zone depleated in fines depending upon seasonal flow conditions or in situ permeability. Colluvium accumulating as 'flushed out' silt is represented in Figure 4.4 by particle size distribution curves showing a greater degree of uniformity than the parental head deposits and which fall immediately below the upper boundary. Those colluvial regoliths that have formed as a result of the removal of fines by higher rates of groundwater flow have been found to occupy a zone close the lower boundary. Within the latter colluvial type coarse gravel sizes clasts contained within the parental head deposits become more abundant as a percentage of the soil mass, comprising greater than 10 per cent of the total.



HEAD DEPOSITS



COLLUVIUM

FIGURE 4.4

PARTICLE SIZE DISTRIBUTION ENVELOPES FOR HEAD DEPOSITS AND COLLUVIUM

The frequency distribution for the mean grading curve of colluvium may therefore be seen to be bimodal to trimodal as a combination of both 'flushed out' and residual extremes. Peaks of pronounced kurtosis lie in the coarse silt to fine sand and coarse gravel sizes.

4.3.2 Particle bivariate scatter

From the analysis of particle size distribution curves for 204 samples of glacigenic and various Post glacial and recent soils, the five percentile diameters ϕ_5, ϕ_{16}, ϕ_{50}, ϕ_{84} and ϕ_{95}, were recorded. From this data the phi median diameter (the central tendency) and the phi deviation measure (the grading coefficient), were plotted as a bivariate scattergram (Figure 4.5). This method of soil classification is based upon an approach to the distinction of a wide variety of sediments by grading characteristics alone, as documented by Mitchell (1976).

Grading curves, sorting and particle size data for a wide variety of soils from lodgement and melt-out tills to fluvioglacial and fluviatile deposits are exhibited in Fookes, Gordon and Higginbottom (1975) and Mitchell (1976). These data have been plotted on to a scattergram to provide a series of discontinuous, genetic zones. These were then used as a guide to the classification of the soils of the Taff Valley that plotted into these areas. Field studies in the valley and a visual classification of the soils based on the work of Boulton, McGown et al in areas of active glacial deposition, provided a means by which the envelopes on the scattergram were defined more specifically in terms of the mode of genesis and nature of the soils.

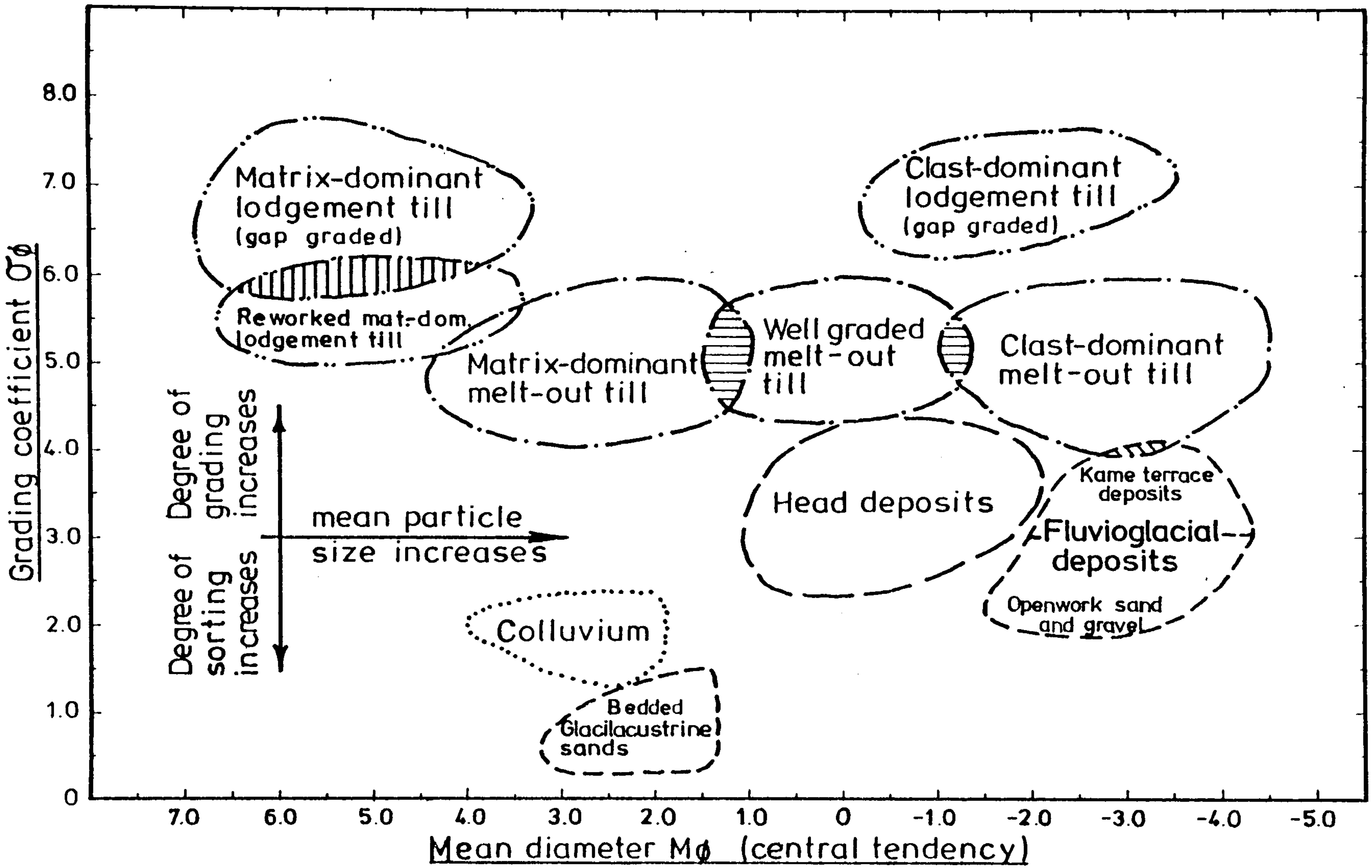


FIGURE 4.5

CLASSIFICATION OF SOIL TYPES IN TAFF VALLEY BASED ON PARTICLE SIZE

(Central Tendency/Grading Coefficient)

The latter has particularly been so with the distinction of clast-dominant and matrix-dominant states. Individual soils produced in differing depositional environments and having distinct particle size distribution curves reflecting their modes of formation, may therefore be seen to lie within the clearly defined envelopes of the scattergram. Localised variations in the method of deposition and depositional environment, typical of lowland glaciation, has resulted in overlap of zones of grading coefficient between individual glacigenic soil types.

Initial genetic classifications of the soils of the valley based upon field identification was seen to closely correspond with this statistical method of classification in nearly all cases. Slight discrepancies were principally noted to occur at the boundaries of adjacent envelopes where genetic transition types occur.

The tills sampled are classified in Table 4.1 in terms of their degree of clast dominance and the central tendency of the particle size distribution :-

Table 4.1 Till classification in terms of size of particles

DOMINANCE	MELT-OUT TILL	LODGEMENT TILL
Matrix-dominant	M_ϕ = 4.5 to 1.0	M_ϕ = 6.5 to 3.0
Well graded	M_ϕ = 1.5 to -1.5	NONE
Clast-dominant	M_ϕ = -1.0 to -4.5	M_ϕ = 0 to -3.5

The absence of well graded lodgement tills within the classification would appear to be essentially due to the development of bimodal grading curves only within the tills. The particle distribution is concentrated as peaks in the clay/silt and gravel sized modes, probably reflecting the crushing characteristics of the predominantly argillaceous parent material. Under impact loading the bedrock has a low crushing strength, disintegrating into gravel sized clasts. With further crushing (simulating subglacial attrition), the material rapidly reduces to silt sized mudstone fragments. Post-depositional breakdown of particles by the presence of water within the till (melted ice and groundwater) may well account for the presence of up to 25 per cent of clay sized particles.

Of the fluvioglacial and glacilacustrine deposits shown in the scattergram, the sands of the latter exhibit the greatest degree of grading uniformity. They lie little displaced above the base line where σ_ϕ equals zero.

The head deposits shown in Figure 4.5 exhibit a moderate degree of grading and sorting, containing a variety of clasts of differing sources, rock type and size. Some clasts have been glacially transported prior to solifluction whilst others are very locally derived from bedrock exposures upslope. The head deposits shown in Figure 4.5 are therefore concentrated in an area of the graph that is common to the majority of the soils. They lie to the right of $M_\phi = 1.0$ as a consequence of typically coarsely grained source deposits and the flushing out of fines by groundwater. The flushing action produces colluvium as lensoid accumulations of relatively well sorted silt and fine sand contained within and overlying the head deposits. This material is recorded in the lower left hand quadrant of the scattergram.

The scattergram method of soil classification has been found to be of particular use in the labelling of tills in the context of plasticity characteristics; this is discussed below in section 4.4.2.3.

4.4 Index Properties

This investigation is principally concerned with determining the engineering properties of tills in the Taff Valley, therefore, in the subsequent summary of the index properties of the deposits encountered, particular attention has been paid to these soils rather than to the analysis of specimens of fluvioglacial and Post glacial origin.

4.4.1 In situ moisture contents

The statistical analysis of the moisture content of 91 samples of melt-out and lodgement till is graphically represented in the form of a histogram as shown in Figure 4.6A.

The mean moisture contents for each soil type exhibit very little difference, with that for lodgement till being marginally lower. Field observations accompanied by borehole data show that the majority of groundwater flow in the superficial deposits is through the relatively permeable melt-out till overlying clay rich lodgement tills. The melt-out till therefore acts as the main soil aquifer and

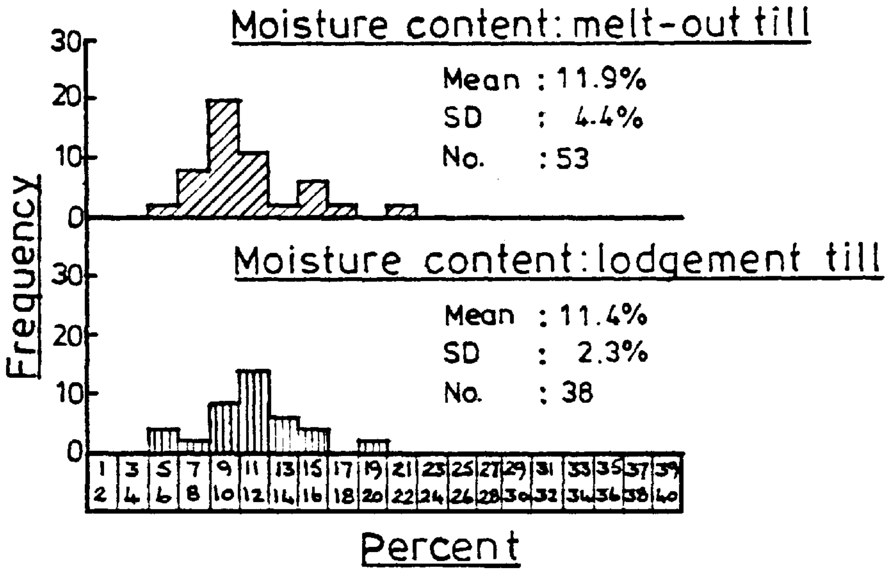


FIGURE 4.6a

MOISTURE CONTENTS : MELT-OUT AND LODGEMENT TILLS

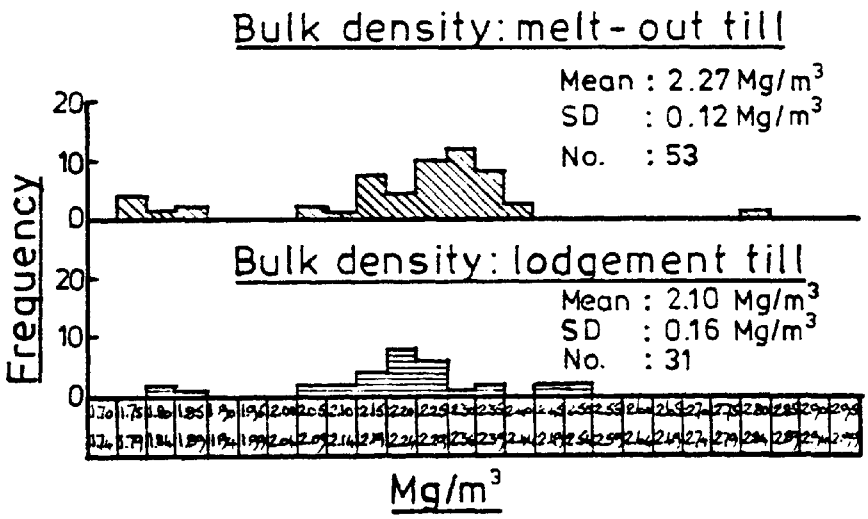


FIGURE 4.6b

BULK DENSITIES : MELT-OUT AND LODGEMENT TILLS subsequently has the marginally higher mean moisture content. Localised textural heterogeneity within the melt-out till, more strongly pronounced than within the lodgement till, may account for the wider scatter of data either side of the mean, as shown by a standard deviation of 4.4 per cent. Moisture contents within lodgement till show less scatter about the mean due to the relatively homogeneous nature of these clayey gravels.

4.4.2 In situ bulk density

Data for a total of 84 samples of melt-out and lodgement till, measured using the sand replacement (large pouring cylinder) method, is graphically shown in Figure 4.6B. The mean bulk density for lodgement till is 7.5 per cent lower than that obtained for melt-out till, (2.10 Mg/m^3 as opposed 2.27Mg/m^3). When considered in the light of its mode of genesis, lodgement till would be expected to have the greater bulk density of the two soils as a consequence of its subglacially induced state of overconsolidation, in comparison with typically normally consolidated melt-out till. This principle would particularly apply to two soils with very similar grading curves and hence the degree of packing obtained for a given surcharge load. The samples of till in this paticular case however, have markedly different grading curves as discussed in section 4.3.1; silts and clays are abundant in the lodgement tills and sands and gravels in the melt-out tills. The sand and gravel sized particles in the melt-out till have a greater specific gravity than the clays and silts in the lodgement till. The well graded nature of the former with its well rounded clasts also enables a better degree of packing to be obtained (in accordance with Fuller's Curve) than may be achieved with silty clayey soils. The combination of these two factors may therefore have resulted in the density differences obtained.

Several problems were encountered during determination of the in situ density of the tills tested :-

1. The presence of large clasts of coarse gravel and cobble size within the melt-out tills presented problems in the excavation of many of the holes to perform the test, especially where near-surface cobble clusters were encountered.

2. The removal of some of the larger clasts increased hole diameter beyond approximately 200mm ; extreme care, during excavation was thus necessary in many cases.

3. The density of clasts excavated from the testing hole is greater than that of the surrounding matrix and hence varying clast percentages, common within the melt-out tills, produced a wide scatter of densities, many of which were high where high clast contents existed.

4. In the highly granular melt-out tills where little cohesion was apparent (particularly in the uppermost weathered layers with low fines contents and frequent points of seepage), problems were encountered due to collapse of the sides of the excavated hole. The resultant errors induced may further account for over-estimates of the in situ density.

5. Only a limited number of flat or shallowly dipping exposures of lodgement till (mainly in stream beds) that were suitable for the sand replacement method of test, were encountered. Hence only 37% of the total number of tests on till were performed on that deposited by a lodgement process. The results obtained may not, therefore, provide a true indication of the full range of densities that are to be expected for lodgement till as a consequence of the smaller number of tests.

6. The relative shallowness of the majority of lodgement till exposures (only up to a maximum of 6.5m), has meant that it was not possible to perform density measurements on the most heavily overconsolidated deposits at or in the proximity of rockhead.

4.4.3 Consistency limits

In the analysis of consistency limit data for the tills studied three separate approaches have been adopted :-

1. the statistical analysis of data to graphically represent the scatter of results obtained by laboratory testing

2. a study of the plasticity characteristics of the tills as a function of the relative percentages of the fine fraction (less than 425 microns) contained

3. an interpretation of the relationships that may be drawn between the consistency limits and the bivariate grading characteristics (central tendency ($M\phi$) and grading coefficient($\sigma\phi$)) of the soils

sampled.

4.4.3.1 Liquid and plastic limits

From the data represented in Figures 4.7A and 4.7B for 128 samples of till it may be seen that lodgement till has a greater moisture content than melt-out till at the liquid and plastic limits. This is consequence of the much greater percentage of silt and clay contained within the former, whilst the presence of up to 30 per cent sand within melt-out tills has resulted in 17 per cent of the specimens tested being non-plastic. The scatter of results about the mean of each soil type is insignificantly different.

4.4.3.2 Plasticity characteristics

The influence of varying concentrations of fine sand, silt and clay upon the plasticity characterisitcs of the tills sampled is demonstrated in Figure 4.8. The 128 samples occupy five clearly defined envelopes through which two divergent lines, the upper and lower Taff Valley lines (TV-U and TV-L respectively), have been drawn.

The lower line, running parallel to the A-line between the rectangular co-ordinates (22,4) and (45,22) approximately, may be expressed in terms of the equation, PI=0.7(LL)-11.8. Upon this line lies the plasticity envelopes for weathered lodgement till (WL2) and silty lodgement till (L2). The mean silt and clay contents for specimens plotting close to the head of the grading arrows (left and right of the envelopes) are shown along the arrow shaft. Silt and

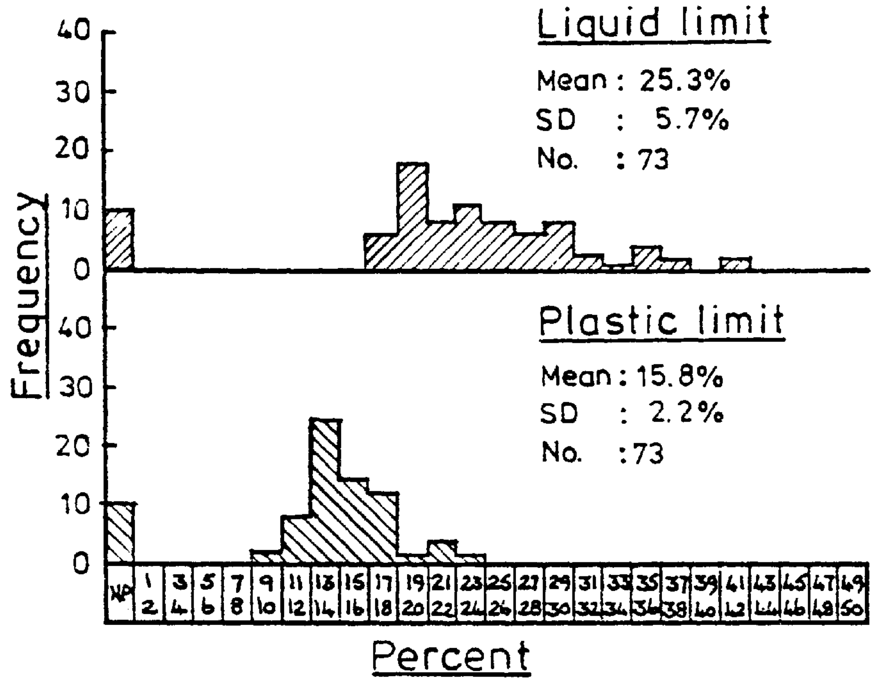


FIGURE 4.7a

LIQUID AND PLASTIC LIMITS : MELT-OUT TILL

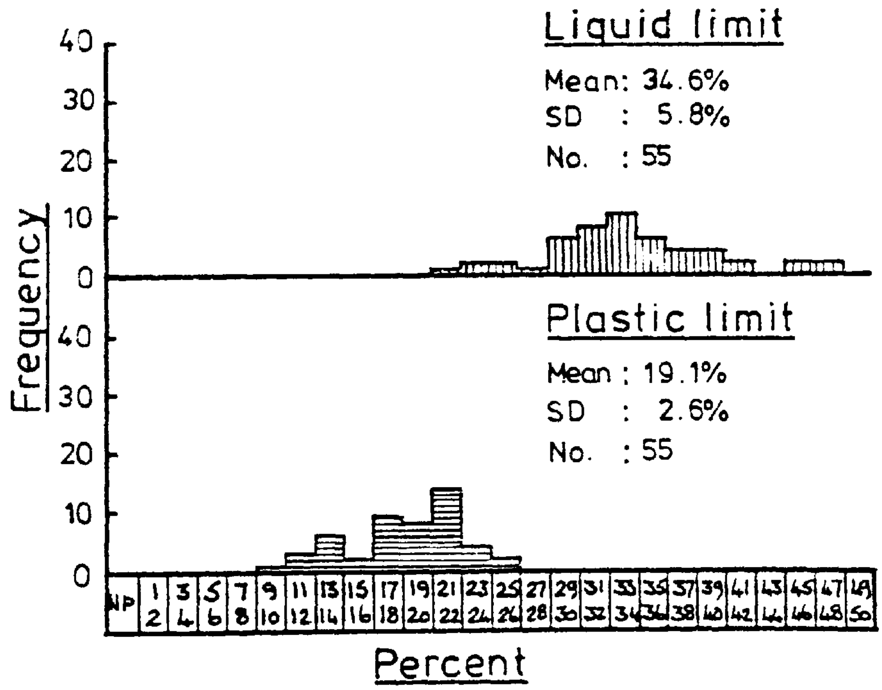
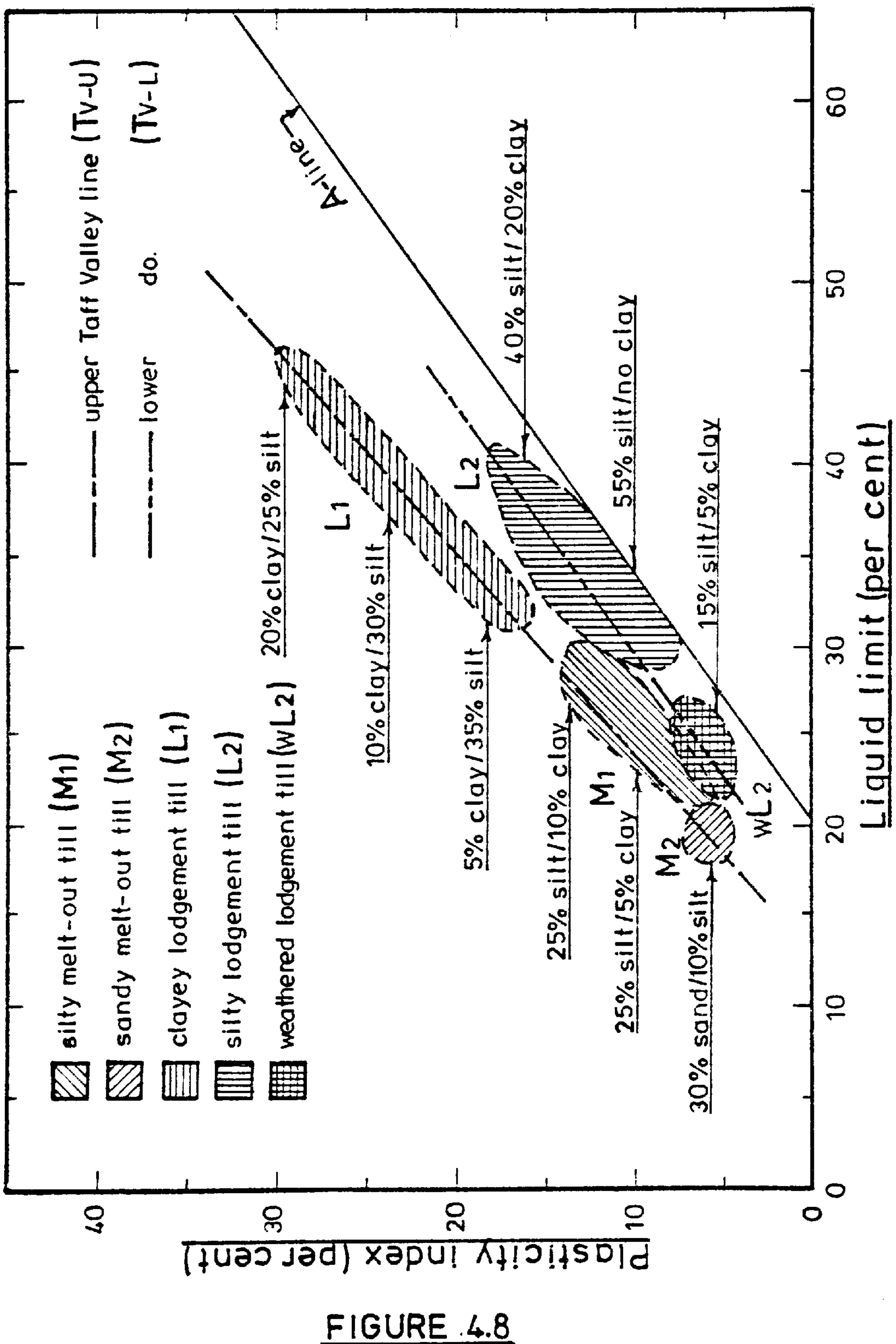


FIGURE 4.7b

LIQUID AND PLASTIC LIMITS: LODGEMENT TILL



<u>FIGURE 4.8</u>

THE PLASTICITY CHARACTERISTICS OF TILLS IN THE TAFF VALLEY clay contents within the till of envelope WL2 are lower than for the majority of envelope L2, probably as a consequence of weathering and the flushing out of fines by groundwater flow. This has consequently boosted the relative percentage of coarse silt and fine sand included such that the zone falls low in the CL range (clay of low plasticity), close to the A-line. In envelope L2 the lodgement till contains high silt contents of between 40 and 55 per cent, however, between liquid limits of 31 and 38 per cent some specimens lie close to or on the A-line. Grading curves for many of these specimens show a zero clay content at this well defined interface between clays and silts of low to medium plasticity. Further up the TV-L line, within the confines of envelope L2, clay contents increase to greater than 20 per cent, drawing the envelope boundary upwards away from the A-line, well into the CI range.

The upper TV-U line diverges upwards away from the TV-L and A lines, running from co-ordinates (16,2.5) to (50,34). The equation representing the slope of the line is PI = 0.9 (LL) - 11.8. Three envelopes, M1, M2 and L1 have been differentiated along the line, for melt-out and lodgement tills respectively. Envelope M2, sandy melt-out till, lies at the lowermost end of line TV-U, approaching the zone of cohesionless sands. The grading characteristics of the soils in this envelope relate closely to the plasticity chart categorisation in that the soil is composed of approximately 30 per cent sand (of particle diameter less than 425 microns), with 10 per cent silt sized material present. The latter provides the specimen with some degree of plasticity for the determination of its plasticity characteristics.

The specimens in envelope M1, silty melt-out till, have a range of plasticity characteristics from similar to the specimens in envelopes M2 and WL2 (but clearly lying in the CL range) to specimens at the other end of the envelope bordering onto clays of medium plasticity in their characteristics. The low clay contents obtained for samples in the envelope (5 to 10 per cent as shown in the figure) may thus be seen to play an important role in determining the behaviour of the fine fraction of what is essentially a silt rich soil. Specimens lying in the zone of overlap between envelopes M1 and WL2 have been differentiated by field observations of in situ textural properties and by the study of undisturbed samples under the scanning electron microscope, (see sections 3.3.1 and 3.3.2).

A surprisingly systematic variability of silt and clay contents for specimens contained in envelope L1 (clayey lodgement till) has been observed. The mean silt and clay contents of individual samples contained within three divisions of the envelope have shown a progressive, gradational range. Low clay and high silt contents are recorded at the lower end of the envelope whilst approximately equal silt and clay contents are present in the soils at the upper end. The clay content increases at a faster rate than the silt content decreases. As a consequence of this characteristic the TV-U line is pulled more steadily away from the A-line such that the specimens of highest clay content lie close to the CI/CH boundary, deepest into the clay range of the plasticity chart. The specimens of till within this envelope are those that have been found to lie at the greatest depth at sampling locations. This suggests that the high clay contents may reflect an increased abundance of the results of subglacial bedrock attrition in the argillaceous areas of the valley, accompanied by the lowest degree of flushing out of fines by any possible groundwater seepage in such potentially impermeable deposits.

4.4.3.3 Relationships between plasticity and grading characteristics

Consistency limit data for the tills and colluvium sampled at one principle site near Nantgarw have been compared with the bivariate grading characteristics of the soils, as shown in Figure 4.9. Soil types with similar consistency limits are grouped according to Figure 4.5, for example the clast and matrix-dominant lodgement tills with essentially similar plasticity characteristics for the finer fraction lie in the upper left and right hand quadrants of the figure. Zones of consistency limit ranges are delineated using a contouring system. The tentative position of some contours lacking sufficiently specific data points is labelled with question marks.

A non-plastic zone lies in the lower right hand portion of the figure. Within this area lie the fine fractions of head, fluvioglacial and glacilacustrine deposits with a large mean particle size. They have a greater degree of sorting than the other soil types sampled and contain a sufficiently high proportion of sand to be rendered unworkable for the determination of plastic limits and hence plasticity characteristics.

It became impracticable to undertake this complete exercise for other sites within the valley. Insufficiently comprehensive site investigation and laboratory testing at other sites has resulted in problems with the correlation of plasticity characteristics with grading curves for individual samples.

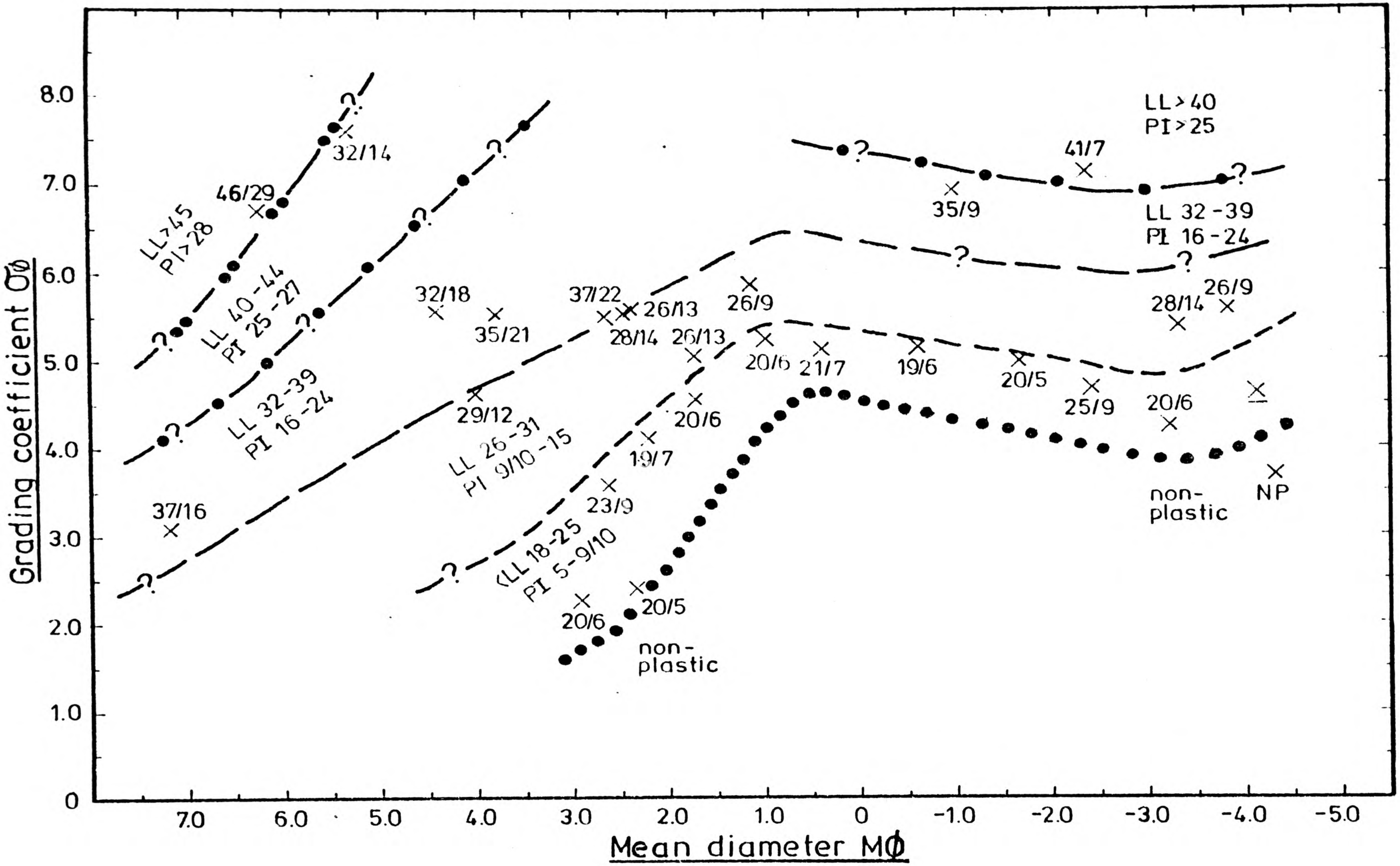


FIGURE 4.9

CORRELATION BETWEEN INDEX PROPERTIES AND GRADING CHARACTERISTICS FOR MELT-OUT AND LODGEMENT TILLS IN THE TAFF VALLEY

4.5 Soil Profiling as Allied to the Study of Geotechnical Properties

As a further experiment in the analysis of data a typical series of results subjectively chosen from one principle site with an abundance of soil test results (at Nantgarw), were taken and plotted against depth as shown in Figure 4.10. Relationships were drawn between the properties determined and a genetic classification of the soils sampled; these are shown in the figure. The effective stress shear parameters of the soils have been included for comparison, however this data is analysed and discussed in greater depth in the following chapter.

A distinct pattern emerges down through the profile :-

1. The uppermost strata, the head deposits and colluvium (typically 1 to 1.5m thick), are the most susceptable to fluctuations in moisture content. The influence of a long period of heavy rain prior to sampling is shown by the high moisture contents obtained, typically greater than 16 per cent. A high proportion of the data for index properties and bulk density are non-plastic and loosely compacted (approximately equal to 2.15 Mg/m^3), respectively.

2. The uppermost layers beneath the head deposits at 1.5m below ground level (fluvioglacial sands and gravel) are depleted in fines in comparison with the soil at greater depth. The coarser grading therefore provides a low moisture content, typically 6 to 8 per cent; daily moisture content fluctations become negligible beneath the head deposits. Values for the index properties in this zone are extremely low, as shown, with many of the samples being non-plastic. The coarse grading of soil results in a large

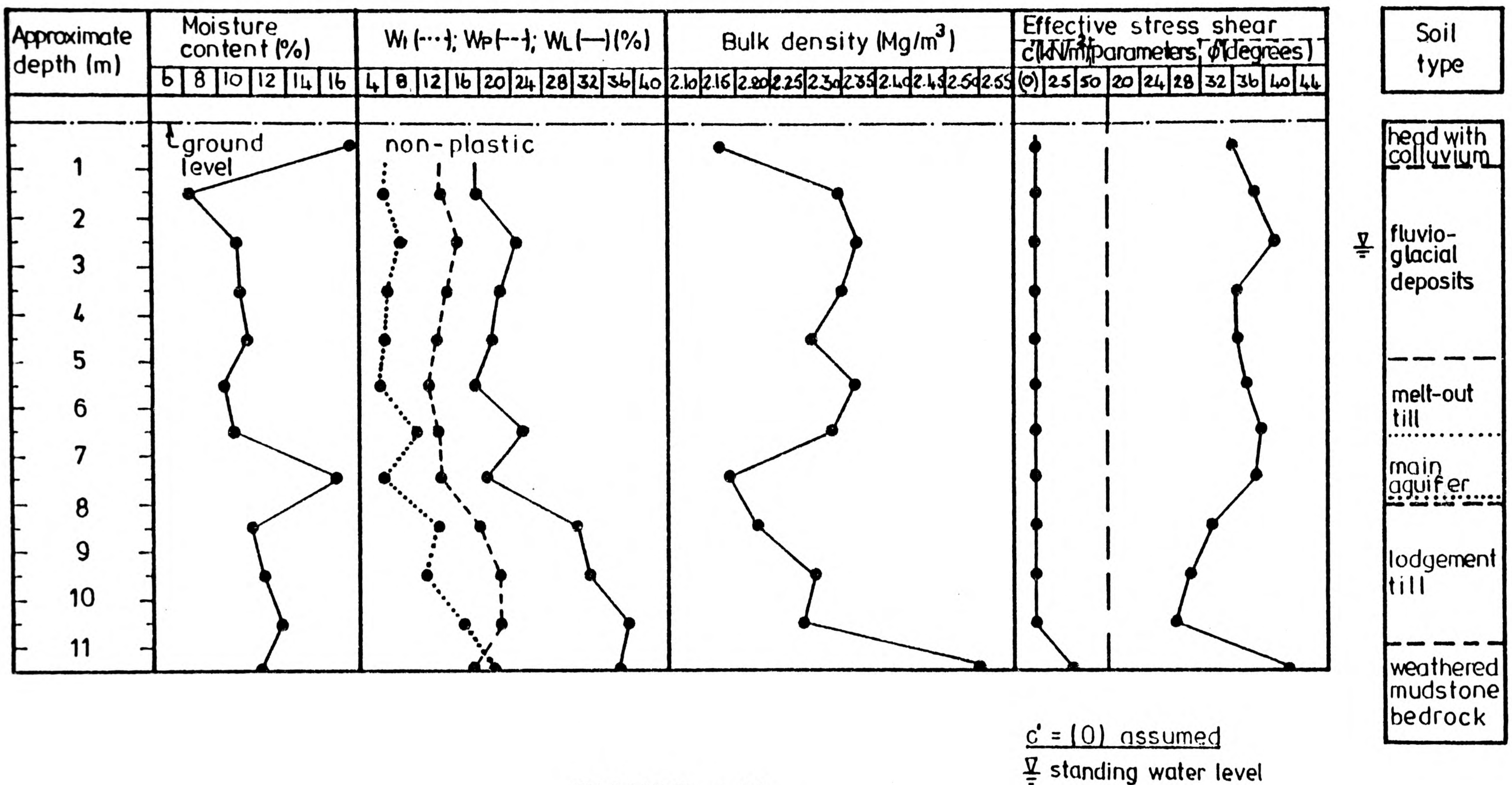


FIGURE 4.10

GRAPHIC REPRESENTATION OF TYPICAL CHANGES IN SOIL PROPERTIES WITH DEPTH : TAFF VALLEY increase in bulk density, usually to 2.30 - 2.35 Mg/m^3, as the head/fluvioglacial deposits interface is exceeded. To a depth of 2.5 to 3 metres moisture contents, plasticity characteristics, and bulk density progressively increase. The plasticity characteristics and bulk densities reach a peak at approximately this depth, where the deposits are most well graded with high silt and gravel contents, providing a basis for the peak values recorded. The higher fines fraction in this zone corresponds with the approximate limit of weathered soil, as frequently observed in trial pits and exposures. Clay minerals are probably present as weathering products - accumulated at this depth by downward leaching - to increase the plasticity characteristics.

3. At approximately 4 - 5 metres melt-out till is reached. The soil properties vary over short distances, probably due to localised heterogeneity throughout the till. This is a characteristic of the variable modes of genesis and deposition involved in its accumulation.

4. At a depth of between 7 and 8 metres, an abrupt change in soil properties is widely recorded. The soil moisture content rapidly increases to an average of 15 to 16 per cent (almost identical to surface values), whilst the plasticity characteristics and bulk density drop in magnitude, the former to their lowest workable states. Borehole and piezometric data suggest that this zone is the main aquifer within the superficial cover, present as a sandy till overlying a thickness of almost impermeable lodgement till. Groundwater flow within this zone, probably from a source at the ground surface, produces the increased moisture contents and

flushes out the fines present at this level. The consequence is a reduction in the plasticity characteristics - except for plastic limit which appears to be less susceptable to change - and the introduction of an openwork texture with a subsequent reduction in the soil bulk density to 2.10-2.15Mg/m^3.

5. The lowermost stratum of the soil succession observed is the lodgement till. The profile of soil properties within this unit exhibits strong differences with the overlying deposits. The higher silt and clay contents determined are reflected in the increased moisture contents observed (11 to 13 per cent), and greater values for index properties than were obtained for the melt-out till. The bulk density steadily increases with depth away from the low values for the main aquifer, reaching a maximum of approximately 2.30 Mg/m^3 close to rockhead. This maximum obtained at the greatest depth in the profile, would appear to reflect the highest degree of overconsolidation achieved for the subglacially deposited till. The typical abundance of high gravel and cobble contents in the lowermost metre of lodgement till (deformed mudstone bedrock at this site) would have the effect of further increasing the bulk density of the soil.

6. The properties of the underlying bedrock differ markedly from those of the overlying soils, as is to be expected. Description of the mechanical characteristics of the material is however beyond the scope of this study.

4.6 Summary of the Conclusions

The analysis of data relating to the grading characteristics and index properties of glacial and post glacial deposits has highlighted major differences between soils of differing genetic modes.

1. Recognisable differences have been shown to exist between the grading characteristics (grading curves, central tendency and grading coefficient) of each of the seven main soil types sampled. The data has been plotted in two main forms :-

    1. employing the bivariate scattergram method

    2. using grading curves and envelopes to emphasise these differences.

    Sub-types within the tills have been delineated using these methods, textural descriptions of the soils in situ and upon the basis of degree of clast dominance with its effect upon the mean particle size.

    Relationships were also drawn between the bivariate grading characteristics and the index properties of the soils of differing types. It would be of interest to compare the results of this systematic approach with those obtained at other major sites, both within and outside the Taff Valley.

2. Distinct ranges of index and mechanical properties have also been shown to be apparent within soils deposited in genetically different environments. These ranges are principally a

consequence of the grading characteristics of the materials and the stress history through which the soils have passed.

The stratigraphic position of the soils in the depositional sequence, accompanied by post-depositional processes of modification, for example weathering and flow of groundwater, have been shown to strongly influence the mechanical properties exhibited and the potential behavioural characteristics.

FIVE

CHAPTER 5

SHEAR STRENGTH CHARACTERISTICS OF TILLS AND ASSOCIATED DEPOSITS

5.0 Introduction

The geotechnical characteristics of the more granular lodgement and melt-out tills deposited towards the margins of continental glaciation, for example those of South Wales, has been little investigated. By contrast the matrix-dominant, stiff, fissured tills of the north of England and central Scotland have been widely studied. In this area McKinlay, Tomlinson and Anderson (1974) and Marsland (1977) have investigated the undrained strength and the deformation characteristics of tills with clay contents of 20 to 65 per cent. Triaxial tests were performed on specimens of 38 and 100mm diameter together with in situ tests using 190mm and 865mm diameter loaded plates.

In the discussion of the boring and sampling procedure in unweathered lodgement till, McKinlay et al found that sample recovery was poor and that the degree of specimen disturbance was difficult to reduce to acceptable levels. Thin wall (38mm diameter) samplers were found to be completely unsuitable for the cobbly soil, whilst U100 samplers frequently did not yield the required pair of samples for comparative testing in the laboratory.

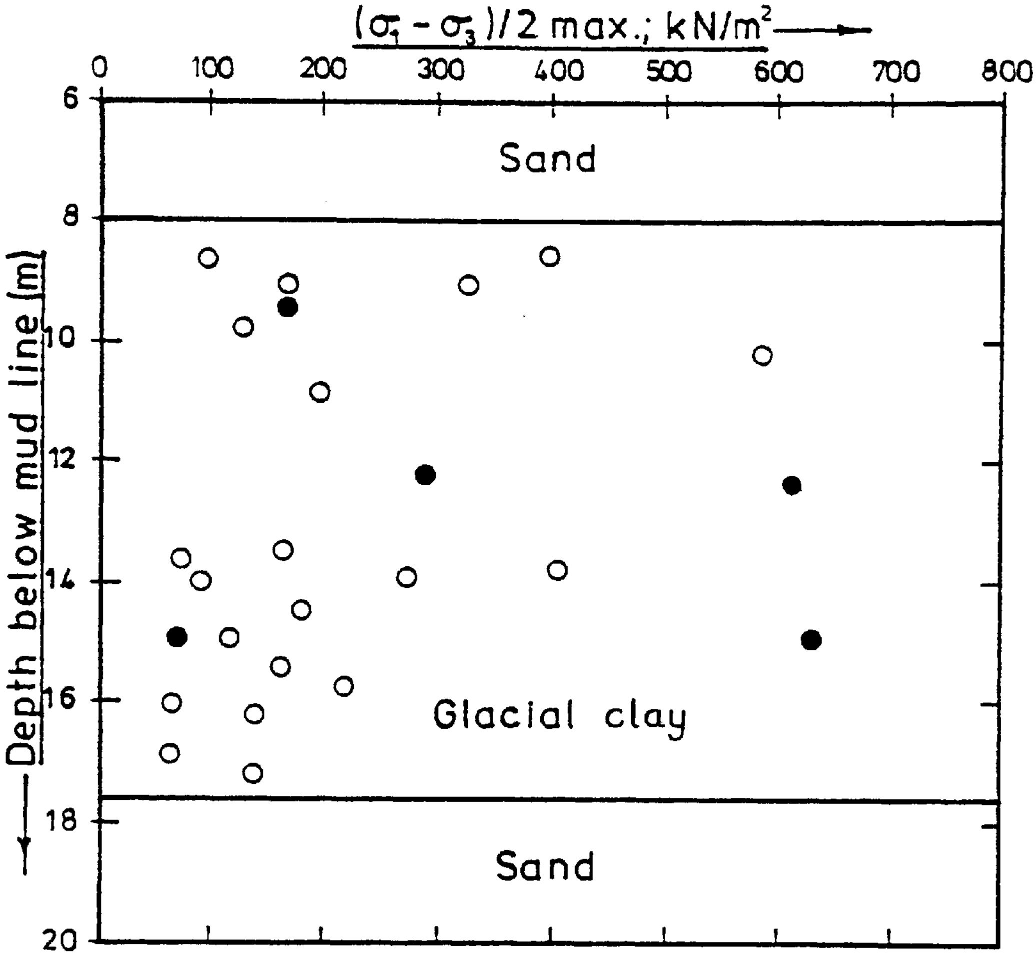
They further discuss the effect of prolonged storage of specimens, (using standard wax sealing and capping), prior to testing. A storage period of eight weeks gave only a marginally greater increase in strength (as a consequence of slight dessication) than obtained for fresh specimens.

Whilst discussing undrained shear strength results, both groups of workers comment that strengths measured in till at any one site vary appreciably. These were especially over-estimated when a standard pressuremeter was used. Marsland illustrates the basic problem with data obtained during a recent investigation for a drilling platform in the North Sea, as shown in Figure 5.1. A six-fold variation in strength was found for 54 and 71mm diameter specimens obtained from a 9 metre thickness of stiff, matrix-dominant till.

In order to understand the wide variations observed in Figure 5.1 it is necessary to know both the effective stress conditions during testing and to have details of the soil composition and texture. A reasonable assessment of the overall parameters for design purposes can then be made. Marsland therefore recommends that :-

(i) Shear tests should be undertaken at a rate of strain that is sufficiently slow to allow reasonable equalization of porewater pressures to occur within the specimen.

(ii) The number of tests should be sufficient to determine the strength characteristics of the main fractions of the soil that are likely to affect the overall behaviour of the soil mass.



Key:

- ● quick undrained tests; no consolidation; time to failure 30 - 45 mins.
- ○ slow undrained tests with pore pressure measurements; time to failure 6 - 9 hours

FIGURE 5.1

UNDRAINED SHEAR STRENGTH DETERMINED FROM TRIAXIAL TESTS FOR NORTH SEA PROFILING (after MARSLAND, 1977)

(iii) A detailed examination and description of both tested and untested specimens is an essential requirement in the grouping of like soils. This can provide considerable insight into the reasons for the variations in parameters determined by both laboratory and in situ testing.

In the investigation of the shear strength parameters of glacigenic and associated soil types of the Taff Valley, as with other methods of soil testing undertaken, detailed attention was paid to the method of collection of samples, their preparation prior to testing and also the method of testing. This ensured that the data collected was representative of the soils in situ. The degree of field exposure of individual soil types dictated the number of specimens tested, and hence the volume of data analysed fluctuated accordingly. For example, there is limited exposure of flow and lodgement tills whilst the shear strength parameters of melt-out till, fluvioglacial and head deposits were more readily determined as a consequence of their greater exposure. It was therefore possible to make a quantitative assessment of the degree of variation in properties between individual soil specimens and types.

Soil sampling procedures, as discussed in section 4.1, were analysed to determine the most suitable method to be used for the soils of the valley. The mass of soil sample collected directly depended upon the predominance of individual particle fractions and the size of clasts present. The size and frequency of clasts also affected sample preparation and the type and size of testing apparatus used. The latter was adjusted according to the clast characteristics so that the data obtained could be considered to be a reliable determination of the shear strength parameters of the total soil mass.

Fissuring of the mesostructure was negligible and did not present problems during sampling. Consequently it is considered that anisotropy of the soil structure and any effect on strength under test, as induced by fissuring, was similarly non-existant. Specimens under test were sheared at a rate of strain that was calculated from the rate of consolidation to be sufficiently slow that porewater pressures were allowed to equalize.

Laboratory test data was supplemented by results of triaxial consolidated drained tests, undrained tests with pore pressure measurement and consolidated drained shear box tests performed on disturbed and undisturbed soil specimens. This data was obtained from site investigation schemes within the valley. It was accompanied by borehole and laboratory descriptions which were used to differentiate the soils into head deposits, melt-out and lodgement tills. This was used to supplement data obtained in the research testing program. The quantitative analysis of soil data employed standard statistical methods to determine estimates of mean effective shear strength parameters (c' and ϕ') of samples, accompanied by upper and lower data limits. This has provided an indication of the degree of scatter of results and hence allowed determination of the relative variability within and between soil types as a whole. Conclusions concerning the degree of soil data variability are drawn with regard to in situ textural heterogeneity.

5.1 Sampling Procedure

The texture of all glacigenic and associated soil types in the Taff Valley is invariably granular. This made undisturbed sampling on a large enough scale for shear strength determination, virtually impossible. More than 95 per cent of all soils sampled had clast contents in excess of 40 per cent. This includes lodgement till which has been widely reported (and has been observed in other areas of Britain) to be typically matrix-dominant. The granular nature of the deposits observed in the Taff Valley completely eliminated the collection of undisturbed block samples for the $0.1m^2$ shear box and the use of driven tubes for undisturbed sampling.

All material, where accessibility of exposure and soil texture allowed, was excavated and removed in a state where sample disturbance was kept to a minimum. In cohesive soils, samples were extracted as intact units, however, the degree of soil disturbance became a function of textural variability. Patches of sand in melt-out till, accompanied by clast dominance, in many cases caused specimen disintegration by acting as predetermined zones of weakness.

5.2 Sample Storage

5.2.1 Preparation prior to storage

As samples were removed from the trial pit or exposure face they were placed in clean, dry storage containers with the minimum of disturbance and were then double sealed in polythene bags. To minimise moisture loss from the sample the inner bag was especially selected so that it fitted tightly around the storage containers. This was then double sealed by polythene coated wire ties knotted either side of a twist and a knot in the neck of the polythene bag. A second larger bag was similarly tied following the inducement of a partial vacuum between inner and outer polythene layers.

5.2.2 Storage conditions

Short duration storage areas were chosen within the laboratory where temperatures were lower than standard room temperature and where diurnal fluctuations could be kept to a minimum. Storage in these areas reduced the level of moisture lost from the samples; this was noted to condense on the inside of the inner sealed polythene bag in a situation of recorded temperature fluctuation.

5.2.3 Storage time

McKinlay, Tomlinson and Anderson (1974) recommend that samples should not be stored prior to testing for periods in excess of eight weeks. During the research program the storage duration was kept to within a maximum of six weeks. Whenever exposure availability and weather conditions dictated samples were collected almost immediately prior to testing so that moisture losses became negligible.

5.3 Sample Preparation

5.3.1 Specimens for the 3600mm^2 shear box

5.3.1.1 Intact specimens

For all soils sampled a limiting clast size of 10mm along the major axis and a 2:1 relationship of major to minor axes, was used. These sizes were deemed to be the maximum that could reasonably be accommodated within a 3600mm^2 shear box, provided that the sample was taken parallel to any noticable prefered clast orientation. Areas within the lodgement and melt-out tills sampled where matrix predominated, were frequently found to be of suitable size for testing in an undisturbed state within the 3600mm^2 shear box. The results obtained would, however, not have been representative of the shear strength of the total soil mass for which the clasts play an important role. The testing of this portion alone was not therefore pursued.

5.3.1.2 Fractioned specimens

When individual soil specimens were fractioned to determine the shear strength characteristics of portions of the total sample (section 5.6) the limiting maximum size of clast for use in the 3600mm^2 shear box was enforced. In splitting samples either side of the gap in the particle size distribution curve (this coincided with the 425 micron size), the limiting size criterion became ineffective.

5.3.2 Specimens for the $0.1m^2$ shear box

In determination of the shear strength parameters of the total soil mass of melt-out and lodgement tills and fluvioglacial deposits, the presence of clasts in excess of cobble size necessitated the use of $0.1m^2$ shear box.

Inaccessibility of exposures, typically with vertical and near vertical faces, made it impossible to extract undisturbed block samples of till in excess of $0.1m^2$. Specimens were cut with care, however, where edge breakages occurred, voids were filled with disturbed material from the same specimen location. Undersized specimens were placed in a $0.1m^2$ shear box with as little sample disturbance as possible and packed such that the presence of air voids was kept to an absolute minimum. Where the presence of voids necessitated excess packing, disturbed material was compacted to a bulk density as close as possible to that determined for the 'undisturbed' blocks. In preparation of the fluvioglacial sands and gravels disturbed samples were placed in the shear box so that clast long axes were approximately horizontal. This simulated the in situ conditions where the lowest shear strength tends to be parallel to clast orientation in these anisotropic materials. Care was taken to avoid segregation of sand from the clasts.

5.4 Testing Apparatus and Monitoring System

As discussed above, two main sizes of standard constant rate of strain shear box apparatus were used depending upon the size of clasts present within individual soil specimens. These were the $3600mm^2$ and $0.1m^2$ boxes. A third box of $0.01m^2$ was used for determining the shear strength parameters of fractional constituents of fluvioglacial material of clast size 5.0mm to 14.0mm.

The samples were relatively free draining, therefore consolidated drained tests were undertaken. Under test the vertical and horizontal loads in strains were monitored by virtually infinite resolution displacement transducers. At intervals these were used in conjunction with dial gauges as a cross reference. Displacements recorded by the rectilinear potentiometers were automatically monitored at specified time intervals and data translated by a Mycalex data logging system.

5.5 Methods of Testing

A standard procedure of testing under consolidated drained conditions was followed for each specimen of lodgement and melt-out till and fluvioglacial material tested in order to determine the effective shear strength parameters. The samples were consolidated and the coefficient of consolidation was determined according to the method described in BS 1377:1975 and by Bishop and Henkel (1951), and modified for the shear box.

The consolidation data, (values of t_{90}), accompanied by initial height of sample (H_0) and new height (H_1), were used to estimate the rate of strain required to shear the sample without the build-up of pore pressure. This rate was determined as follows :-

(i) Average length of drainage path, $\bar{H}^2 = \dfrac{H_0 + H_1}{2}$ mm

then,

(ii) Coefficient of consolidation, $C_v = \dfrac{0.111\ \bar{H}^2}{t_{90}}$ mm/minute

and

(iii) Time to sample failure, $tf = \dfrac{H^2}{\eta\ Cv\ 0.05}$ minutes

where,

H_0 is in mm,

H_1 is in mm,

H = Half height of the sample

η = 3.0 (for drainage at both ends of sample)

The rates of strain employed are shown in Table 5.1.

5.6 Critical Analysis of Data

Two main approaches to the analysis of data have been adopted :-

(i) The determination of mean, upper boundary and lower boundary effective shear strength parameters of lodgement and melt- out tills

SOIL TYPE	SIZE FRACTION	SHEAR BOX SIZE	RATE OF STRAIN (mm/min.)	TIME ELAPSED UNTIL FAILURE (MINUTES)
MELT-OUT TILL AND FLOW TILL*	total soil mass *	$0.1m^2$	0.045 - 0.083	360 - 660
	<425 μm	$3600mm^2$	0.024 - 0.0073	360 - 1140
	>425 μm	$0.1m^2$	0.50	60 minutes allowed
WEATHERED LODGEMENT TILL	total soil mass	$0.1m^2$	0.017 - 0.063	480 - 1680
	<425 μm	$3600mm^2$	0.012 - 0.0033	660 - 2520
	>425 μm	$0.1m^2$	0.50	60 minutes allowed
FLUVIOGLACIAL MATERIAL	total soil mass	$0.1m^2$	1.00	30 minutes allowed
	cumulative and fractioned masses	$3600mm^2$ $0.01m^2$ $0.1m^2$	0.24 - 1.00	30 minutes allowed

TABLE 5.1

RATES OF STRAIN EMPLOYED IN TESTING TILL AND FLUVIOGLACIAL MATERIAL UNDER DRAINED CONDITIONS in the Taff Valley. This included the mean parameters for the few specimens of head deposits tested.

(ii) An investigation of the effect of relative dominance of certain soil fractions upon the shear strength of the total soil mass sampled.

5.6.1 The effective shear strength parameters of glacigenic and head deposits

Site investigations undertaken in the Taff Valley in association with highway schemes and spoil tip stability have provided laboratory test data to supplement that obtained by the candidate as part of the research programme.

Work documented by Boulton, Fookes, Goldthwaite and McGown opp cit, has shown that site investigation in glacial materials is interdisciplinary with regard to the techniques employed. These range from geomorphological to geological and engineering methods. Their work describes modes of till genesis, the typical soil types produced in glacial and periglacial environments, and the ranges of soil properties that are to be expected. They also provide suggested methods of soil description. This information appears to have been used to aid the interpretation of modes of soil genesis and enrich the description of soil conditions in site investigation reports dated later than 1974/75. These reports were therefore found to be much more comprehensive than reports produced prior to 1974 and hence were of more relevance with regard to use in this research investigation.

In reports produced before 1974 genetic classification of till by the author, has, in particular, been aided by interpretation of the particle size distribution curves and range of index properties exhibited. Use of geotechnical data has also enabled corroboration of data and soil classification in later reports with that undertaken in a more detailed manner upon soil types documented by the candidate. It has also allowed comparisons to be drawn between soil texture and shear strength.

The effective shear strength parameters of each soil type have, where possible, been related to the effect of degree of clast dominance upon the overall strength of the soil mass. Estimation of the relative degree of clast dominance has been based upon qualitative soil textural descriptions and comparison of particle size distribution curves with Fuller's grading curve of maximum particle packing density, (Figure 5.2).

5.6.1.1 Shear strength parameters of lodgement till

Interpretation of strength data for lodgement till has been related to soil texture variability. Test data has shown effective cohesion (c') to be zero whereas values in the region of 30 to 50 kN/m^2 would have been expected for these typically overconsolidated tills. This may be due to sample disturbance, however, shear fabrics have been recorded in borehole data for lodgement till at Nantgarw and Abercynon spoil tips, whilst slump fabrics with clast reorientation downslope have been noted near Troedyrhiw. The presence of these features suggests that the till has undergone post-depositional movement associated in the former case with being overridden by

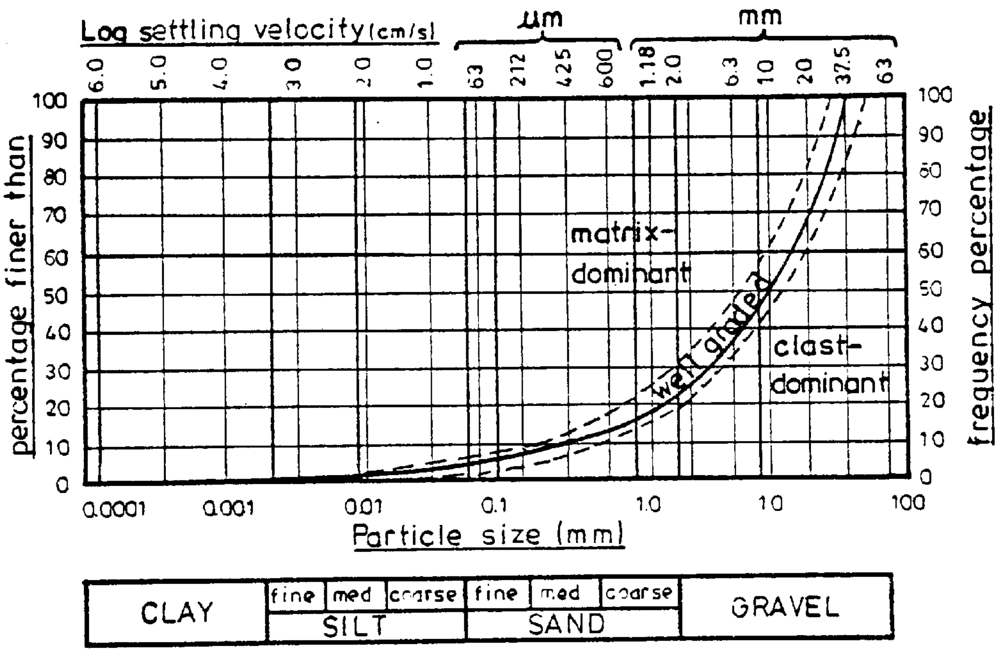


FIGURE 5.2

FULLER'S CURVE OF MAXIMUM PARTICLE DENSITY
FOR GRANULAR MATERIAL

glacial ice, and in the latter, with slope instability subsequent to lodgement on oversteepened valley sides. Disturbance of both till meso and microstructures by movement is likely to have resulted in disruption of the originally overconsolidated depositional state, remoulding the soil and reducing the effective cohesion to zero. The latter would reflect the residual strength of the soil mass.

In Figure 5.3 the effective stress envelopes shown have been produced to pass through the origin at zero cohesion. The upper and lower boundaries for lodgement till have been drawn at $\phi' = 31^{\circ}$ and $c' = \text{zero}$, $\phi' = 23^{\circ}$ respectively. The upper boundary is tentatively drawn since some overlap of textural descriptions and soil properties occur where well graded to clast-dominant lodgement tills become difficult to distinguish from melt-out till. This is particularly apparent where matrix is abundant in the latter.

Some samples of lodgement till, for example those discussed in section 5.6.2, lie above the upper boundary, probably as a consequence of their highly weathered state. Here the removal and downward flushing of fines has resulted in a residual, mostly clast-dominant soil mix in which the soil strength is mainly due to clast contact. Any remaining matrix plays a negligible role.

The lower boundary has been determined for a small number of samples of lodgement till in which the matrix predominates over the essentially mudstone clasts. In this instance the effective shear strength parameters are a characteristic of the strength of the matrix alone; the clasts behave as 'plums in a pudding', very seldom lying in contact with one another. The particle size distribution curves lie to the left of Fuller's curve of maximum particle packing density,

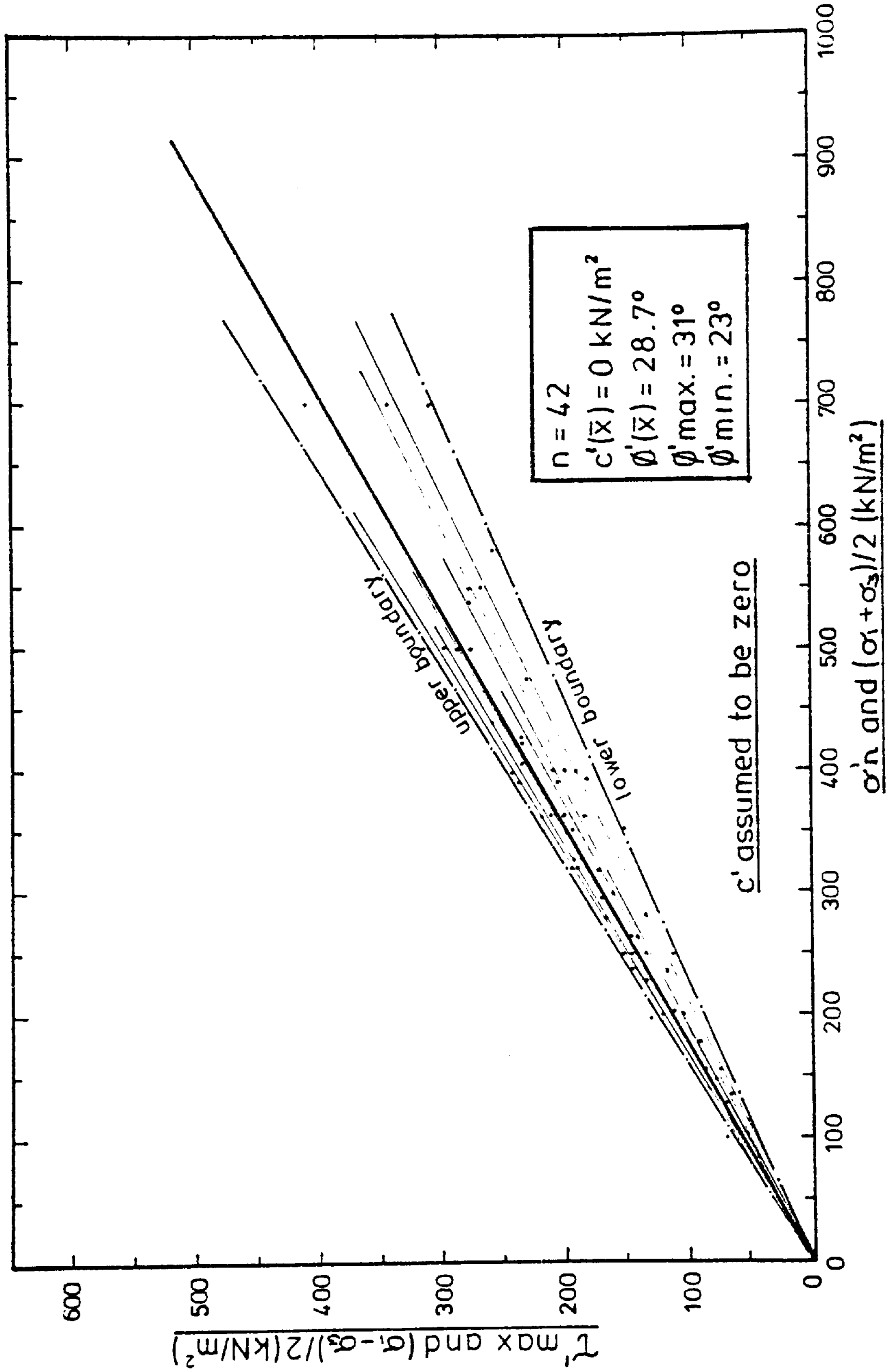


FIGURE 5.3

SHEAR STRENGTH PARAMETERS OF LODGEMENT TILL IN THE TAFF VALLEY

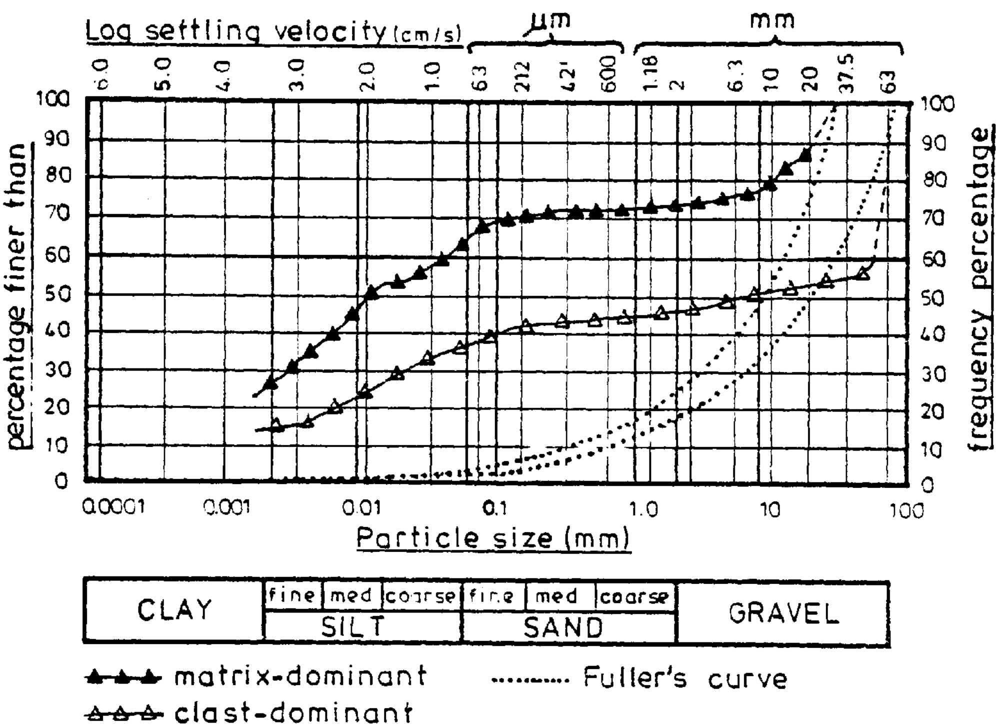
(Figure 5.4).

The mean effective shear strength parameters for lodgement till in the Taff Valley are $c' = \text{zero}, \phi' = 28.7^\circ$. This shows that a majority of the samples tested had shear strength parameters approaching the upper boundary. They tend to be well graded to clast-dominant with the clasts having the most predominant influence on soil strength. In these specimens the clasts of coarser than medium gravel size constitute up to 45 per cent of the soil mass by weight. This coarse fraction lies to the right of Fuller's curve in the zone of clast dominance whilst the matrix less than medium gravel size lies to the left.

5.6.1.2 Shear strength parameters of melt-out till and head deposits

As with the discussion concerning the absence of cohesion in lodgement till in the above section, mesofabric evidence for melt-out till and particularly head deposits suggests that these have undergone some transportation, post-depositional in the case of the former. This subsequently suggests that effective cohesion (c') may similarly be assumed to be reduced to zero.

The upper effective stress boundary for lodgement till, (c' = zero, $\phi' = 31^\circ$) has here been used as the lower limit for melt-out till and thus the boundary between melt-out and lodgement tills, as shown in Figure 5.5. The boundary has been drawn on the basis of field descriptions and electron microscopic study of textural properties, accompanied by interpretation of the plasticity characteristics of the soils. The upper boundary for melt-out till lies at



LODGEMENT TILL

FIGURE 5.4

DEGREE OF CLAST DOMINANCE OF LODGEMENT TILL IN RELATION TO FULLER'S CURVE

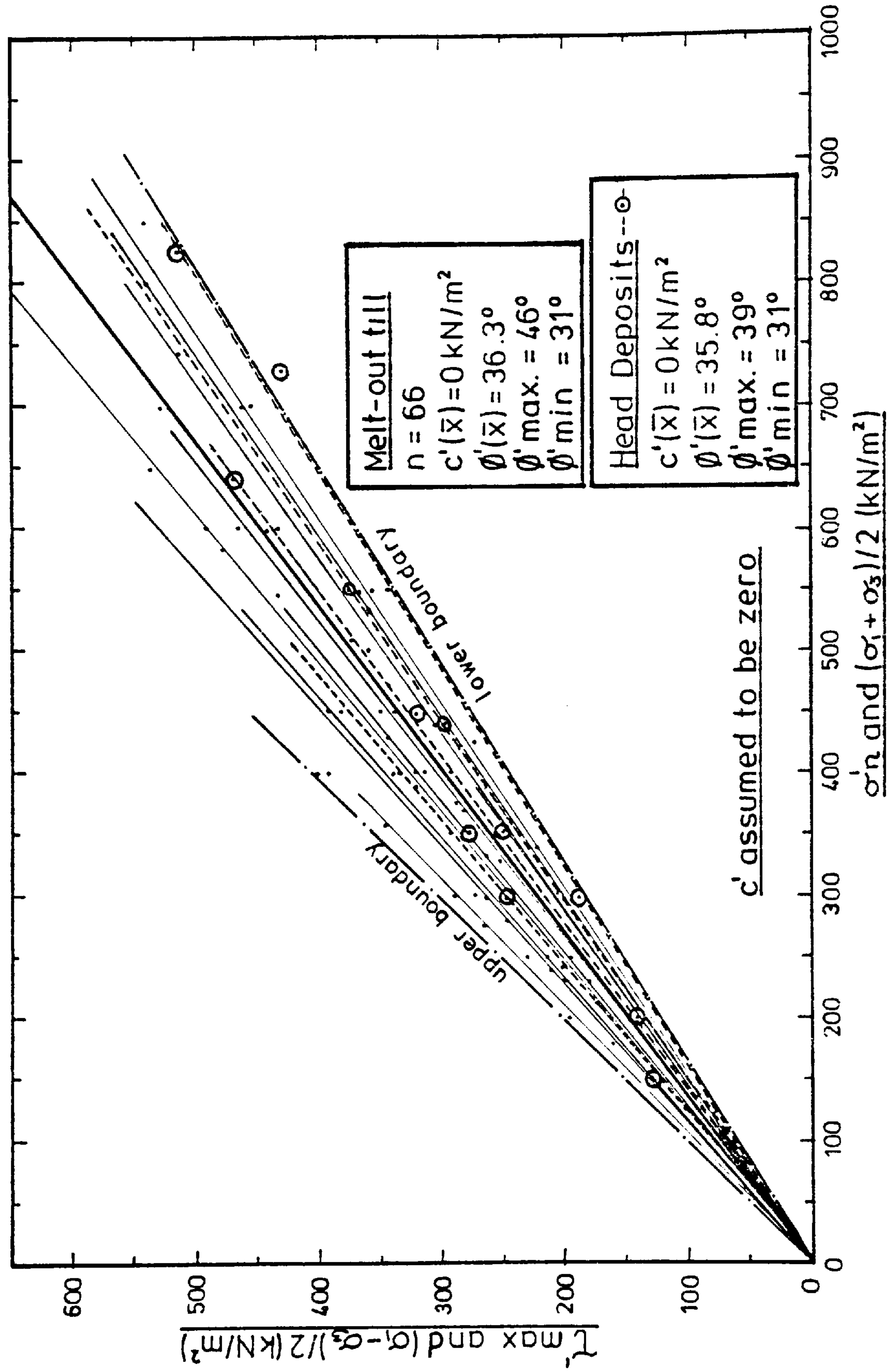


FIGURE 5.5

SHEAR STRENGTH PARAMETERS OF MELT-OUT TILL AND HEAD DEPOSITS

$c' = $ zero, $\phi' = 46^{\circ}$, whilst the mean lies at $c' = $ zero, $\phi' = 36.3^{\circ}$.

A wider range of variability in shear strength than that observed for lodgement till is noted. This is essentially a consequence of :-

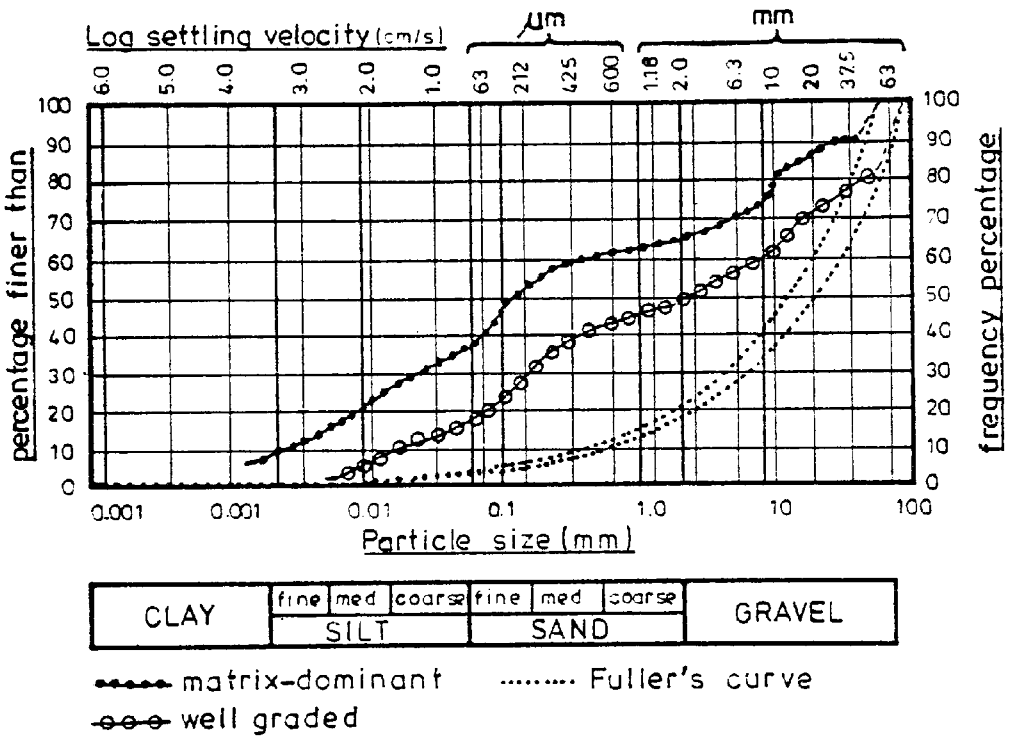
(i) the influence of syn-depositional environmental fluctuations, for example, the amount of water present and the subglacial or supraglacial sources of debris

(ii) the degree of post-depositional textural modification by flow of groundwater resulting in the washing out of fines

(iii) slope instability mechanisms producing shear fabrics.

Interpretation of the effect of clast dominance upon soil strength within the upper and lower boundaries suggests that the presence of sand and gravel sized clasts constituting up to 80 per cent of the soil mass produces shear strength parameters close to the upper boundary. In accordance with Fuller's curve this soil may be classified as being well graded (see Figure 5.6). A well graded melt-out till may thus be seen to have a greater effective angle of internal friction ($\phi' = 40^{\circ} - 46^{\circ}$) than a clast-dominant lodgement till. In the latter a clay sized fraction of in excess of 15 per cent has a significant effect in reducing ϕ' to below 30°, probably to the 'lubricating' action of clay particles at the points of clast contact.

The mean effective shear strength parameters of head deposits ($c' = $zero, ϕ' 35.8°) approximates to that of melt-out till ($c' = $ zero, $\phi' = 36.3^{\circ}$), from which much of the material is genetically derived. The slightly lower values of ϕ' observed for the head deposits is reflected



MELT-OUT TILL

FIGURE 5.6

DEGREE OF CLAST DOMINANCE OF MELT-OUT TILL IN RELATION TO FULLER'S CURVE by the typically lower maximum size of clast (mean diameter = 37.5mm in comparison with a mean maximum size of 63mm for melt-out till) and a greater proportion of clay and silt which has been found to be typically present. Shear strength parameters of head deposits in the region of the upper boundary for melt-out till (as shown in Figure 5.5) have not been observed. This is essentially due to relatively high percentages of sand sized material (frequently greater than 35 per cent by weight) present in these more coarsely graded deposits. This sand fraction tends to dominate the strength of the soil mass as it bridges between individual clasts.

5.6.2 The shear strength profile with depth

A profile of the effective shear strength parameters with depth for a variety of soil types near Nantgarw in the south of the valley is shown in Figure 5.7, (see also Figure 4.10). This data has been obtained from a series of 24 boreholes in the locality and represents the association between lithological heterogeneity and changes in soil properties down through the typical range of soil types exhibited in the valley.

Shear strength data suggests that to depths up to approximately 3.0 metres shear strength increases from $c' =$ zero, $\phi' = 34^{\circ}$ in head deposits to around $c' =$ zero, $\phi' = 40^{\circ}$ in the fluvioglacial deposits. Below this zone, from approximately 3 to 4.5 metres, strength drops to around $c' =$ zero, $\phi' = 34^{\circ}$. The latter may be due to :-

(i) variations in the depositional environment (possibly a reduction in flow of melt-water, reducing clast size and predominance), or

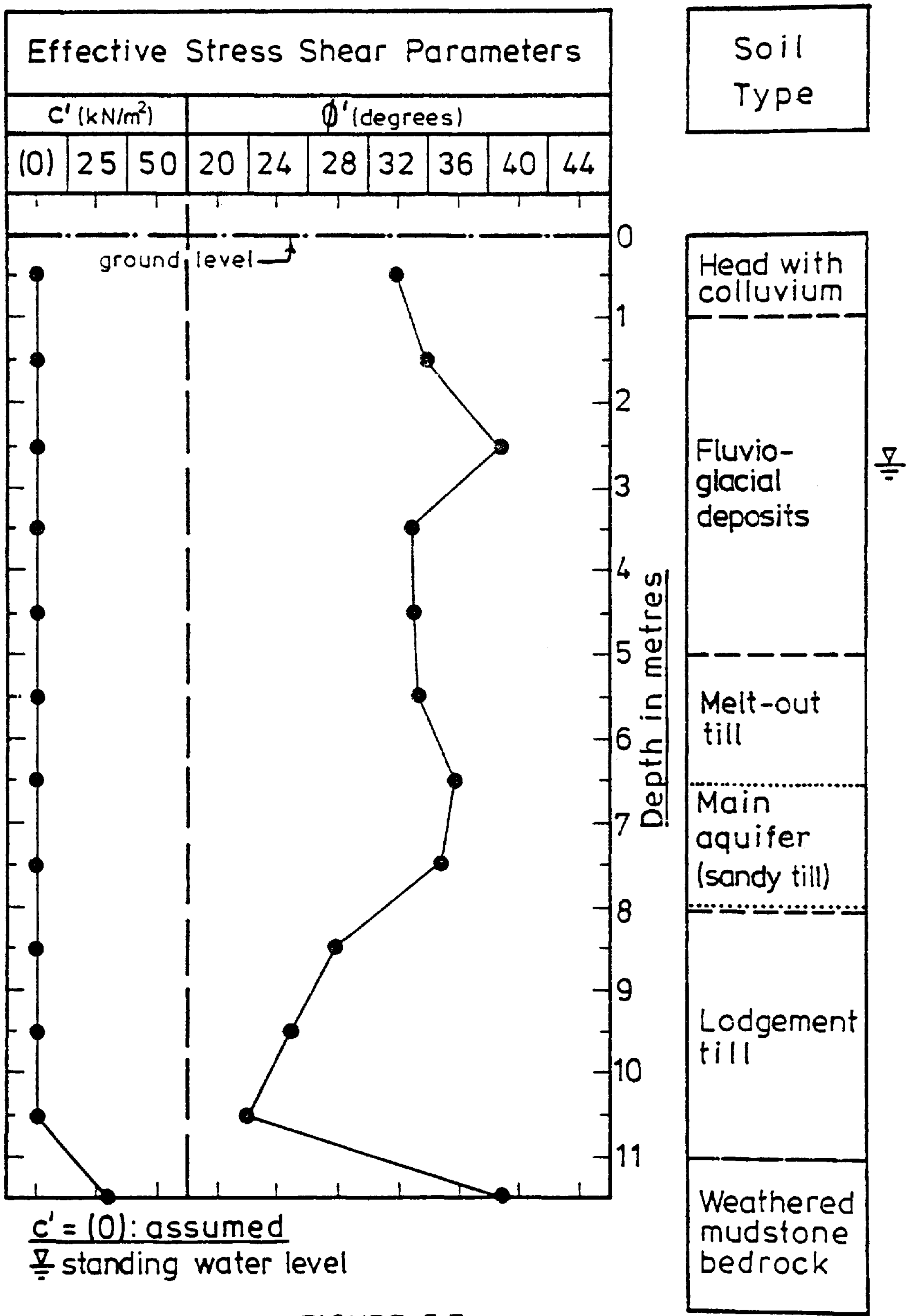


FIGURE 5.7

SHEAR STRENGTH VARIABILITY WITH DEPTH IN GLACIGENIC AND ASSOCIATED SOILS IN THE TAFF VALLEY

(ii) collection of fines flushed out by weathering from overlying head and colluvial soils.

Below approximately 4.5 metres the melt-out till is somewhat constant in mean strength, lying at $c' =$ zero, $\phi' = 34\text{–}36°$. At depths of between 6.0 and 8.0 metres the downslope flow of groundwater is concentrated where the relatively impermeable boundary of underlying lodgement till is approached. Field studies have shown that this zone is severely depleted in fines (producing an openwork microstructure) due to flushing out by groundwater flow; this then becomes the main aquifer through the superficial deposits. The granular nature of this lower unit within the melt-out till characteristically results in a shear strength of approximately $c' =$ zero, $\phi' = 36\text{–}38°$.

Below this zone lies the lodgement till which becomes increasingly matrix-dominant with depth. Shear strength decreases from approximately $c' =$ zero, $\phi' = 30°$ to $c' =$ zero, $\phi' = 23°$ over a distance of typically up to three metres. A greater degree of comminution of bedrock and debris towards the sole of the glacier and the till/bedrock interface is reflected in a steadily decreasing angle of shearing resistance with depth, as exhibited by the lodgement till in this area of the Taff Valley. A sharp change in the effective shear strength parameters is subsequently noted as the till/bedrock interface is exceeded. The characteristically weathered mudstone bedrock at locations where lodgement till deposition is greatest has shear parameters of $c' = 30\text{–}35$ kN/m^2, $\phi' = 40\text{–}42°$.

5.6.3 The influence of individual soil fractions upon the shear strength of till and associated deposits.

Whilst investigating the shear strength characteristics of lodgement and melt-out tills and of head deposits, it was noted that the strength of the soil mass was strongly influenced by the relative dominance of clast or matrix soil fractions present and hence which was a consequence of the processes of soil genesis. A series of tests were therefore undertaken to determine which portion of the soil mass most strongly influenced the overall strength.

Soil strength determined during testing is strongly influenced by the degree of disturbance of the microstructure, hence, wherever possible specimen disturbance was kept to a minimum by manual separation of soil fractions rather than by mechanical sieving.

Further to the recommendations of McGown (1971), specimens were separated either side of the gap in the particle size distribution curve. For all soils (excluding fluvioglacial deposits) gap grading was noted to occur at approximately the 425 micron particle size. An investigation revealed that this is essentially due to an abundance of particles with sizes of less than 425 microns in the local Coal Measure Series mudstone, siltstone and sandstone bedrock types. Further influences appear to include the bedrock crushing characteristics and mutual particle attrition in the subglacial environment. At sizes larger than 425 microns coarse sand to boulder sized particles tend to be clastic (composed of a varying amount of granular material) and more sporadic in terms of the percentages of individual modes present.

5.6.3.1 The influence on lodgement till properties

Under drained conditions in the $0.1m^2$ constant rate of strain shear box the effective shear strength parameters of partially disturbed specimens of weathered lodgement till (as shown in Figure 5.8) were determined to be c' = zero, $\phi' = 36°$. Post-depositional disturbance, as discussed above, reduces c' to zero. These values fall almost midway between those for the material greater than 425 microns (c' = zero, $\phi' = 49°$) and for the fraction of the specimen in which particle diameter is less than 425 microns (c' = zero, $\phi' = 22°$). This suggests that both the clasts and the matrix influence the shear strength of the total soil mass to an almost equal degree; those of the former having a marginally greater effect.

Of the soil fraction with particles greater than 425 microns, the clasts larger than 14.0mm (medium to coarse gravel and cobbles) are the dominant factor in providing the strength because of their relative abundance within the fraction. This dominant role is shown by the close positioning of the two uppermost failure envelopes in Figure 5.8. The matrix of material 425 microns to 14.0mm fills voids between the larger clasts, providing a negligible coating to these particles as they lie in contact with one another.

Weathering and downward leaching out of fines induces a clast-dominant state within these weathered tills such that the shear strength parameters lie in the zone typical of melt-out tills.

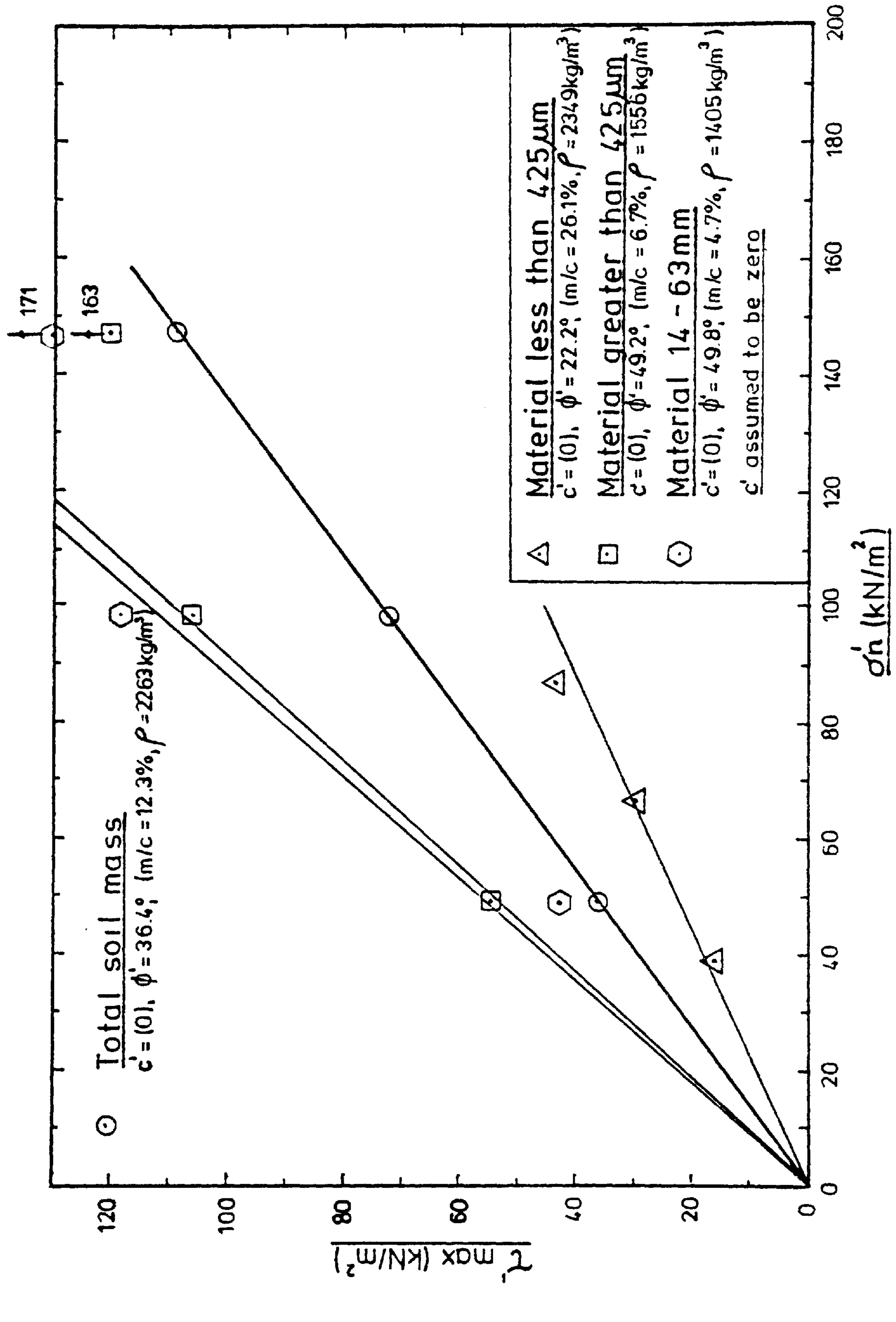


FIGURE 5.8

SHEAR STRENGTH PARAMETERS
OF WEATHERED LODGEMENT TILL

5.6.3.2 <u>The influence on melt-out till properties</u>

When considered in the light of the effective shear strength parameters of melt-out till material greater and less than 425 microns, the parameters of the total soil mass (c' = zero, ϕ' = 33.4°), lie closer to the former (c'= zero, ϕ' = 36.9°), as shown in Figure 5.9. The melt-out till, accompanied by the flow till immediately derived from it, is clast dominant where once again clasts lie in contact with one another whilst the matrix is interstitial. The soil strength is a function of clast contact, being only partially influenced by the fine grained matrix of less than 425 microns. The total soil mass has a shear strength 27 per cent greater than the similar sized fraction in weathered lodgement till. This is essentially due to lower clay and greater silt contents exhibited.

5.6.3.3 <u>Effects of further specimen subdivisioning</u>

In order to ascertain the influence on shear strength of the more minor portions of the particle size distribution than those investigated in sections 5.6.3.1 and 5.6.3.2, each specimen required further separation into individual particle fractions. The degree of specimen disturbance becomes greatly increased as each soil sample is subdivided either side of the split at 425 microns. It was therefore felt that this further subdivision would not allow reasonable conclusions to be drawn concerning the strength of the finer soil fractions in which the texture would have been most strongly disturbed. Thus an investigation of the influence of individual soil modes or fractions upon the soil strength en masse was undertaken for

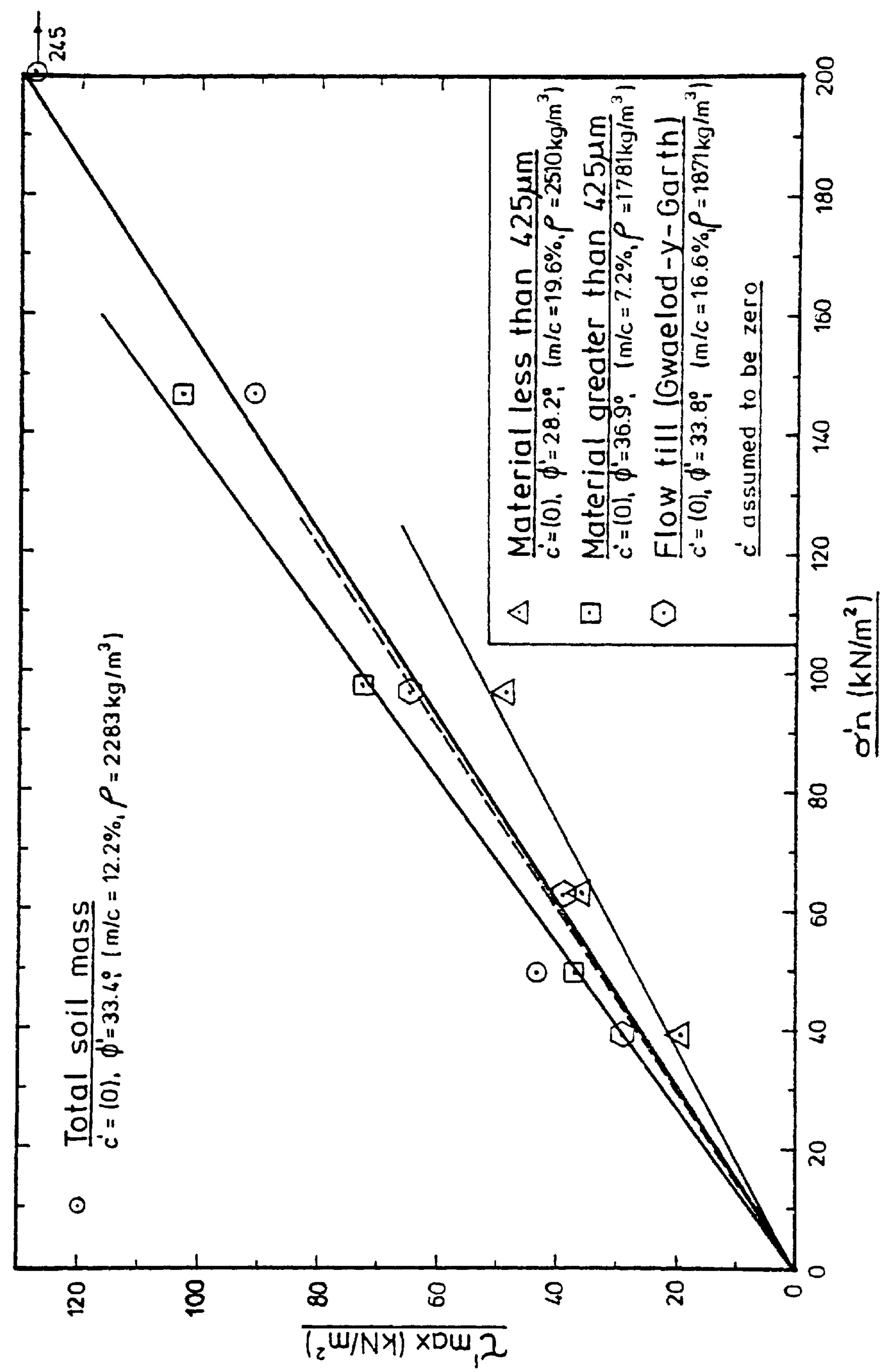


FIGURE 5.9

SHEAR STRENGTH PARAMETERS
OF CLAST-DOMINANT MELT-OUT TILL

a soil in which the degree of sample disturbance was not likely to be a governing factor on the strength recorded. This factor and the availability of a comparatively large exposure of material resulted in the use of fluvioglacial deposits.

It was stated in section 5.6.2 that no recognisable gap in the particle size distribution of fluvioglacial material was noted to occur at or near to 425 microns. The grading very closely conforms to Fuller's curve for a well graded soil. A characteristically high energy depositional environment of these essentially openwork sandy gravels would severely limit the development of such subtle breaks in the grading distribution. Therefore, in order to standardise test procedure, sample divisioning included separation of material less than 425 microns from the bulk of the specimen. The finest particles are marginally coarser than 63 microns.

Employing the use of such granular deposits ensured that methods of sample preparation became less time consuming, for example, mechanical sieving could be undertakn to accurately separate the finest sample fractions from the soil mass. An additional advantage was that shear of samples could be undertaken at greater rates of strain (up to 1.0mm/min. in the larger shear boxes) without inducing a build-up of pore pressures.

Two methods of investigation of the effective stress shear parameters of fluvioglacial materials have been undertaken :-

(i) the effect upon shear strength as soil fractions are cumulatively added

(ii) the relationship of individual fractions to the shear strength parameters of the soil mass as a whole.

5.6.3.4 <u>Shear strength characteristics of fluvioglacial deposits under cumulative divisioning.</u>

The initial specimen fraction tested was that of 63 - 425 microns (18.5 per cent of the total soil by weight) and the results of which are shown in Figure 5.10. To this mass was added material of between 425 microns and 1.18mm (a further 16 per cent of the soil) so that the effect of increased particle size on shear strength could be observed. The angle of shearing resistance (ϕ') was recorded to increase by 20 per cent from $\phi' = 32.8^{\circ}$ to $\phi' = 39.3^{\circ}$.

By the further addition of 11.7 per cent of the soil mass (the 1.18 to 5.0mm fraction) and 17.2 per cent (the 5.0mm to 14.0mm fraction), the shear strength was noted to increase progressively less each time (as clast size increased), by 6 per cent (to $\phi' = 41.6^{\circ}$) and 1.8 per cent (to $\phi' = 42.3^{\circ}$) respectively. This appears to be associated with a continuous change from a subangular particle shape in the former to well rounded clasts in the latter.

The presence of progressively larger clasts within a soil mass increases the shear strength obtainable. However, decreased particle angularity provides a reduced probability of interlocking, successively lowering resistance and frictional drag for clasts and matrix in contact. Hence, as particle size increases, the effective surface area of individuals in contact becomes reduced, further accentuating the progressive decrease in frictional resistance noted

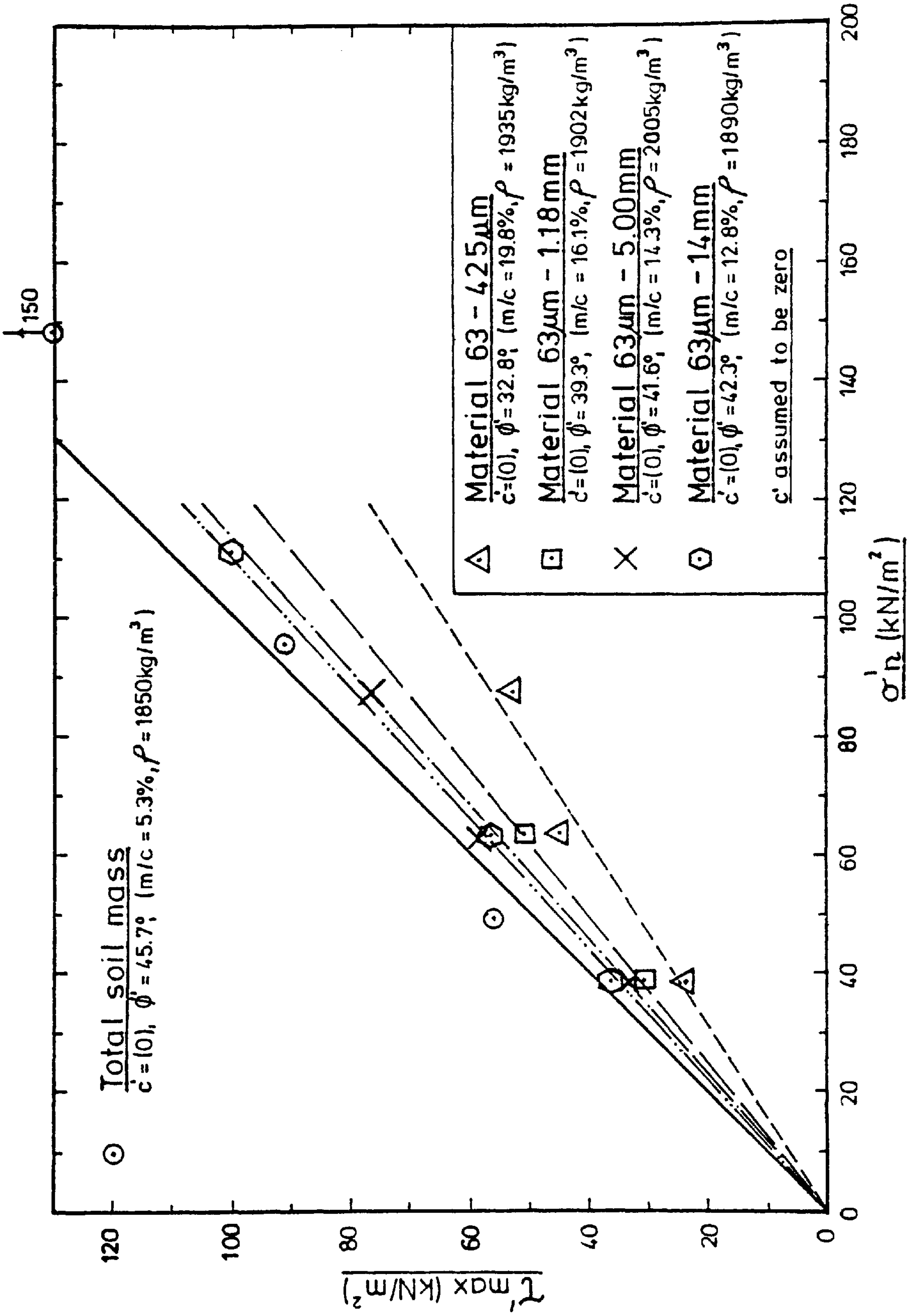


FIGURE 5.10

SHEAR STRENGTH CHARACTERISTICS
OF FLUVIOGLACIAL MATERIAL
UNDER CUMULATIVE DIVISIONING

in the data.

As would be expected, the effective shear strength parameters of the total soil mass (c' = zero, ϕ' = 45.7°) can only be obtained when all components of the soil are accumulated, both larger clasts and the smaller constituents of the matrix. Each fraction has its own role to play in the development of the total soil strength, some however, may be seen to have a more dominant role to play than others. This latter point is discussed further in the subsequent section.

5.6.3.5 The role of certain soil fractions upon the shear strength of some fluvioglacial material

It was stated in an earlier discussion of soil strength data, (section 5.6.1.2), that the coating of individual clasts by silt and clay sized material significantly reduces the shear strength of a soil mass by the smaller particles acting as a 'lubricant'. Identification of the particle fraction that acts as the 'lubricant', (dominating the total soil strength) may assist in the interpretation of shear strength development as a function of particle size interrelationships.

Figures 5.11 and 5.12 relate the behaviour of individual fractions within a fluvioglacial deposit to the behaviour of the total soil mass under shear.

The data exhibited in Figure 5.11 shows that the clasts greater in size than some value between 425 microns and 5.00mm, have an effective angle of shearing resistance greater than that of the total

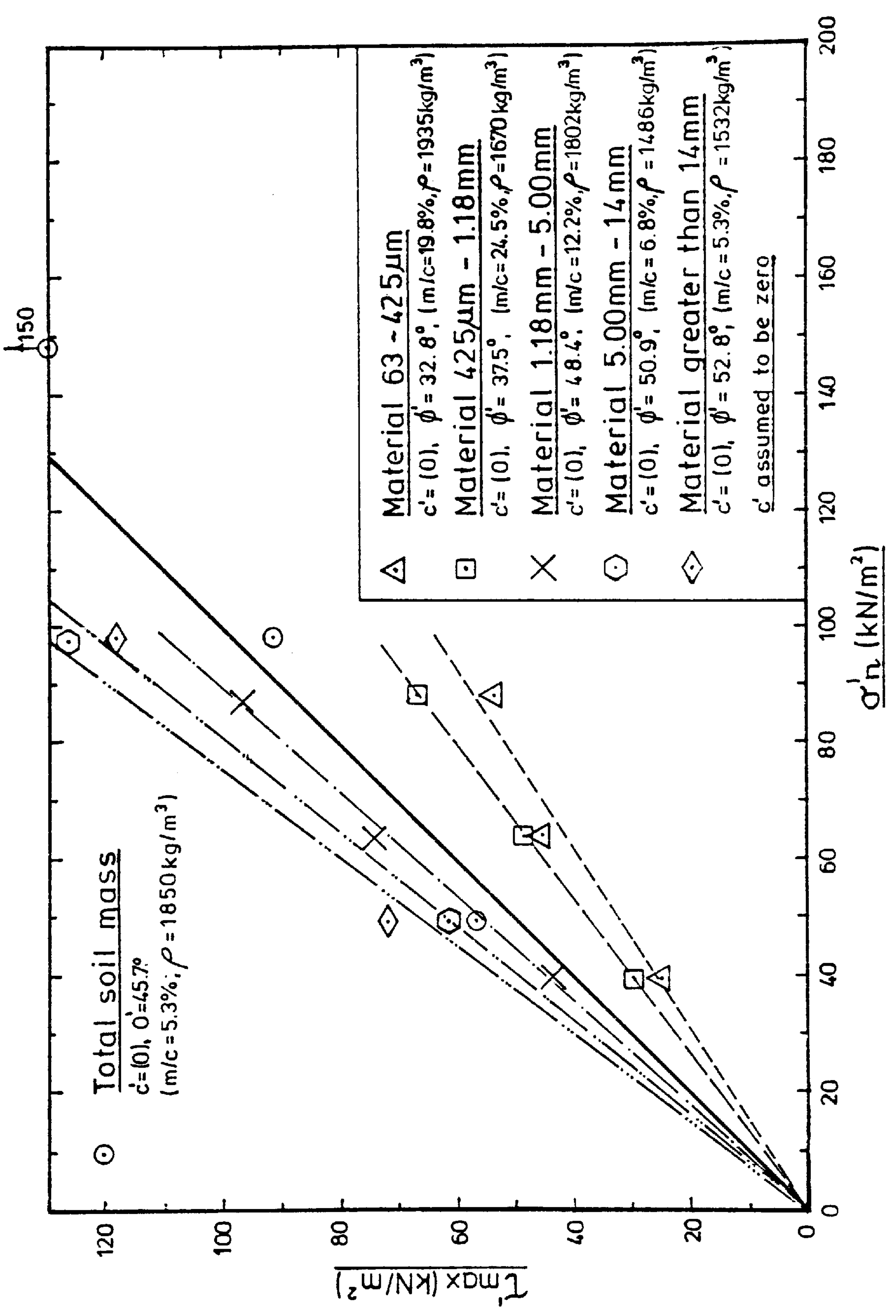


FIGURE 5.11

SHEAR STRENGTH CHARACTERISTICS
OF FRACTIONED FLUVIOGLACIAL MATERIAL
(63µm to greater than 14mm)

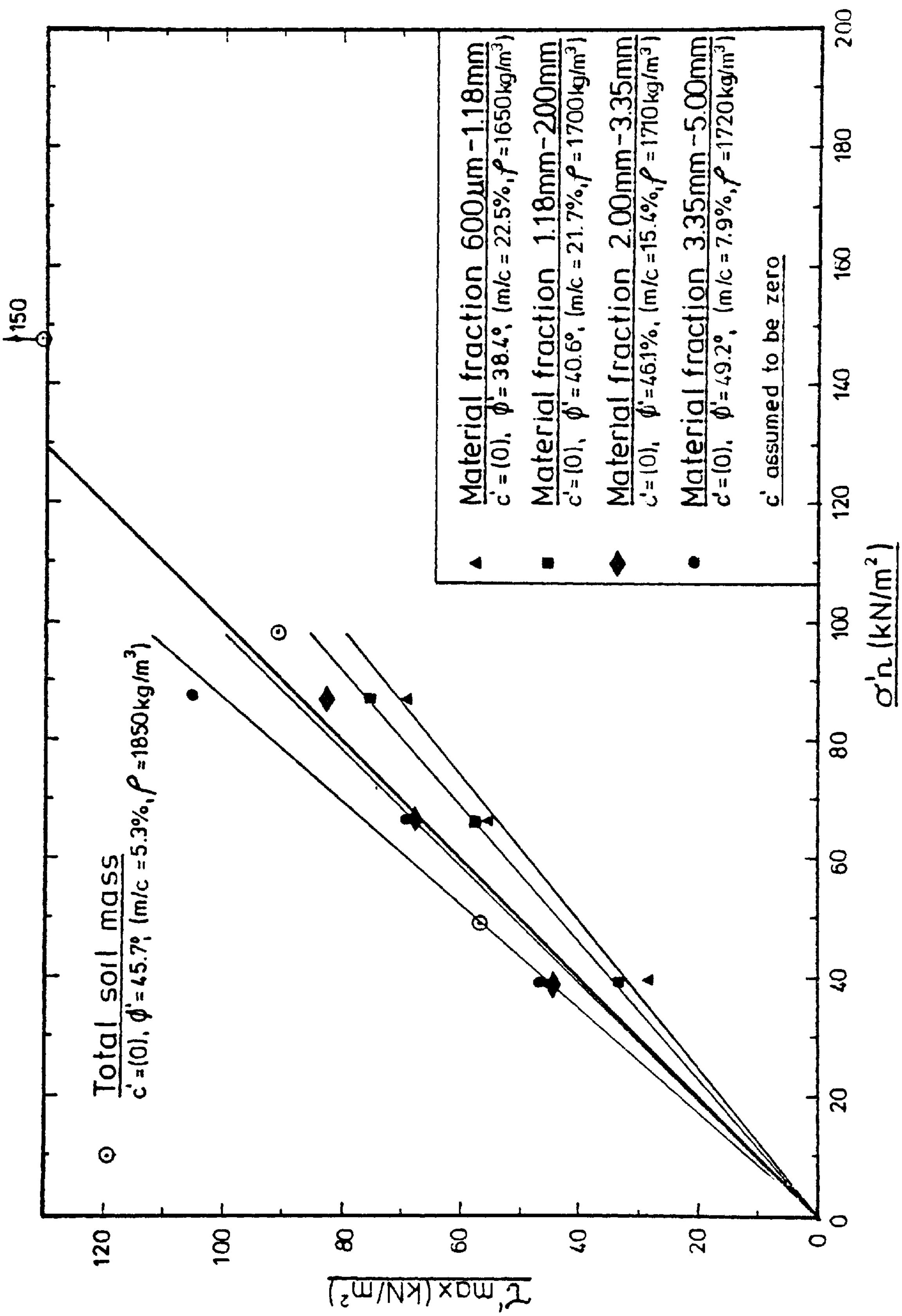


FIGURE 5.12

SHEAR STRENGTH PARAMETERS OF FRACTIONED FLUVIOGLACIAL MATERIAL

(600μm to 5.00mm)

soil mass, whilst matrix material lower in size than this determine that lower values of are produced. This suggests that a certain particle size of between 425 microns and 5.00mm diameter has a predominant effect on the shear strength parameters of the soil mass as a whole.

It is unlikely that material between 425 and 600 microns will have a sufficiently high shear strength to affect the whole soil mass, therefore only the fraction between 600 microns and 5.00mm was further divisioned. Splitting was undertaken at the standard BS sieve sizes of 1.18mm, 2.00mm and 3.35mm.

Figure 5.12 exhibits the shear strength data obtained from testing portions of the 600 microns to 5.00mm fraction. It may be noted that the portion of soil between the particle sizes of 2.00 and 3.35mm has effective shear strength parameters almost identical to those of the total soil mass, that is, $c' =$ zero, $\phi' = 46.1^{\circ}$ for the former and $c' =$ zero, $\phi' = 45.7^{\circ}$ for the latter. This portion constitutes 10 per cent of the soil by weight, however, its effects are widely felt throughout the soil mass since it coats larger clasts, acting as the 'lubricant' between them and dominating the overall strength. This fact assumes that no segregation of fractions occurs in the soil as a whole and field data suggests that this does not occur in situ. Attention is also paid to the fact that the shear strength of the soil is likely to be a result of the interrelationship of the relative proportions of the soil fractions present, however, data suggests that some fractions certainly have a more predominant effect than others.

5.7 Discussion

The recommendations of McKinlay et al (1974) concerning sample storage times, of Marsland (1977) concerning rates of strain employed when testing till specimens under drained conditions, and of McGown (1971) with regard to the splitting of a test specimen either side of the gap in the grading curve prior to testing, have been regarded with due attention and should be considered in all investigations. This has provided a deeper appreciation of the more detailed aspects of shear strength determination of soil samples and has assisted in the planning of experimental procedure.

The inherent textural variability of the local glacigenic and associated deposits of the Taff Valley has been further expounded. In this chapter the influence of heterogeneity upon development of the shear strength characteristics of the soils in fractioned and mix states has been discussed. This has also involved an assessment of the relative variability of shear strength parameters between soil types of differing genetic modes.

The results presented above have demonstrated that a specific range of shear strength parameters exists for glacigenic and associated soils of differing modes of deposition. It is clear, however, that soil texture data from an initial pre-sampling field investigation and/or detailed laboratory study, (including, for example, the use of a scanning electron microscope), is most suitable for separating soils with very similar shear strength parameters. These may lie within a specific but indistinguishable range of values. An example of the latter assisted the interpretation of the range of parameters for melt-out and lodgement tills. The strengths obtained initially fell within an envelope that appeared to be a gradual, boundary-free transition from one soil type to the other. However, when the specimens were related to in situ textural properties, microstructural evidence and plasticity characteristics, and the mode of genesis that was cumulatively inferred by this information, data points for almost 97 per cent of all specimens tested were seen to fall either side of a genetic boundary at $\phi' = 31^{\circ}$. The head deposits sampled exhibited a range of parameters that fell within the envelope of its principle source material, melt-out till.

By fractioning a soil (in this investigation fluvioglacial deposits were used) it was demonstrated that certain fractions of the soil mass have a predominant influence on the shear strength of the material. The matrix in a matrix-dominant soil (identified using Fuller's curve), even though it may be composed of a series of particle sizes, appears to carry the majority of the strength; the clasts have little influence. The converse was demonstrated to be true for the clast-dominant soils. In testing a well graded soil that closely resembles Fuller's curve of maximum particle packing density, it was shown that a very small percentage of the soil mass, here 10 per cent, has a major role to play in the overall soil strength. It provides a mechanism of 'lubrication' between larger clasts that are in contact.

In conclusion, it would therefore be reasonable to suggest that provided that the grading characteristics of a soil are known and related to Fuller's curve, then it may be possible to reasonably estimate which portion of the soil could be tested to provide a reliable determination of the total soil strength. If, therefore, one was to test a matrix-dominant soil for example, an indication of the total soil strength could be obtained by testing the matrix alone and using small scale apparatus. The soil could also be more easily sampled (due to the smaller scale) to obtain undisturbed specimens which are extremely difficult to collect when sampling in tills. This capacity would limit the problems involved with sampling and testing large specimens containing clasts which would play a negligible role in providing strength. The results obtained may also present a marginally conservative estimate of strength for design purposes. In a well graded or poorly graded soil the situation becomes more complicated and may require a more critical approach to the design of the soil sampling procedure and testing program.

SIX

CHAPTER 6

PERMEABILITY CHARACTERISTICS OF GLACIGENIC AND ASSOCIATED DEPOSITS

6.0 Introduction

In the evaluation of soil permeability, direct methods (in situ and laboratory tests) are employed to measure actual rates of water flow through a soil mass. In situ permeability testing in soil and rock masses is frequently undertaken as part of a site investigation scheme. Falling and constant head methods of test are the most commonly used within superficial deposits, depending upon the type of soil tested; falling head for fine grained soils of low permeability and constant head for the more granular soils of higher porosity. The test results however are likely to be unreliable where the soil is sensitive to disturbance and in situ tests are likely to prove expensive.

A wide range of values for the coefficient of permeability is to be expected within tills and associated glacigenic soils as a consequence of their differing modes of genesis and post depositional histories. Fookes, Gordon and Higginbottom (1975) comment upon the ranges of permeabilities that have been obtained in tills, as previously discussed in section 1.1.6. The permeability of the deposits is predominantly influenced by the range of particle sizes of the component clasts and the interstitial matrix. A progression of permeabilities for tills of different genetic modes have been recorded. This ranges from $2x10^{-8}$ cm/s for the finely grained lodgement tills at the site of Bradon Dam, Ayrshire, which have a densely packed arrangement of particles that is partially induced by overconsolidation, through to $2x10^{-5}$ cm/s for the more granular melt-out tills. Data is more scarce for other glacigenic soils, for example fluvioglacial deposits and Post glacial regoliths. The coarse grading of fluvioglacial outwash deposits provides permeabilities of greater than 30 cm/s for some openwork gravels whilst a wide range of values is to be expected for head deposits as a consequence of their inherent, source dependant, heterogeneity.

The nature of the deposits presents problems with regard to in situ testing procedure and the reliability of the results obtained. The principle problems are :-

1. Smearing of the test pit face or borehole sides in cohesive soils, particularly in the matrix-dominant lodgement and melt-out tills and in some fine grained head deposits. This will tend to reduce the flow of water during infiltration testing. It will give lower than actual permeabilities as a consequence of reorientation of matrix particles at the cut face, presenting a reduced soil surface area suitable for water uptake. In trial pits it is possible to carefully cut the face so as to expose the true soil texture and present it in a state suitable for testing. In boreholes the problem is more acute.

2. In the non-cohesive granular soils, for example some melt-out tills and fluvioglacial deposits, problems can be encountered with the support of pit or borehole walls in preparation for infiltration. Even within the more cohesive melt-out tills lensoid accumulations of sands and gravels present collapse

problems, especially when associated with points of seepage.

3. Melt-out tills and ice contact fluvioglacial deposits are the most heterogeneous of all soil types observed in the Taff Valley. In these soils in situ test results from site investigations indicate wide variations in permeability at individual sites. This appears to be due to the depositional stratification. The coefficient of permeability of the soil mass measured in situ therefore tends to give an indication of the average permeability in a horizontal plane.

4. It is important to keep regular records of the current level of local water table when undertaking permeability tests by infiltration methods. Practice has shown that the phreatic surface should not ideally lie at less than 0.5m below the base of the test section. If the surface is any shallower infiltration may be reduced to a rate that is slower than evaporation. This is particularly the case in the matrix-dominant tills of very low permeability, for example, most lodgement tills.

5. Fissures common within lodgement tills, (to some degree a function of overconsolidation) are likely to significantly increase permeability beyond that of the interstitial soil mass. This will provide misleading test results but will give conservative estimates of a greater soil permeability, suitable for conservative design estimates of groundwater seepage rates and the impermeable nature of the soils as construction materials.

In the laboratory the size of particles that may be included within the standard testing apparatus presents the most significant problem in terms of obtaining values for soil permeability. The coefficient of permeability determined tends to be more of an estimate for the finer soil fractions, essentially the matrix, rather than for the total soil mass including the larger clasts of gravel, cobble, and boulder size.

In view of the problems experienced with in situ and laboratory testing, their dubious reliability, the time consumed in many instances, and the expense that is incurred when employing such methods, indirect means of estimating soil permeability have been developed. These are based upon the interpretation of soil particle size and size distribution and the characteristics of the soil volume. Soil volumetric characteristics are influenced by the textural properties, for example, particle shape (the degree of angularity and sphericity), packing variability, and the porosity. The permeability considered is the apparent permeability with water as the pore fluid, the viscosity of which must also be considered.

6.1 Summary of Indirect Methods of Estimating Permeability

Early nineteenth century hydrological studies of the presence and flow of groundwater accompanied by simple experiments on the hydraulics of water flow through a sand medium, resulted in the formulation of Darcy's Law, stating that,

$$Q = Aki$$

where,

Q = discharge, mm^3/s

A = soil cross-sectional area, mm^2

i = hydraulic gradient, dimensionless.

At this time it was also noted that the pore size within a porous medium through which groundwater flowed played an important role in the rate of discharge; the size of the particles between which the pores were located is directly related. Several indirect methods of varying degrees of reliability were subsequently developed to estimate soil permeability based upon particle size distribution characteristics. The principle formulae developed are :-

1. Hazen (Taylor, 1948) for uniform filter sands,

$$k = 100(D_{10})^2$$

where,

k = coefficient permeability, cm/s

D_{10} = effective particle size by mass, cm.

Other workers have extended Hazen's relation, for example,

2. the U.S.Army Corps of Engineers (Sherman and Banks, 1970) who developed a similar equation to that of Hazen;

$$k = 45(D_{50})^2$$

where,

D_{50} = the median grain size of the particle distribution, cm.

The effect of porosity is disregarded here but the porosity is unlikely to vary outside 35 to 45 per cent with these granular soils. However, with well graded soils the porosity is likely to vary over a wide range and hence will have an influence on the permeability of the soil. The range of porosities of some typical soil types, including glacial deposits is exhibited in Table 6.1.

Table 6.1 Porosities of some soil types

SOIL TYPE	POROSITY (%)
Uniform sand, loose	45
Uniform sand, dense	35
Fluvioglacial sand and gravel	30-40
Glacial till, clast-dominant	20-40
Glacial till, matrix-dominant	40-60
Soft glacial clay	55
Stiff glacial clay	37
Soft very organic clay	75
Soft bentonite	85

Casagrande and Fadum (1940) developed a useful guide (Figure 6.1) for comparing the permeability and dry density of an assortment of soil types. An increase in dry density is shown to reduce the permeability of soils containing a significant

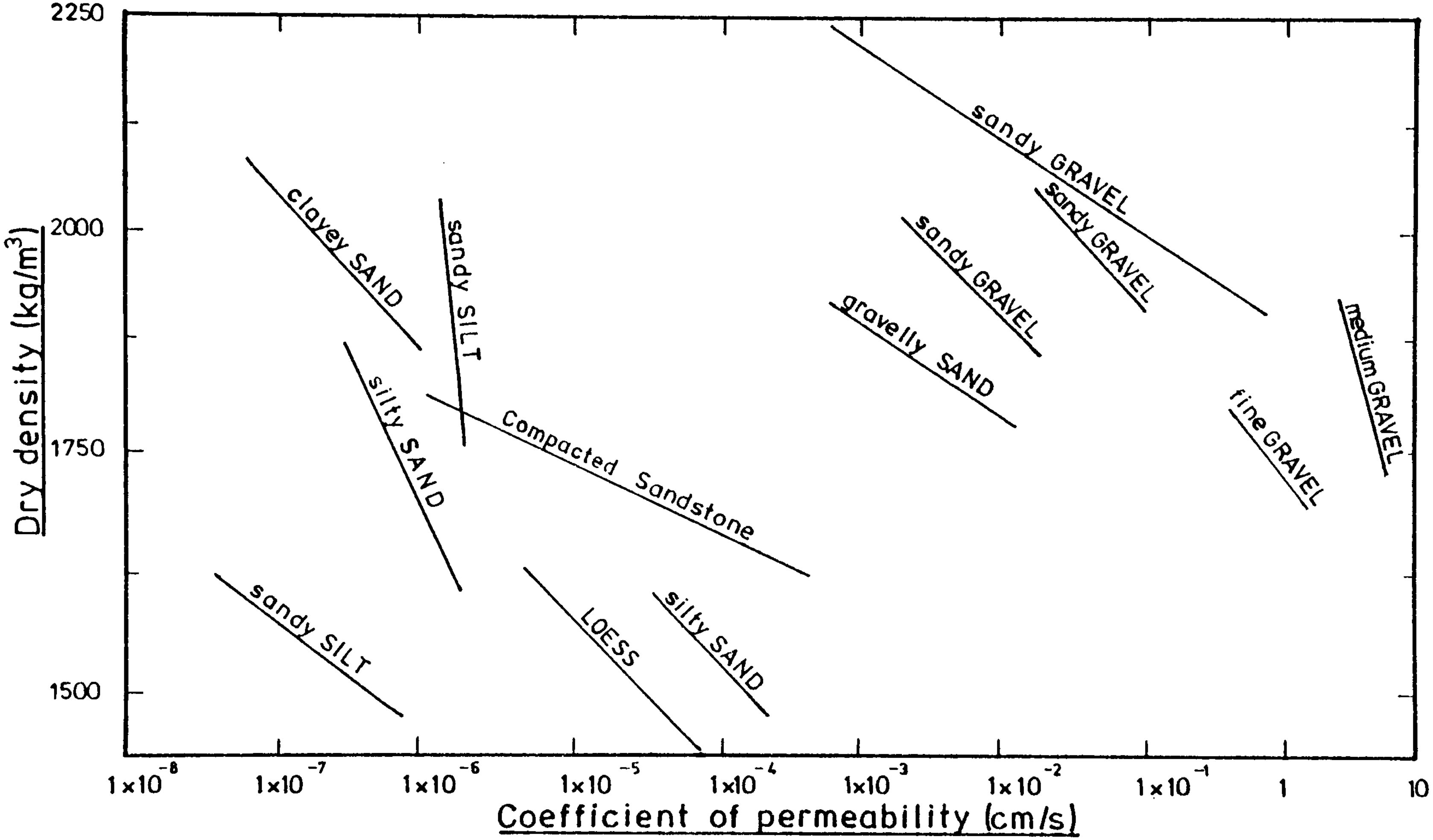


FIGURE 6.1

THE EFFECT OF DRY DENSITY UPON THE PERMEABILITY OF A VARIETY OF SOIL TYPES proportion of silt and clay. However, the presence of sand and gravel in some cases increases permeability even if the dry density is increased. A similar relationship should exist with bulk densities and hence may influence the permeability of melt-out and lodgement tills having undergone different degrees of consolidation at the time of deposition.

3. Using capillary models of porous media Kozeny (1927) developed an expression to determine permeability;

$$k = c^{1} n^{3}/TS^{2}$$

where,

c^{1} = Kozeny constant (dependant upon the shape of the pore cross-section), theoretically taken as 0.5

n = porosity, dimensionless

T = tortuosity, dimensionless

and,

S = specific surface area, cm^{-1} (as surface area exposed to the fluid per unit volume of the porous medium).

4. Carman (1937) expanded this to include derivation of the Navier Stokes equation for channel cross-sectional areas, hence,

$$k = \frac{n^{3}}{CT(1-n)^{2} So^{2}}$$

5. This was modified by Duncan et al (1972) to include a particle shape factor, ϕs;

$$K = \frac{\phi s^{2} n^{3} \ dp^{2}}{36CT(1-n)^{2}}$$

where,

k = specific permeability, cm^2

and, dp = diameter of particles, cm

Some examples of particle shape factors, as determined by Carman (1937) are given in Table 6.2.

Table 6.2 Particle shape factors

MATERIAL TYPE	ϕs
Spheres	1.00
Ottowa sand (almost spherical)	0.95
Sand, rounded	0.83
Sand, average for various types	0.75
Sand, angular	0.73
Flint sand, jagged	0.66
Natural coal dust	0.65
Flint sand, jagged flakes	0.43
Mica flakes	0.28

The above formulae are only suitable for the determination of the permeability of uniformly graded soils. Hence, Rowlands (1980) has further modified equation 5 to take into account well graded and gap graded materials. The modified Kozeny-Carman equation then becomes sensitive to the amount and distribution of all particle sizes and fractions within the size distribution curve. The equation is now expressed as :-

6. $$k = \frac{\phi^2 S \quad n^3}{36CT(1-n)^2} \quad d^2m$$

where,

C = shape factor (= 2.5 for granular soils)

T = tortuosity (= 2.0 for granular soils)

and, dm = particle mean surface diameter, cm.

Rowlands comments that although the fine soil fraction of the particle size distribution may only constitute a very small percentage of the total soil mass, it will significantly influence the total specific surface of the material, hence the value of dm and subsequently the permeability of the soil mass.

6.1.1 Relationship to current research investigation

Very little published data is available to provide a comprehensive comparative study of the relationships between permeability determined by direct methods, i.e. in situ and laboratory testing, and that calculated by indirect, semi-empirical methods. In order that some of the problems encountered in permeability testing in glacial soils (see section 6.1) may be by-passed, indirect methods may be used. By investigating the reliability of the empirical formulae presented above, using the grading curves of fluvioglacial outwash gravels, it was found that the most suitable method for estimating the permeability of well graded and gap graded glacial soils was the modified Kozeny-Carman equation as described by Rowlands (1980). The reliability of this formula was stringently tested by using grading and permeability data for a variety of glacial soils, including tills and fluvioglacial deposits of the Taff Valley. Permeabilities estimated by using grading curve data were compared with actual permeabilities determined by in situ and laboratory testing techniques. Permeability data for the glaciagenic soils of the valley (in particular the tills), and the corresponding grading curves for the specimens tested, was found to be limited. Laboratory based constant head tests were therefore performed on some of the deposits logged and studied at earlier stages of the research investigation. This had a two fold objective :-

1. to increase the amount of test data for statistical purposes

2. to test the reliability of the data made available from other local site investigation schemes.

The method of testing undertaken is presented below.

6.2 Description of the Constant Head Testing Apparatus Used

In the laboratory determination of the permeability of melt-out till, fluvioglacial deposits, a building sand and Leighton Buzzard sand, a constant head method of testing was chosen as being the most suitable since permeabilities were not expected to be lower than approximately $1x10^{-8}$ cm/s. The melt-out till and fluvioglacial deposits were tested using especially constructed perspex cylinders with an internal diameter of 139mm, tapping point separation of 143mm and a length of 1000mm and 2000mm. The 1000mm cylinder was used for melt-out till of which only a limited amount of suitable material was available. The 2000mm cylinder was used for fluvioglacial deposits of which there was not shortage of readily accessible soil. Data for the building sand and Leighton Buzzard sand was obtained using standard laboratory constant head apparatus of internal diameter 75mm and tapping point separation of 150mm.

6.2.1 Details of the Large Constant Head Permeability Apparatus

The type of equipment used is illustrated in Figure 6.2. The system principally consists of a perspex cylinder with a series of manometer tappings and tubes along one side, connected to a pressure head maintained by an upper reservoir and with a lower settling reservoir at the outlet.

The one metre long cylinder has five manometer tapping points spaced at 143mm centres whilst the longer two metre unit has eight tappings located at a similar spacing. Each tapping point (sealed by screw in polythene tappers) is connected to valved manometer tubes on a graduated wall board by flexible thin bore manometer tubing. In order to reduce clogging of the tubes by silt sized particles, Terram filter material was inserted around the interior of the cylinder wall adjacent to each tapping point, as shown in the figure.

The top of each cylinder was sealed with a 1.5mm thick flexible, discoid rubber membrane with a centre tapping point and a covering metal top plate with tap. The thickness of the rubber membrane was chosen to ensure that a secure, water tight seal was maintained when the system was under pressure. Location and sealing of the top plate and membrane was ensured by a system of threaded clamping screws with butterfly nuts, fitted to an annular plate which was in turn seated

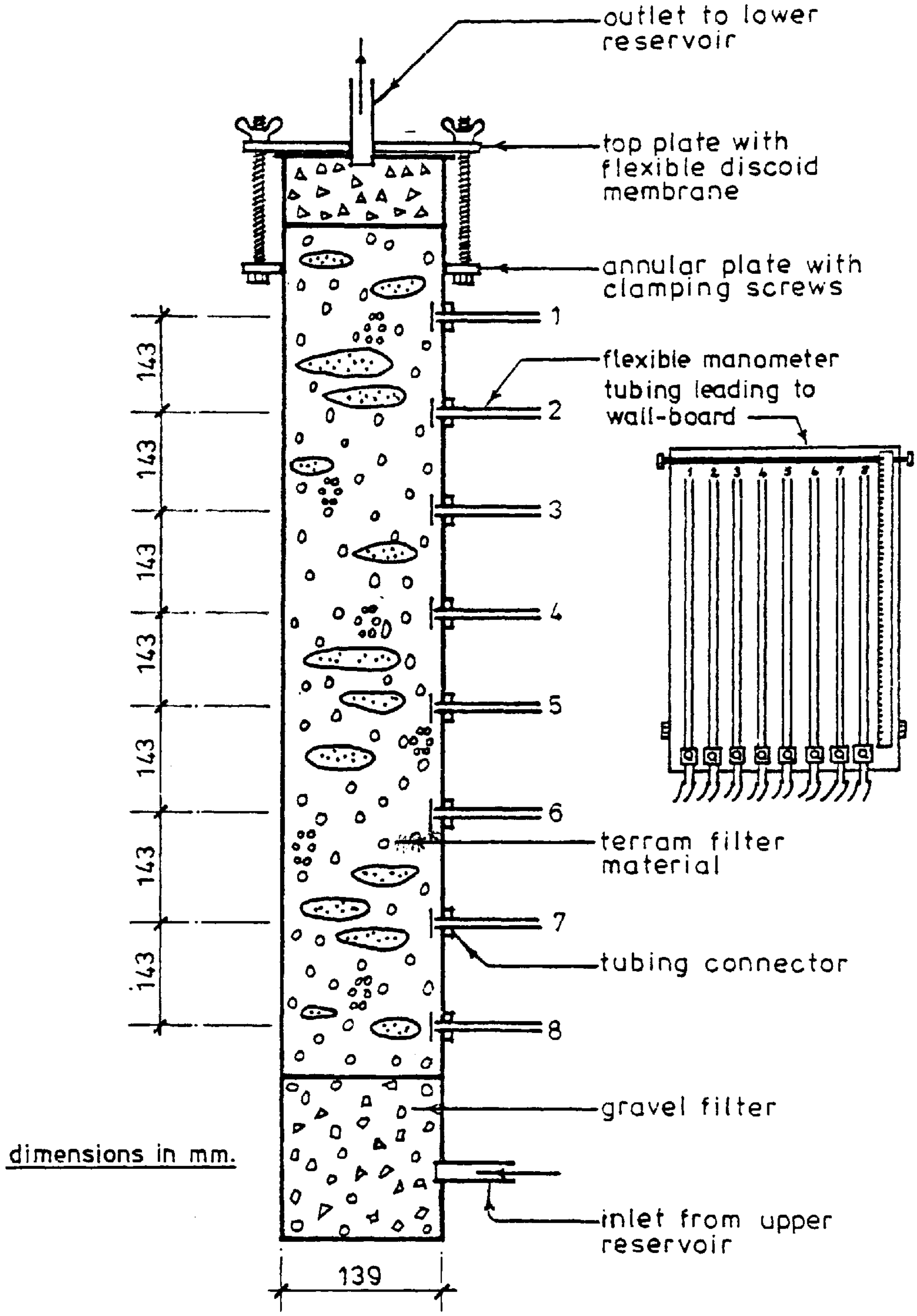


FIGURE 6.2

2000mm CONSTANT HEAD PERMEAMETER WITH UPWARD FLOW beneath perspex tensioning lugs affixed to the cylinder body.

6.3 Sampling Procedure, Specimen Preparation and Data Monitoring

6.3.1 Sampling Procedure

In the collection of samples of melt-out till and fluvioglacial deposits for the determination of their permeabilities in the laboratory, the sampling procedure adopted was essentially that employed in the collection of specimens for shear strength determination discussed in Chapter 5. Briefly this was :-

1. Sampling by using a two-dimensional stratified random method.

2. Sample disturbance was reduced to a minimum by careful extraction of block specimens of melt-out till. Because of the granular nature of the soil, it was impossible to extract truely undisturbed samples. As the diameter of the permeameter cell was only 139mm it was possible to extract up to 80 per cent of the till block samples in units of this diameter or larger.

3. The maximum clast size used in the permeameter cell had to be limited to a length of approximately 70 per cent of the cell diameter. This limitation was adopted so that cell blockage by large clasts and the consequent flushing-out of fine particles at the clast margin by concentrated flow, was minimised. Even with this size of apparatus some cobbles and boulders (amounting to approximately 10 per cent by weight in the clast-dominant melt-out till), were still therefore excluded from testing.

4. Care was taken to ensure that in the placement of samples in the storage containers following extraction in situ specimen orientation was maintained. This allowed the recreation of the in situ textural characteristics in the permeameter cell and provided a more representative determination of the permeabilities of individual units within a stratified soil sequence, than could be obtained with mixed samples.

5. Specimens were sealed and transported in rigid storage boxes. Sample dessication was reduced to a minimum by storage in two double sealed polythene bags.

6. By choosing readily accessible exposures it was possible to collect samples (in most instances) immediately before testing, thus reducing storage problems. Some samples had to be stored,however, up to six weeks before testing. In these cases storage was in a basement room under relatively constant temperature conditions.

6.3.2 Specimen preparation and placement

The procedure adopted in the placing of specimens in a permeameter cell plays an important role in the determination of soil permeability under laboratory conditions.

Samples were obtained in the field from vertically faced exposures hence the method of sample extraction only allowed the removal of material in a vertical plane. This immediately limits determination of permeability (if the specimen is to be tested in a relatively undisturbed state) parallel to bedding and normal to the subhorizontal orientation of clasts within the soil mass.

Sample placement was preceded by deposition of a filter of 19mm gravel, under water, at the base of the cylinder. The gravel was placed to a depth of three-quarters of the distance between the basal inlet/outlet point and the lowermost manometer tapping.

The collection of air voids within and between individual specimen blocks in the permeameter (which would considerably inhibit the measured permeability) was avoided by underwater placement and sample saturation. Underwater placement, however, initially resulted in the removal of some silt and clay sized material. Each block placed was carefully trimmed to a diameter of approximately 140mm (where size allowed) and placed in layers stratigraphically identical to the in situ conditions. The voids between individual units were filled with smaller fragments of the soil and the whole mass was compacted to a density as close as possible to the field condition.

Finally, a second layer of gravel filter was placed underwater on top of the uppermost soil layer such that its level was inline with the top edge of the cylinder. Upon this was clamped the rubber sealing membrane and top plate.

Following the connection of inlet and outlet pipes to the permameter from the upper and lower reservoirs the system was allowed to run until the water levels in the manometer tubes reached equilibrium; these levels were noted and recorded.

A 300ml volume of water out-flowing in unit time was collected. This procedure was then repeated six times to determine an average rate of flow.

6.3.3 Discussion

The test results indicated that the value of the coefficients of permeability of the soils tested was greater when the water flowed upwards through the soil than for the downward flow condition. This was interpreted as being a consequence of :-

1. the upward seepage forces tending to loosen the soil mass giving rise to increased porosity.

2. The downward seepage forces tending to compact the sample thus reducing the permeability in the downward direction.

Since the permeability of melt-out till was found to vary within approximately two orders of magnitude along the length of the permeameter cell, the particle size distributions of the soil were determined for sections between each manometer outlet. The reasons for the observed variance were investigated. Grading comparisons were drawn with particle size distribution curves of riffled, representative, control samples of each section/stratum within the permeameter cell which were taken prior to placement within the cell. Results have shown that a reduction of 5 to 6 per cent of silt and clay between two adjacent, texturally similar sections/strata within the cell, has provided an increase in permeability from 7×10^{-9} to 5×10^{-7} cm/s. This change in fines content is common within these heterogeneous soils as a consequence of their mode of origin and deposition.

It was noted that the soil at the outlet end of the cell only was depleted in fines (clay 2 per cent, silt 3 per cent) in comparison with the control sample of that level. The fines would appear to have been removed by the flushing action of water flowing through the soil mass in conjunction with some particle disaggregation at the end of the cell. A portion of the silt sized fraction had collected in the settling reservoir at the cell outlet.

Alteration of the grading curve of fluvioglacial outwash deposits (a sandy gravel), in comparison, was noted to be negligible. The particles were larger and denser and hence the rate of water flow was insufficient to disturb and transport them.

6.4 Comparison of Measured Permeability with Estimated Permeability using the Particle Size Distribution curve

Grading curves for both melt-out till and fluvioglacial outwash deposits, discussed above, were used to calculate the coefficients of permeability of the soils by indirect, semi-empirical methods. These methods have been found to be quick, inexpensive and reliable for estimated the in situ permeability of many soil types, but principally those that are uniformly graded and predominantly granular. Using the results of computation of the indirect permeability from the grading curves (calculated employing the modified Kozeny-Carman equation described by Rowlands, 1980), comparisons were drawn with the permeabilities of the soils determined by the direct, laboratory based methods discussed in section 6.3. This also allowed stringent testing of this formula to assess its suitability for estimating the permeability of gap graded and well graded glacial soils.

A comparison of direct laboratory permeability for four different soil types with that obtained by the indirect method is shown in Table 6.3.

Table 6.3 Comparison of permeabilities determined by direct and indirect methods

SOIL TYPE	AVERAGE PERMEABILITY (cm/s)	
	DIRECT METHOD	INDIRECT METHOD
MELT-OUT TILL	1.1×10^{-8}	5.7×10^{-2}
FLUVIOGLACIAL MATERIAL	0.48	3.1×10^{-2}
BUILDING SAND	5.2×10^{-2}	3.0×10^{-2}
LEIGHTON BUZZARD SAND	7.3×10^{-2}	4.7×10^{-2}

A good correlation is obtained between actual and estimated permeability for the uniformly graded Leighton Buzzard sand (a medium to coarse grained sand) and the building sand (coarse sand with some gravel). However, in the case of the fluvioglacial outwash deposits (which are predmoninantly a sandy gravel) and the silty and clayey melt-out tills a very poor correlation was obtained. The degree of correlation appears to be influenced by the percentage of silt and clay sized particles present. The measured and estimated values of permeability were found to differ by the order of 10^6.

Obviously a greater number of samples would be required to check the reliability of the modified Kozeny-Carman equation in its present form for soils of differing fines percentages.

Laboratory and in situ permeability data accompanied by particle size distribution curves (determined by wet sieving and sedimentation methods), have been obtained for a wide variety of soil types. The soils have been genetically identified using geomorphological mapping techniques, fabric analysis, in situ and laboratory textural identification (including use of the scanning electron microscope) and by a study of the range of mechanical properties exhibited. The permeability data has been obtained from site investigation work undertaken in deposits of Pleistocene age, (including some for glacial materials in the Taff Valley), and by testing undertaken as part of this research program. A comparison of laboratory and in situ permeabilities determined by falling and constant head methods with permeability estimated using the modified Kozeny-Carman equation, is graphically represented in Figure 6.3. Data points have been enclosed within envelopes according to the mode of genesis of the soil type. These envelopes, labelled according to the grading coefficient of the soil type, may be seen to fall approximately on two lines :-

1. The almost uniformly graded fine sands of fluviatile origin, having a grading coefficient of less than 1.5, lie on the line of equality. In this group of specimens (a total of nine) the estimated permeability (ke), computed using the grading curve, is

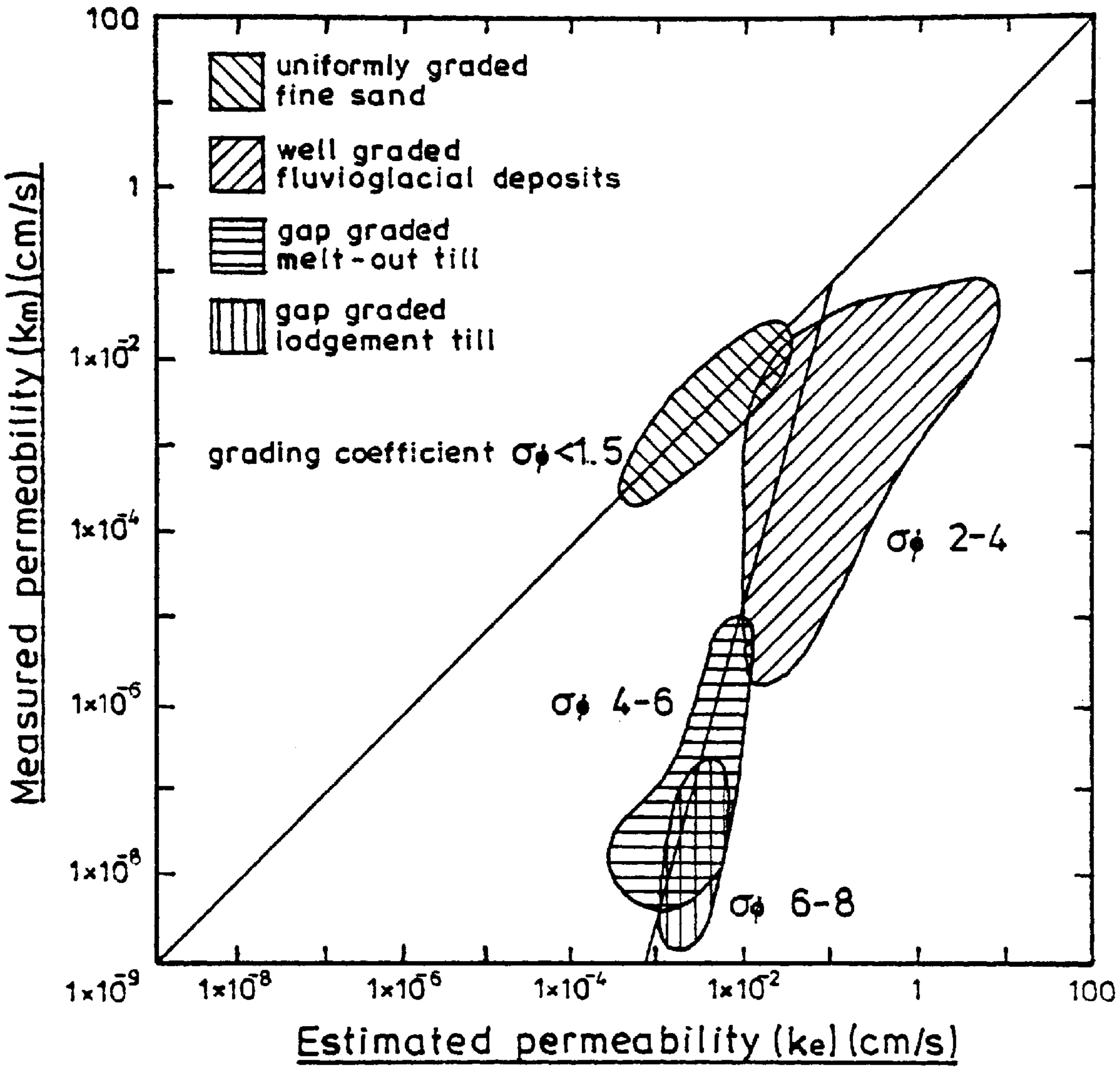


FIGURE 6.3

COMPARISON OF MEASURED PERMEABILITY (LABORATORY AND IN SITU) WITH PERMEABILITY ESTIMATED FROM PARTICLE SIZE DISTRIBUTION CURVE EMPLOYING MODIFIED KOZENY-CARMAN EQUATION almost equal to the measured permeability (km).

2. Envelopes for fluvioglacial deposits, melt-out till and lodgement till, (a total of forty two specimens) lie progressively further away from the line of equality as the measured permeability (km) decreases in value. A second steeper line has been drawn through these envelopes. The relative widths of the envelopes indicates the degree of textural variability exhibited by the soils and its influence upon the scatter of permeability data. In all cases the range of measured permeability is greater than the values determined by semi-empirical methods. This is a consequence of similarities in the particle size distribution curves between soils of differing modes of genesis, providing similar values for the estimated permeability (ke).

The slope of the second, steeper line, away from the line of equality, suggests that the modified Kozeny-Carman equation, in its present form, does not provide a reliable estimate of the permeability of soils that are other than uniformly to somewhat well graded and contain a small amount of fines. An increase in fines content, in turn increasing the grading coefficient, draws data points away from the line of equality due to the insensitivity of the equation to the presence of varying proportions of silt and clay, i.e. the average surface area does not adequately compensate for this.

In order to obtain a reasonable estimate of the actual permeability of the soils tested, a new correction factor needs to be applied to the second steeper line in the figure. The correction must be a function of the slope of the line and should transpose the

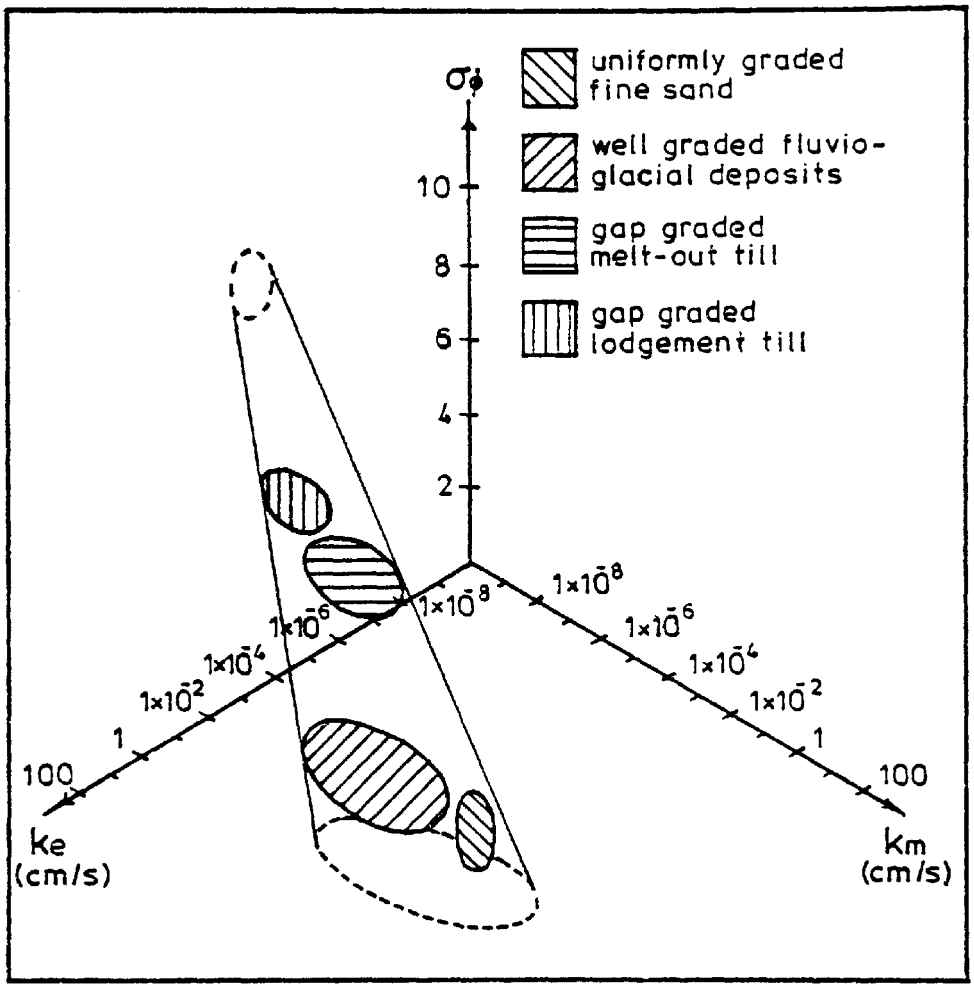


FIGURE 6.4

THREE-DIMENSIONAL COMPARISON OF MEASURED PERMEABILITY (k_m) EMPLOYING LABORATORY AND IN SITU TESTS WITH PERMEABILITY (k_e) ESTIMATED FROM PARTICLE SIZE DISTRIBUTION EMPLOYING MODIFIED KOZENY-CARMAN EQUATION AND GRADING COEFFICIENT estimated value of ke by a sufficient portion so as to lie on the line of equality. With uniformly graded soils, the correction factor need not be applied, but with estimates of ke calculated for well graded to gap graded soils (in particular tills and fluvioglacial deposits) which fall on or close to the steeper line, it is suggested that the equation below is used.

Using the log of the co-ordinates of intercept of the two sloping lines with the base line in Figure 6.3, and the similar triangles method to transpose the steep line on to the line of equality, the following equation was derived :-

$$\log_{10} \text{ km} = 3.8095 \log_{10} \text{ke} + 2.8095 \quad \text{cm/s}$$

Employing this equation, a more reliable estimate of the in situ or laboratory permeability of well graded and gap graded soils maybe obtained solely by performing a fast and inexpensive wet sieve analysis on the soil specimen.

Figure 6.4 is an isometric representation of the data plotted in Figure 6.3 to include the grading coefficient (σ_ϕ) and graphically show its relationship to the measured and estimated permeabilities of the Pleistocene deposits studied.

The envelopes of the lacustrine soils and tills lie within a cone which has its upper and lower limits on the ke/σ_ϕ and ke/km axes, marked with a broken line. The figure further demonstrates the narrower range of permeabilities that maybe obtained (shown by the tapering of the cone) as lithological heterogeneity decreases. This is particularly apparent between melt-out and lodgement tills where higher fines contents in the latter reduce the range of permeabilities to a narrower zone (and therefore smaller envelope) than may be recorded for the coarser, more texturally variable melted-out deposits.

6.5 Discussion

Several workers have produced semi-empirical equations to estimate the permeability of a soil mass, solely based upon the soil volumetric characteristics. By using data concerning particle shape, packing variability, porosity, tortuosity and the range of particle sizes within specific soils (some of which have been taken as constants and others readily obtained by simple laboratory tests), ranges of permeabilities have been outlined by many workers. These equations have, however, only proved reliable for uniformly graded soils. Rowlands (1980) modified the Kozeny-Carman equation so that it became effective in providing an estimate of the permeability of somewhat well graded granular soils. The presence of a fine soil fraction, however, limited the applications of the equation to a wider range of soil types.

By comparing the measured permeability of a number of soils of differing genetic modes with the permeability estimated from the particle size distribution curve of the soils tested, two lines (shown in Figure 6.3) about which data are scattered, have been delineated. The line with the steepest gradient, drawn for well graded and gap graded glacigenic deposits, has been used to adjust the modified Kozeny-Carman equation so that it becomes sensitive to soils that are other than well to uniformly graded. Provided that the estimated permeability of a soil (calculated using the modified Kozeny-Carman equation) lies on or adjacent to the steeper of the two lines in Figure 6.3, a true indication of the permeability of a soil mass may be obtained using the correction factor that has been derived and which is presented above.

SEVEN

CHAPTER 7

CONCLUSIONS, RECOMMENDATIONS AND SCOPE OF FURTHER WORK

7.0 Introduction

This investigation has attempted to provide a guide to the range of engineering properties that are to be obtained for the tills and associated fluvioglacial and periglacial soils of the Taff Valley. Reasons for the range of properties observed have been attributed to textural variability within the soils which is, in turn, a function of their mode of genesis and post-depositional history.

Studies of glacigenic soils undertaken within the past thirty years have shown that in order to obtain a true indication of the reasons for mechanical variability of the soils, relationships have to be drawn with standard modes of soil genesis in glacial and periglacial environments. Much work has been undertaken in these environments with regard to understanding the processes of soil formation and deposition that are involved. Boulton and others have described modes of till genesis at the margins of modern glaciers and the textural properties exhibited by these soils. They suggest that their work may be taken as a guide to the investigation and interpretation of Pleistocene deposits. Their studies also involved an appraisal of the landforms of glacial deposition. From a study of the range of glacial and periglacial landforms in the Taff Valley and by using genetic models of deposition it was possible to classify the soil types comprising individual land elements. Relationships have subsequently been drawn between the genesis of these soils and their inherent variability in terms of texture and engineering properties.

The conclusions presented hereunder are based upon the following stages of the investigation :-

1. the literature review

2. the field investigation phase, which included :-
   - (i) geomorphological and geological mapping
   - (ii) a statistical analysis of the mesofabric of the glacigenic soils delineated
   - (iii) a programme of soil sampling

3. the laboratory work phase, which included :-
   - (i) soil microfabric studies using a scanning electron microscope
   - (ii) soil testing to determine particle grading, index properties, shear strengths and permeabilities

4. the analysis of the results from :-
   - (i) mapping
   - (ii) in situ fabric analysis
   - (iii) laboratory testing.

It is recognised that the results of the research investigation are principally applicable to the glacigenic soils of the Taff Valley, however, they are not solely restricted in usage to that area. The techniques used both on site and in the laboratory are standard in format, hence the results produced are of a recognisable nature and may be readily compared with those from other localities. It is consequently felt that the basic theories of soil genesis, relationships drawn between soil types and landforms, and the soil test data, may be used in part, or as a whole in comparison for, and as a guide to, the interpretation of site investigation data in other localities that have undergone or are in the process of undergoing glaciation.

The following conclusions have therefore been drawn, based upon the data presented in earlier chapters.

7.1 Geological and Geomorphological Mapping

1. On a scale of 1:10000 stereo pairs of aerial photographs are of a sufficiently 'small' scale for the delineation of large geomorphological features, for example, kame terraces of length greater than 1.5km. They are also suitable for distinguishing individual landforms of less than 5 metres diameter, for example, solifluction lobes.

2. Seasonal conditions were shown to strongly influence the efficiency of aerial photographs for geomorphological and geological mapping purposes. Photographs that are taken in the wetter seasons, chiefly the spring and early summer months when crops are in an early stage of growth, prove to be the most useful for the interpretation of soil types present and their surface distribution. Photographs taken in the later summer months are particularly useful for the delineation of low relief landforms where longer shadows emphasise their morphology.

3. Aerial photographs were, in the majority of cases, successfully used to differentiate and delineate fine and coarse grained soil types below a cover of post glacial soliflucted head deposits of up to 6 metres thick. This interpretation was made on the basis of drainage patterns and densities and tonal contrasts. Where slopes were smooth and often greater than 15° post-depositional processes of slope instability, principally solifluction, appear to have caused an intermixing of soil types such that no recognisable drainage patterns are apparent and hence differentiation of soil types on this basis is limited.

4. By interpretation of the mode of genesis of the depositional landforms observed within the valley it was possible to reliably estimate the types of soil present. For example, the presence of kettle holes within kame terrace deposits suggested the presence of lenses of silty clay within the sand and gravels of the feature; their presence was subsequently proved by detailed geological mapping. This technique was particularly of use where the interpretation of soil types on the basis of drainage characteristics etc. in areas of thick head deposits was difficult.

Geomorphological mapping techniques using aerial photographs and a walk-over field survey were extensively used to locate areas of specific interest and thus formulate a basis upon which to plan the research site investigation programme. Areas of detailed study were principally located upon the basis of an estimation of the range of soil types that were likely to be present in that locality, as inferred by the landforms from an interpretation of their mode of genesis. Where a limited range of soil types (as inferred by the geomorphology) occurred in two areas of marginal importance, preference was given, for further study, to the one with the greater exposure potential in the form of stream sections and earthworks shown in the photographs. Geological mapping and soil sampling were carried out at these locations.

Geomorphological mapping of landform types provides a means of assessing the soil types that may be present at a locality by drawing relationships with a glacial model. Interpretation of the mode of genesis of the landforms enabled successful prediction of the relative distribution of individual soil types within and adjacent to the feature. Areas of particular interest, especially those that were readily accessible for the removal of soil samples, were mapped in detail and relationships between lithology and landform type were used to classify the soil types present.

5. Differentiation and classification of the soils encountered was made on the basis of :-

    1. in situ textural properties, including lithology, sedimentary structures, colour, particle size and degree of sorting

    2. characteristics of the macro, meso and microfabric. Seven principle soil types were identified :-

- lodgement till
- melt-out till
- flow till
- fluvioglacial deposits (outwash gravels and kame terrace deposits)
- reworked till
- head deposits and colluvial slopewash
- screes and talus deposits.

The principle textural characteristics of these essentially granular soils, as observed in situ, are shown in Table 7.1. The superposition of the depositional suite within the overburden was found to be generally as exhibited below :-

	head deposits and colluvium
Thickness	fluvioglacial deposits or reworked till
approximately	melt-out till and flow till units
5 to 20 metres	lodgement till
	bedrock

This succession was frequently incomplete, especially at an elevation of greater than one third up the valley sides where head deposits, colluvium and screes principally overlie bedrock.

6. The texture of tills, especially those deposited by the process of lodgement, was found to be critically dependant on the local bedrock geology. Melt-out tills exhibit sedimentary features and a mixture of clast lithologies that reflect their limited dependancy on the local bedrock as a source of debris.

SOIL TYPE	IDENTIFYING FEATURES		TYPICAL ENGINEERING PROPERTIES			
	FIELD DESCRIPTION	GEOMORPHOLOGICAL CHARACTERISTICS	CLASSIFICATION		SHEAR STRENGTH	PERMEABILITY (cm/sec)
LODGEMENT TILL	Typically matrix-dominant, brownish grey gravelly clayey SILT. Contains subhorizontal fissures and microfaults. Localised pockets of sandy comminution till with bouldery deformation till common at rock-head. Typically 3-5m thick. Clast long axis mainly parallel to ice flow (shear fabric), dip predominantly downstream.	Present in drumlins (not recorded as such in Taff Valley). May be reworked in morainic ridges and hummocky melt-out moraine. May form floor of kettle holes in the latter. Underlies all till in Taff Valley.	$\sigma\phi$ =5.7 to 7.8 $M\phi$ =7.0 to -3.5 M/C= 5 - 20% ρd =1.83 to 2.52Mg/m^3	WL = 21 - 48% WP = 10 - 26% FRESH -CI WEATHERED-CL	c' = 0 kN/m^2 ϕ'(max) = 31° ϕ'(min) = 23° ϕ'(mean) = 28.7°	2 x 10^{-7} to 1.5 x 10^{-9}
MELT-OUT TILL	Grey brown silty gravelly SAND with inclusions of reworked lodgement till and fluvioglacial deposits. Sandy aquifer usually present at base, in contact with lodgement till. Weathered to approx. 2.5m. Clast long axis parallel to ice flow, dip upstream. 10 - 15m thick.	Common as hummocky melt-out moraine and in morainic ridges. May occur as lensoid accumulations in kame terrace, lateral and medial moraines and in drumlins; usually as a thin cover to latter. Slope angles = 2° to 36°.	$\sigma\phi$ =3.9 to 6.0 $M\phi$ =4.5 TO -4.5 M/C= 5 - 22% ρd =1.76 to 2.44Mg/m^3	WL = 17 - 38% WP = 9 - 23% CL but occasionally non-plastic	c' = 0 kN/m^2 ϕ'(max) = 46° ϕ'(min) = 31° ϕ'(mean) = 36.3°	1 x 10^{-5} to 4 x 10^{-9}
FLOW TILL	(i)Upper allochthonous, bedded SAND and sandy SILT Winnowed remains of underlying unit. Flow texture visible. (ii)Lower autochthonous unit similar to underlying melt-out till, mainly a sandy SILT with gravel and cobbles. Fabric similar to parent material.	Occurs in close association with melt-out till in hummocky melt-out moraine. Too localised to produce specific land elements	Characteristics very similar to parental melt-out till but likely to be non-plastic		Characteristics very similar to parental melt-out till, but strength distribution will be anisotropic for allochthonous units	Similar range to melt-out till
FLUVIOGLACIAL DEPOSITS	(i)Outwash — Openwork, well rounded sandy GRAVEL. Clast imbrication dips upstream. Pockets of glacilacustive sands and possibly varve-like silts present. (ii)Ice contact kame terrace deposits. Bedded grey-brown sandy GRAVEL with silty and cobbly lenses. Boulders common towards base. Variable thickness.	(i)Outwash planes and terraces, flat and elongate. Max. of 5 terraces recorded; two main terraces recorded at 6-8m and 17-24m above river level. (ii)Two principle elongate kame terraces of 0.5 to 4.0km long, at 20-35m and 90-120m above river level. Slope angles=2° to 27°	$\sigma\phi$ =1.7 to 4.1 $M\phi$ =-1.4 to -4.3 M/C= 2 - 19% ρd = -	OUTWASH : WL WP NON-PLASTIC KAME TERRACE : WL 16 - 27% WP 11 - 17%	-	0.1 to 2 x 10^{-6}
SOLIFLUCTED TILL	Texture very similar to source material (usually melt-out till). Slump and shear fabrics common. Clasts orientated with long axis downslope. Dip occasionally into slope, especially at depth. Some parental clast dip and orientation may be retained. May be found to be up to 10m thick.	Hummocky topography of lobate form. Lobes between 18 and 105 metres wide recorded. Relief of 1 - 2.5 metres along rampart front. Lobes may coalesce into solifluction terraces, but usually where soil is thickest.	Characteristics of parent material		Characteristics of parent material but shear strength likely to be lower due to shear fabric discontinuities	-
HEAD AND COLLUVIUM	Orange-brown to light grey silty fine SAND with angular gravel and cobbles. Texture mainly depends on soil and bedrock lithology upslope. Cobble percentages increase with depth. Usually 1-2m thick. Clasts orientated and dipping downslope. Colluvium as slope-wash deposit, typically a greyish fine sand as lenses within and overlying head.	Hummocky topography, usually lobate. Lobes usually less than 30m wide. Relief of 0.5 - 1.5 metres along rampart front. Widespread as featureless covering to bedrock. Slope angles = 0° to 47°	$\sigma\phi$ =2.2 to 4.3(H) $M\phi$ =1.1 to -2.2(H) M/C= 10 - 17% ρd = - WL = Occasionally CL but WP = usually non-plastic	1.2 to 2.3(C) 4.0 to 1.8(C)	c' = 0 kN/m^2 ϕ'(max) = 39° ϕ'(min) = 31° ϕ'(mean) = 35.8°	-
SCREES AND TALUS DEPOSITS	Accumulation of angular clasts, usually associated with head deposits. Clast azimuth orientation and dip is downslope, approx. parallel to ground surface.	Lobate, usually arcuate accumulation at base of rock outcrop. Slope angles = 27° to 42°	-		-	-

KEY TO SCIENTIFIC NOTATION

$\sigma\phi$ = GRADING COEFFICIENT
$M\phi$ = CENTRAL TENDENCY (MEAN DIAMETER)
M/C = NATURAL MOISTURE CONTENT
ρd = BULK DENSITY
WL = LIQUID LIMIT
WP = PLASTIC LIMIT
CL = CLAY OF LOW PLASTICITY
CI = CLAY OF INTERMEDIATE PLASTICITY
c' = EFFECTIVE COHESION
ϕ' = EFFECTIVE ANGLE OF SHEARING RESISTANCE

TABLE 7.1

THE MAIN IDENTIFYING FEATURES AND ENGINEERING PROPERTIES OF THE PRINCIPLE SOIL TYPES IN THE TAFF VALLEY

Argillaceous substrates would appear to be readily worked to produce matrix-dominant lodgement tills greater than 5 metres thick. The harder, more resistant arenaceous types produce a silty sandy essentially clast-dominant till of usually less than 2 metres thick.

By reference to geological maps on a scale of 1:10000 or larger it was found that a reasonable estimate could be made of the distribution of lodgement till at depth within an area, solely by recording the distribution of the argillaceous bedrock units and relating this to the local model of glacial deposition. Slight additions to the distribution have to be made due to the downstream 'over-carry' of argillaceous till on to areas with an arenaceous bedrock. The distance of over-carry to the south of Abercynon was estimated to be less than 1km beyond the most southerly limit of the predominantly argillaceous Productive Coal Measure Series. The interpretation of existing geological information using this technique may be advantageous in enabling estimates to be made of the approximate distribution of low strength cohesive tills for foundation design purposes. This may assist in the planning of a subsurface investigation to prove the extent and thickness of these deposits as potentially unstable materials when in close association with a high water table on the valley sides.

7.2 Fabric Analysis

The classification of the soil types observed on the basis of lithology and their spatial relationships in a geomorphological context was greatly assisted by statistically analysing the orientational characteristics of clasts larger than fine gravel size. Soil mesofabric analysis employing the techiques outlined by Curray (1956) and Doornkamp and King (1979) enable the production of rose diagrams and contoured stereonets to show the principle directional qualities of clasts within lodgement till, melt-out till, reworked till and head deposits. The principle conclusions that may be drawn from this phase of the investigation are that :-

1. Within lodgement and melt-out tills clasts of all sizes are preferentially orientated with their long axes pointing in the direction of local ice flow. Clasts within lodgement till dip downstream as a consequence of the relative influence of high subglacial normal stress and subhorizontal shearing stress. Clasts within melt-out till exhibit an upstream dip, probably due to retention of an englacial shear fabric.

2. The process of solifluction of soil in the periglacial environment has erased much of the original depositionally induced clast orientations of the glacigenic soils sampled. Particles have become reorientated such that the clast long axis dips essentially downslope. The amount of clast dip is closely related to the local slope angle of the soliflucted regoliths. The head deposits, typically 1 to 1.5 metres thick, exhibit the greatest degree of consistency in orientation for these soils, (vector

magnitude (L) of 63 per cent), since they have undergone the greatest degree of periglacial transportation. Localised variations in orientation were recorded at depth within reworked till. Clast dip was shown to be into the valleyside (a characteristic of soliflucted deposits), however this preferred orientation was also concluded as possibly reflecting Post glacial slope instability in the form of shallow circular failures. Evidence from site investigation schemes associated with the A470 suggest that failure planes are probably seated at the melt-out till/lodgement till interface. Areas of instability may thus be located by mesofabric analysis where surface evidence of failure has been erased or masked by subsequent transportation of head deposits.

7.3 Sampling Techniques

1. Careful sampling to reduce specimen disturbance was of particular importance within soils where preferential orientations of microclasts of the micro and mesofabric impart anisotropic properties. Following a review of sampling techniques the optimum method used was a two-dimensional stratified random system for the location of sampling points. A system incorporating representative subjectivity was found to be an additional necessity in highly heterogeneous soils, for example, as used when sampling some melt-out till units.

2. Block samples were collected for the cohesive soils. These were principally collected as 0.1m^3 units for the determination of shear strength parameters, whilst small samples of soil matrix were collected in an undisturbed state for the study of the microfabric using a scanning electron microscope. Non-cohesive soils, principally fluvioglacial and head deposits, were collected as bulk disturbed samples. The quantities collected for the laboratory determination of index properties and particle gradings were dependent upon the size of particles contained. The minimum quantities that were deemed to be required for comprehensive testing were as shown in Table 7.2.

Table 7.2 Minimum quantities of soil sampled

Quantity of soil fraction contained	Total mass collected (kg)
>30% coarser than medium gravel size	>15
>30% sand	10 - 15
Predominantly silt and clay	< 5

7.4 Sample Storage

1. The optimum method of limiting sample dessication and disturbance was concluded to be one of storing specimens in partially vacuum sealed polythene bags in a cool, constant temperature storage area for periods not exceeding six weeks.

2. The most efficient system to minimise specimen deterioration was deemed to be one of sampling within a period of twenty four hours prior to the scheduled testing date.

7.5 Sample Preparation

1. In the research programme, two principle criteria were adopted in sample preparation in order to reduce disturbance of the soil microfabric :-

    1. Manual preparation in preference to automatically controlled mechanical systems where convenient, for example, in the separation of material less than 425 microns from a soil mass for the determination of plasticity characteristics. In this case a system of hand picking followed by manual sieving was the technique preferred. It resulted in limited disturbance of the sensitive matrix microfabric and it is felt that this assisted in making the results obtained more indicative of the in situ behavioural characteristics of the soil. The time effectiveness of this technique does, however, render it somewhat inefficient in anything other than a research

environment.

2. As a method of simulating and, as closely as possible, recreating the in situ environment of specimens for the determination of shear strength parameters and permeability characteristics, the samples collected were orientated in the testing apparatus in the manner in which they were orientated in situ. It was therefore important that close attention was paid to accurately recording the orientational characteristics of the samples during exposure logging, sample collection and storage.

2. In order to remove the possibility of air being trapped between block samples comprising the permeability test specimen (the permeability would be significantly influenced if air was present), placement of samples within the permeameters was most efficiently conducted under water. This system may, however, have the effect of flushing out a small proportion of fines within some matrix-dominant soils if not performed with extreme care.

7.6 Conclusions from Laboratory Testing

7.6.1 Index properties and grading characteristics

1. It was found that the differentiation of lodgement and melt-out tills in some specific cases where lithological classification was insufficiently precise, was assisted by interpretation of the

range of index properties and grading characteristics exhibited. For example, this was of particular use in distinguishing lenses of reworked lodgement till (shown to be silty clays of intermediate plasticity) within lithologically identical low plasticity melt-out tills.

2. Specific differences exist between the grading characteristics (grading curve and central tendency/grading coefficient values) of each of the seven principle soil types. However, some transition zones of overlap, typically lying between lodgement and melt-out tills, and kame terrace deposits and outwash, as classified by field evidence. The transition zones are interpreted as being a consequence of localised reworking of deposits at the subglacial/englacial interface and in the fluvioglacial environment respectively. Sub-types within the soils could be readily distinguished in terms of degree of clast dominance by using the bivariate scattergram method of data presentation. This method was also demonstrated as being a useful tool for the expression of the direct relationships between the bivariate grading characteristics and the index properties of soils of differing genetic modes.

3. Operator influences affect consistency in data obtained in the determination of some index properties. For example, the determination of the plastic limit of a soil according to Test 3 (BS 1377:1975) was found to be particularly operator susceptable during the 'rolling' and 'gathering' stages when performed by inexperienced staff. It is suggested that wherever economic constraints allow skilled operators should perform such tests so

that data quality and consistency may be controlled.

4. A study of the influence of certain soil fractions on the behaviour of a soil mass in terms of its plasticity characteristics showed that a clay content of as low as 5 to 10 per cent within a silt rich soil dominates the plasticity characteristics to such a degree that the soil behaves as a clay rather than as a silt.

5. Relationships drawn between the spatial arrangement of individual units within a glacigenic succession and the range of index properties exhibited by the component soil types, show that till specimens containing the highest clay and silt contents and having the greatest plasticity lie at the greatest depths in the soil profile. This was concluded as being a consequence of :-

   (i) an increase in the amount of clay sized derivatives of subglacial bedrock attrition due to the proximity of the original level of the glacier sole

   (ii) limited inclusion of the coarser soil fractions by association with overlying melt-out till and fluvioglacial deposits.

6. Distinct ranges of moisture contents, index properties and bulk densities are apparent within soils deposited in genetically dissimilar environments. These ranges are principally a consequence of the grading characteristics of the materials and the stress history through which the individual soils have passed.

7. Moisture content studies have shown that the predominant concentration of groundwater within the soil sequence is at the interface between the melt-out and lodgement till units. The latter acts as an almost impermeable boundary for the downward percolation of rainwater, but also acts as an impermeable seal to the bedrock. It traps water within the joints of the substrate resulting in a build-up of pressure head. This subsequently causes a rise in the phreatic surface within the bedrock such that upslope overtopping of the lodgement till at its valleyside upper limit occurs. This consequently produces the common slope instability problems that occur in the South Wales valleys; the Aberfan Disaster of November 1966, for example, was probably attributable in part to this effect.

The widest range of moisture contents was recorded in the head deposits and colluvial soils, principally in response to climatic fluctuations.

7.6.2 Shear strength

1. Soil sampling was carefully undertaken to overcome sample disturbance, however, it was concluded that this could not be completely eliminated using the existing techniques. A study of the *in situ* textural properties of the tills and head deposits sampled suggests that genetic or post-depositional processes have themselves caused some disturbance of the soil fabric. Therefore many of the samples were regarded and thus analytically treated as being effectively disturbed. The consequence is that the

effective cohesion (c') of these soils was taken to be zero and thus the shear strengths obtained were closer to residual than peak strength.

2. A specific range of shear strength parameters has been shown to exist within and between soils of differing modes of genesis as a consequence of the depositional mechanisms involved. This is shown in Table 7.2. Reworking of specific types has resulted in varying degrees of overlap of parameters between individual genetic classes. A progression exists from the low strength cohesive lodgement tills with high fines contents, through the melt-out tills and head deposits with an admixture of soil fractions, to the non-cohesive granular fluvioglacial deposits.

3. A detailed examination of the texture of both tested and untested specimens was concluded to be an essential requirement for the grouping of soils which were of a similar mode of genesis. This was found to provide a considerable insight into the reasons for the variation in parameters determined by the testing method adopted.

4. This investigation has shown that the number of strength tests performed on soil specimens should be sufficient to determine the properties of all the principle fractions of the soil that are likely to affect its overall behaviour as a mass.

Certain fractions of a soil mass were shown to have a predominant influence on the shear strength characteristics of the soils studied. The matrix in the matrix-dominant soils (for example lodgement till), was shown to be the critical fraction in terms of providing the strength of the soil, whilst the clasts contained have a negligible influence. The converse was shown to be true for the clast-dominant soils, for example the fluvioglacial deposits. In the well graded soils investigated (a typical type being melt-out till), a small percentage of the soil mass, as low as 10 per cent in some cases, has a major role to play in the strength of the complete soil. This fraction provides a mechanism of 'lubrication' between larger clasts that are in contact with one another.

It was further concluded that providing the grading characteristics of a soil are known and related to Fuller's Curve of maximum particle packing density (to determine the relative degree of clast dominance), it may subsequently be possible to reasonably estimate which portion of a soil sample could be tested alone to provide a reliable estimate of the total soil strength. The matrix alone could therefore be tested for a matrix-dominant soil. This would be advantageous because :-

1. the soil could be more easily sampled using standard sampling tubes without the presence of gravel or cobbles to hinder the technique

2. undisturbed samples could be more easily collected, a problem that is inherent when sampling tills and till-derived head deposits.

A marginally conservative estimate of the shear strength parameters of the soils for design purposes would be obtained by adopting this procedure.

7.6.3 Permeability

The laboratory determination of permeability characteristics of tills and fluvioglacial deposits has shown that the fine soil fraction, the silt and clay sized particles, have the greatest influence on the coefficient of permeability (k) of a soil. This is so under both laboratory test conditions and also as shown whilst adopting theoretical empirical techniques (using the grading curves of the soils tested and standard empirical equations to calculate k).

The principle conclusions drawn from the comparison of laboratory/in situ and theoretical methods of determining permeability are :-

1. For uniformly graded soils with a grading coefficient of less than 1.5 a good correlation is obtained between the two methods.

2. As grading coefficient increases with an increased fines percentage in fluvioglacial deposits, melt-out and lodgement tills, the modified Kozeny-Carman equation becomes less sensitive when used to provide a reliable estimate of the soil permeability. A good correlation for these well graded and gap graded soils was obtained by applying a correction factor that increased the sensitivity of the modified Kozeny-Carman equation to the presence of the fine soil fraction.

In conclusion it may be stated that the determination of soil permeability by using the particle size distribution curve and a suitable empirical equation, rather than by laboratory testing, can be reliably undertaken. It would be a cost effective technique since the time spent in testing specimens (which are inherently problematic due to their high fines contents, for example in tills), could be drastically reduced.

7.7 Scope for Further Work

1. Only selected areas of the Taff Valley were studied in detail in this investigation. As a source of further work the mapping techniques applied in this research investigation could similarly be applied to the areas of the valley not studied to date; this could include areas where work is currently in progress for highway schemes and industrial sites.

2. A particularly useful exercise in terms of determining the spatial variation of soil types and hence engineering properties would be to cut a long trench (preferably down to rockhead) through a principle land facet, for example a drumlin or a recessional moraine. If it were possible, the trench should be kept open for several weeks; time could then effectively be spent in :-

   (i) relating the distribution of the soil types observed to the mode of genesis of the land facet (as inferred using the aerial photographic mapping techniques) and also to the glacial model of deposition

   (ii) logging the distribution of soil types throughout and immediately adjacent to the land facet

   (iii) performing in situ tests (in particular permeability tests) on the soils present

(iv) the collection of undisturbed block and bulk disturbed samples of the range of soils present to obtain a comprehensive assessment of the scope of engineering properties that may be exhibited by the soils.

3. A statistical study of till mesofabrics along the length of the valley to map out local ice flow fluctuations. An analysis should also be undertaken of clast orientations and dips within the soliflucted soils at shallow depths to assess areas of recent and past slope instability.

4. Further work is required to be undertaken in assessing the relationships between plasticity and grading characteristics of a wider variety of soils within the valley than those studied. Analysis of results should be greatly assisted by using the bivariate scattergram method of presentation. Initial studies that were undertaken in this investigation suggest that direct relationships exist between the overall grading distribution of a soil mass (not solely the portion passing the 425 micron sieve size) and the plasticity characteristics of the finer constituents.

5. A comprehensive study of the relative effects of clasts and matrix on the overall strength of lodgement and melt-out tills was curtailed in this investigation by a limited exposure of soil and hence supply of suitable samples. Hence, a more detailed study could be undertaken with a greater bulk of material, possibly supplied using shell and auger sampling techniques.

6. Further studies are required to determine the coefficient of permeability (k) of the glacigenic and associated soils of the valley, using the 1000 and 2000mm permeameters employed in this investigation for testing undisturbed samples. The work undertaken and documented herein may be used as a base upon which to build a more detailed programme of research. A study could be undertaken of a wider range of soil types to determine the ranges of permeabilities that are to be expected due to localised textural differences, for example lenses of sand and gravel within melt-out tills, that greatly increase the overall permeability of the soil mass.

7.8 Discussion

This research investigation has attempted to draw together three geologically allied disciplines, geomorphology, Quaternary geology and geotechnical engineering. The analytical techniques that have been used throughout the study are all standard within each discipline. However, some techniques, for example the hand preparation of specimens to reduce sample disturbance, are only suitably applied in a research environment due to the time spent in sample preparation. This could not be feasibly spent in an industrial situation. It has been possible to improve existing techniques of determining certain soil properties (for example in the theoretical estimation of soil permeability) and to accurately determine physical and mechanical parameters during soil testing, by recreating in situ conditions. This has only been possible by successfully performing the tasks in a research environment.

It has become quite apparent that it has always been necessary within the investigation to relate all geological and geotechnical aspects of the study to a model of glacial deposition which has been developed from a comprehensive geomorphological appraisal of the area. From this model it has been possible to plan, in detail, the site investigation programme. The model has been consulted in the initial stages of the programme for choosing the location of areas for a detailed geological appraisal. At times it was used on a highly localised scale to assist in choosing the location of specific sampling points such that a full range of soil properties may be recorded. Throughout the soil testing programme it was necessary to refer to this glacial model to :-

1. assist in choice of the method of sample preparation and testing suitable for each soil type

2. enable conclusions to be drawn concerning reasons for data variability within and between soils

3. assist in the interpretation of the results obtained such that relationships may be drawn between mechanical and physical data in terms of the local geomorphology.

Without drawing together the three disciplines encompassed in this investigation such that they become fully integrated, the methodology of a geotechnical appraisal of ground conditions in an area of former glaciation cannot be expected to fully succeed in providing reliable estimates of the inherent variability of the soils.

Site investigation is the method by which to appraise the ground conditions so as to form a basis for the engineering design. It should thus be executed with all available sources of information and techiques at hand.

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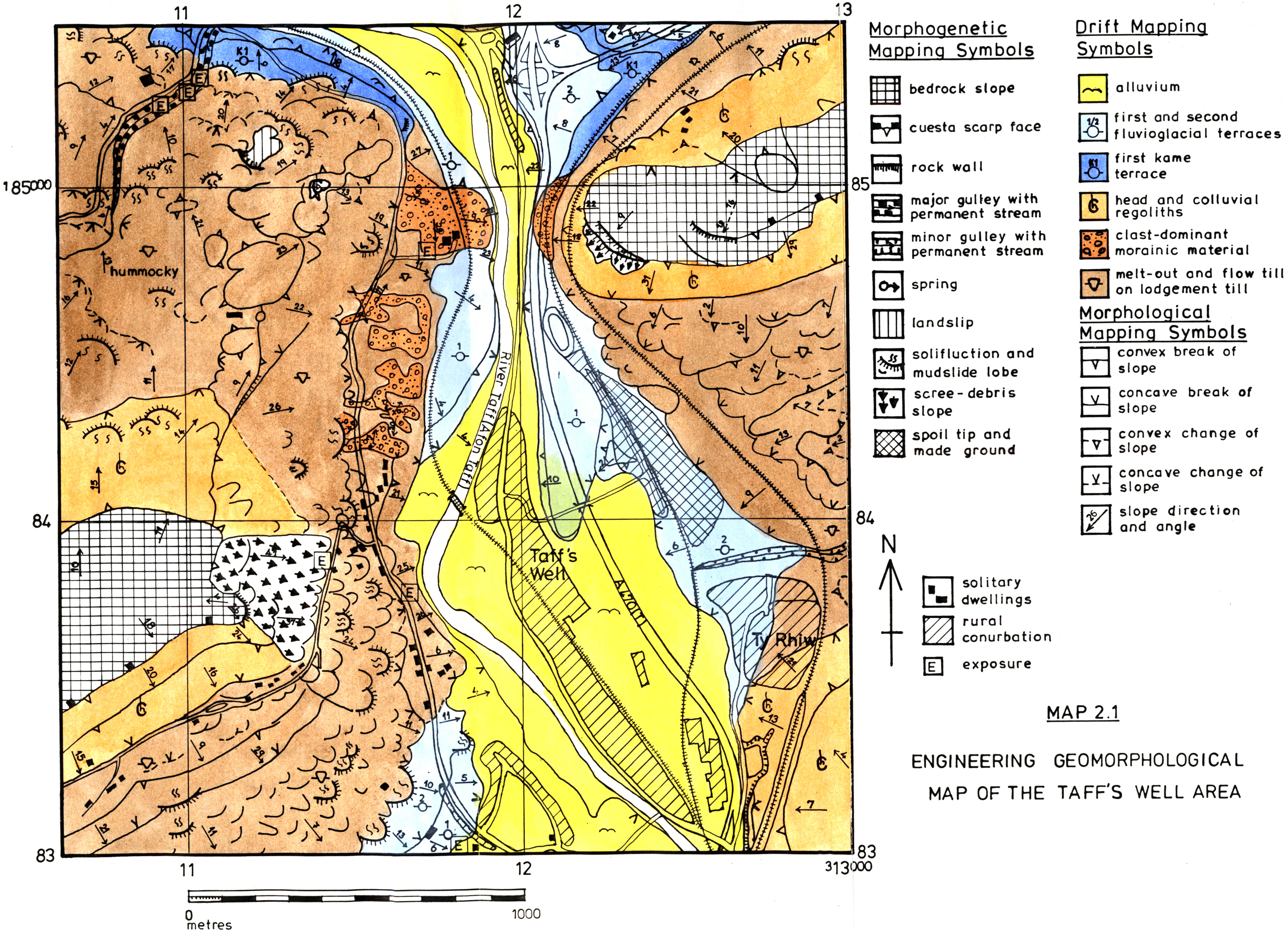
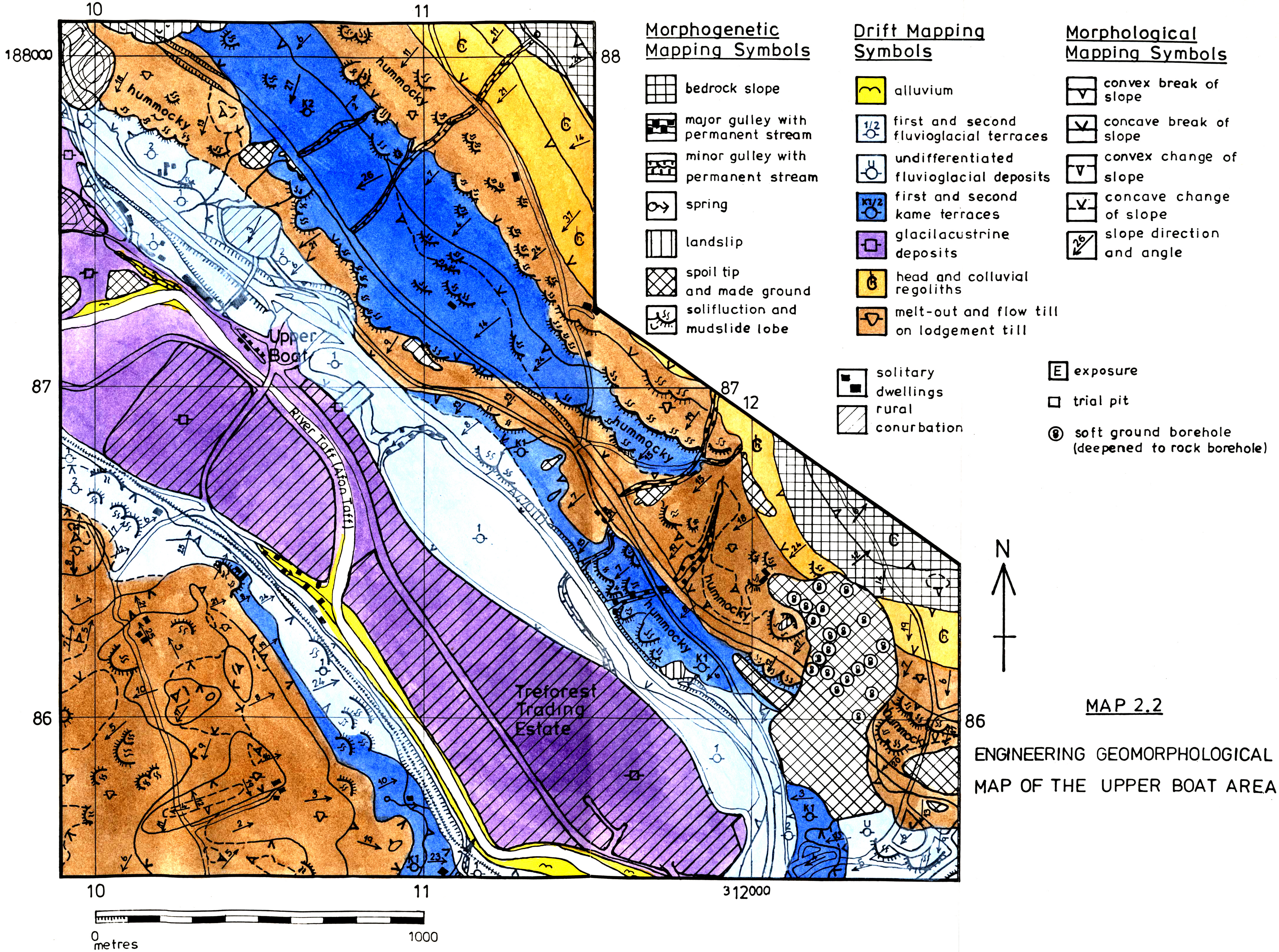


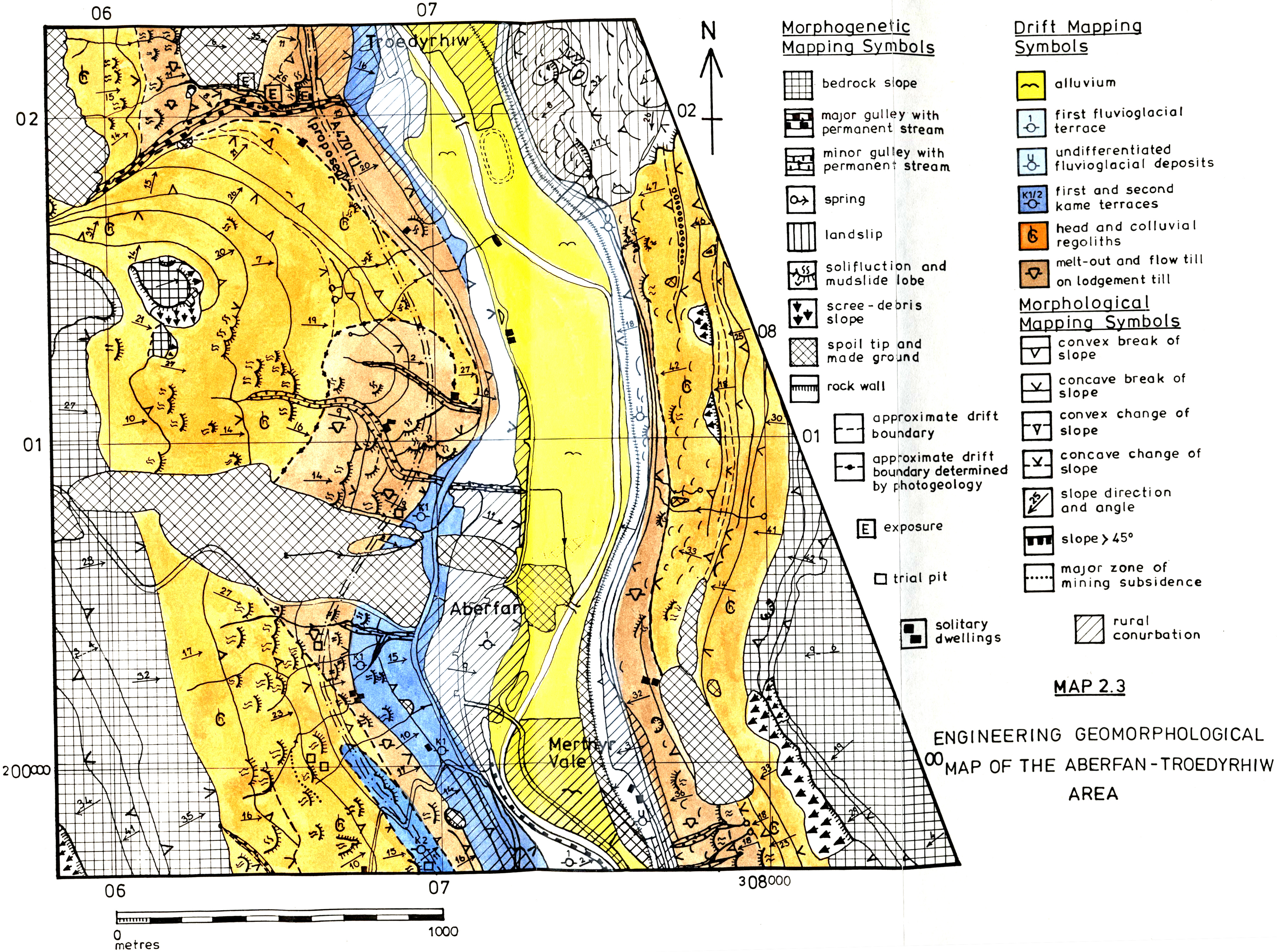
MAP 2.1

ENGINEERING GEOMORPHOLOGICAL MAP OF THE TAFF'S WELL AREA



MAP 2.2

ENGINEERING GEOMORPHOLOGICAL MAP OF THE UPPER BOAT AREA



MAP 2.3

ENGINEERING GEOMORPHOLOGICAL MAP OF THE ABERFAN-TROEDYRHIW AREA