Soil genesis in south-west Dyfed, Wales

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SOIL GENESIS IN SOUTH-WEST DYFED, WALES

by

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A thesis submitted for the degree of
Doctor of Philosophy in the University of Durham,
September 1976

Tę pracę poświęcam rodzicom moim.

(This work is dedicated to my parents.)

"I think it is finished - always spoken comparatively, for in reality I shall never think of my own work as finished."

Vincent Van Gogh, 1885,
referring to the painting of "The Potato
Eaters" in a letter to his brother, Theo. *

---

* Stone and Stone (1973, p 344).

Cliffs of red siltstone supporting the thin plateau soils at St Ann's Head, Dale (804 031)

ABSTRACT

A study of soil genesis in a small area of south-west Wales is presented.

The soil-forming factors are considered first in the context of time. The evolution of the factors and the importance of past environments and conditions in affecting these factors, and hence less directly the present-day soils, is emphasised. The soil-forming factors are also examined in the spatial dimension. Two of these factors - "topo-drainage" and "parent material" - are particularly important as determinants of soil type and are plotted on the Pedogenetic Map.

The Pedogenetic Map is a map of the soil-forming environment and not of soils as such. Its relationship to the soils of the study area is discussed, however. Soil types are also described according to the new classification (Avery, 1973) of the Soil Survey of England and Wales, and selected properties are examined.

The second part of the thesis concerns itself principally with the soil sand fraction.

The lithological composition of the sand fraction is investigated, and it is shown that the coarsest sand fraction (2,000 μm - 1,200 μm) can be used as an indicator of the provenance of the soil "parent material". Contamination of finer sand fractions is also encountered and this is pursued in the analysis of detailed size distributions of the soil sand fractions. These studies also suggest a mechanism of weathering by surface granular disaggregation of sand-sized red siltstone fragments in the soils. Additional evidence is given for this

mechanism from scanning electron microscopy, followed by a brief discussion of the theory of grain size distributions.

Finally, the different sources of information are drawn together in an attempt to effect a reconstruction of the environment that has influenced soil genesis in the area.

DECLARATION

The work described in this thesis was carried out in the University of Durham between September 1972 and July 1975. This work has not been submitted, either completely or in part, for a degree in this or any other university and is the original work of the author except where acknowledged by reference.

J Horbaczewski

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Most of soil research is concerned either with the compilation of a soil map with all its attendant problems of soil classification and mapping, or with the analysis of particular soil properties in a study of genesis; very often the former is a pre-requisite to the latter. Currently, with the increasing use of computers, various attempts are being made to marry the two objectives. An unfortunate consequence is that selected parameters become rigidly defined and accepted, principally for ease of manipulation. It is the author's contention that too little is known about many soil properties and that more attention should be directed to empirical studies.

Little is known, in particular, about the soil sand fraction - a particle size range rather neglected in comparison with the clay, or even silt, fractions. Often described as an "inert soil skeleton", the sand grades act as a source of finer soil particles as they are commonly not composed entirely of quartz (Stewart, Adams and Abdulla, 1970), and they are also very valuable as provenance indicators for soil materials (Blatt, 1967). The lack of interest in the soil sand fraction is surprising but is probably due, in part, to its peripheral academic "status" falling, as it does, between the three "stools" of pedology, engineering geology and sedimentology.

1.2 THESIS STRUCTURE

The objective of the thesis is to investigate development of the soils in a small area. The temporal element of the soil continuum is considered first (Chapter 2) in a necessarily deductive manner; the spatial dimension (Chapter 3) is approached in a more inductive manner on the basis of evidence from air photograph interpretation and field survey, and with reference to the Pedogenetic Map. Chapter 4 describes the soils of the area, their relationship to the Pedogenetic Map and their general properties, providing, in effect, a survey base for more detailed studies.

Succeeding work (Chapters 5 and 6) is directed towards an analysis of the soil sand fraction, considered to be the best genetic indicator in this case study. Samples are confined to comparable sub-areas. The lithological composition of the soil fraction is used (Chapter 5) to check the field classification of soil material types, and an empirical criterion is derived for distinguishing between soils formed from bedrock and other soils. Contamination of apparently "pure" soils (soils derived exclusively from bedrock) is also investigated.

Analysis of the size distribution of the sand fraction (Chapter 6) offers an insight into some of the fundamental mechanisms involved in the weathering of red siltstones. The origin of the silt and clay fractions is discussed in this context.

Finally, the evidence from all these sources is employed to effect a reconstruction of the pedogenic environment, both past and present (Chapter 7).

1.3 THE STUDY AREA

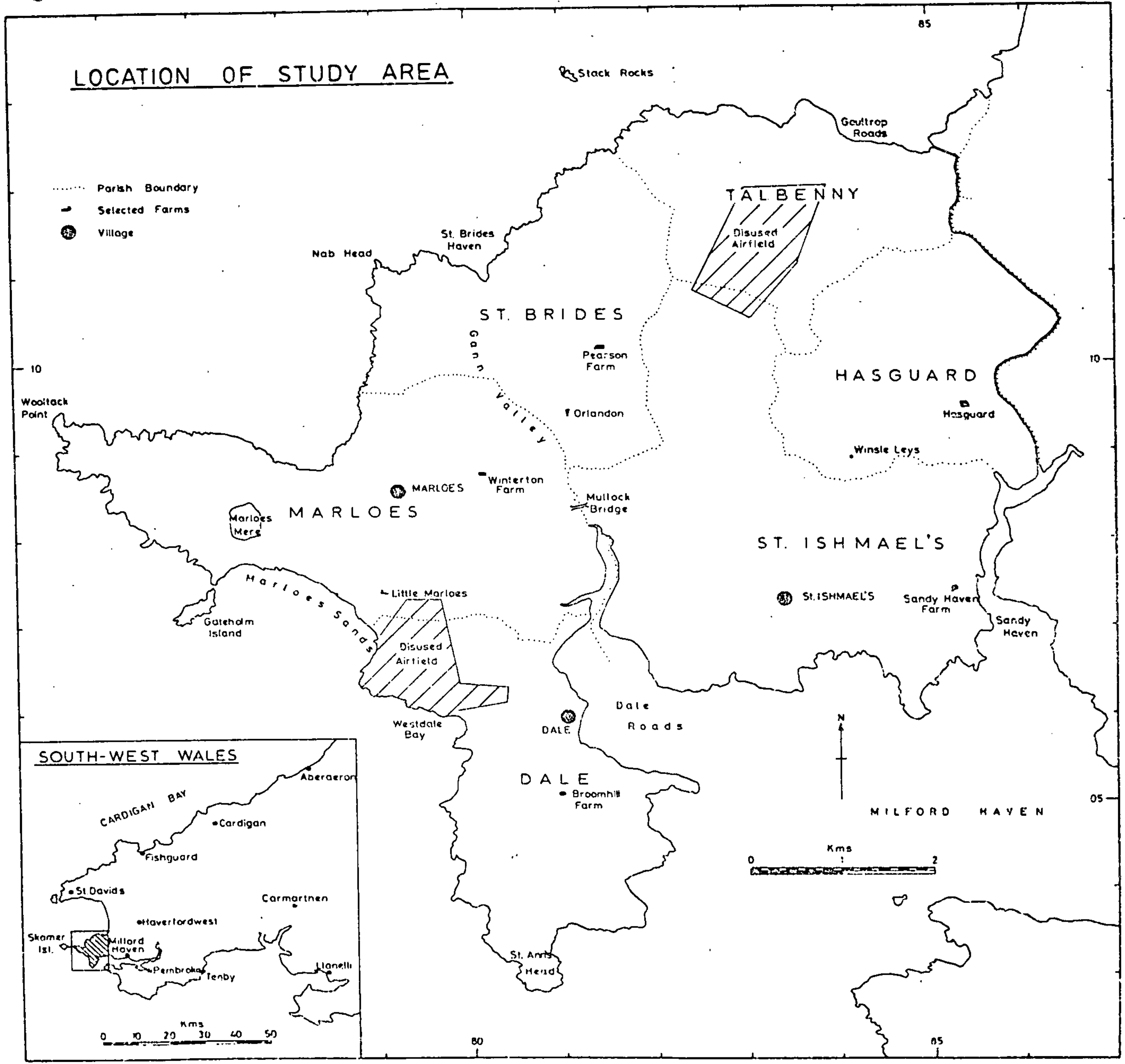
1.3.1 General

The study area extends over the central of the three peninsulas of south-west Dyfed (formerly Pembrokeshire) and is generally known as the Marloes (or Dale) Peninsula, although this latter term is also sometimes applied to the smaller peninsula occupied by Dale parish (Fig 1a). The area is bounded to the east by drainage lines which also define parish boundaries, and ends in sheer cliffs along much of the coast-line (see Frontispiece). A surface of approximately 50km^2 is thus demarcated. The island of Skomer, lying to the west, is not included, but Gateholm island is.

In terms of agriculture, the study area coincides exactly with the Dale Peninsula "Land Use Region" described by Davies (1939, pp 154-155). It is the unusual climate of the area which warrants this distinction (see section1.3.3). Both soils and climate combine to make this region very attractive for growing "early potatoes" (Rudeforth, 1971), although beef cattle are also kept, necessitating some growing of feeding stuffs; some horticulture has also been practised (Dresser, 1959). A survey of the land use of west and central Pembrokeshire is the most recent detailed source of information (Rudeforth and Bradley, 1972).

The study area is located entirely within the Pembrokeshire Coast National Park and offers facilities for sailing and sub-aqua diving. It

Fig 1a


LOCATION OF STUDY AREA
Parish Boundary
Selected Farms
Village
Stack Rocks
Gaultrop Roads
TALBENNY
Disused Airfield
Nab Head
St. Brides Haven
ST. BRIDES
Pearson Farm
Orlandon
Gann Valley
HASGUARD
Hasguard
Winsle Leys
Wooltack Point
MARLOES
Winterton Farm
Marloes Mere
Mullock Bridge
ST. ISHMAEL'S
St. ISHMAEL'S
Sandy Haven Farm
Sandy Haven
Marloes Sands
Little Marloes
Gateholm Island
Disused Airfield
Westdale Bay
DALE
Dale Roads
DALE
Broomhill Farm
St. Ann's Head
N
MILFORD HAVEN
Kms
0
1
2
SOUTH-WEST WALES
CARDIGAN BAY
Aberaeron
Cardigan
Fishguard
St Davids
Carmarthen
Haverfordwest
Skomer Isl.
Milford Haven
Pembroke
Tenby
Llanelli
Kms
0 10 20 30 40 50
85
10
05
80
85
10

is also of great interest to naturalists, with bird sanctuaries in the nearby Skomer and Skokholm islands. The importance of the coastal scenery for tourism has been recognised in the recent designation in South Wales of "Heritage Coasts", including the entire coastal perimeter of the study area (Hughes, 1976).

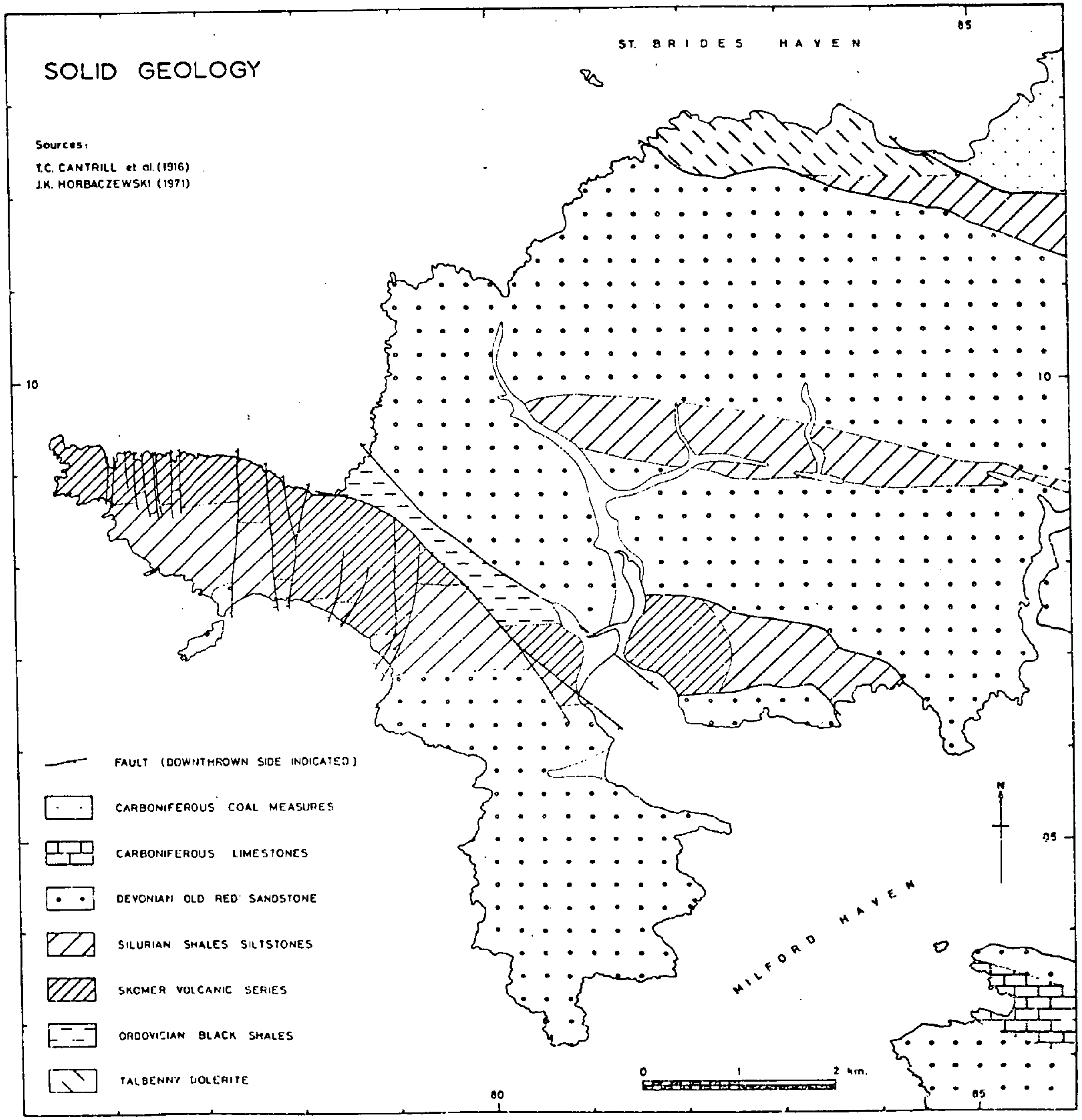
The particular topography and weather of south-west Pembrokeshire was, in addition to strategic considerations, especially well suited for the location of airfields in the Second World War (Thomas, 1956). Two of these were constructed in the study area (see Fig 1a) and have yet to be returned fully to agriculture. Not only are they taking up valuable agricultural land, but they are unsightly and undesirable in a National Park (Price, 1973).

1.3.2 Geology

The rocks in the study area span the geological succession from the Ordovician to the Devonian Periods, with the Carboniferous represented just beyond the northern margin (Fig 1b; see also Table 2(i)). In detail, the geology of the area is complex as a result of dense faulting that has been obscured by superficial material.

Geological investigations of the region are few in number, and the only complete survey of the whole study area is that of Cantrill et al (1916). Subsequent research has been carried out by Thomas (1911), Ziegler et al (1969), Horbaczewski (1971), Sanzen-Baker (1972), and Allen (1974). As a result of these additional studies, the stratigraphic sequence has been revised, with the Skomer Volcanic Series post-dating the Ordovician black shales rather than preceding them in

Fig 1b


SOLID GEOLOGY
Sources:
T.C. CANTRILL et al. (1916)
J.K. HORBACZEWSKI (1971)
ST. BRIDES HAVEN
MILFORD HAVEN
85
10
10
05
80
85
N
0
1
2 km.
FAULT (DOWNTHROWN SIDE INDICATED)
CARBONIFEROUS COAL MEASURES
CARBONIFEROUS LIMESTONES
DEVONIAN OLD RED SANDSTONE
SILURIAN SHALES SILTSTONES
SKOMER VOLCANIC SERIES
ORDOVICIAN BLACK SHALES
TALBENNY DOLERITE

the geological column (Ziegler et al, 1969; Horbaczewski, 1971).

In general terms, the geological succession in the study area "youngs" southwards owing to a regional dip of about 20° to the south. In places, however, strata may be vertical due to faulting. The shape of the study area is also partly explained by this faulting which has progressively downthrown westwards and given rise to headlands of resistant volcanic rock and bays of eroded sediments. The faulting is, in fact, a manifestation of much larger-scale structural features described by Sanzen-Baker (1972).

Details of lithologies and geological evolution are given in the next chapter (section 2.2).

1.3.3 Climate

An exhaustive analysis of the climate of Dale parish has been provided by Oliver (1959), while the regional precipitation patterns in south Wales have been investigated by Faulkner and Perry (1974).

In essence, the study area is distinguished by the mildness of its climate and by its relatively low rainfall due respectively to the proximity of the sea - no further than 3 kms from any part of the study area - and to its unobstructed exposure to the Atlantic Ocean.

Temperature

The moderating effect of the sea on air temperatures is apparent when the data for the Dale Peninsula are compared with those for Haverfordwest (Table 1(i)). Temperature ranges on the coast are reduced on both diurnal and annual scales. (In this connection it is also probable that the climate of the study area has also been stabil-

TABLE 1(i)

Monthly Averages of Daily Maximum and Minimum Temperatures (°C)

Haverfordwest - Alt 40 m (131 ft) OD
Dale Fort - Alt 33 m (109 ft) OD

	J	F	M	A	M	J	J	A	S	O	N	D
Haverfordwest*												
Maximum	7·8	7·9	9·9	12·3	15·2	17·8	19·0	19·3	17·3	14·0	10·8	8·9
Minimum	2·6	2·2	3·2	4·9	7·2	10·1	11·9	11·9	10·3	7·5	5·2	3·6
Range	5·2	5·7	6·7	7·4	8·0	7·7	7·1	7·4	7·0	6·5	5·6	5·3
Dale Fort+												
Maximum	8·0	7·5	9·3	11·6	13·4	16·9	18·6	18·3	16·4	14·1	10·9	9·8
Minimum	4·0	2·9	4·7	5·8	8·2	10·9	12·9	13·2	12·1	9·8	7·1	5·9
Range	4·0	4·6	4·6	5·8	5·2	6·0	5·7	5·1	4·3	4·3	3·8	3·9

* (1931-1960) - Rudeforth (1974, p 11)

\+ (1950-1957) - Oliver (1959, p 43)

ised relative to the hinterland since the Flandrian return of the sea to its present level.) There is a considerable difference between the two stations in the minimum temperatures which are higher than inland at all times of the year but especially so in the winter months.

As far as plant growth is concerned, the threshold temperature (taken as 6·0°C) is exceeded by the mean monthly average at Dale Fort in all months except February, so that the growing season extends almost the whole year (Oliver, 1959), whereas it is reduced to about 320 days further inland around Haverfordwest (Rudeforth, 1974, p 11).

Perhaps of more importance to "early potato" growers is the incidence of frost. Around Haverfordwest, frost is likely until the third week of April, and in exceptional years can occur even in the second half of May (Rudeforth, 1974, p 11). Nearer the coast, air frosts are relatively few (Oliver, 1959), and are practically unknown west of Orlandon and the Gann Valley (Davies, 1939, p 155).

Wind

Exposure to wind is possibly the limiting climatic factor to arable farming in the study area, often causing salt scorch from sea spray and lodging of cereals. Oliver (1960) has shown that the dominant wind direction is from the west and south-west : it is sufficiently powerful and consistent to deform trees and shrubs. The severest gusts in winter are usually from this direction and are liable to have gusts of 90 to 100 mph (Thomas, 1956).

Rainfall

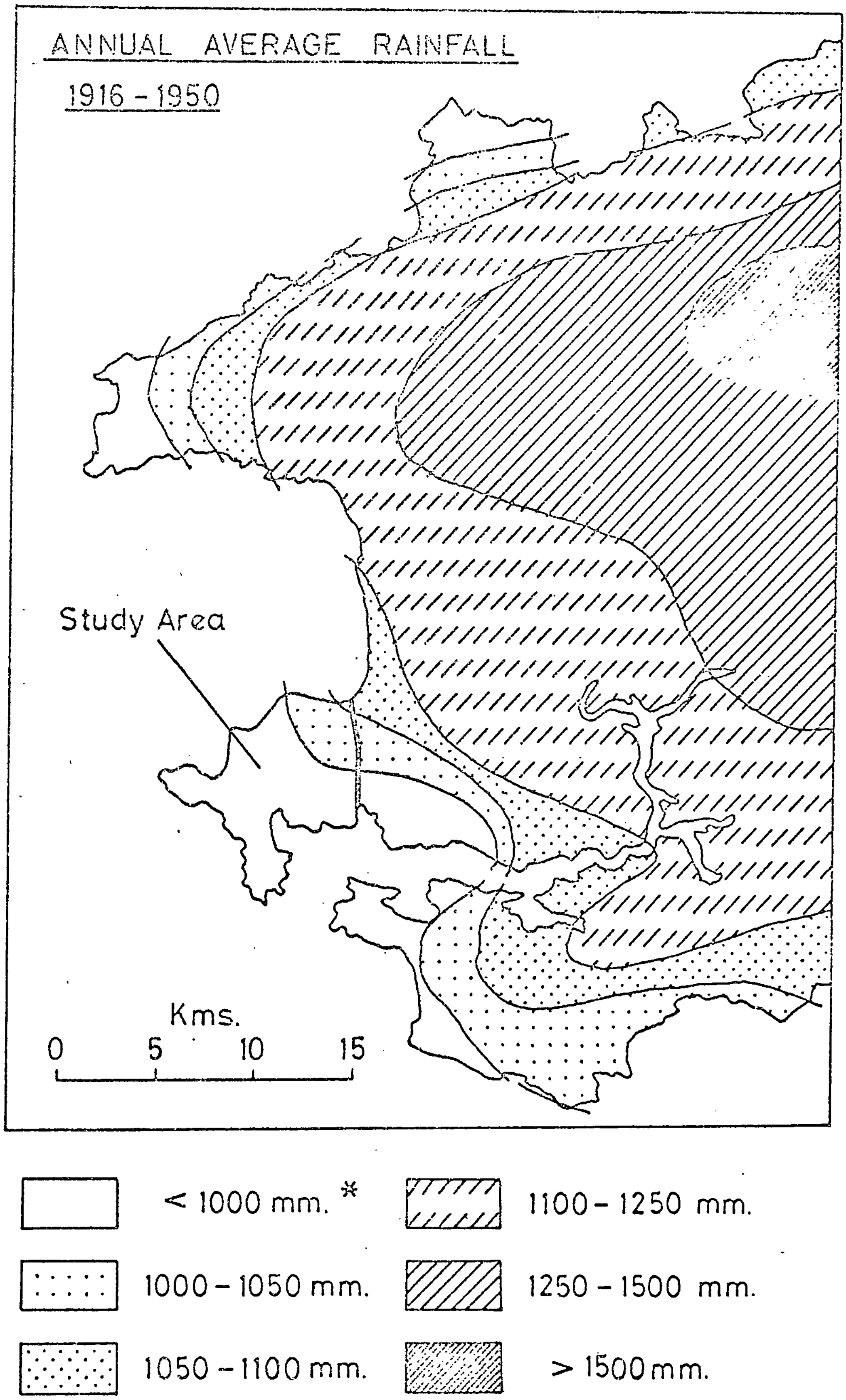
A steep gradient exists in the annual rainfall from the study area further inland (Fig 1c), lending some credibility to the local axiom that there is an increase of an inch of rainfall per mile between Marloes and Haverfordwest. Faulkner and Perry (1974) stress the importance of topography and shelter on precipitation patterns in south Wales. The study area, as noted earlier by Oliver (1959), is shown to be particularly sheltered and has lower annual precipitation totals than the eastern shores of Carmarthen Bay or Swansea Bay.

Regardless of the weather type, precipitation in the study area is much lower than at sites further inland (Faulkner and Perry, 1974). The south-westerly types with moist maritime tropical air does not shed its load till it reaches higher ground; the westerlies likewise reveal much higher falls over higher ground to the east; easterly types emphasise the sheltering effect of the uplands on the west coast, while north-westerlies may be moderated by Ireland. Longest spells of showery weather appear to be associated with south-west to westerly polar airstreams circulating around deep polar-air or well-occluded depressions showing little movement over the sea areas to the west of Ireland (Thomas, 1956).

However, much of the rainfall in the study area is distributed in small showers. The frequency of heavy daily precipitation (greater than 25 mms) at Dale Fort over the 1956-61 period, for example, was less than one-fifth of the number recorded at Blyntrawe, Brecknock, South Powys (Faulkner and Perry, 1974).

The combination of a relatively mild climate and low rainfall in the study area would suggest the frequent occurrence of soil moisture deficits in the drier summer months. Rudeforth and Bradley (1972,

Fig 1c



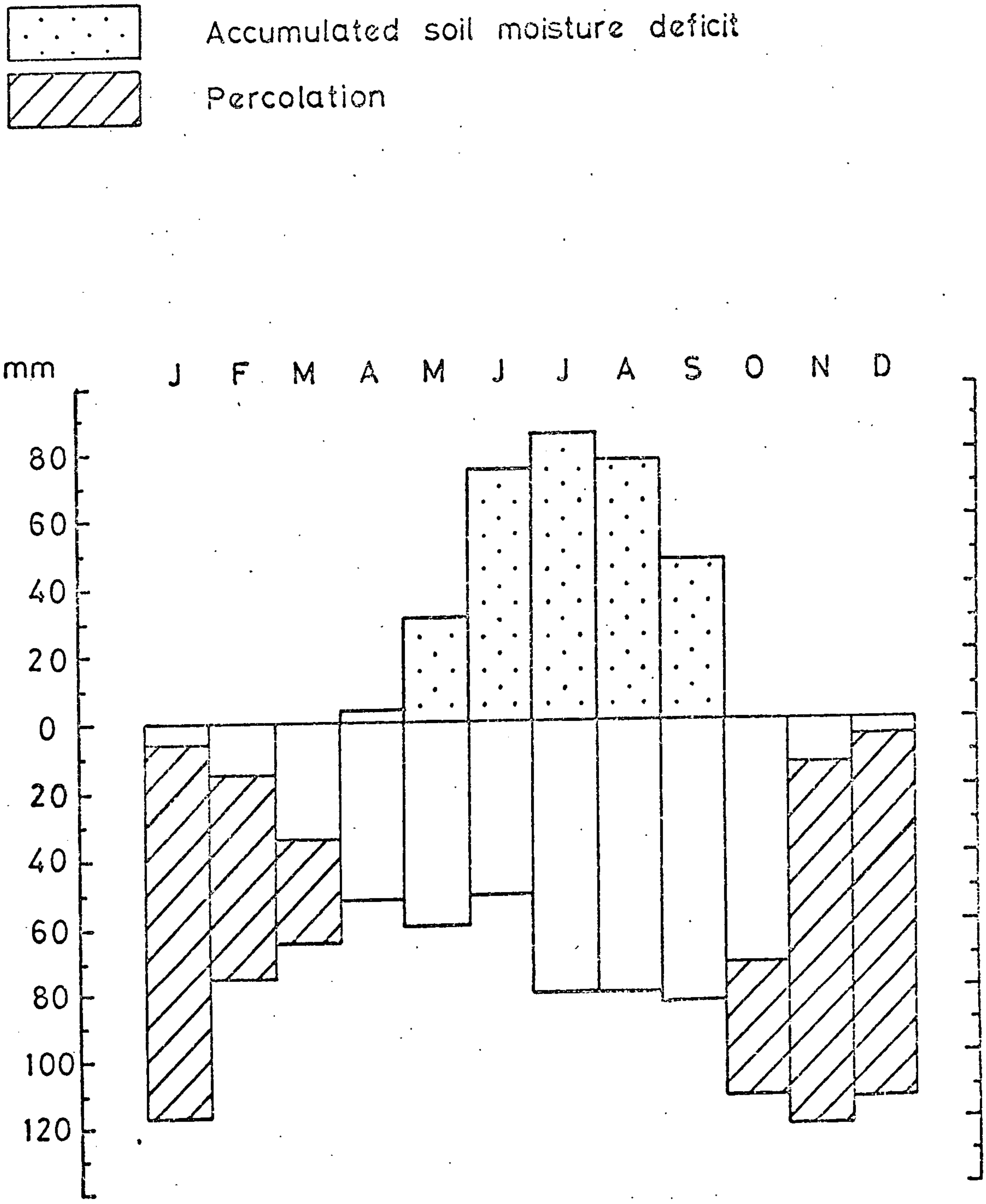
Adapted from: C.C. RUDEFORTH & R.I. BRADLEY 1972

* 1000 mm = 40 inches

Fig 1d

ESTIMATED SOIL MOISTURE REGIME FOR SITES NEAR MILFORD HAVEN

— at about 1000 mm (40 in.) annual rainfall (1916–1950)



Potential Transpiration (mm)	6	15	34	56	86	95	92	77	55	24	13	5

Source: RUDEFORTH, 1974 p12

p 2) report deficits of 75 mm (3 inches) or more as often as eight years in ten for such an area. The average monthly distribution of rainfall over the period of 1916-1950 and an estimate of the soil moisture regime at sites near Milford Haven is given (Fig 1d). In drier years, soil moisture deficits may occur early, and irrigation is then recommended to increase early potato yields (Rudeforth, 1974, p 13).

It should be stressed, however, that climatic conditions are so variable in such coastal situations, particularly with respect to humidity, that detailed local studies are necessary before the magnitude and extent of soil moisture deficits can be accurately evaluated (Oliver, 1959).

1.4 PREVIOUS WORK

Some of the earliest, indirect references to the soils of Pembrokeshire are to be found in the sixteenth-century "Description of Pemrokeshire" by George Owen of Henllys (Owen, 1892); distinctions are drawn between different types of land and how they should be managed for maximum profit.

The first specific classification of Pembrokeshire soils, however, is to be found in Hassall's (1794) - "General View of the Agriculture of the County of Pembroke". Four classes of soil were recognised (pp 8-10) :-

> "The first (class) is the strong red loam, with a substratum of red rock, or what is here provincially called Rabb. This red rabb, when thrown up and exposed for

> some time to the sun and air, becomes friable, and breaks down to a saponaceous substance . . .. The general thickness of the red loamy soil, is from 6 to 14 inches. Average about 10 inches.
>
> The next soil in value, is the grey loam, composed of a mixture of sand and brick earth, with a sub-stratum of brown and blue rock or rabb. Of this soil, the largest portion of Pemrokeshire consists . . .. This soil is generally from 6 to 12 inches thick. In some parts of the district, this kind of soil is found upon a clay bottom.
>
> The next (third) class is a light peaty soil, upon a clay bottom; and justly deemed the worst of all. The lands of this class are generally wet and cold; and in their natural state, very unproductive . . ..
>
> The fourth class is the peat, which abounds in the mountainous parts of the county . . .."

The first class clearly refers to the ranker soils derived from Devonian red siltstones (still called red rabb locally), corresponding almost exactly with the present-day criteria (section 4.4).

Results of the Soil Survey of Wales began to be published from 1925 onwards, but no detailed work was undertaken in the study area (Ball, 1959). Robinson (1935) provides a comprehensive classification of Welsh soils based on profile morphology and laboratory analysis. The red siltstone soils are briefly mentioned (p 266):-

> "With the skeletal soils one may venture to group certain soils which appear to be pedologically undeveloped, but which, from the agricultural standpoint, are definitely soils. Such soils occur associated with Old Red Sandstone and Triassic Marls."

This classification and guide to the soils of Wales did not include a soil map, however.

Rudeforth and Bradley (1972) covered the study area, describing soil profiles and sampling on a 1km grid basis, in the course of a broader survey on the "Soils, Land Classification and Land Use of West and Central Pembrokeshire". Point distribution maps of Soil Groups, Land Use Capability Classes, Land Use Capability Subclasses and Land Use were included with this publication, and the information gathered is being used in the preparation of the new series of Soil Survey Records.

To date, two such surveys have appeared in print : one covers a $100km^2$ block near Carmarthen (Clayden and Evans, 1974), and the other comprises two such blocks and extends from Haverfordwest to Pembroke (Rudeforth, 1974). This latter area is separated by a zone about 5kms wide from the study area. As yet, the study area has not been investigated by the Soil Survey.

The Soil Survey Records are essentially concerned with the compilation of a soil map (in these cases at a scale of 1:25,000) and a description of the soils; land use and capability assessments are also included. Very little consideration is given to soil genesis and therefore these publications, though of considerable general interest, have proved to be of limited use in this study.

1.5 CONCEPTS

(i) Factorial Concept

Possibly the key concept in pedological theory is the concept of the "soil-forming factors" formalised by Jenny (1941) from the body of thought that had developed from the initial ideas generally accredited to Dokuchaiev (Basinski, 1959). Five factors were defined:- Parent Material, Topography, Climate, Time, and the "Biotic" or "Organic" Factor (Jenny, 1941). A sixth factor, acknowledging Man as an influence on soil-formation, has been recommended for cultivated soils (Bidwell and Hole, 1965; Yaalon and Yaron, 1966).

Since its publication, Jenny's treatise has been subject to much criticism and discussion including Nikiforoff (1942), Crocker (1952), Bunting (1967).

Recent reviews are provided by Birkeland (1974), Yaalon (1975).

The genius of the concept lies in the analytical perspective it offers to the study of soil genesis. By selecting areas where only one factor varies and all the others are constant, nature can be consciously used as "a laboratory" and the variations in soil morphology and properties can be related to the variable factor.

One of the weaknesses is that, despite the mathematical notation (Jenny, 1961), the "factor equation" is difficult or even impossible to solve (Yaalon, 1975).

Moreover, the concept does not help at all in the elucidation of the fundamental mechanisms involved in pedogenesis - it may, at best, give an indication of the kind of processes in operation. In fact, the factors are composed of components, and these have to be resolved into the fundamental variables (defined by parameters) that operate in particular soil systems for more detailed studies, and in many cases these parameters will not be measurable for technical reasons.

(ii) Concepts of Weathering and Soil-formation

One of the principal problems in differentiating between weathering and soil-formation is that both processes are often operating simultaneously and over a similar depth in the earth's crust. Weathering profiles can be observed well below the surface soil horizons under tropical conditions (Ollier, 1969, pp 120-134), but the two are usually coincident in temperate climates.

Nikiforoff (1949) describes the mode of action of weathering as "rectilinear" and that of soil-formation as "cyclical". (Other terms have been used, such as "run-down" or "irreversible" for the former, and "steady-state" or "equilibrium" for the latter.) Thus the disintegration and decomposition of rocks and minerals is non-reversible and qualifies as weathering, while the recycling of nutrients or organic matter by various agents of the "biotic" factor is called soil-formation:-

> "All cyclic processes of soil formation are kept in motion by the living matter which controls migration of the elements and energy that are involved in these processes. This is the principal determining characteristic of all strictly pedogenic processes. The dynamics of weathering depend upon the climate; the dynamics of soil formation, upon the organic world."
>
> (Nikiforoff, 1949, p 227)

(iii) Concept of Cumulative and Non-Cumulative Soils

The simple distinction between weathering and soil-formation processes is somewhat obscured by the action of the geomorphic processes of erosion and sedimentation. These interfere with weathering by removing only partly weathered material and exposing fresh surfaces. Were it not so, then the surface of the earth "would be wrapped in a lifeless mantle thoroughly deprived of the unstable minerals, composed entirely of those most resistant to any further changes, and, hence, essentially static" (Nikiforoff, 1949, p 222).

As far as soil-formation is concerned, the geomorphic processes cause erosion or burial of the surface soil horizons. The designation of soils as cumulative or non-cumulative (Nikiforoff, 1949) serves to distinguish the soils that are built up from above by sedimentation from the soils that are developed from underlying material as a result of surface erosion. The soil horizons migrate in response to these changes in the position of the soils surface as "each soil horizon develops at a certain depth, at which its parent material is continuously affected by some specific process that is peculiar to such a horizon. As soon as this process ceases to operate in any part of the horizon, this part loses its individual characteristics and, figuratively, dies off, becoming subject to remaking into a different horizon." (Nikiforoff, 1949, p 228).

(iv) Concepts of "Steady State" and "Periodic" Phenomena in Soil-Landscape Systems

Steady state soils have been defined as "those that are in equilibrium with their conditions, especially topographic conditions, and although not inert they retain the same morphology" (Ollier, 1969, page 167). Thus, besides the steady state conditions operating within the soil profile with respect to processes of soil-formation (see Concept (ii)), steady state conditions can also prevail in the relationship between soils and slopes (see concept (iii)), and occur when the rate of addition equals the rate of removal of material on the different slope elements.

In contrast, periodic soils are thought to result from catastrophic events (Butler, 1959; Curtis, 1975). Rapid erosion or deposition affects the entire soil profile during an "active" phase which is then followed by a more stable phase. Ollier (1969, pp 169-170) points out, however, that periodic phenomena are still little understood and suggests that soil-formation and weathering are continuous, but that erosion and deposition are periodic at any one place.

(v) Concept of Weathering Intensity/Leaching Intensity in Pedogenesis

Crompton (1960), in a development of work on the variability in mobility of soil chemical constituents (Polynov, 1937), suggested that weathering and leaching should be regarded as separate processes, and that the differentiation of the main soil profiles of the world can be broadly explained in terms of the weathering/leaching ratio.

As such the concept is process-oriented, as for example Simonson's (1959) theory of soil genesis, and appeals as a more rigorous and quantifiable proposition than Jenny's (1941) factorial concept. However, it implies that soil-formation is, to a large degree, a function of leaching. While the interaction of weathering and leaching is of considerable importance in soil genesis, it should be recognised that the soil is more than just a mineralogical/chemical system, and that a powerful homogenising and recycling counteraction is exerted by the "biotic" agents.

CHAPTER 2

HISTORY OF THE SOIL-FORMING FACTORS AND THE EVOLUTION OF THE SOIL

2.1 INTRODUCTION

Soil is commonly described as a "continuum in space and time"; the implication being that a strong influence is exerted on the appearance and properties of a soil by factors that were operating in the past as well as those acting at present. The concepts of a "historical hangover" and "dynamic equilibrium" associated with the development of slopes (Chorley, 1964) apply equally well in pedogenesis.

Attractive though it may sound, the concept of a temporal continuum needs to be modified to accommodate the "catastrophic" or "periodic" phenomena in soil formation reported by Butler (1959), and Curtis (1975). In truth, the question is one of scale; some processes requiring much more time than others (Yaalon, 1971).

It should also be recognised that, on broader time scales, pedogenesis (in this case including weathering and soil-formation) is a cyclic process embodied in even greater geological and geomorphological cycles (Nikiforoff, 1949). Therefore, time, like space, can be used as a framework for the evaluation of the environmental or "active" (Duchaufour, 1960, p 153) factors involved in weathering and soil formation:-

> "Time and space are elements of the essence of being but not factors in any particular form of being. Every material object occupies a certain space, but its existence is not caused by the space. Every change takes a certain time, but, again, it is not caused by mere passing of time."
>
> (Nikiforoff, 1959,p 192)

2.2 GEOLOGICAL EVOLUTION

Where soils are derived from bedrock, some of their fundamental properties - such as texture, mineralogy and, to a certain extent, chemistry - are inherited with little change. These lithological properties have been, in turn, strongly controlled by the original environment of formation and subsequent geological history. A consideration of the geological evolution can be helpful in predicting the potential variability of these soil properties.

Essentially, the sedimentary sequence of the study area represents a land-mass emerging from seas which gradually became more shallow (see Table 2(i)). The Skomer Volcanic Series is evidence of an episode of volcanicity in shallow seas (Ziegler et al, 1969), associated perhaps with the subduction of the lithosphere in an "island arc" situation (Fitton and Hughes, 1970; Sanzen-Baker, 1972). Shallow-marine and eventually brackish-water conditions are indicated by the fossil communities in the succeeding Silurian sediments (Ziegler et al, 1969), while the onset of truly terrestrial conditions is represented by the red-coloured Devonian strata.

In terms of areal extent, it is these latter which constitute the most important geological formation in the study area (approximately

TABLE 2(i)

Geological History of the Study Area

PERIOD	LITHOLOGY	ENVIRONMENT OF DEPOSITION
TERTIARY	Marine Planation	
TERTIARY	Alpine Tectonic Movements	
DEVONIAN/ CARBONIFEROUS	Hercynian Tectonic Movements	
DEVONIAN	Red siltstones, sandstones and conglomerates	Terrestrial floodplain. Braided river and alluvial flats
SILURIAN	Yellowish-grey siltstones/ sandstones	Shallow marine/ deltaic
	Coralliferous shales/ siltstones	Shallow marine
	Small Unconformity	
	Fossiliferous shales/ siltstones	Shallow marine
	Series of lavas and thin sediments (Skomer Volcanic Series)	Terrestrial and shallow marine
ORDOVICIAN	Nature of Contact Unknown	
	Black shales with limy bands	? moderately deep geosynclinal sediments

Sources (varied) include : Cantrill et al (1916); Ziegler et al (1969); Horbaczewski (1971); Sanzen-Baker (1972)

60%). For this reason, and also because most of the detailed analyses of Chapters 5 and 6 are confined to soils overlying Devonian bedrock, special attention will be given to the geological evolution of this unit.

The best interpretation to date of the palaeoenvironment of formation is that originally advanced by Allen (1963). The fining-upwards cyclothems of the Lower Devonian Formation - the Red Marls Group - are taken to represent episodes of crevassing of rivers on a braided-river flood-plain, probably draining northwards in the Marloes area (Sanzen-Baker, 1972). Each cycle displays a transition upwards from channel deposits, through point bar deposits to flood-plain sediments.

Thus each of the lithologies can be interpreted as follows (Allen, 1963):-

(i) Siltstone/mudstone. These flat-bedded sediments are indicative of sedimentation on a flood-plain. They fine upwards, accordingly, sometimes from fine sandstone, but generally siltstone to much finer muds. These latter may suggest the existence of mud-flats and temporary lakes. Carbonate concretions (cornstones) are thought to have formed in the uppermost layers under repeated dessication on the flood-plain.

(ii) Sandstone. Generally speaking, the sandstones represent material that was deposited fairly rapidly from flood-waters and are, therefore, found in fan-shaped systems of braided distributaries opening from crevasses on to the flood-plain. They may also record deposition on the banks and margins of channels, and on flats between channels.

(iii) Cross-bedded sandstones and conglomerates. By their texture and structure, these sediments indicate high energy environments and are therefore probably attributable to the lower parts of channel beds.

The most extensive and least variable are the flood-plain deposits. The name "Red Marls" for the Lower Devonian of the area is derived from these sediments, although it is a misnomer as the requisite calcium carbonate is not always present. Where it does occur, it is in the form of concretions which Allen (1973) ascribes to a pedogenic origin : they appear "to have formed under sub-humid to arid conditions from alluvial silts at times in association with hitherto unrecognised compressional fold structures probably expressing a type of patterned ground."

Examination of thin sections and hand specimens supports Allen's (1963) findings:-

> "The rocks (siltstones) are typically carbonate-free and coloured red or, less commonly, bright green. Only the coarser varieties are bedded internally, being thinly striped with layers of very fine-grained sandstone and clean quartz silt. In thin sections the rocks show coarse quartz silt embedded with clastic mica in an abundant matrix of moderately birefringent clay minerals mingled with iron ores."

Sandstones, particularly the finer-grained types, characteristically possess weak current-bedding and are generally lighter in colour than the siltstones, probably due to their lower clay content with which the iron pigmentation is associated. Some of the soft chlorite-bearing sandstones have, in fact, a pale green colour. These sediments are relatively thin and laterally impersistent so that they appear as lenticles or horizons within a broader succession of siltstones.

Strongly current-bedded sandstones and conglomerates are even more restricted. They range in grain size from coarse sandstones to gravel conglomerates, sometimes revealing a bi-modal grading (Allen, 1963). Bedding units tend to be strongly cemented by quartz and are resistant to weathering and erosion, projecting along the coastline and giving rise to very thin stony soils in the field. In the overall succession of lithologies, these sediments are not significant.

Following the deposition of the Devonian sediments, the entire region was strongly affected by Hercynian tectonicity. This is evident both in the tight small-scale folding visible on air photographs in the bedrock underlying thin soils, and also from structural and stratigraphical regional studies (Sanzen-Baker, 1972).

The net effect has been to obscure entirely the original geometry of the sedimentary palaeoenvironment. However, the overall proportions and local relationships between litholgical units still remain, as, indeed, do the properties acquired at that time by the sediments.

2.3 EVOLUTION OF TOPOGRAPHY AND DRAINAGE

The topography of South Wales can be described as a succession of stepped platforms ranging from 183 m (600') OD to sea level. They are considered to have been formed in the late Tertiary as they cut across Caledonian, Hercynian and even Alpine geological structures (George, 1970, p 122). Marine erosion has been invoked for such a marked regional planation (Burton, 1952; George, 1970), although there is no conclusive evidence. Brown (1960, p 103) indeed, is an advocate of subaerial erosion for a less distinct set of higher platforms ranging up to 610 m (2,000').

Within the study area, Burton (1952) has plotted platform remnants at 90 m (295'), 73 m (240'), 58 m (140') and 23 m (75') as shown in Figure 2a. The occurrence of these surfaces at particular heights was interpreted by him as representing still-stands of sea level, with respect to an emerging land-mass, when thorough erosion could take place.

Burton also argued that such a pulsatory emergence could explain the evolution of drainage in the area. Consequent streams were considered to have formed perpendicular to a contemporary coast-line and to have grown in the same fashion with the drop in relative sea level (Fig 2b). Control over drainage morphology had therefore been exercised by the position of successive coast-lines rather than by the geology.

The arrangement of the plateau levels on a regional scale, with the highest furthest inland, is consistent with such an explanation. In some cases, Burton claimed to have found the backslopes between successive platforms (indicated by tie-lines in Figure 2a), although these are far from evident in the field. Nevertheless, though it remains unproven, Burton's (1952) thesis of pulsatory land emergence is acceptable as an interpretation of drainage evolution in the study

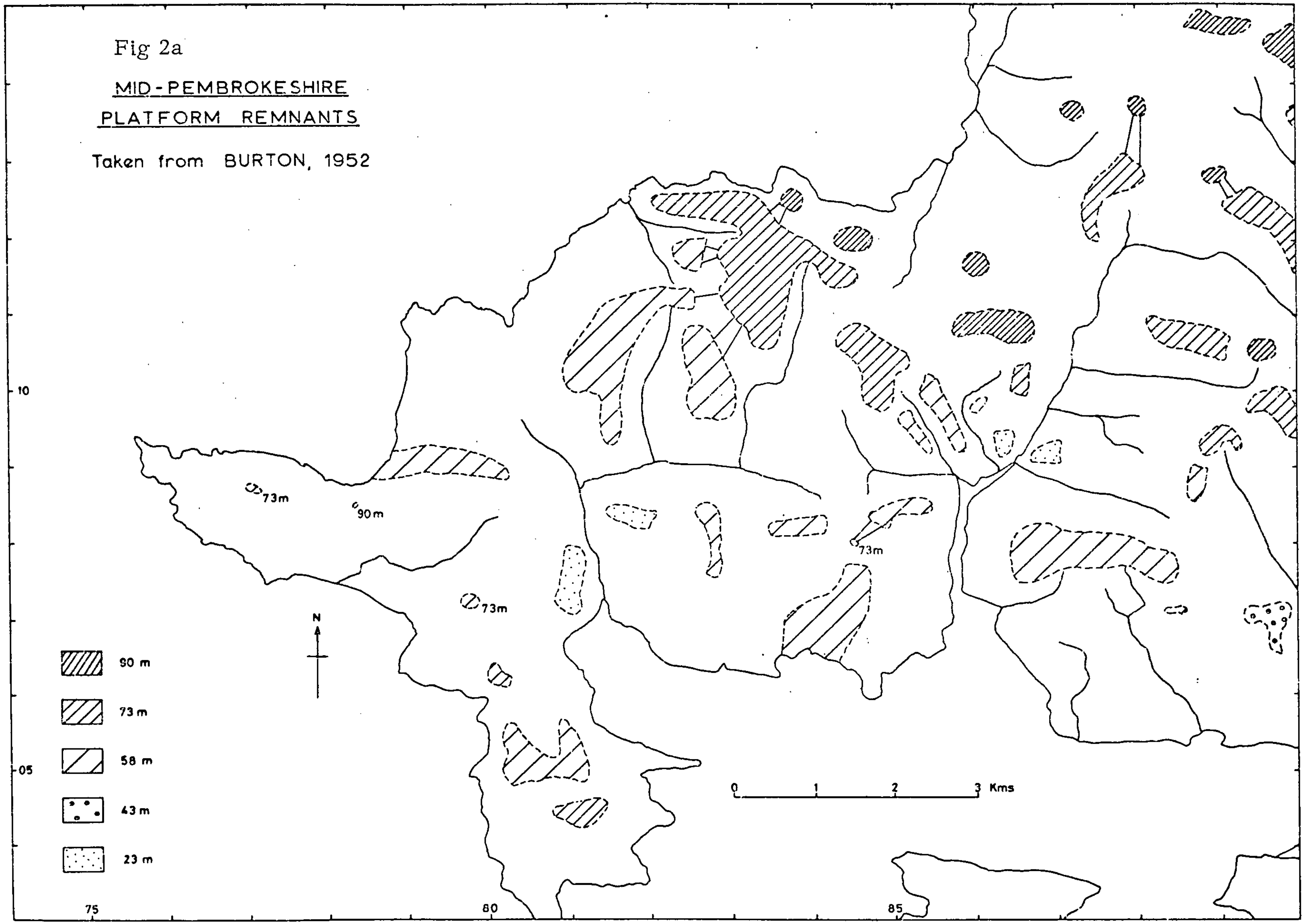


Fig 2a

MID-PEMBROKESHIRE PLATFORM REMNANTS

Taken from BURTON, 1952

area.

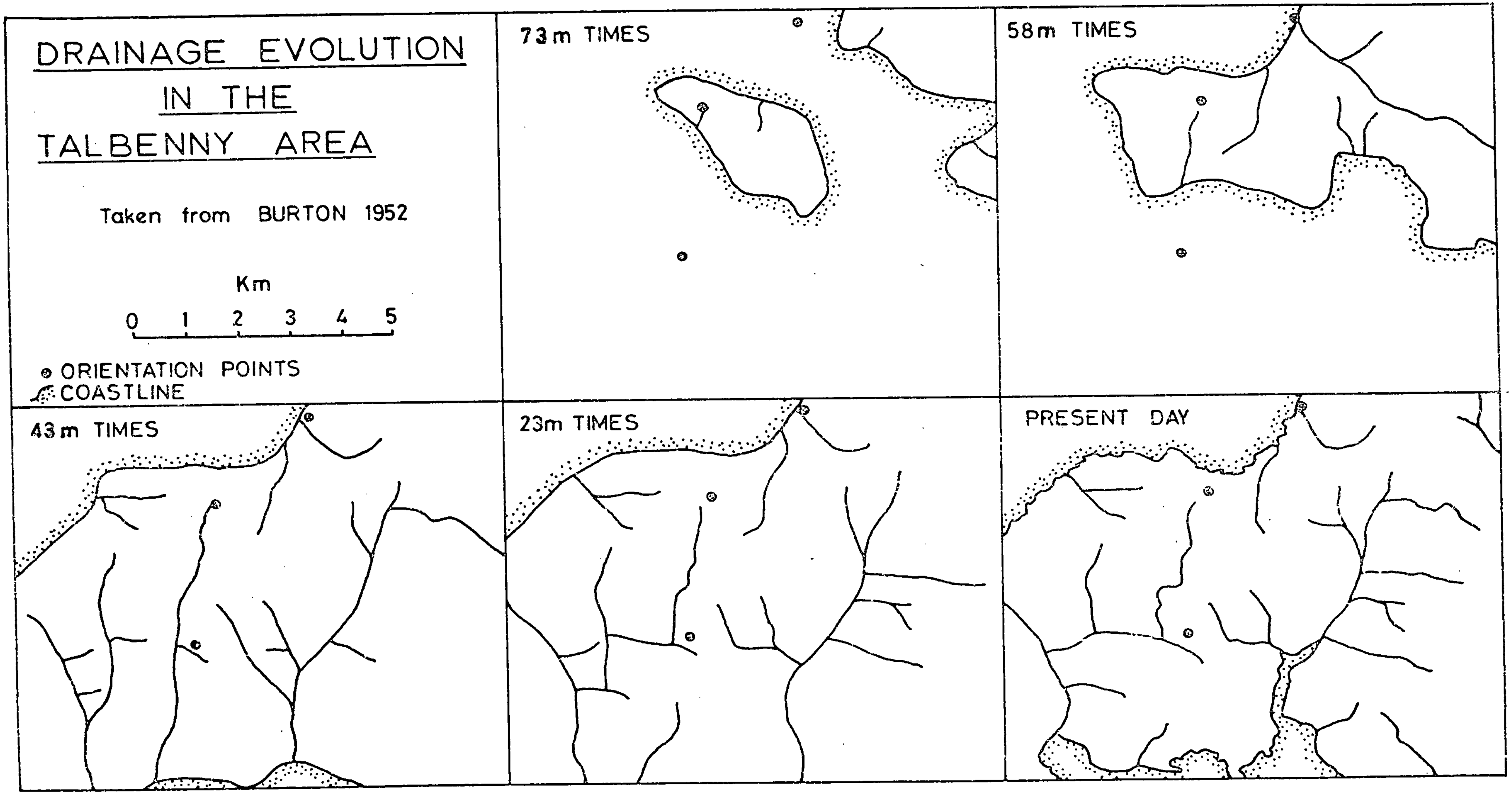
By assuming a uniform (level) rise of the land-mass relative to sea level, Burton could use appropriate present-day contour information to reconstruct a former coast-line; and by progressing to lower levels, with greater exposure of land surface, he was able to trace the evolution of the drainage system.

The sequence of maps (Fig 2b) portrays the initiation and development of the drainage within the main block of the study area. Simple consequents prevailed in "58 m times", but there was some capture by Sandy Haven Pill in the following still-stand at 43 m above present sea level, and a strong east-west drainage line was established by the Gann stream in "23 m times" by capture of the southward-flowing neighbour.

It should be noted that this map, showing a drainage pattern attributed to "23 m times", is misleading in so far as Burton has used a different criterion in determining the contemporary sea level. He interpreted this "platform" (Fig 2a) as an aggradational, rather than erosional, feature. Thus the recession of the sea, interpreted by him as greater than at present, caused over-deepening of drainage channels, with subsequent aggradation on the rise of sea level.

Certainly, local inundation was clearly responsible for the formation of the Milford Haven "ria" system, and this may be related to the growth and decline of the polar ice-caps during the Glacial period. However, it has also been shown that the 23 m platform at the bottom of the Gann Valley is a Kame Terrace (John, 1972) - a fluvio-glacial feature highly dependent on local conditions for its

Fig 2b



DRAINAGE EVOLUTION IN THE TALBENNY AREA

Taken from BURTON 1952

dimensions, rather than on sea level.

Other effects of the glaciation have been negligible in altering the general drainage pattern. On the plateau surfaces, the thinly-smeared glacial drift has been eroded into patchy till sheets, with no major effects on the drainage morphology. Some of the glacial material may have been eroded by slope-wash, particularly in the early post-Glacial before the establishment of a complete vegetation cover, and may be represented in the alluvial deposits occurring high up the courses of smaller streams (for example, P 13 - see section 6.2).

In one place (see Plate 3) re-routing of a drainage channel can be attributed to glacial action, but with the complete melting of the ice the stream has resumed its former course (see section 3.4). Other drainage systems that have fallen into disuse include the channels evident in water-sorted glacial deposits, such as those entering the Kame Terrace in the Gann Valley.

Much more subtle and problematical are the very fine drainage networks which do not carry surface drainage, but clearly bear a greater throughflow than surrounding soils. These are integrated into the present-day drainage network and, at first sight, appear to be similar to the percolines described by Bunting (1961, 1964). Some of these have been shown, however, to possess water-sorted sediments, and, hence, must have borne surface drainage at one time. Such a possibility was mentioned by Kirkby (1969) and discussed more explicitly by Huggett (1974). (This subject is returned to in section 3.4.)

2.4 GLACIAL AND PERIGLACIAL ACTIVITY

Two sources of glaciers existed in Wales during the Pleistocene. One occupied the Irish Sea Basin, advancing southwards as a broad ice-sheet to impinge on the Lleyn and Pembroke peninsulas. The other source of ice was highly localised, in the glaciers of the Welsh mountains, and did not reach the study area.

The glacial history of Wales remains to date unresolved, particularly with respect to the number of glaciations. The bi-partite division, based on stratigraphical evidence, into "Older Drift" and "Newer Drift" (Charlesworth, 1929) is of little value in southern Pembrokeshire, where glacial deposits are sporadic and poorly developed. The subjective element involved in distinguishing these two units has led to the controversy concerning the limits of the glaciations, and of the limits of the latest Weichselian (Devensian) Glaciation, in particular.

The earlier Saale (or Riss) Glaciation is generally considered to have submerged Wales, including the Pembrokeshire peninsula, beneath a cover of ice, although the evidence is derived from regional studies and correlations rather than detailed local studies owing to the severe denudation of these deposits (Bowen, 1970).

The Weichselian Glaciation, on the other hand, was not as extensive as the former and the precise location of its maximum advance remains in dispute (John, 1974). One school of thought places it along the north coast of Pembrokeshire (Mitchell, 1960; Stephens and Synge, 1966), while the other believes that Pembroke was at least partly, if not totally, glaciated at that time (Bowen, 1973a, b; John, 1971; Garrard and Dobson, 1974).

John (1970) argues that only one suite of glacial deposits is present in Pembrokeshire (provisionally termed as representing the "Dewisland" Glaciation) and consequently should be ascribed in its entirety to either the Saale (Riss) or the Weichselian (Devensian, Würm) Glaciations. He himself (John, 1970, 1971) favours the latter as a period of till deposition with evidence of the earlier Saale (Riss) in the form of melt-water channels and "early" erratics.

At the level of the study area, John (1972) has dated a Kame Terrace at Mullock Bridge as late Weichselian on the basis of radiocarbon and stratigraphical evidence. This dating has been challenged subsequently (Bowen, 1973a), and this question of glacial limits is returned to in a later section (section 7).

Of more importance here is the extent and duration of the periglacial period, following the last Glaciation, which prepared the "parent material" for colonisation by vegetation leading to the initiation of soil-forming processes.

Periglacial conditions prevailed in south-west Wales at several stages of the Weichselian Glaciation (John, 1973), though few of the characteristic features can be dated conclusively.

If a late Weichselian age is accepted for the Kame Terrace at Mullock Bridge, then the ice-wedge casts found in these deposits are late-Glacial in origin (Pollen Zone I-III). Some of the solifluction deposits at West Dale Bay may also be attributable, on stratigraphical evidence, to this period (Groom, 1956; John, 1972).

Other features provide circumstantial evidence and, from their freshness and undisturbed condition, are considered to date from the late-Glacial period (Pollen Zones I-III). Cryoturbation, albeit weakly developed, has been found in the water-sorted sediments of a Glacial/late-Glacial channel at St Brides Haven (8024 1108). Stone lines found beneath thin top-soils on plateau-edge slopes may also be of periglacial origin (Ball, 1967).* Finally, a loamy sand horizon overlying Kame Terrace sediments has been interpreted as an aeolian deposit and has been tentatively dated at Zone III or later (John, 1972). (Evidence for late-Glacial/post-Glacial aeolian activity is presented in Chapters 5, 6 and 7).

On the other hand, there is a conspicuous absence of indurated soil horizons in the study area, though these have been found at Aberystwyth (Stewart, 1961) and in the Fforest Fawr - Brecon Beacons and the South Wales Coalfield regions (Crampton, 1965) where they are interpreted as relict features of permafrost. Their absence within the study area is probably due to the stoniness of the thin regolith which is unsuited to such processes. However, it may also reflect the undoubtedly milder periglacial climate of the coastal zones (John, 1973).

For similar reasons, the formation of late-Glacial solifluction terraces, as found in the Mynydd Bach, Radnor Forest, Mynydd Eppynt and Fforest Fawr regions of south Wales (Crampton and Taylor, 1967), was also inhibited, although the Head deposits at West Dale Bay (799 058) may be a smaller-scale equivalent.

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* See Plate 2

St Bride's Haven (8032 1119)

Stone line at 25 cms depth overlying shattered red siltstone rock. The pale-coloured stones are probably derived from the sandstone bed visible in the foreground. Their present distribution may represent basal incorporation through soil creep or burial or a periglacial stone pavement.

Recently, greater attention has been directed to the study of pingos as indicators of past permafrost conditions (Washburn, 1973, pp 153-162; Flemal, 1976). Presumed pingo scars have been reported from central and south-western Wales (Pissart, 1963; Trotman, 1963; Watson, 1971, 1972; Watson and Watson, 1972). In the last case, a Late-Glacial origin (Pollen Zone II/IV) has been suggested (Watson and Watson, 1972). Flemal (1976) concludes in his review (p 49):-

> "Of the pingo scars in former permafrost regions, the majority appear to have formed during the last stage of the last glaciation or during the last deglaciation. No pingo scars of pre-Wisconsinan time have yet been identified."

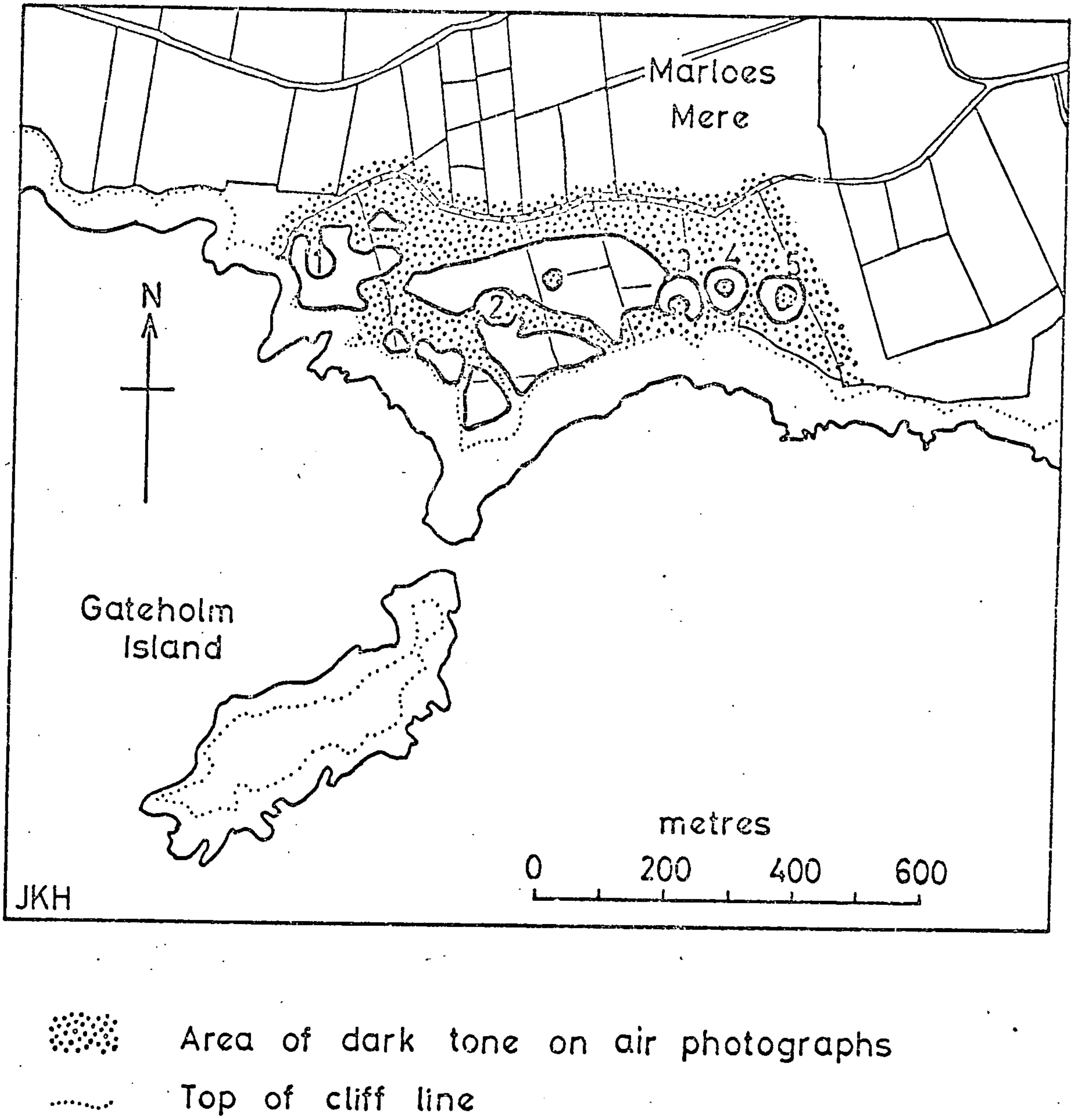
In this context, it is very interesting to consider some features, found in the study area, as possible pingo scars. In the course of air photograph interpretation, a number of circular patterns were observed on the mainland just north of Gateholm Island (see Figure 2c).

In morphology, they satisfy the conditions for identification (Flemal, 1976) : they have a ring-like rim and a central depression; they are highly symmetrical in plan (circular) and have horizontal dimensions of about 100 m. They appear to have formed in glacial, or possibly fluvioglacial, material occupying a low "topo-drainage" position, in agreement with Flemal's conclusion (1976, p 49) that pingos are "probably best developed in water-saturated and loosely consolidated surficial materials . . .".

Nevertheless, although the evidence appears to fit into the regional distribution, it is clear that a conclusive identification of these structures

Fig 2c

DISTRIBUTION OF PRESUMED PINGO SCARS



as pingos requires supporting evidence from detailed field-work.

2.5 PRE-NEOLITHIC SOIL EVOLUTION

In the absence of pollen-stratigraphic data from the study area and its environs, extrapolations have to be made from the evidence collected in west central Wales (reviewed by Taylor, 1973). Interpretations of late-Glacial/post-Glacial conditions in the study are thus, to a considerable extent, speculative.

The initial climatic amelioration (Pollen Zone I) was slight, and this period did not witness a dense vegetation cover, supporting only the hardy tundra birches (Taylor, 1960). Under such conditions, physical weathering, erosion and deposition of wind-blown material would have dominated over soil-forming processes. A brief thaw in the Allerød (Zone II) was succeeded by a return to tundra and the final phase of periglacial activity (Zone III).

The post-Glacial epoch is marked by the rapid melting of the glaciers at about 10,000 BP (Zone IV). An anomalous climatic regime is thought to have been established due to the positioning of the circumpolar vortex over northern North America rather than the pole, leading to the extension of anticyclonic situations over Europe, and producing warm and dry weather (Lamb, 1965). Coniferous forests became established with the probable inception of soil-forming processes (Taylor, 1960; Smith and Taylor, 1969).

The gradual improvement of climate encouraged a change to oak-dominated woodland (Zones V and VI), with the development of a climate intermediate in nature between those of the present-day Mediterranean and British types up to about 5,000 BP (Lamb, 1965). The higher temperatures and rainfall than at present are thought to have favoured "brown earth" formation under mull organic matter rather than the earlier coniferous "forest podzols" associated with mor humus. It is at this climatic optimum that the arrival of Neolithic man is dated.

2.6 MAN AS A SOIL-FORMING FACTOR

Although Mesolithic fishermen/hunters are known to have been present on the Pembrokeshire coast (Grimes, 1973), it was not until the advent of Neolithic colonisation and primitive cultivation that man began to affect seriously his environment.

The concentration of remains along the coast-lines suggests a sea-borne incursion of this culture, although one group, at least, came overland to settle in the Black Mountains in Breconshire (Webley, 1959). From the distribution of these Neolithic features (Grimes, 1973), it seems that there was little or no settlement within the study area itself.

One possible reason is that the lower sea-level at that time created a low-lying, marshy fringe around the area, discouraging the pioneers (Emery, 1969, p 11). Another hindrance to settlement may have been caused by the type of vegetation cover in existence over the study area. It has been argued that damp oak-woods (Quercus robur) with a dense undergrowth were more difficult to clear, and hence less attractive for settlement, than the open oak woods (Quercus petraea)

(Grimes, 1945). It seems most probable that the exposed position of the study area would have precluded the development of the dense variant (Edlin, 1960), though an equally discouraging thorn or scrub cover may have existed.

Nevertheless, there are clear signs that settlement had taken place by the Bronze Age and that it had become comparatively dense in the Iron Age. Remains of the latter include the numerous "raths" serving as coastal defensive positions, as well as the ancient small field systems still visible on nearby Skomer Island (Grimes, 1973).

The impact of man on soil evolution can best be imagined as a series of important innovative steps from initial forest clearance and cultivation:-

(i) Forest clearance and cultivation
(ii) Invention of plough and rudimentary tillage implements
(iii) Drainage of wet-lands
(iv) Application of soil fertilisers
(v) Mechanisation and crop specialisation.

Forest clearance and settlement gradually spread from the areas first encountered and found to be suitable - the coastal zones and uplands (Edlin, 1960). Even at this early stage, however, this activity was not undiscriminating. Soils of intermediate texture, and hence most easily worked, were selected for cultivation, while poorer, heavier land was reserved for the erection of burial chambers (Grimes, 1945; Crampton and Webley, 1960 and 1963).

The removal of permanent vegetation not only upset soil nutrient cycles, but also exposed the soil surface, increasing the risk of erosion

(Stewart, 1961). Climatic changes occurring at the same time are thought to have caused an overall rise of the water-table (Taylor, 1960), leading to the resumption of peat accumulation in higher areas which had slowed down before the Neolithic immigration (Smith and Taylor, 1969), and increasing the intensity of leaching.

With the invention of the plough and the general agricultural improvements of the late Bronze Age and early Iron Age (Fowler, 1971), man greatly increased his effect on the soil. Whether these implements were used in the study area at such an early period is uncertain. Turner (1965) provides pollen-stratigraphic evidence for corn-growing in the area around Tregaron, west central Wales, and Anglesey has also been mentioned (Pennington, 1969, p 91). The only positive evidence available is indirect and lies in the regular shape of the fields on Skomer Island and the presence of faint linear traces visible on air photographs.

Reclamation of poorly-drained soils is generally attributed first to the Romans (Emery, 1969, p 20) and meant that settlements were no longer restricted to areas of suitable land. However, it is unlikely that this practice penetrated to the remote study area where the influence of the Romans was very slight. Following the withdrawal of the Romans, there seems to have been a regression in farming standards, and this would have been particularly acute in the coastal areas which suffered constant harrassment from the Vikings.

Resettlement of land became possible with the establishment of the Norman manorial estates, the feudal system of land tenure, and organised trading which encouraged large-scale agriculture. This, however, was a slow process, and it was not until the sixteenth century, when pressure on land began to increase, that waste lands were taken in and the trend towards enclosures strengthened (Howells, 1956, Part II).

Also by this time, as George Owen's accounts reveal, various forms of soil fertiliser were in common use:-

> "It is a saieinge amonge the Countrye men of the contynuance of these foresaid amendementes that a man doth sande for himselfe, Lyme for his sonne, and Marle for his graunde child, thereby describinge and comparinge the contynuance of each kinde thereof."
>
> ('The Description of Penbrokshire'
> by George Owen, 1552-1613,
> edited by H Owen, 1892, p 75)

Of these soil "conditioners", burnt lime was to become the most important and eighteenth century accounts record the use of small coastal kilns, which were supplied with both coal and lime from the upper reaches of Milford Haven (Dresser, 1959; Hassall, 1794, p 18).

As agriculture began to flourish in the "Golden Age of Farming" (ca 1835-1875), the area of land under cultivation was brought to a maximum, and subsistence farming gave way to cash-cropping and specialisation. Drainage and irrigation techniques were vigorously introduced, and it is probably in this period that Marloes Mere was drained.

In the study area, arable farming began to assume primacy, despite Hassall's (1794, p 12) contention that:-

> "The mildness of the climate, the moisture of the atmosphere, the very little frost to which the country is subject, and the perpetual vegetation which is uniformly going on, even in the winter months, seem

> to point out this tract* in so peculiar a manner favourable to grass, that one cannot but lament to see so much of it under the plough".

By 1939, the arable acreage in the study area equalled that of permanent grass and at 46% was the highest relative proportion for the entire county of Pembroke (Davies, 1939, p 154). Local specialisation included barley and sugar beet.

Since the Second World War, the study area has become increasingly involved in the highly profitable "early potato" market, with considerable success owing to ideal frost-free conditions. Moreover, the acidic red rabb soils have been found to be well suited to potato-growing and, by 1971, constituted nearly 50% of "early potato" soils in Pembrokeshire (Rudeforth, 1971).

Such intensive farming, necessitating a high degree of mechanisation to produce two or more varied crops per year, has taken its toll of the soil. It is very sobering to realise that over 80% of poorly-structured soils were found under potato crops (Rudeforth, 1971; see also MAFF - "Modern Farming and the Soil", pp 38-39, No 212, p 106, Nos 602 and 603).

Even more significant is the longer-term and more insidious erosion of soil left bare for long periods in such situations (Morgan, 1974). With root crops, natural erosion is reinforced by the removal of some of the soil in harvesting (Tupper, 1974). This problem is particularly acute where the depth of soil to bedrock is little more than a plough layer, as in large parts of the study area.

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* Referring to Castlemartin hundred but equally applicable to the study area.

CHAPTER 3

SPATIAL DISTRIBUTION OF THE PEDOGENETIC ENVIRONMENT

3.1 INTRODUCTION

The importance of topography to soil genesis was acknowledged in the concept of the soil catena:-

> ". . . a regular repetition of a certain sequence of soil profiles in association with a certain topography."
> (Milne, 1935)

The relevance of the spatial dimension was stated more explicitly by Jenny (1941, p 89):-

> "Physiographers and geomorphologists have no generally accepted definitions of topography and relief. In the present discussion, the terms are used synonymously and denote the configuration of the land surface."

More recent theories stress soil-landscape associations (Ruhe, 1956, 1960; Ruhe and Walker, 1968a, b; Huggett, 1975; and Butler, 1959).

Two major spatial effects of topography should be noted:-

(i) The modification of gravitational forces on the soil (often taken as granted - Bunting, 1967, p 23).

(ii) The control of drainage (referred to here as topo-drainage, to distinguish from the control of drainage exerted by soil texture and structure).

The former determines, to a large extent, the movement of soils on slopes as a result of soil creep and slope-wash. The significance of this in pedogenesis is rooted in the distinction between cumulative and non-cumulative soils:-

> ". . . the A horizon of every mature, non-cumulative soil develops from the material that previously passed through the stage of the B horizon, rather than directly from the C material."
>
> "The A horizon of the cumulative soil develops from the fresh assorted sediments that settle on its surface rather than from the material that previously passed through the stage of the B horizon, whereas the B horizon follows the A and develops from the sediments that passed through the stage of the A."
>
> (Nikiforoff, 1949)

Nikiforoff also avers that continuous shifting of the A horizon often occurs without any true (net) accumulation. While the terminology of the horizons may be outmoded, the simple concept of cumulative and non-cumulative soils, with an intermediate phase where neither dominates, remains valid.

Topography does not control drainage patterns exclusively; neither do they correspond to geomorphic units (Bunting, 1961, 1964). Hence the term "topo-drainage" has been used - to emphasise the dependency of drainage on topography without excepting other factors.

Another aspect of drainage concerns the movement of water within the soil profile. This is controlled also by soil properties - to a large degree a function of the "parent material". Textural horizonation is very important in this context, although the effects of management on the structure and drainage of the soil can be locally pre-eminent.

Not only does the "parent material" affect the mechanical properties of the soil, it also serves as the "reaction flask" of soil chemical reactions and, indeed, provides many of the reactants itself. Thus different "parent materials" will impart different chemical properties to a soil depending on their mineralogical constitution.

Both chemical and mechanical properties of soil can be severely altered by the "organic" factor (Jenny, 1941). Micro-organisms are particularly important as mediators in complex oxidation-reduction reactions characteristic of soil water-logging conditions (Evans, 1971). On the other hand, the "macro-organic" factor, represented by vegetation and animals, has been virtually eliminated as a natural variable under prolonged cultivation and crop rotation.

Not only has Man altered completely the spatial distribution of the "organic" factor, it could also be argued that he constitutes a "factor" of soil formation in his own right by his control of certain soil properties to suit his own needs.

Some factors, however, remain very difficult to change. Such "fundamental" factors include climate, "parent material" and topography (and implied topo-drainage). These, then, are the relatively unchanging factors, which are suitable for representation on maps, and the spatial distribution of which should be amenable to a genetic interpretation.

3.2 THE PEDOGENETIC MAP

The Pedogenetic Map (see inside back cover) shows the spatial variation of the factors of "topo-drainage" and soil "parent material". It does not show the spatial distribution of soils as such. The Map can be used, however, to predict the most probable kind of soil in any locality.

Over a larger area, climatic variability would also assume importance and would need to be plotted. It has been omitted from the Pedogenetic Map in this case, because the study area is small enough for climatic variations to be considered negligible as far as pedogenesis is concerned (see Figure 1b).

The Map has been specially designed to give the factors of "parent material" and "topo-drainage" equal weighting, as these are considered to be equally important in the soil genesis of the study area. Such an approach differs from the practice of the Soil Survey of England and Wales, which emphasises the role of the "parent material" lithology at the comparable level of the soil series (Avery, 1973), for reasons which may be, in large part, historical (Bridges, 1976).

By keeping to a genetic basis, the Pedogenetic Map is unique in that it is independent of soil classification revisions. On the other hand, prediction of soil properties may not be as accurate as from a special soil map at the same scale, although the accuracy of the latter is only as good as the purity of the soil mapping units (Simonson, 1968).

3.3 CLASSIFICATION

Two partly independent classifications have been used in the construction of the Pedogenetic Map. One concerns the dominant component of infiltrating surface water - "topo-drainage"; the other refers to the type of "parent material" from which the soil is derived. These are not entirely independent, as the topographical element may influence the distribution of some parent materials. Thus, water-sorted glacial material and alluvium are concentrated along drainage lines and are, therefore, associated with a particular range of topo-drainage classes.

Three such class have been defined - moisture shedding (I), moisture transmitting (II), and moisture receiving (III). At moisture-shedding sites, the main component of water movement is vertical, with infiltration proceeding directly to the underlying bedrock. Transmitting zones exhibit a strong component of lateral water movement through the soil, while receiving sites are characterised by the accumulation of this moisture in topographic "lows". A fourth class (IV) has been included to distinguish sites affected by sea-water, differing entirely in its chemical composition to rain-water.

"Parent material" classes are based on the composition and geological history of the soil inorganic material, especially that of the plough layer. The careful delimitation of superficial deposits, particularly till sheets, is therefore critical. In the peninsula west of Marloes, the solid geology is also very complex, and for this reason only broad geological groupings have been defined for that part. In sum, only four geological units have been recognised - Black Shales (Ordovician), Skomer Volcanic Series (Ordovician/Silurian), Grey siltstones/sandstones (Silurian) and Red siltstones/sandstones (Devonian). These have been selected on significant differences in lithology rather than chrono-stratigraphical grounds.

The subdivision of superficial deposits has likewise been made not from a glaciologist's point of view but according to properties relevant to pedogenesis. The classes of unsorted glacial, water-sorted glacial, soliflucted and alluvial materials are based primarily on the textural properties of the sediment, which also influence - to a certain extent - the mineralogy of these deposits.

Organic soils pose problems in this classification. By convention, a peat has an organic horizon of over 40 cms thickness (Avery, 1973). Such a peat probably only exists at Marloes Mere (776 082). However, west of the Mere there is a low-lying stretch of land having soils rich in organic matter though not exceeding a thickness of 20 cm (see Plate 11). On the Map these have been delineated separately but have not been classed as peats.

3.4 DISTRIBUTION OF "TOPO-DRAINAGE"

The drainage pattern in the study area is shown on the Pedogenetic Map (inside back cover). With the exception of Dale Valley and the Gann Valley (both shaped by glacial and periglacial processes), the surface drainage is confined to small, moderately-incised basins. Between these lie broad plateau surfaces.

The delineation of topo-drainage zones is based almost exclusively on air photograph interpretation (API) at the same scale as the Pedogenetic Map (for information on air photographs, see Appendix 9). In some cases, adjacent basin "heads" were resolved using the topographical evidence of the base maps.

"Shedding" sites have been defined as possessing no visible drainage pattern whatever, and it is therefore inferred that rain-water percolation is mostly vertical, with only a very small lateral component. On air photographs, "shedding" zones appear light in tone over bedrock and freely-draining superficial deposits, and slightly darker, though still uniform, over the clay-rich glacial tills. A considerable proportion of the study area (70%-80%) is comprised of "shedding" zones.

The distinction between "shedding" and "transmitting" zones is a very fine one, and for this reason boundaries are depicted by a broken line. Nevertheless, API gives clear evidence for lateral drainage in the form of dark, very fine, branched or unbranched lines, strung out on the slopes, leading to receiving sites. Such lines of moisture movement have been termed percolines by Bunting (1961, 1964) and are regarded as the outer fringe of a drainage network. In the field, the very localised deepening of the soils along a percoline is encountered only infrequently.

It is critical, in the context of soil genesis, to decide whether these channels have been formed by processes connected with the movement of water through the soil (percolines) or whether they are relict features of surface drainage (palaeorills). Though they are not readily distinguishable from their surface appearance (Kirkby, 1969; Huggett, 1974), differences in soil properties, and especially soil texture, are quite marked. Where surface drainage has existed, water-sorted material is to be expected; where water movement has been restricted to throughflow, only limited sorting (mostly of clay or fine silt material) is possible.

Soil types found over palaeorills should, therefore, differ greatly (and sharply!) from surrounding soils (see, for example, section 6.2, and Appendix 3). The action of sorting by running water would tend to create a coarser (i.e., sandy or gravelly) material located clearly within a channel. In profile, horizons or rather sedimentary units, should be evident, and analysis of the deposits should indicate non-derivation from sub-adjacent bedrock.

Percolines, on the other hand, show little sorting of material by comparison and, in any case, the tendency is towards finer-grained material (Bunting, 1964). Transitions in soil properties are laterally more gradual, and widths of percolines have been described as varying from about 30 to 90 m, although even deeper areas were encountered in such a zone (Bunting, 1964).

In fact, on air photographs, the distinction between percolines and palaeorills is moderately easy to make in most cases. Percolines rarely occur singly and have the general appearance of a series of thin dark threads running in relatively straight lines downslope, eventually coalescing into thicker "seepage" lines, or even entering the broader and permanent "receiving" sites. Palaeorills tend to be well-defined, often occupying a visible topographical depression, and are isolated. They are dark in tone, despite their coarser texture, owing to their high moisture content from the throughflow. Often they are associated with plateau till sheet upslope and alluvial deposits downslope, illustrating their role in the redistribution of surficial material (see section 6.2).

Somewhat similar in many respects are the channels superimposed on water-sorted glacial deposits. On air photographs these appear as very prominent dark bands in tonally very light areas (as at the Mullock Bridge Gravel Quarry - 811 077). Although they no longer conduct surface drainage, they are still important in transmitting sub-surface moisture, and in this sense are integrated with the existing drainage system, despite their different origins (one derived from rain-water infiltration; the other from local melt-waters).

The effect of glaciation on drainage is even more strongly expressed in a feature just north of St Ishmael's Parish. Here a relict channel (Plate 3) takes a "short-cut" across country (from 832 097 to 829 091) connecting two existing lines of drainage located at a lower altitude. The channel is, in fact, "hump-backed", and the "hump" lies at 15 to 23 m above the present-day stream at the northern end, and 30 to 38 m above the stream at the lower, southern end.

A possible explanation is that melt-water escaping from the north (possibly from the Talbenny till sheet) was checked by "dead" ice downstream and diverted over the brow of the nearby slope, eventually eroding a channel along this course. A poorly-defined channel further west (824 092) may have a similar origin.

It should be noted that in some cases wind-blown or colluvial material may help to infill old channels, as perhaps at Broomhill Farm (809 051), which remain active in transmitting subsurface water by reason of their low relative topographic position.

Finally, there is no evidence in the study area of sub-surface mass water transport by soil-piping as has been recorded in the upper Wye Valley, Plynlimon, Wales (Newson, 1976).

In the topographically lowest situations, a state is reached where the water-table intercepts the soil profile. These "receiving" zones are usually clearly demarcated from the "transmitting" zones

KEY

(to face Plate 3)

"Topo-drainage" classes:-

- I - Shedding
- II - Transmitting
- III - Receiving

"Parent Material" classes:-

- r - Red siltstones (Devonian)
- g - Grey siltstones/sandstones (Silurian)
- a - Alluvium
- u - Unsorted glacial deposits
- w - Water-sorted glacial deposits

The area shown has co-ordinates:-

818 108	833 108
818 087	833 087

Two north-south trending streams are seen feeding the main east-west drainage line. A now-disused channel taking a "short cut" between these drainage systems is seen on the right-hand side. It is hump-backed and therefore thought to be of glacial origin.

The thin plateau soils are underlain by two different geological formations - Silurian siltstones/sandstones and Devonian siltstones. These can be distinguished by their structure, as seen through the thin soil cover (lower right and upper half of Plate, for example). These features are obscured by till sheets (upper right-hand side).

RAF 30 JUN 1959 (F 22 No. 0192 58 .RAF 2985)

Plate 3

on air photographs. Often there is a break of slope, a line of springs (though some of these may be attributable to perched water-tables on till sheets - Cantrill et al, 1916, p 167, or old blocked drains - Rudeforth, 1974, p 17), and the open drainage along the lowest course. In the field, periodic or permanent water-logging is indicated by the presence of manganese cutans and partial or total gleying.

Where water-logging is particularly persistent and bacterial activity sufficiently reduced, the accumulation of organic matter is encouraged and peat formation is possible. This occurs, to a limited extent, at Marloes Mere (777 082) where API reveals a very light (seasonally dry ?), irregular tone, becoming darker and spreading westwards over several fields. In an area a little west of the Mere itself, several soils (P 16 - P 19 at 767 083) were found to have horizons rich in organic matter to a depth of about 20 cms.

The final topo-drainage class (IV) refers to the area of the Gann Valley south of Mullock Bridge where water-logging by sea-water has led to the characteristic development of "crescent" morphology in the saltings (815 077).

3.5 DISTRIBUTION OF "PARENT MATERIAL"

The definitions of soil "parent material" are varied and still controversial. In this study, the soil "parent material" is defined as the material from which the present-day top-soil (0-25 cms) has been derived. The point needs to be made that the origin of this material is often not fully apparent in the field, and laboratory analysis is needed to determine the effects of wind-blown or anthropogenic contaminants.

As far as API is concerned, the thinness of the plateau soils is of enormous advantage. Soils thinner than 25 cms are "transparent" to underlying geological features on the air photographs. Geological formations tend to have different structures, especially in the thickness and degree of folding of beds (Plate 3), and this has proved a useful criterion for identification and mapping.

The characteristic appearance of each rock type is almost unmistakable. The red siltstones of the Devonian appear as highly folded, thinly bedded units, with occasional lighter partings attributable to sandstone horizons. The Silurian siltstones/sandstones of the Winsle inlier form thicker beds and are darker in tone. Darker still are the Ordovician black shales, although their faulted boundary with the Devonian red stilstones , north of Marloes village, is often lost among the tonal variations due to "topo-drainage". Igneous rocks outcropping at Marloes Beacon (785 085), Verna Cottage (778 081) and north Talbenny (837 126) exhibit a light tone with a rough, irregular, "granular" texture.

With a thickening of the soils beyond the "threshold of transparency", the geology is no longer visible, and it is on this basis, with the support of field observations, that the boundaries of the plateau till sheets have been mapped. API is particularly useful in defining the edges of till sheets which grade imperceptibly into surrounding bedrock soils and which prove very difficult to delimit in the field. A broken line emphasises the nature of these boundaries, better regarded as transition zones. Hence the seemingly paradoxical position of P8 (8107 0952) - actually derived from Silurian siltstones but occurring in the fringe zone of water-sorted glacial deposits and mapped as such. Speculative boundaries are indicated by interrogation marks, as in the case of the Upper Winsle Sheet which, with the confirmatory evidence of three soil inspection pits (P37, P96 and P97 - at 8382 0956, 8355 0987, 8422 1003 respectively), has been shown to be little more than a thin (35 cms) veneer of unsorted glacial material overlying bedrock.

The existence of these ephemeral glacial deposits had not been recorded by the Geological Survey (Cantrill et al, 1916), who only mapped superficial deposits with a thickness of at least a few metres. Thin though they may be, these sediments are highly significant in soil genesis, as is seen in later studies (Chapters 5 and 6).

Not all of the glacial sheets are so indefinite. The Dale Till Sheet displays a thickness of several metres at its western edge in the cliff section at P64 (8014 0379), and then tapers eastwards. A detailed transect across the eastern boundary from P57 to P58 (8069 0442 to 8160 0444) reveals a change in profile morphology and soil properties, and allows the placing of a boundary inside a distance of 20 m. Additional evidence for till sheet boundaries comes from the location of springs which seem to be particularly consistent in the case of the Dale Sheet (Cantrill et al, 1916, p 167).

Problems with the definition of "parent material" arise with the "cumulative" downslope soils, where the addition of fresh soil material takes place from above rather than from below (Nikiforoff, 1949). In many cases, the colluvial material is the same as further upslope, and while reasonable extrapolations can be made from an appraisal of the geology, numerous ground checks are required. This is particularly necessary, as many of the drainage basins have been lined with water-sorted material from previous times - as, for example, the Gann Valley and the stream draining into Marloes Sands (780 076).

Unsorted glacial deposits are rarer in such situations, and API of the water-sorted glacial material is aided by their very light tones, indicating freely-draining materials located in shedding "topo-drainage" zones.

Solifluction deposits require field identification, while alluvium occurs only in "receiving" zones and is easy to identify by its flatness, and sharp boundaries with adjacent slopes.

CHAPTER 4

THE SOILS AND THEIR PROPERTIES

4.1 INTRODUCTION

The basis of any detailed pedogenetic study must be a description of the overall distribution and variability of the soils and their properties - essentially a soil survey. This chapter is an attempt at a brief appraisal of the soils in the study area. A soil map has not been constructed, however. Instead, the Pedogenetic Map is used in conjunction with the information gathered in the course of field survey as well as laboratory analysis.

The soils of the study area are unusual in many respects - not least of all in the extreme thinness of the plateau lithosols. By far the largest proportion of these are derived from Devonian red siltstones - a source of additional pecularities. Differences and similarities of these soils are therefore evaluated both within the study area and on a higher regional level.

4.2 REGIONAL CONTEXT

When the study area is considered in a broader regional context, the role of the climatic factor in soil genesis becomes more apparent. Climate is a composite factor and can be reduced to the components of precipitation, temperature and wind. These components can be combined and resolved into more specific "causative factors". The most important in soil genesis is the precipitation available for leaching (often approximated to the excess winter rainfall - MAFF, 1971). Temperature and the related variable of exposure affect the chemical activity of micro-organisms in the soil. Finally, wind, in combination with precipitation, governs the deposition of salt in the form of sea spray.

The importance of the climatic factor was not fully recognised at first. Robinson (1935, p 273) concluded that "whilst the equable climate of Wales dominates soil development, important differences between soils can be traced to the influence of parent material."

It was not till much later (Ball, 1959) that the climatic factor was suggested as being responsible for a division of the soils in Wales into two broad zones - the brown earths and the podzols. The boundary between these was broadly drawn along the isopleth of 1,500 mm (60 inches) of annual rainfall, a level above which the podzols were said to become prevalent.

Rudeforth (1967) has offered a refinement of this figure, claiming that for the Silurian siltstones in central Wales (a lithology similar to the Devonian siltstones in the study area) : "podzolized soils rarely occur under a rainfall of less than 1,375 mm (55 inches) a year in the west, and yet are common under rainfalls about 1,125 mm (45 inches) a year in the east."

He further suggested a relationship between summer temperatures and podzolisation, invoking a close fit of the 14°C (57°F) July isotherm with the lower limit of general podzolisation (Rudeforth, 1967). The explanation advanced for the importance of summer temperatures was that they controlled the activity of soil organisms which cause the decay of plant debris - one of the important determinants of podzolisation in upland soils in mid-Wales. While this is indisputable, some doubts over the precise correlation of zonal soils with the July isotherm have been voiced (Ball, Oliver in discussion of Rudeforth, 1967). As leaching is so important in soil genesis, the annual rainfall measure is rather crude, and a more accurate parameter is that of the excess winter rainfall, when vegetation growth is negligible and evapo-transpiration low.

As far as soils in the study area are concerned, the problem with evaluating the role of the climatic factor lies in finding a similar "parent material" in a different environment. A rare chance is presented in Crampton's (1963) study of soils derived from Devonian red siltstones on Mynydd Eppynt near Brecon, south Wales.

As in the study area, the red siltstone parent rock on Mynydd Eppynt occurred at less than 30 cms below the surface of the inorganic horizon, and mineralogical analyses confirmed the derivation of the soil material from the subadjacent rock. The mineral soil was overlain by organic horizons of between 10 and 20 cms consisting of root mats with underlying well-decomposed organic matter. These soils were identified as <u>podzols with gleying</u> and <u>peaty gleyed podzols</u>, although this simple terminology belies their complex morphology (Crampton, 1963).

The excess winter rainfall on Mynydd Eppynt can be estimated at a mean of at least 625 mm (25 inches) on the basis of 1,125 mm

(45 inches) average annual rainfall (MAFF, 1971, p 40) - the figure reported for the Brecon Meteorological Station and hence likely to be an underestimate of the rainfall on the mountain. Excess winter rainfall in the study area, on the other hand, is at most an average of 500 mm (20 inches) by a similar reckoning. If this is reduced further on account of the unusual local climatic conditions (see section 1.3), it becomes evident that there is probably twice as much rainfall available for leaching on Mynydd Eppynt as in the study area.

Other climatic factors that should be considered in this comparison include the reduced soil homogenising activity of the soil fauna in the mountain podzols, the greater accumulation of organic matter mentioned above, and the more continuous leaching on Mynydd Eppynt resulting from a more even annual rainfall distribution and lower evapo-transpiration rates.

Salt Sea Spray

One rather unusual feature of the study area is the frequent "fall-out" of sea spray. This can have severe effects on the vegetation, and "burning" of trees and plants is common even at Marloes village.

The effects on the soil, however, do not appear to be significant. There is no clear evidence of illuviation in soils, even along coastal exposures, despite the fact that sodium acts as a deflocculant on clay minerals. Not only are the micas structurally resistant to sodium absorption, but they also absorb the bivalent calcium and magnesium ions on to exchange sites in preference to the monovalent sodium (Carroll, 1962). Thus, in combination with the overall climatic regime, the effect is to allow sodium and chloride ions to pass unhindered through the soil. This is confirmed by the general absence of salt efflorescences or accumulations in the soils, even over dry summer spells.

4.3 RELATIONSHIP OF SOILS TO PEDOGENETIC MAP

The Pedogenetic Map was designed as a basis for the study of soil genesis in the study area. As such it shows the spatial distribution of the topo-drainage regime and the soil "parent materials". Topographical information in the form of contours was also included. With the additional aid of a ground survey and laboratory analysis, a tentative prediction of soil distributions in the area can be attempted. This is particularly desirable in view of the detailed soil surveys (on the scale of 1:25,000) carried out in nearby areas by the Soil Survey (Clayden and Evans, 1974; Rudeforth, 1974).

On the basis of Avery's (1973) classification, only a few of the Major Soil Groups are represented in the study area. These include the Lithomorphic soils, the Brown soils, and the Ground-water gley soils; smaller areas are covered by surface-water gley soils, Hydric raw soils, Peat soils, and Podzolic soils.

The lithomorpic soils occur typically on the plateaux surfaces, directly overlying bedrock and in shedding (I) and transmitting (II) topo-drainage zones. Brown soils are associated with glacial till sheets on the plateaux, with colluvially-thickened slope soils, and with some of the deeper plateau soils underlain by basic igneous rocks.

They range over all three topo-drainage classes, grading into the ground-water gleys and gley soils in moisture-receiving sites (III).

Of the less extensive Major Groups : surface-water gley soils (stagnogleys) occur in some of the clay-rich plateau till sheets; hydric raw soils (raw gley soils) correspond to topo-drainage class IV - the estuarine marine sediments at the southern end of the Gann Valley; a podzolic soil has been encountered in an unusually coarse sandstone over a small area; peat soils of significant extent (several hundred square metres) are located in and around Marloes Mere.

Classificatory problems arise, however. Particularly problematical are the soils derived from the Devonian red siltstones, in which the stability of the red iron oxide (hematite) hinders the differentiation of horizons by colour. In spite of Avery's assertion that structural or illuvial features should be recognisable (1973, p 33), there is no clear evidence of a B horizon at the virgin sites, and elsewhere ploughing has removed any evidence that may have existed. At the "Soil Group" level according to Avery's classification (1973) the plateau red siltstone soils can range from raw skeletal soils (with bedrock or non-alluvial fragmental material at 30 cms or less), through rankers (with non-calcareous top-soil over bedrock or C horizon at 40 cms or less) to brown earths (sensu stricto) (non-alluvial, non-calcareous, loamy or clayey, without an argillic horizon and no diagnostic gleyed horizon at 40 cms or less).

In the study area these arbitrary divisions are unsatisfactory. A much more meaningful limit could be set at 25 cms for the bedrock-derived "Lithomorphic soils". Not only is this limit traceable on the air photographs - using the 'transparency" criterion mentioned earlier (section 3.5) - but it is also of practical significance. Normal ploughing reaches to 20-25 cms depth and soils thinner than this require careful management both to avoid damage to equipment and to minimise the risks of soil erosion. It is interesting to note that Clayden and Evans (1974) specifically include non-calcareous soils with bedrock at less than 25 cms as "ranker" soils (p 24), while Rudeforth and Bradley (1972) less explicitly appear to have done the same (p 20).

Red siltstone soils thicker than 25 cms and not showing any diagnostic features are allocated to the brown earths by Clayden and Evans (1974, p 24). The implication is that if the soils had not been hematitic they would have possessed a colour-differentiated profile. It appears that "cumulative" soils (see section 1.2), although lacking an obvious horizonation, may be classified on arbitrary depth criteria as brown earths by default.

To some extent this problem of classification is avoided by the use of soil mapping units. Rudeforth (1974), working in the nearby Pembroke/Haverfordwest area, defines (p 89) the Milford Series as:-

> ". . . a fine loamy brown earth over red Devonian siltstones and fine sandstones with silty variants . . . . Drainage is usually good or moderate. A subordinate well drained shallow ranker variant is also included."

The Shallow ranker variant is defined as having rock at less than 25 cms (p 90). Thus the shallow ranker variant of the Milford soil series is probably equivalent to the soils in the study area generally termed as "thin red siltstone plateau soils".

The brown earths of the Milford Series described by Rudeforth (1974, pp 92-97) have no counterparts in the study area.

4.4 SOIL GROUPS AND SOIL PROPERTIES

4.4.1 Soil Groups

The soils of the study area (see Appendix 10 for selected soil profile descriptions) are covered by just a few soil Groups (as defined by Avery, 1973). These include:-

(i) The rankers (approximately 50% of the study area)
(ii) The podzols (*sensu stricto*) (negligible)
(iii) The brown earths (*sensu stricto*) (approximately 40% of the study area)
(iv) The ground-water gley soils (approximately 5% of the study area)
(v) The stagnogley soils (*sensu stricto* Pseudogley) (rare).

(i) Rankers (Avery, 1973)

The rankers correspond to the "thin plateau soils." They are formed in material derived from Devonian red siltstone (locally called "red rabb"), Silurian yellow-grey siltstone/sandstone, and Ordovician black shale, and generally occur on shedding sites (I) but are also encountered in transmitting zones (II).

The uncultivated red siltstone variant - P62 (Plate 4) - can be classified, in fact, as a fibric ranker at the Subgroup level (Avery, 1973), but under prolonged cultivation the organic content becomes

P62 - Soil Profile Description

0-8 cms	A_1	Dark red-brown (2·5YR 2/4) organic mat, very porous, dry, no mottles, OM very high, abund. roots, small red siltstone fragments (pH 5·0). Boundary sharp and regular.
8-25 cms	A_2	Reddish (5YR 3/4) stony silty clay, columnar and irregular large peds, mod. compact, mod. moist, OM low, few roots, stones progressively larger towards base - up to 2 cms across (pH 5·1). Boundary sharp and regular.
25-40 cms	C	Red, very stony silt clay. Flat frags. of red siltstone.
40+ cms	R	Jointed bedrock - red siltstone.

Horizon	M C	L OI
A_2	3·5	5·1

Plate 4

Soil Profile - P62

Location	8047 0318
Topo-drainage Class	Shedding (I)
"Parent Material"	Red siltstone
Altitude	46 m ± 2 m (150' ± 5')
Slope and Aspect	Flat, profile to south-west
Land Use	Virgin site

much reduced and rock fragments from the bedrock become thoroughly mixed into the soil. After ploughing, these rankers may resemble raw skeletal soils (for example, P 112 - Plate 5), especially following a root crop such as potatoes. However, laboratory analyses reveal that these soils exceed the stipulated minimum content of organic matter in the top-soils (1% - Avery, 1973), qualifying them as rankers.

Soils derived from geological formations other than the Devonian red siltstones can be classified as rankers only if the depth to bedrock is less than 25 cms - the approximate depth of ploughing. In such cases, the top-soil is homogenised and the A/C configuration of the lithomorphic soils remains. Where the soil depth to bedrock is greater than 25 cms, the "non-red" soils invariably exhibit some colour differentiation (not always distinguishable with the Munsell colour charts) warranting a designation as a weathered B (B_w) horizon - one of the characteristics of the Major Group of Brown soils.

The problem lies in recognising such weathered B horizons in the "red" soils. Avery (1973, p 338) maintains that : "Where such horizons cannot be identified by colour differences, they can usually be recognised by structural characteristics or by an increase in clay content, compared with the original material". This assertion is particularly unsatisfactory in view of the well-known resistance of the Old Red Sandstone soils to processes of pedogenesis, remarked on even in the early stages of surveying (Robinson, 1935, p 266):-

> "Apart from the addition of humus and structural modification, they rarely differ from the parent geological

P112 - Soil Profile Description

0-28 cms	A_p	Reddish-brown (5YR 3/4) stony silty clay loam, large crumb, good tilth, mod. moist, no mottles, O M low to mod., occ. roots, rare worms, abund. stones (all red siltstone fragments) (pH 6·4). Boundary regular and quite sharp.
28+ cms	C	Red siltstone fragments (up to 5 cms across) in finer matrix.

Horizon	M C	L O I
A_p	3·1	3·3

A. Fragments of red siltstone bedrock brought up by ploughing in this thin plateau soil at Sandy Haven Farm (8470 0822).

B. P 112 (8460 0821) Cultivated thin red siltstone soil at Sandy Haven Farm. Note size of rock fragments. Trowel is resting directly on bedrock.

> formation, and exhibit no mechanical or chemical eluviation . . . . . They reflect the character of the geological parent material, rather than the operation of contemporary pedogenic processes."

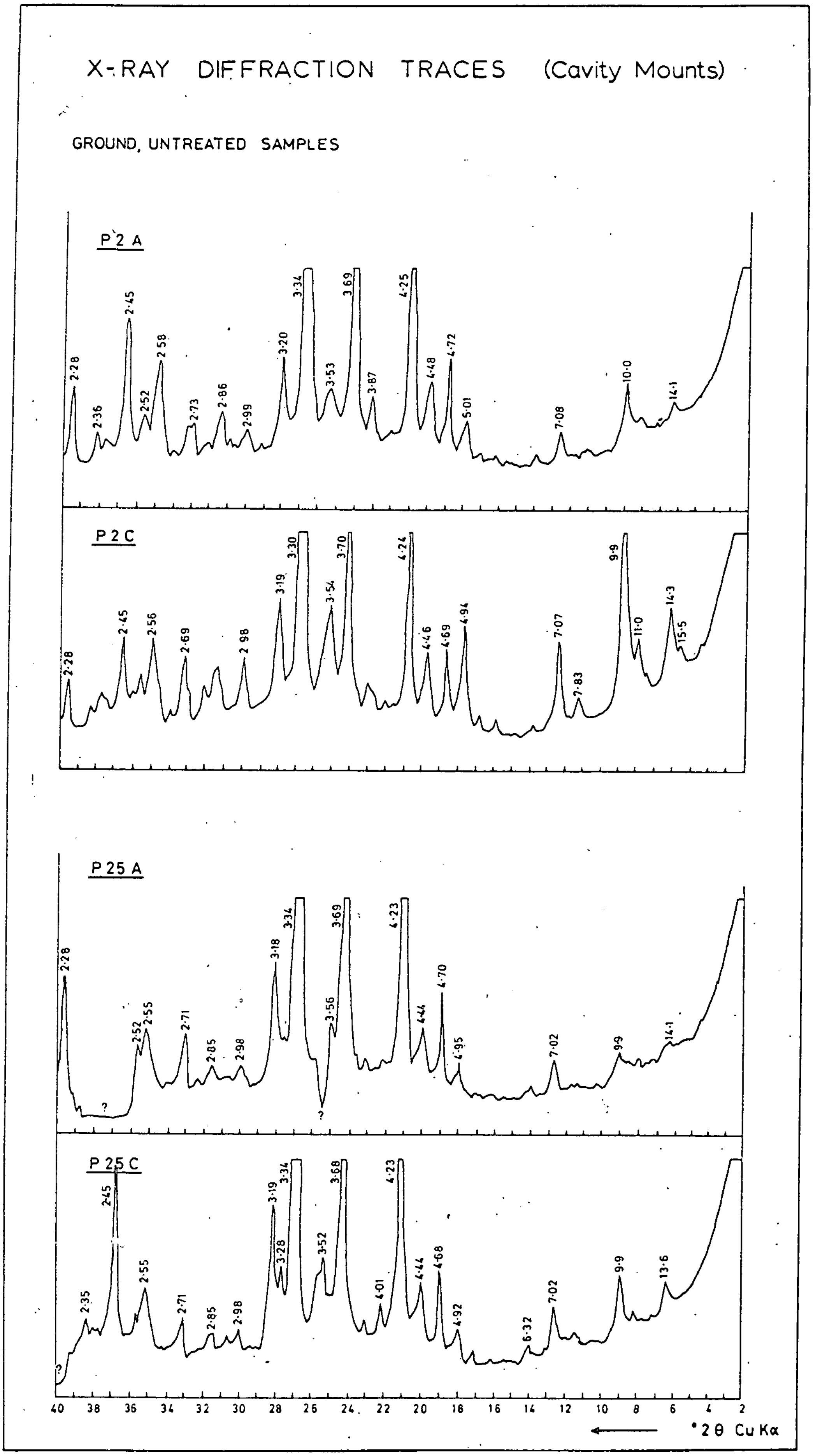
The reason for this resistance to weathering lies in the mineralogy of the source rock. The red siltstones soils (P2 - Fig 4a) are composed dominantly of quartz, mica (muscovite) and plagioclase feldspar, with subsidiary chlorite, hematite, and perhaps Kaolinite (see Appendix 1 for method). Detailed analyses of the clay minerals have not been carried out, although interstratification of other phases (Millot, 1970) is suspected.

However, the major minerals have been shown to be relatively stable (Jackson and Sherman 1953). The apparent decline in the feldspar (3·2 Å) is most likely to be due either to variations in the parent material itself or to the "dilution" effect of quartz added to the top-soil (see Chapters 5 and 6).

Some weathering, however, does take place, accounting for the high natural fertility of these soils. Potassium is available in sufficient amounts for most crops. On the other hand, regular liming is necessary to maintain calcium levels and to prevent metal toxicity from too low a pH (Horbaczewski, 1975 - Appendix 3).

Hematite, responsible for the red colouration of the Devonian rocks and soils derived from them, is particularly stable (Oades, 1963; Gotoh and Patrick, 1974). Eluviation, were it to occur in the red siltstones, would be masked by the strong body colour of the soil material and total disintegration to silt grades would be necessary for any "bleaching" to become apparent in such situations.

Fig 4a


X-RAY DIFFRACTION TRACES (Cavity Mounts)
GROUND, UNTREATED SAMPLES
P 2 A
2·28
2·36
2·45
2·52
2·58
2·73
2·86
2·99
3·20
3·34
3·53
3·69
3·87
4·25
4·48
4·72
5·01
7·08
10·0
14·1
P 2 C
2·28
2·45
2·56
2·69
2·98
3·19
3·30
3·54
3·70
4·24
4·46
4·69
4·94
7·07
7·83
9·9
11·0
14·3
15·5
P 25 A
2·28
?
2·52
2·55
2·71
2·85
2·98
3·18
3·34
3·56
?
3·69
4·23
4·44
4·70
4·95
7·02
9·9
14·1
P 25 C
2·35
2·45
2·55
2·71
2·85
2·98
3·19
3·28
3·34
3·52
3·68
4·01
4·23
4·44
4·68
4·92
6·32
7·02
9·9
13·6
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
°2θ Cu Kα

In terms of general mineralogy, there is little difference between the red siltstone soil (P2 - Fig 4a) and the soil derived from grey Silurian siltstone/sandstone (P8 - Fig 4b); the former displaying a higher hematite content (2·71 Å), and the latter a higher feldspar content (3·20 Å). The Ordovician black shales (P22C - Fig 4b) differ in that, despite their name, they are deficient in clay minerals (10 Å, 14 Å) but rich in quartz (2·46 Å) and feldspar (3·20 Å).

(ii) Podzols (sensu stricto) Avery, 1973)

As a general rule, podzols do not occur in the study area. However, in one small locality the conditions have been sufficient to effect eluviation and to produce a small area - in effect, a pedon (Soil Survey Staff, 1960) of podzol (Plate 6).

The virgin soil occurs on a shedding site (I) and has formed in one of the sandstone phases of the red siltstone succession. The presence of mor humus, together with the extremely permeable soil material, has led to strong leaching and the formation of a bright sesquioxide horizon.

Though interesting as an illustration of potential pedogenic processes given extreme conditions, the soil is not dealt with in detail as it is completely unrepresentative of the study area as a whole.

(iii) Brown Earths (sensu stricto) (Avery, 1973)

The brown earths on the "shedding" plateau surfaces characteristically occur in material derived from basic igneous rocks - P21, P27 (Appendix 10), or in the glacial till sheets - P 37, P53 (Appendix 10). They are recongised generally by a colour differentiation into a

P86 - Soil Profile Description

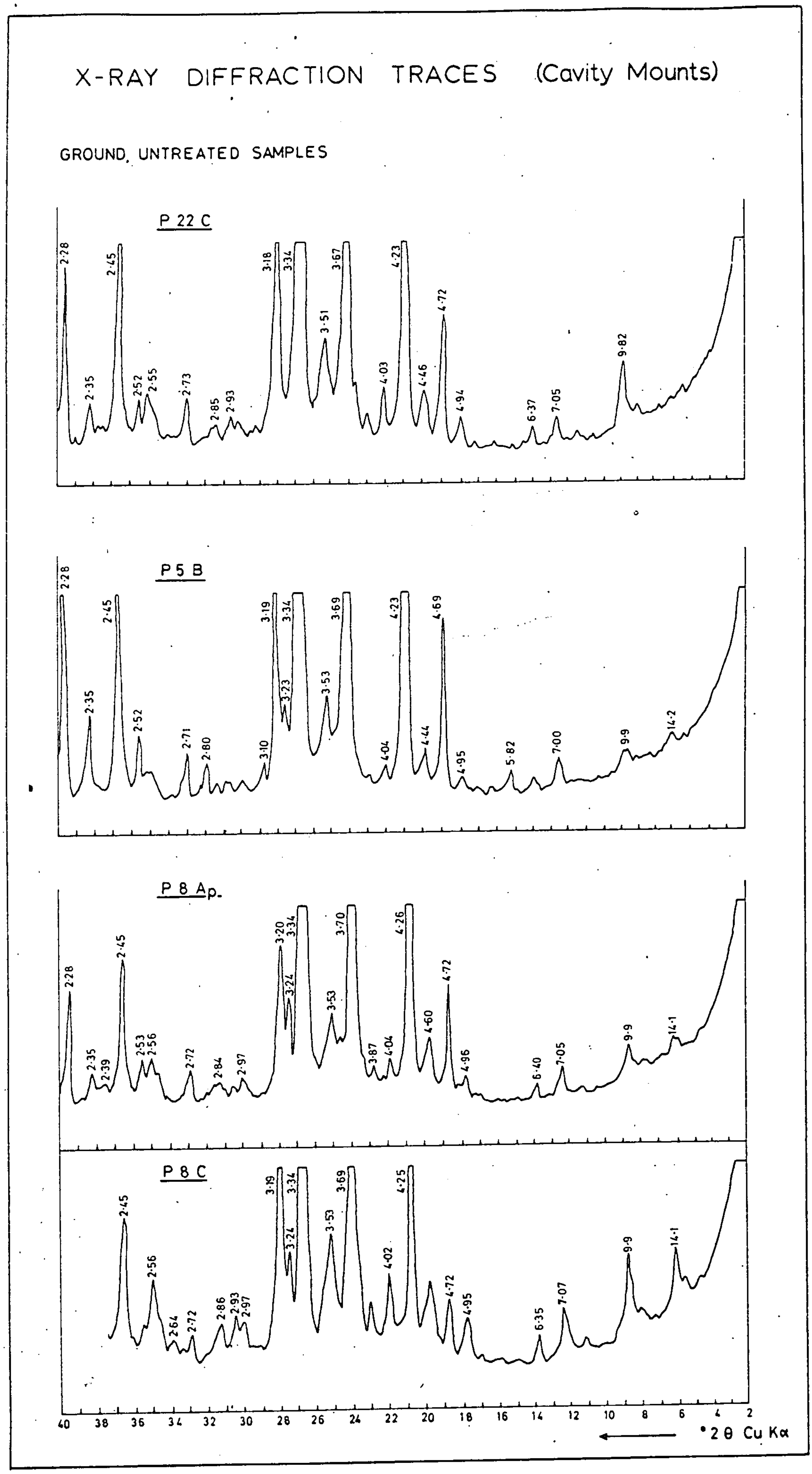
0-5 cms	A_o	Very dark brown (10YR 2/2) humic (mor) with pale quartz particles (coarse sand) very porous. Boundary merging (1 cm) and regular.
5-15 cms	A_{e1}	Rose-coloured (7·5YR 8/3) stony coarse sand. Single grain, dry, OM low, abund. quartz pebbles up to 1 cm across. Boundary merging (1 cm) and regular.
15-30 cms	A_{e2}	Very pale grey (7·5YR 8/1) sand and fine sand. Massive. A little moist, no OM, Boundary merging (2 cms) and irregular.
30-40 cms	B_s	Brown sand (7·5YR 5/6) single grain, mod. moist, no OM, stony in places.
40-50 cms	C	Current-bedded conglomeratic sandstone.

Plate 6

Soil Profile - P86

Location	8031 1120
Topo-drainage Class	Shedding (I)
"Parent Material"	Devonian sst/cong
Altitude	15 m ± 2 m (50' ± 5')
Slope and Aspect	10°, north-west
Land Use	Virgin site

Fig 4b



X-RAY DIFFRACTION TRACES (Cavity Mounts)

GROUND, UNTREATED SAMPLES

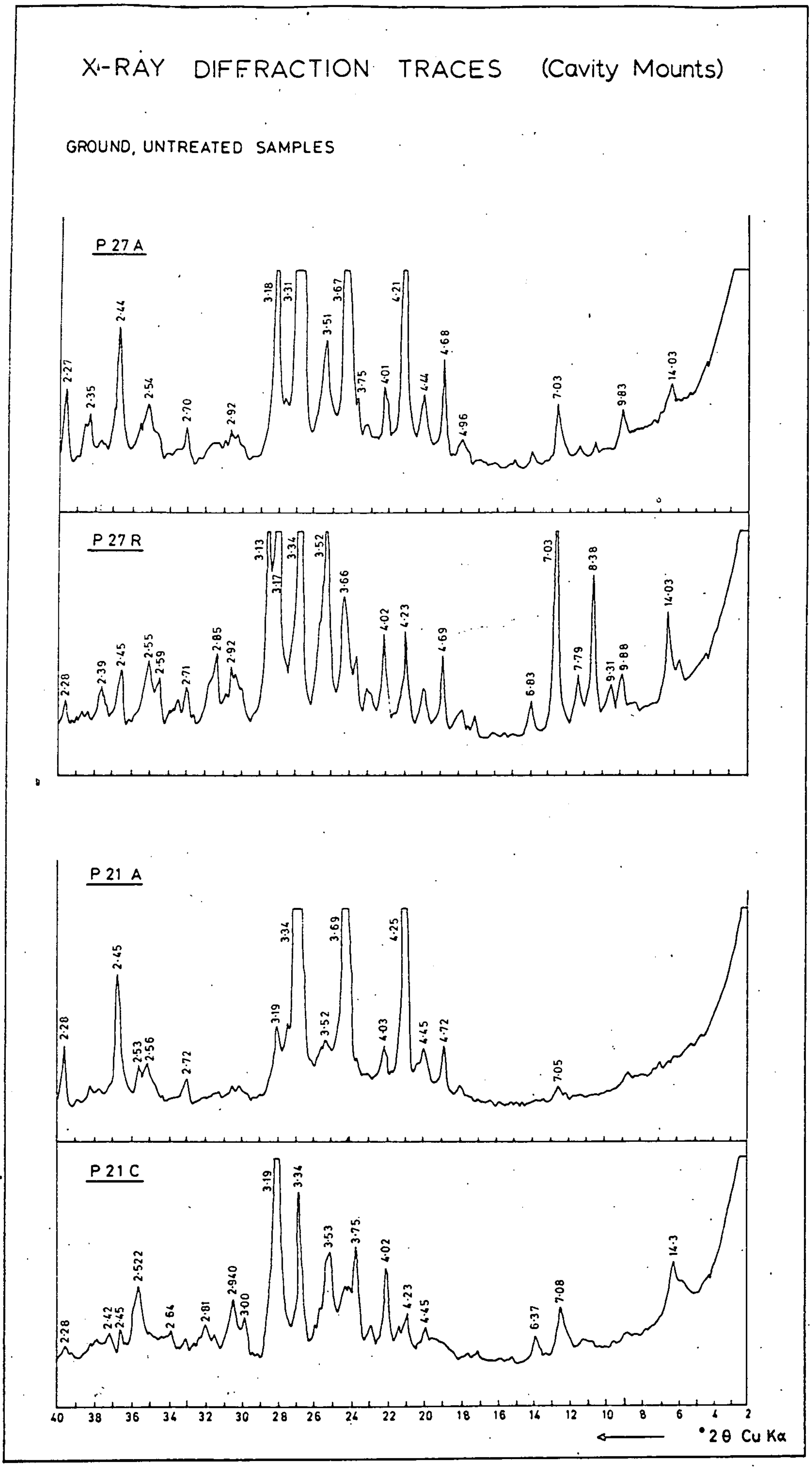
more yellow sub-soil, and sometimes a structural horizon.

It is the chemical weathering of the mafic minerals, such as hornblende, pyroxene, chlorite and biotite, in the basic igneous rocks which releases iron to form coloured horizons. Some of these mineralogical differences become apparent from X-ray diffraction analysis (Fig 4c). In contrast to the sedimentary rocks (Figs 4a, 4b), quartz is subordinate to feldspar in the basic igneous bedrock. (The reversal of this situation in the top-soils is an indication of the degree of contamination by "foreign" quartz sand - see Chapters 5 and 6.) Of the layer silicates, micas show the lowest contents : P21 has none at all, while P27 has a low peak, probably representing biotite. Similarly, chlorite is much higher in content in the coarser-grained dolerite. Sharp reductions in the chlorite basal reflections in the top-soils, and especially in their relative heights, indicate the effects of weathering and a trend towards less iron-rich phases (Petruk, 1964).

Brown earths are also identifiable in the glacial, both water-sorted and unsorted, surficial materials, occurring on shedding and transmitting sites. A "weathered B" horizon is suspected at P15 (Plate 8) in water-sorted glacial deposits, although the apparent horizonation may be a sedimenatry feature.

Eluviation of hematite has been observed in the very unusual situation at P5 (Appendix 10; see also Figure 4b) where a red siltstone "top-soil" has been spread over a disused sand pit. Visual inspection and, to a certain extent, X-ray diffraction, indicates the accumulation of hematite to form a "coloured B" horizon below the transported top-soil. (The sand pit was in use as recently as 1959 from air photograph

Fig 4c


X-RAY DIFFRACTION TRACES (Cavity Mounts)
GROUND, UNTREATED SAMPLES
P 27 A
2·27
2·35
2·44
2·54
2·70
2·92
3·18
3·31
3·51
3·67
3·75
4·01
4·21
4·44
4·68
4·96
7·03
9·83
14·03
P 27 R
2·28
2·39
2·45
2·55
2·59
2·71
2·85
2·92
3·13
3·17
3·34
3·52
3·66
4·02
4·23
4·69
6·83
7·03
7·79
8·38
9·31
9·88
14·03
P 21 A
2·28
2·45
2·53
2·56
2·72
3·19
3·34
3·52
3·69
4·03
4·25
4·45
4·72
7·05
P 21 C
2·28
2·42
2·45
2·522
2·64
2·81
2·940
3·00
3·19
3·34
3·53
3·75
4·02
4·23
4·45
6·37
7·08
14·3
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
°2θ Cu Kα

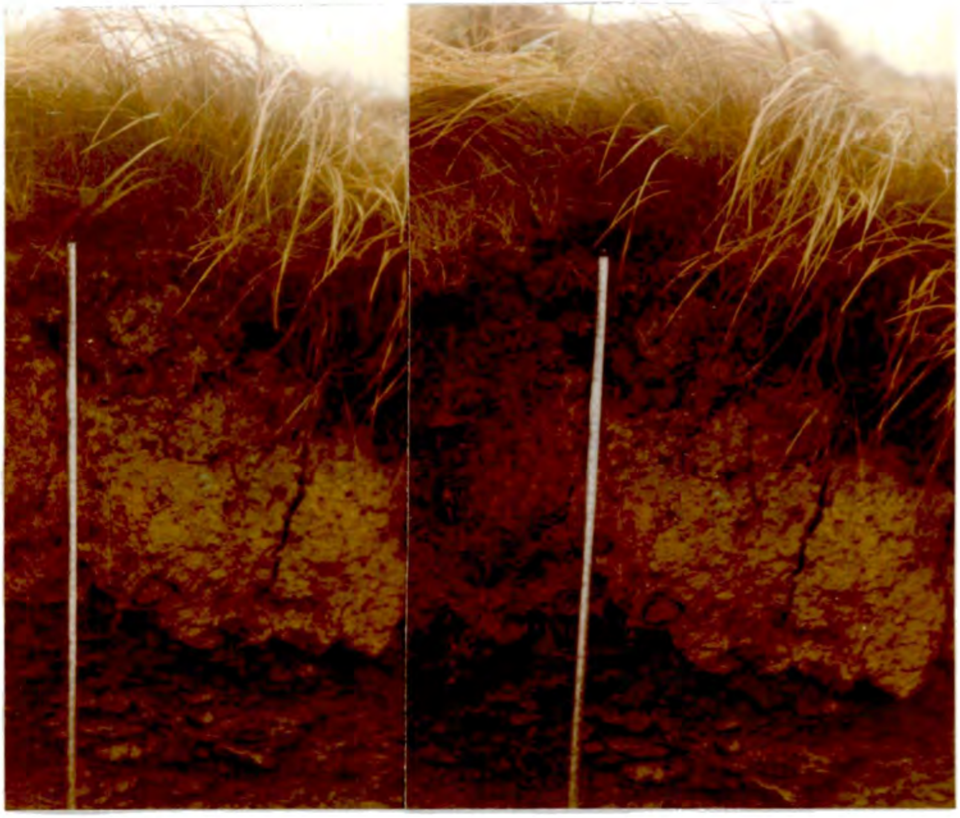
P4 - Soil Profile Description

0-5 cms	A_1	Brown (10YR 3/4) silty clay loam, small angular peds, dry, no mottles, abund. roots, no stones. Sharp and regular boundary.
5-18 cms	A_2	Lighter brown (10YR 4/3) clay silt, hard peds up to 0·5 cm across, dry to mod. moist, no mottles, no OM, few roots. A few fragments of black shale up to 1·5 cms across (pH 4·4). Boundary sharp but irregular.
18-40 cms	C_1	Orange-brown (10YR 4/4) clay silt, compact, massive and hard when dry, dry to mod. moist, no mottles, OM low, very few roots, little fauna (pH 4·9). Sharp but regular boundary.
40-160 cms	C_2	Black shale fragments in yellowish-grey matrix (2·5Y 4/4). Fragments of shale aligned parallel to surface. At base, however, parallel to cleavage plans of bedrock, moist, no fauna, no roots (pH 6·4). Boundary grading.
160+ cms	R	Black shale with cleavage.

Horizon	Soil Texture			Sand Fractions				MC	LOI
	Sand	Silt	Clay	F Gr	Co S	Med S	Fine S		
A_2	30·4	28·7	40·9	7·7	6·5	7·0	8·4	3·6	6·0
C_1	29·0	27·1	43·9	10·5	7·0	6·6	10·6	1·5	4·3
C_2	40·1	21·4	38·5	37·3	10·8	5·8	10·3	1·6	0·1

See Appendix 1 for Methods.

Plate 7



(Stereopair)

Soil Profile - P4

Location	7865 0889
Topo-drainage Class	Transmitting (II)
"Parent Material"	Ordovician black shale
Altitude	33 m ± 3 m (110' ± 10')
Slope and Aspect	10°-15°, north-east
Land Use	Virgin soil

P 15 - Soil Profile Description

0-5 cms	A_1	Very dark brown (7·5YR 2/2) sandy loam, loose, porous, large crumb (1 cm), mod. moist, no mottles, high OM, roots abund., no stones. Boundary merging and regular.
5-25 cms	$A_2/?B_w$	Dark brown (7·5YR 3/2) sandy loam, loose, porous, small crumb (0·5 cm), mod. moist, no mottles, high OM, freq. roots, no fauna, no stones (pH 4·6). Boundary merging and regular.
25-40 cms	A_3	Brown (7·5YR 4/2) loamy sand, more compacted, small crumb (0·5 cm), mod. moist, no mottles, OM mod., few roots, a few large stones. Boundary sharp but laterally truncated.
40-64 cms	C_1	Orange brown (7·5YR 4/4) stony sand, single grain, mod. moist, no mottles, no OM, no roots, abund. small stones (2 cms) of very varied lithologies (pH 5·1). Boundary sharp but laterally variable.
64-125 cms	C_2	Orange-yellow (10YR 5/4 - 4/4) sand with black discontinuous thin layers. Single grain, mod. moist - very moist at base over clay, no mottles, ? OM in lenticles up to 1 cm thick, no roots, no fauna, no stones (pH 5·2). Boundary sharp.
125-150+ cms	C_3	Orange (7·5YR 5/4) pebbly clay, very compact, very moist, no mottles, no OM, no roots, no fauna, freq. stones up to 2 cms of varied lithologies.

Horizon	Soil Texture			Sand Fractions				MC	LOI
	Sand	Silt	Clay	F Gr	Co S	Med S	Fine S		
A_2	59·6	22·1	18·3	13·9	7·9	18·3	23·6	4·5	3·9
C_1	80·6	8·2	11·2	32·9	32·7	12·9	7·5	2·2	3·3
C_2	92·5	2·7	4·8	6·0	2·3	60·7	26·8	0·9	0·8

Plate 8

(Stereopair)

Soil Profile - P 15

Location	7825 0765
Topo-drainage Class	Transmitting (II)
"Parent Material"	Water-sorted glacials
Altitude	15 m ± 3 m (50' ± 10')
Slope and Aspect	30°, north-west
Land Use	Virgin soil

evidence.)

"Structural B" horizons are rare in the study area and can easily be confused with depositional stratification as at P4 (Plate 7). The very blocky compact "horizon" is almost certainly slope-wash material that post-dates the stony soliflucted layer. As a slope-wash deposit, it is water-sorted, and the "structural" horizonation may therefore be related to this mode of origin rather than pedogenic processes.

Most of the soils formed in the plateau till sheets betray a faint "colour B" horizon if they are freely-draining - as at P25, P37, P57 (see Appendix 10). They are very variable in texture and mineralogy, but where they are very thin, as at P25 (Fig 4a), they differ but little from the bedrock-derived soils - in this case red siltstone, exemplified by P2 (also Figure 4a). Where drainage is impeded in till sheets, the soils display gleying and are classified as stagnogleys.

Perhaps the greatest difficulties in soil classification are posed by the "cumulative" red siltstone soils. The concept of "cumulative" and "non-cumulative" soils has been outlined already (see section 1.2). In the case of the red silstone soils, the "cumulative" phases appear in profile to be undifferentiated - at best they display a horizon richer in organic matter near the soil surface; at worst they appear to be perfectly homogenous. "Thickened" soils (P81 - P83 - Appendix 10) have been found at the lower end of the St Brides topographical transect and some of their properties are described in later sections (5.4.5, 6.4.5).

Strictly speaking, according to Avery's (1973) classification, these soils are rankers - with bedrock or the C horizon at less than

40cms depth. However, they differ sufficiently in genesis (i.e., "cumulative" rather than "non-cumulative") to be treated separately.

(iv) Ground-water Gley Soils (Avery, 1973)

Gleying, caused by the reduction, and sometimes removal, of iron (Blume and Schwertmann, 1969) is associated with conditions of temporary or permanent waterlogging within the soil profile. Moisture-receiving sites (III) by reason of their relative topographical position are not only heavily affected by percolating moisture but also by the main body of "ground water" - the surface of which is expressed in a water-table. The level of the water-table within the soil profile is also subject to seasonal fluctuations. When soils are gleyed to within 40cms of the soil surface, they are classified as ground-water gley soils (Avery, 1973).

Examples of gleyed soils in the study area are given by P7 (Plate 9), P13 (Appendix 10), P14 (Plate 10) and P16 (Plate 11). P7 (Plate 9) represents a gleyed soils formed in material derived from the underlying Silurian grey siltstone/sandstone. Strictly speaking, as it has a heavy clay (argillic) horizon, it falls into the argillic gley soils Group (Avery, 1973). P13 does not have such a pronounced argillic horizon and is better regarded as a cambic gley soil, although there is some evidence for fluvial deposition of the soil material (see section 6.2) which may qualify it as an alluvial gley soil.

Certainly P14 (Plate 10) belongs to this latter Group, with even a buried sequence of the top-soil horizons testifying to recent deposition of fresh alluvium.

Where soil waterlogging is permanent and strongly reducing

P7 - Soil Profile Description

0-5 cms	A_1	Dark grey brown (2·5Y 3/2) clay loam, plastic, non-sticky, moist to very moist, no mottles, O M mod., abund. roots, no stones (pH 6·9). Boundary sharp and regular.
5-20·5 cms	A_2	Grey-brown with a few orange-yellow patches (10YR 6/4 and 10YR 4/3 respectively). Silty clay, plastic, mod. moist to waterlogged just above lower boundary, a few mottles, O M mod. to low, few roots, few stones (pH 7·0).
20·5-30 cms	B_{1tg}	Grey (10YR 6/8) and orange (10YR 7·1). Heavy clay with some sand, very massive, plastic, very moist but not waterlogged, no O M, no roots, a few stones up to 1 cm across of grey siltstone (pH 7·0). Boundary sharp and regular.
30-45 cms	B_{2tg}	Predominantly orange (10YR 5/4) with grey mottles (7·5YR 5/8), and red patches (10R 3/6) sandy clay, plastic, moist to very moist, abund. mottles, O M low, no roots, abund. stones - mostly grey siltstone, some igneous (pH 6·9). Boundary merging and regular.
45-50 cms	C	Grey siltstone fragments.
54+ cms	C_g/?R	Grey clay (5GY 6/1) water-table level in pit, abund. frags. of grey siltstone in very heavy clay.

Horizon	Soil Texture			MC	LOI
	Sand	Silt	Clay		
A_1	20·8	57·0	22·2	3·9	7·2
A_2	19·2	58·6	22·2	2·7	5·5
B_{1g}	13·0	52·0	35·0	1·6	1·9
B_{2g}	31·3	42·3	26·4	1·8	2·1

Plate 9

Soil Profile - P7

Location	8070 0944
Topo-drainage Class	Receiving (III)
"Parent Material"	Silurian grey siltstone
Altitude	9 m ± 2 m (30' ± 5')
Slope and Aspect	10°, south-west
Land Use	Grass

P14 - Soil Profile Description

0-1 cms	A_1	Dark organic mat (10YR 2/1), silty clay loam, very porous, no crumbs, mod. moist, no mottles, OM very high, abund. roots, no stones. Boundary merging and regular.
1-4 cms	A_2	Dark brown (10YR 3/4) silty clay loam, porous, little to mod. moist, no mottles, OM high, abund. roots, no visible fauna, no stones. Boundary merging and regular.
4-5·5 cms	A_3	Grey (10YR 4/2) silty clay loam, mod. plastic, compact, mod. moist, no mottles, OM high, abund roots, no visible fauna, no stones. Boundary sharp and regular.
5·5-8 cms	A_{1b}	Buried equivalent of A_1.
8-9 cms	A_{2b}	Buried equivalent of A_2.
9-11 cms	A_{3b}	Buried equivalent of A_3.
11-19·5 cms	B_{1g}	Dark reddish-grey (5YR 4/2) silty clay, less compact than underlying clays, mod. plastic, little to mod. moist, OM high, roots rare, abund. small red siltstone frags (pH 5·9). Boundary merging and regular.
19·5-63 cms	B_{2g}	Orange (2·5YR 5/8) and grey (N/5) mottles. Orange colouration also along root channels, Stiff silty clay, mod. moist, OM mod., live roots rare, stones rare, no fauna (pH 6·2). Boundary merging and regular.
63-78+ cms	G	Grey (N/5) stiff silty clay, very plastic, mod. moist, very few mottles, streaks of orange brown, OM mod., rust coloured root channels (2·5YR 5/8), no live roots, no fauna, no stones (pH 6·5).

Horizon	Soil Texture			Sand Fractions				MC	LOI
	Sand	Silt	Clay	F Gr	Co S	Med S	Fine S		
B_{1g}	13·5	55·1	31·4	21·6	3·2	4·8	6·5	2·9	7·5
B_{2g}	8·4	62·1	29·5	3·1	0·2	1·8	6·6	1·9	2·6

(Stereopair)

Soil Profile - P 14

Location	8116 0844
Topo-drainage Class	Receiving (III)
"Parent Material"	Alluvium
Altitude	5 m ± 2 m (15' ± 5')
Slope and Aspect	Flat
Land Use	Long-term grass

conditions are allowed to persist, there is a gradual accumulation of organic matter due to a reduced rate of bacterial activity. The soil profile at P16 (Plate 11) is very humose and therefore classifies as a humic gley soil (sensu stricto) (Avery, 1973). The soils within Marloes Mere itself, although not examined, are expected to have peaty top-soils at least, and can therefore be assigned to the raw peat soils Group.

For the sake of completeness, the saltings of the Lower Gann Valley, questionably soils, are heavily affected by sea-water and can be allocated to the raw sandy gley soils Group.

It should be mentioned that none of the typical orange/grey colours indicative of gleying were found in the red siltstone derived soils. Hematite is particularly resistant to reduction (Oades, 1963; Gotoh and Patrick, 1974), accounting for the general absence of typical gley colours in these soils (Moore, 1973). Moreover, it is likely that the strong red colouration would mask the gleying colours.

Instead, such conditions are usually suggested by the occurrence of manganese cutans, which are also regarded as more sensitive indicators of reducing environments (Gotoh and Patrick, 1972, 1974). Heavy manganese staining has, in fact, been encountered in the channel soils - P70, P71 and P73 - at Broomhill Farm, Dale (Appendix 3 - sites A, B and C).

(v) Stagnogley Soils (sensu stricto) (Avery, 1973)

Stagnogley soils (sensu stricto Pseudogley - Avery, 1973) include those with impeded drainage or excess surface wetness. Where they are of sufficient extent, a "perched" water-table may result. As

P16 - Soil Profile Description

0-10 cms	A_1	Very dark brown (10YR 2/2) sandy loam, porous, little to mod. moist, no mottles, OM high to very high, abund. roots, freq. worms, rare stones. Boundary merging and regular.
10-20 cms	A_2	Very dark brown (10YR 2/2) sandy loam, more compacted but still mod. porous, mod. moist, no mottles, OM high to very high, freq. roots, freq. worms, occ. stones up to 2 cms (pH 5·8). Boundary sharp and irregular.
20-22 cms	A_3	Very dark brown (7·5YR 3/2) silty loam, loose and friable, mod. moist, no fauna, no stones (pH 5·7). Boundary sharp and regular.
22-25 cms	C	Orange-brown (5YR 4/4) sand. Cemented but crumbly, mod. moist, no mottles, no OM, no roots, no fauna, very small stones up to 0·5 cms across (pH 4·9). Boundary merging and irregular.
25+ cms		Coarse orange sandstone (Silurian)

Horizon	MC	LOI
A_2	8·3	12·7
A_3	3·8	12·9
C	3·7	9·3

Plate 11

Soil Profile - P 16

Location	7670 0825
Topo-drainage Class	Receiving (III)
"Parent Material"	Skomer volcanic series (sst)
Altitude	52 m ± 3 m (170' ± 10')
Slope and Aspect	5°, south
Land Use	Barley stubble and grass

in the ground-water gley soils, waterlogging leads to reducing conditions and gleying. In the study area, stagnogleys are most likely to be found in the plateau till sheets where they are sufficiently clayey.

A good example was found at P 10 (Appendix 10) where strong gleying is found despite its "shedding" topo-drainage position (see sections 3.4 and 6.2). The channels in the B_{1g} horizon may be due to the action of deep ploughing or subsoiling, effected to counteract the poor drainage of the soil.

4.4.2 Soil Texture

Soil texture plays an important role in the description and classification of soils and is considered to be one of the primary differentiating criteria (Avery, 1973). In some instances, soils have been mapped on the basis of textural parameters (Van Ruymbeke and De Leenheer, 1965; Vandamme and De Leenheer, 1972). As a crude indicator of particle size distributions, soil texture analysis can serve as the first step in pedogenetic studies.

Size Limits

The designation of three size classes - sand, silt and clay - requires the selection of sharp, but "natural", size limits. The criteria for the American (USDA) system (2,000 μm - 50 μm - sand; 50 μm - 2 μm - silt; < 2 μm - clay) are described in the report of a Special Committee set up to investigate "particle size scales of earthy materials" (Committee Report, 1967). British Standards limits recommended by Avery (1973) differ only in the division between sand and silt, which is placed at 60 μm instead of 50 μm. Strictly speaking, the former figure is more rational, as the geometric size intervals are then equal.

Size (μm)	British Limits	American Limits
2,000	-1·0 Ø	-1·0 Ø
60	+4·0 Ø	
50		+4·3 Ø
2	+9·0 Ø	+9·0 Ø

(Ø = logarithmic size scale devised by Krumbein, 1934).

However, whichever scale is used, the intervals (of about 5 Ø units) are too great for detailed work, and the soil texture is dealt with but briefly here with more detailed size distribution analysis in Chapter 6.

Study Area

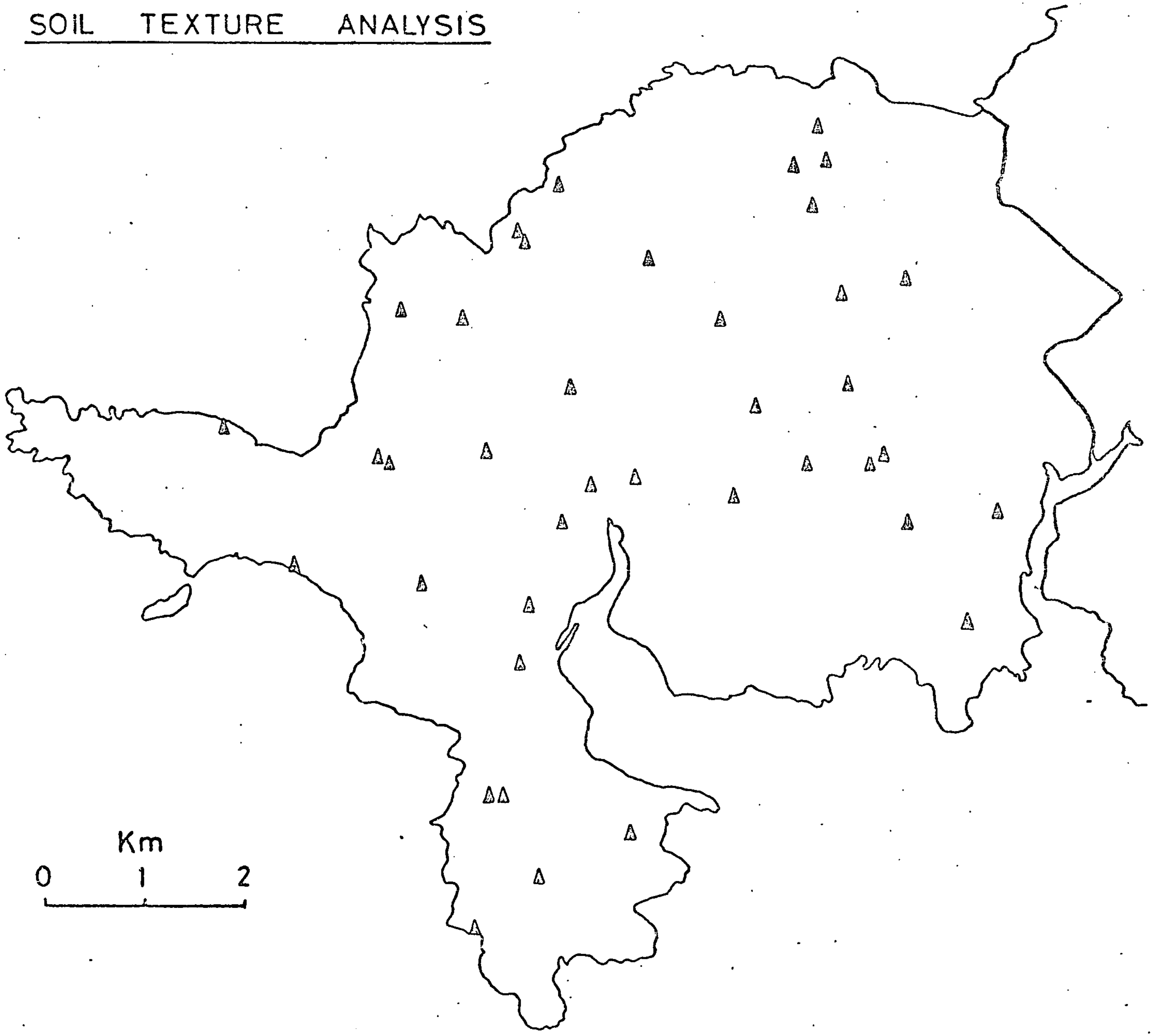
Thirty-nine samples representing the top-soils of the study area (see Appendix 2) were taken on a free survey basis, with due care for proportional representation, at a density of about one sample per km^2 (Fig 4d). Complex areas, such as the south of St Ishmael's Parish, have been omitted as adequate sampling of areally small soil units is difficult (Rudeforth, 1969). Grid-square sampling over the study area has, in fact, already been carried out at the same density (one sample per km^2), and preliminary results have been published (Rudeforth and Bradley).

In terms of soil texture, the similarity between the soils of the study area is very marked. The majority of the soils fall into the category of clay loams or clays (Fig 4e - see also Appendix 2).

Fig 4d DISTRIBUTION OF SAMPLES

FOR

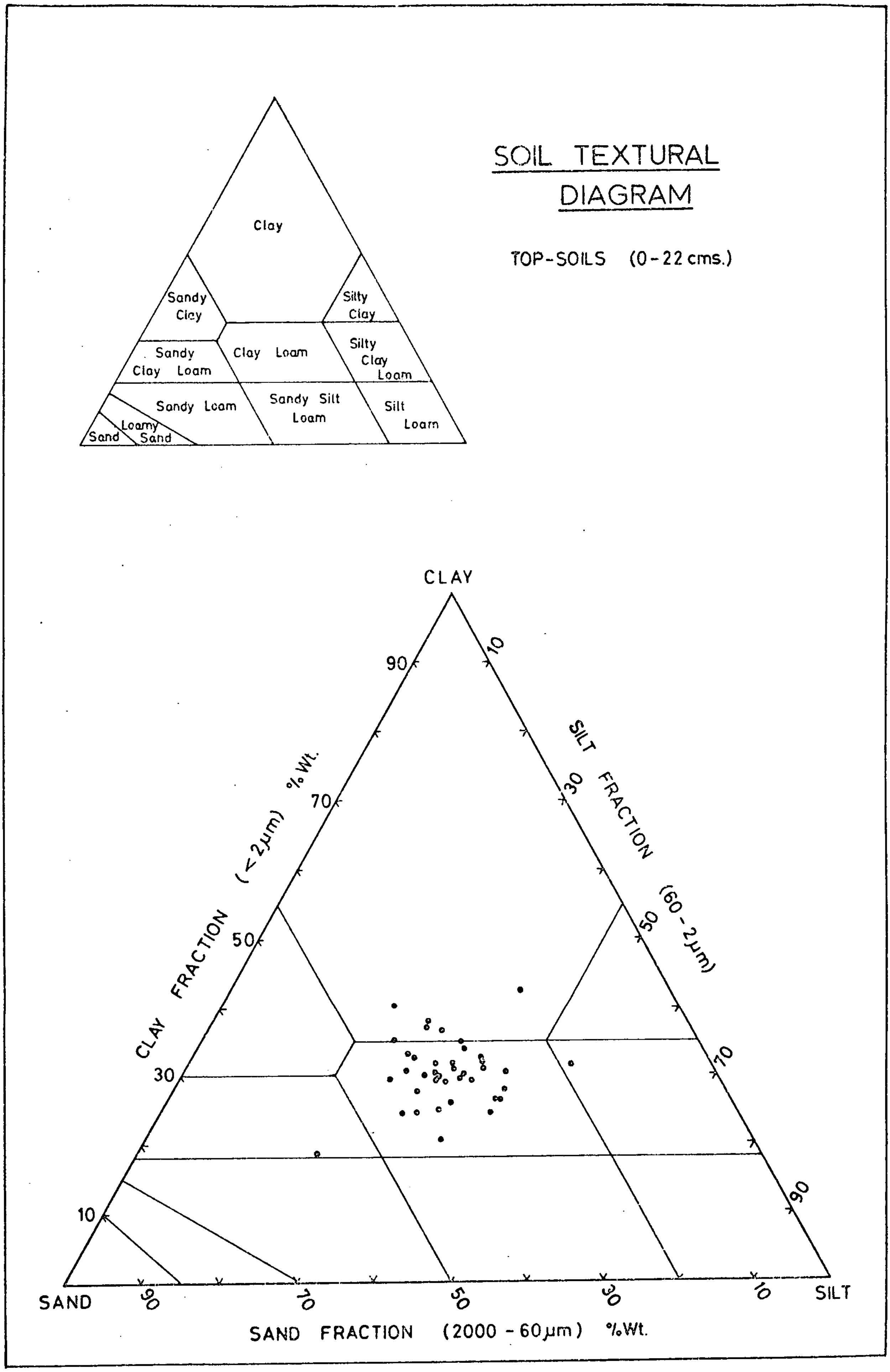
SOIL TEXTURE ANALYSIS



This differs somewhat from their field assessment as silty clay loams - probably a result of the difficulty in distinguishing between fine sand and coarse silt by "feel". The five outermost sample points (Fig 4e) include P15 (58·1% sand), P36 (39·8% clay), P13 (42·5% clay), P14 (50·1% silt), P53 (20·4% clay). Most of these are somewhat unusual in that they are not derived from bedrock or plateau till sheets : P15 is situated in a water-sorted, sandy glacial deposit (Plate 8); P13 (Appendix 10) and P14 (Plate 10) are strongly gley alluvial materials; P53 (Appendix 10) is located in a very stony till sheet; P36 (Appendix 19) is the only soil which is not exceptional and, indeed, is not far removed from the main body of data points (Fig 4e).

The close clustering of soil textures may result from the textural similarity of the bedrock sediments which are dominated by fine sandstones and siltstones of the Silurian and Devonian Formations. Weathering of such material tends to produce constant proportions of silt and clay (Stewart, Adams and Abdulla, 1970), which together with sand-sized rock fragments account for the overall loamy texture. On the other hand, a strong influence on the top-soil texture may be exerted by addition of extraneous material - a point investigated in more detail in succeeding chapters.

Fig 4e



SOIL TEXTURAL DIAGRAM

TOP-SOILS (0-22 cms.)

CHAPTER 5

ORIGIN OF THE SOIL SAND FRACTION - LITHOLOGICAL COMPOSITION

5.1 INTRODUCTION

One of the problems that emerged in the course of field survey was that of distinguishing and identifying soil "parent materials". This is of considerable importance in the accurate prediction of soil properties, and of paramount importance in a study of soil genesis.

Very often, bedrock-derived regolith was found to grade laterally and imperceptibly into thin, patchy till sheets or, even worse, into colluvially-thickened slope material. The delineation of the glacial deposits by the Geological Survey was found to be unsatisfactory (see section 3.5), as "superficial material" less than a metre or so in thickness had generally been considered to be geologically insignificant.

In the case of soils, on the other hand, the thickness of such a deposit needs to be little more than a plough layer to be genetically important. This indeed proved to be an additional problem, particularly in those areas where the "superficial" cover was so thin that it could not be recognised on air photographs.

The usual technique adopted by pedologists for resolving such cases involves a compositional analysis of the heavy mineral suites of the fine sand or silt fractions (Bullock and Loveland, 1974). Though sufficiently accurate for most purposes, this technique has the great disadvantage of being very arduous, and would have been impractical, in terms of time, for the number of samples available.

An alternative but analogous technique was evolved of analysing the lithological composition of the coarse sand fraction. It was reasoned that quartz of this size would be a good indicator of glacial (i.e., foreign) material, as none of the geological formations within the study area (Fig 1b) are potential sources. The only exception possible is that of the sandstone phases associated with the Devonian red siltstones, but these are rare and, in any case, easily distinguished from quartz of glacial origin.

5.2 METHODOLOGY

Four lithological groups were distinguished and have been applied throughout the analysis:-

(i) Red siltstone
(ii) Quartz
(iii) Coal
(iv) "Other lithologies".

(i) Red siltstone rock fragments were easily recognised by their strong maroon colour and by their fine-grained texture - component silt grains only becoming visible under magnification (see section 6.6). The siltstones were often accompanied in the field by sandstone phases of the same "Red Marls" sedimentary unit. These coarser phases had to be assigned to the group of "other lithologies", however, to maintain methodological consistency. Where such a phase became sufficiently important locally in a soil, its presence would be betrayed by an anomalously high level of the "other lithologies" class.

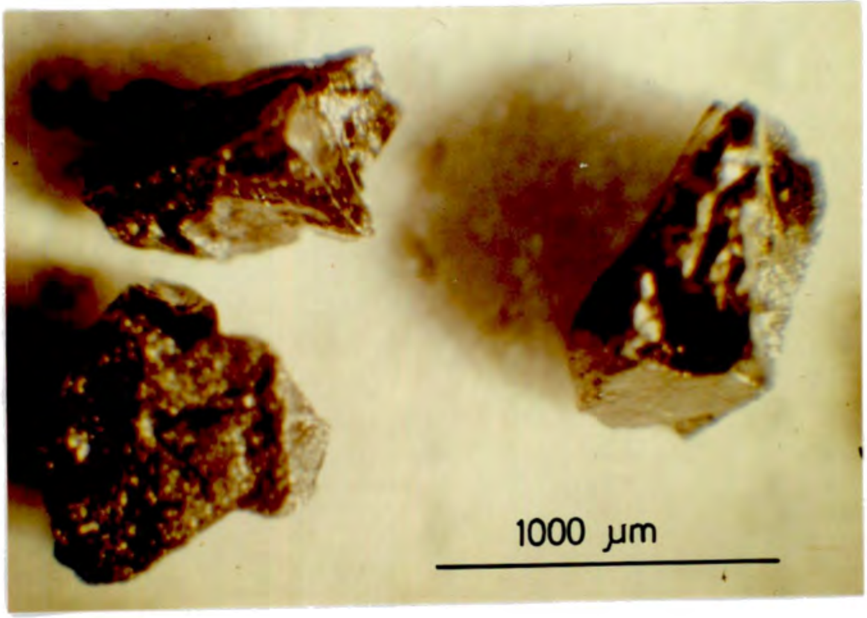
(ii) Quartz grains were encountered in a variety of shapes and colours (Plate 12A). Grains derived recently from bedrock appeared corroded and irregular, and were often stained brown. The most probable sources were the occasional phases of the Devonian formation. The majority of quartz grains, however, were clearly of foreign origin. One variant included very rounded, colourless frosted grains, rarely exceeding 600µm in diameter, and probably of aeolian or fluvial/marine origin. The other type was represented by very angular, clear fragments, clearly of glacial derivation.

(iii) Coal emerged as an unexpectedly common constituent of the soil sand fraction - it was almost ubiquitous in top-soils, and in some cases became very important. Both fresh and corroded examples were noted, but the former were predominant. The black grains were generally very angular, with a high lustre and often conchoidally fractured (Plate 12B). Close examination of larger fragments (up to 1cm across) proved conclusively that this was real coal and not charcoal.

(iv) The group of "other lithologies" comprised, in most cases, a mixture of minor lithologies. Many were unidentifiable, though some were thought to be pieces of slag, volcanic rock, and rock fragments from formations other than the Devonian. Only in a few cases did this class assume importance where the subadjacent rock was not red silt-

P 75 (5-15 cms) Location 8131 0524

A. Quartz grains from sieve fraction (600µm-420µm)
At left - Yellow-stained, very angular grain, probably derived from sandstone
Lower - Very rounded, frosted grains of probable marine/aeolian origin
Upper - Very angular, clear grain of glacial origin



B. Coal fragments from sieve fraction (600µm-420µm)
Note high lustre and angularity

stone, or where there was an intrusion of a sandstone phase as mentioned earlier.

Various methods of estimating and quantifying the proportions of these lithological groups were tested. Initially a visual categorisation into frequency classes was attempted (section 5.3). Physical separation techniques involving magnets, specific gravity liquids and even colorimetric methods were attempted but found to be lacking in accuracy and precision.

It also became apparent that it was not sufficient to determine the proportions of the lithologies (a "relative" measure), but that their absolute contents in the soil were of more significance. The only suitable technique necessitated hand separation and counting of sand grains. Clearly this was only practicable with the coarsest sand grains where numbers were manageable. Even so, the analysis proved very arduous. Total number counts per sample ranged from 100 to over 2,000 grains.

Weighing of the separated lithological groups was found to be unreliable owing to differences in shape, density and size distribution between the groups, and even within the lithological groups.

5.3 COARSE, MEDIUM, AND FINE SAND FRACTIONS

Initial analyses included a visual assessment of the proportions of lithological groups in the three sand fractions described in section 6.3. Results are summarised in Table 5(i).

The most notable trend in the top-soil samples (5-15cms) is

TABLE 5(i)

Lithological Composition of the Three Sand Fractions

Sample (Depth in cms)	Coarse (2,000-600μm)				Medium (600-200μm)				Fine (200-60 μm)			
	RS	Q	C	O	RS	Q	C	O	RS	Q	C	O
P 2 (0-10)	d	i	c	r	c	d	i	r	Not Available			
(10-20)	d	i	i	i	a	a	i	r				
P 3 (5-15)	d	r	i	i	a	a	i	r				
(30-35)	d	r	r	r	a	a	r	r				
P 4 (5-15)	r	r	r	d	c	d	n	c				
(20-25)	n	r	n	d	i	f	n	f				
(50-55)	n	n	n	d	i	r	n	d				
P 8 (5-15)	c	r	i	d	c	a	f	r				
(25-30)	c	r	n	d	c	f	n	f				
P15 (5-15)	c	c	r	c	r	f	r	f				
P20 (5-15)	r	f	r	f	r	d	r	c				
(30-35)	r	d	r	c	r	f	r	f				
P22 (5-15)	r	r	r	d								
P24 (5-15)	f	r	c	f	c	c	c	c				
(25-30)	r	n	r	d	i	n	n	d				
(35-40)	d	n	n	i	f	i	n	c				
P25 (10-20)	f	f	f	i	f	f	f	i				
(45-50)	c	a	n	c	r	a	n	i				
P26 (5-15)	a	i	i	r	f	f	i	r				
(20-25)	d	i	r	i	f	f	r	n				
P27 (5-15)	c	f	i	f	r	a	i	r				
(20-25)	c	f	n	f	i	f	n	f				
P28 (5-15)	d	i	i	r	d	c	i	r	c	d	r	r
P29 (5-15)	f	f	i	r	c	d	n	r	i	d	r	c
P30 (5-15)	d	i	r	c	i	d	n	r	i	d	n	r
P31 (5-15)	d	c	i	r	f	f	n	r	i	d	r	r
P32 (5-15)	d	c	i	i	c	d	n	r	i	d	r	r
P33 (5-15)	d	i	i	i	c	d	r	r	i	d	r	r
P34 (5-15)	i	a	i	i	i	d	r	i	i	d	r	r
P35 (5-15)	f	c	r	f	c	a	r	c	r	d	r	i

TABLE 5(i) (Continued)

Sample (Depth in cms)	Coarse (2,000-600μm)				Medium (600-200μm)				Fine (200-60 μm)			
	RS	Q	C	O	RS	Q	C	O	RS	Q	C	O
P36 (5-15)	i	r	i	d	i	f	r	a	i	d	r	i
P37 (5-15)	d	i	r	i	f	f	r	f	i	d	r	r
P38 (5-15)	d	i	i	r	f	f	r	r	c	d	r	c
P39 (5-15)	d	c	i	i	f	f	r	r	c	d	r	i
P40 (5-15)	d	i	r	i	f	f	r	r	c	d	r	r
P41 (5-15)	d	r	i	r	f	f	c	r	c	d	r	r
P42 (5-15)	d	r	i	r	f	f	r	r	f	f	r	i
P43 (5-15)	d	r	i	r	a	c	r	r	f	f	r	r
P44 (5-15)	d	i	r	i	d	c	r	r	d	c	r	i
P45 (5-15)	d	n	c	r	f	f	f	r	c	d	c	i
P46 (5-15)	d	n	r	r	f	f	r	r	c	d	r	i
P47 (5-15)	c	c	c	c	i	d	i	i	i	d	r	i
P48 (5-15)	d	r	i	r	d	c	i	r	d	c	r	i
P51 (5-15)	r	n	r	d	r	c	r	d	f	f	r	c
P52 (5-15)	i	r	i	d	r	d	i	i	Not Available			
P53 (5-15)	i	c	d	c	i	d	c	r				
P55 (5-15)	d	n	i	i	d	i	r	c				
P56 (5-15)	i	i	r	a	i	d	c	c				

Abbreviations:-

RS - Red Siltstone; Q - Quartz; C - Coal; O - Other Lithologies.

d -	dominant, approximately	80%
a -	abundant, approximately	80-50%
f -	frequent, approximately	50-30%
c -	common, approximately	30-10%
i -	infrequent, approximately	10-5 %
r -	rare, approximately	5%
n -	nil, approximately	0%

the increasing dominance of quartz with decreasing grain size. That this quartz is of foreign origin is evident from its appearance - in contrast to the occasional grains in the coarse sand fraction (2,000μm to 600μm), the quartz of the medium and fine sands (600μm to 200μm, 200μm to 60μm, respectively) is frequently colourless, single-grained (i.e., not polycrystalline) and either very angular or well rounded (Plate 12A). The decline of the proportion of quartz down the soil profile (clarly seen in P4 and P24 - Table 5(i)) is additional evidence of its introduction at the soil surface and not from bedrock.

As a result, it is only the coarse sand fraction (2,000μm to 600μm) that clearly reflects the origin of the soil "parent material". Red siltstone fragments are found to predominate in soils derived either directly from this lithology or indirectly in colluvially "thickened" deposits. Where other lithologies are present underlying soils, these assume dominance in the coarse sand, as at P4 (black shale), P8 (grey siltstone/sandstone) and P22 (black shale). Quartz only becomes a significant component of the coarse sand fraction where the soil material is of glacial or fluvio-glacial origin (as at P25 and P15 - glacial and fluvio-glacial respectively). It is rare for coal to be entirely absent from the coarse sand, and in one case (P53) it is the major constituent.

One of the problems which very rapidly came to the fore in the course of analysis and interpretation of the results was that the frequency values, apart from lacking full quantification, applied to the proportion of one lithological group relative to the others within a single coarse sand fraction. No account was taken of the absolute size of this lithological group. It was entirely possible that a constant amount of quartz would appear to diminish down the soil profile simply because the other constituents increased.

It also became apparent that a subdivision within the coarse sand fraction (2,000μm to 600μm as recommended by Avery, 1973) would greatly improve its efficiency as an indicator of the parent lithology. This was because the quartz contaminant was found to decline rapidly above a size of about 1,000μm (1mm) and, therefore, above this limit the sand fraction became almost fully representative of its "parent material".

5.4 THE COARSEST SAND FRACTION

5.4.1 Presentation

In the succeeding analyses, only the coarsest sand fraction (sometimes referred to more simply as coarse sand, but having a size range of 2,000μm to 1,200μm, instead of 2,000μm to 600μm) has been examined.

Three parameters were obtained:-

(i) The weight percentage of the entire coarse sand fraction (2,000μm to 1,200μm) in the Fine Earth fraction (<2,000μm).

(ii) The "absolute" number of grains of each lithological class in the coarse sand fraction (2,000μm to 1,200μm) present in 100gms Fine Earth (<2,000μm) - effectively serving as a reference base.

(iii) The "relative" proportion of the lithological classes (by number of grains) within the coarse sand fraction (2,000μm to 1,200μm).

In effect, the "absolute" parameter functions in an open number system with almost complete independence of the lithological classes (in the extreme case where all 100gms of the Fine Earth were composed of the coarsest sand fraction, some 20,000 grains would be involved, thereby providing a high "ceiling" for number counts), whereas the "relative" measure has the advantages and defects of a closed number system.

One major problem of the latter, as mentioned already, is its ambiguity. A content of 20% may refer to one grain in five, ten in 50, or 100 in 500. Thus high "relative" contents of a particular lithology may simply be due to a very low overall coarse sand content.

Where contamination is suspected, the distinction between "relative" and "absolute" contents becomes particularly relevant. If there has been uniform deposition of a contaminant (as may happen under aeolian action), then its "absolute" content should remain constant, though its "relative" content would depend on the amount of other lithologies already present in the soil coarsest sand fraction.

Two qualifications need to be recorded in this context:-

(i) The "absolute" content is tied to a base of 100gms of Fine Earth. If this base were enlarged, the measure would become even less constrained.

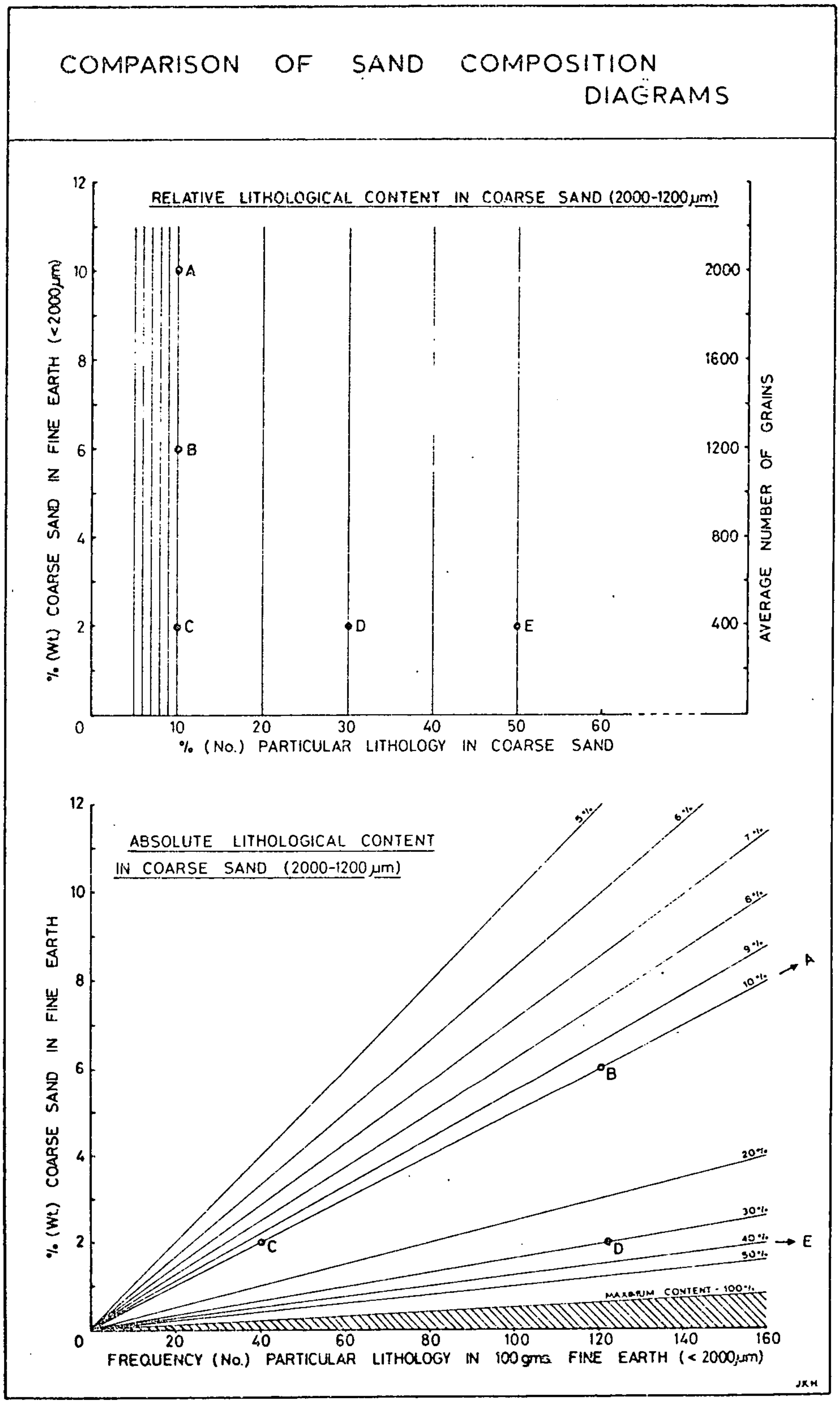
(ii) Few contaminants are composed solely of one distinctive lithology. In this case, quartz is clearly of foreign origin, particularly when it is well rounded or very angular and clear. However, some sand-sized rock fragments may also be incorporated, although they would not be immediately recognisable as such.

In order to present the results, two types of graph have been designed (Fig 5a). The vertical axis in both depicts the overall content by weight of the coarsest sand fraction (2,000µm to 1,200µm) in 100gms of Fine Earth (<2,000µm). The horizontal axis is used to represent the lithological composition of this coarsest sand fraction in either "relative" or "absolute" terms.

The two types of graph are, in fact, related, as shown in Figure 5a. For example, points A, B and C all represent samples with different weights of overall coarsest sand but with a constant proportion (10%) of a particular lithology within that coarsest sand fraction. In "absolute" terms, however, C has only 40 grains; B with three times the overall weight of coarsest sand has therefore 120; and A plots off the graph with five times as many - 200.

Conversely, points C, D and E define samples of Fine Earth with a constant content of the overall coarsest sand fraction (2gms in 100gms of Fine Earth) but with varying proportions of a particular lithology - C has 10%, D has 30% and E has 50%. When plotted on the "Absolute" graph, C remains at 40 grains, D has three times as many - 120 grains - and E falls outside the graph with five times as many - 200 grains. The maximum content possible - 100% - would plot at about 400 grains for an overall coarsest sand content of 2gms in 100gms Fine Earth, and it is from such a calculation that the line of

Fig 5a


COMPARISON OF SAND COMPOSITION DIAGRAMS
RELATIVE LITHOLOGICAL CONTENT IN COARSE SAND (2000-1200 µm)
% (Wt) COARSE SAND IN FINE EARTH (<2000µm)
0
2
4
6
8
10
12
A
B
C
D
E
AVERAGE NUMBER OF GRAINS
400
800
1200
1600
2000
10
20
30
40
50
60
% (No.) PARTICULAR LITHOLOGY IN COARSE SAND
ABSOLUTE LITHOLOGICAL CONTENT IN COARSE SAND (2000-1200 µm)
% (Wt) COARSE SAND IN FINE EARTH
5%
6%
7%
8%
9%
10%
→ A
20%
30%
40%
→ E
50%
MAXIMUM CONTENT - 100%
FREQUENCY (No.) PARTICULAR LITHOLOGY IN 100 gms. FINE EARTH (< 2000µm)
20
40
60
80
100
120
140
160
JKH

maximum content is constructed.

The gradient of this maximum boundary line is, therefore, scale-dependent, although the "absolute" content graph itself remains orthogonal. The two axes are independent because they measure two entirely different properties - one is the content of the coarsest sand fraction in the Fine Earth, and the other is the lithological composition of that sand fraction.

5.4.2 Sampling

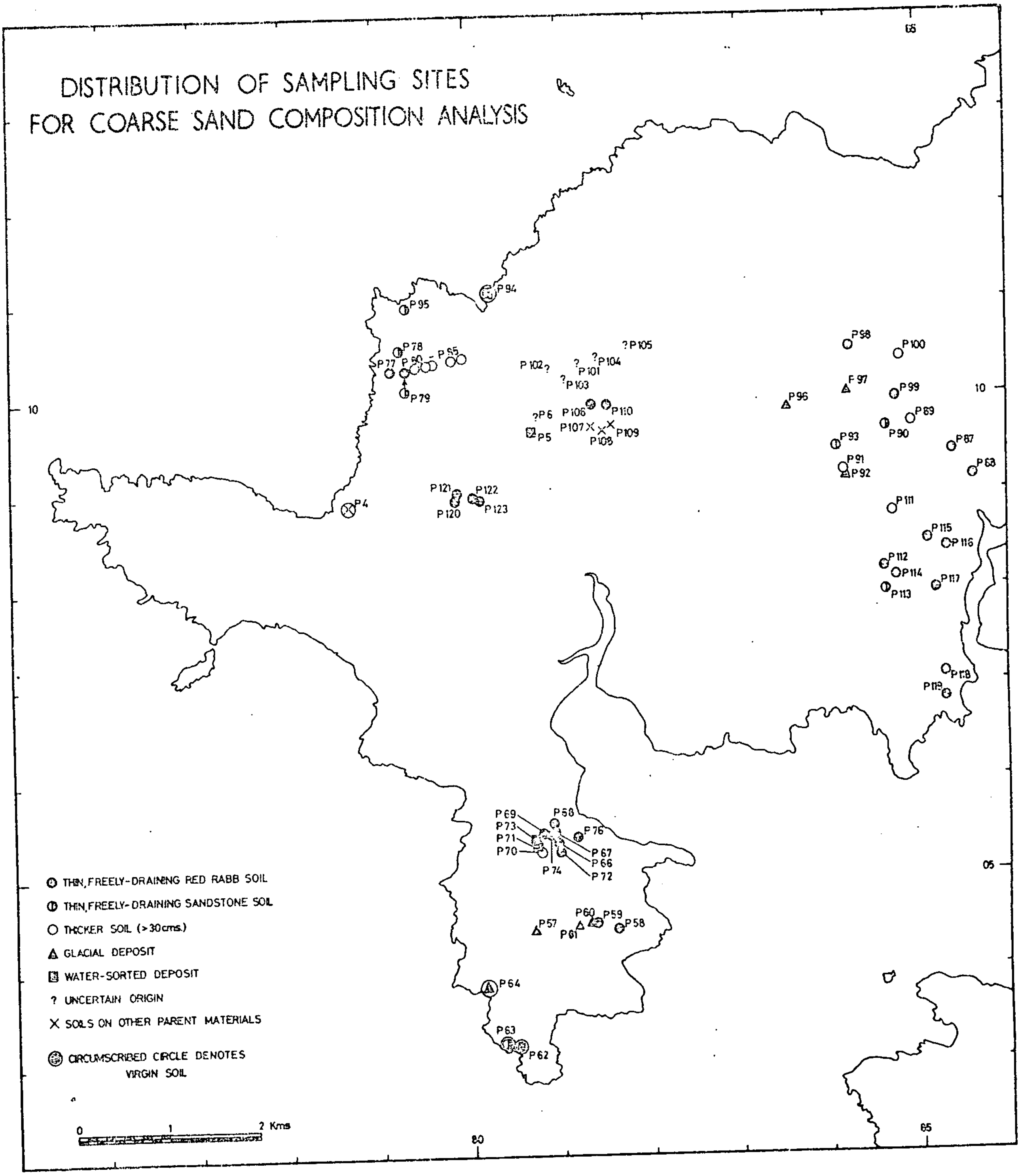
Sampling for the succeeding analyses was confined to three sub-areas (Fig 5b) owing partly to research requirements and partly to field work limitations. Also, in order to ensure comparability of sites, only level upland areas with Devonian bedrock and associated superficial deposits have been considered. Two large airfields, situated at Talbenny and Dale (Fig 1a) have been avoided as soils bore signs of considerable disturbance.

The composition of the coarsest sand fraction (2,000µm to 1,200µm) was determined for 63 samples, mostly of cultivated top-soils, with six so-called "duplicate" samples, each taken from a single plough layer though at different levels.

5.4.3 Red Siltstone Content

The "absolute" content of red siltstone in the coarsest sand fraction (2,000µm to 1,200µm) of soils associated with the Devonian Formation is a measure of the degree of derivation from bedrock. The thin plateau soils have the highest levels, with a minimum of about 700 grains per 100 gms Fine Earth (Fig 5c, see Appendix 5 for raw data).

Fig 5b

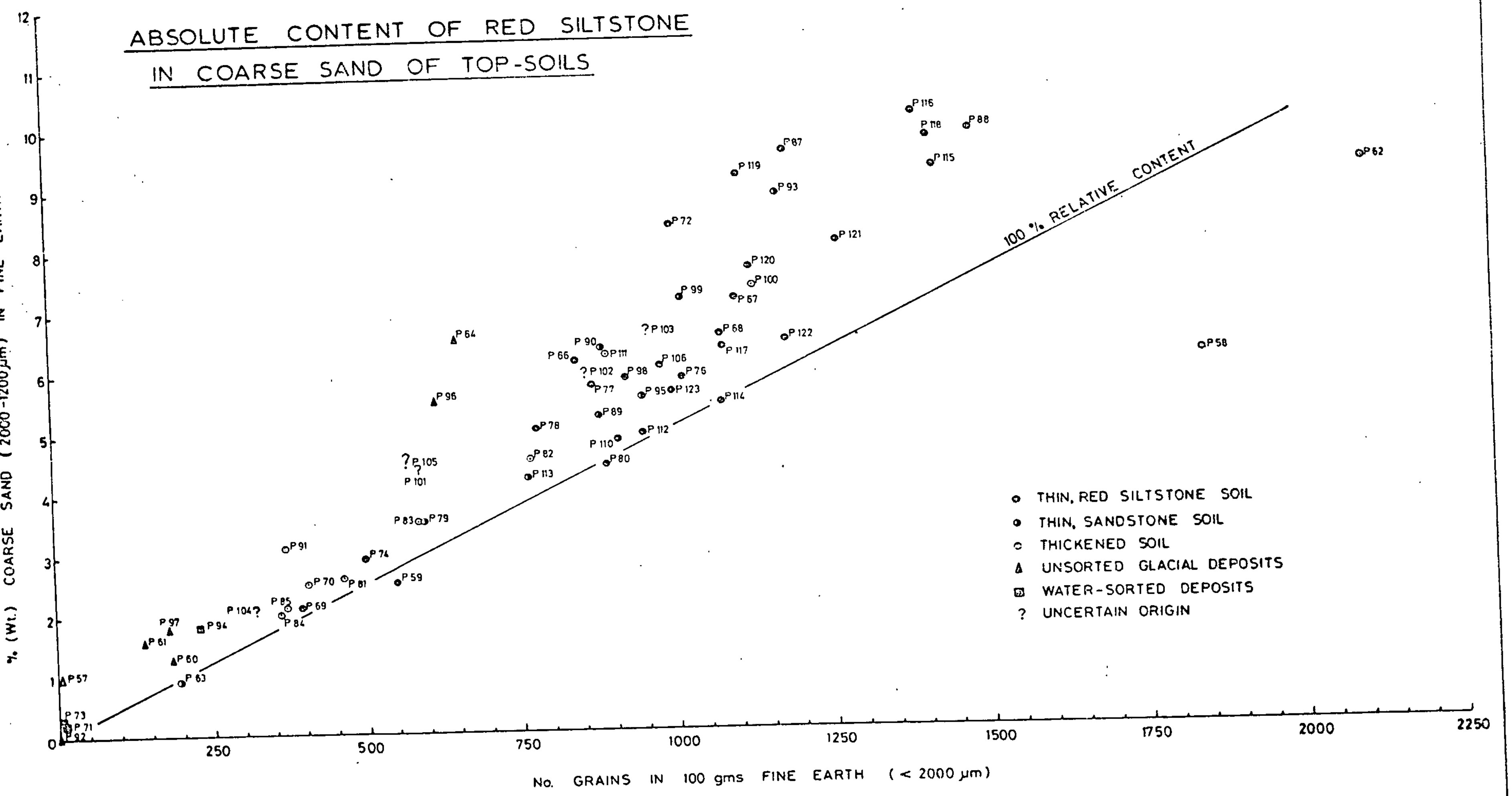

DISTRIBUTION OF SAMPLING SITES
FOR COARSE SAND COMPOSITION ANALYSIS
P94
P95
P78
P77
P80
P65
P79
P102
P101
P104
P105
P103
P106
P110
P6
P5
P107
P108
P109
P96
P98
P100
P97
P99
P89
P90
P93
P87
P91
P92
P68
P4
P121
P122
P120
P123
P111
P115
P116
P112
P114
P117
P113
P118
P119
P69
P73
P71
P70
P56
P76
P67
P66
P72
P74
P57
P60
P61
P59
P58
P64
P63
P62
10
10
05
65
80
65
THIN, FREELY-DRAINING RED RABB SOIL
THIN, FREELY-DRAINING SANDSTONE SOIL
THICKER SOIL (>30cms.)
GLACIAL DEPOSIT
WATER-SORTED DEPOSIT
? UNCERTAIN ORIGIN
X SOILS ON OTHER PARENT MATERIALS
CIRCUMSCRIBED CIRCLE DENOTES VIRGIN SOIL
0
1
2 Kms

This is followed by a transition zone of 700-500 grains per 100gms Fine Earth, occupied by soils of uncertain origin (P101, P105), soils near the edges of till sheets (P59), some slope-thickened soils (P79, P83) and some exceptional glacial tills (P64, P96). Below this range, thin plateau soils are rare, and glacial material, both sorted and unsorted, predominates together with the remaining slope-thickened soils.

The results are not unexpected. The thin plateau soils reflect the proximity of the bedrock in their high "Absolute" contents. It is interesting to observe that the bulk of these soils fall within limits that are quite sharp and not very broad. The much lower contents of the so-called "slope-thickened" soils indicate the non-availability of the underlying bedrock. These soils are firstly composed of finer slope-wash material, and secondly are underlain by bedrock that is beyond the reach of the plough (unlike the case of the thin plateau soils).

Both unsorted and sorted glacial material is very variable in its lithological composition. Unsorted till displays a broad range depending on the vagaries of erosion and deposition of the ice and availability of the red siltstone. In some cases (P96, P64) a considerable amount of local bedrock appears to be present in the till, and red siltstone contents are high, though clearly not approaching the levels in the thin, plateau soils. Water-sorted glacial material is also subject to this variability, and also to the effects of sorting which control the overall coarsest sand content.

Fig 5c


ABSOLUTE CONTENT OF RED SILTSTONE
IN COARSE SAND OF TOP-SOILS
% (Wt.) COARSE SAND (2000-1200μm) IN FINE EARTH
No. GRAINS IN 100 gms FINE EARTH (< 2000 μm)
0
1
2
3
4
5
6
7
8
9
10
11
12
250
500
750
1000
1250
1500
1750
2000
2250
100 % RELATIVE CONTENT
THIN, RED SILTSTONE SOIL
THIN, SANDSTONE SOIL
THICKENED SOIL
UNSORTED GLACIAL DEPOSITS
WATER-SORTED DEPOSITS
? UNCERTAIN ORIGIN
P 116
P 118
P 88
P 115
P 62
P 87
P 119
P 93
P 72
P 121
P 120
P 100
P 99
P 67
P 103
P 68
P 117
P 122
P 58
P 64
P 90
P 111
P 66
P 102
P 98
P 106
P 76
P 77
P 95
P 123
P 114
P 96
P 89
P 78
P 110
P 112
P 82
P 80
P 105
P 101
P 113
P 83
P 79
P 91
P 74
P 70
P 81
P 59
P 104
P 85
P 69
P 84
P 97
P 94
P 61
P 60
P 63
P 57
P 73
P 71
P 92

5.4.4 Contamination of the Coarsest Sand Fraction

While the red siltstone contents indicate the degree of influence of underlying bedrock, they give no information about the intensity of contamination by material of foreign origin (i.e., derived from outside the study area). For this, it is necessary to refer to the lithological group of quartz and "other lithologies".

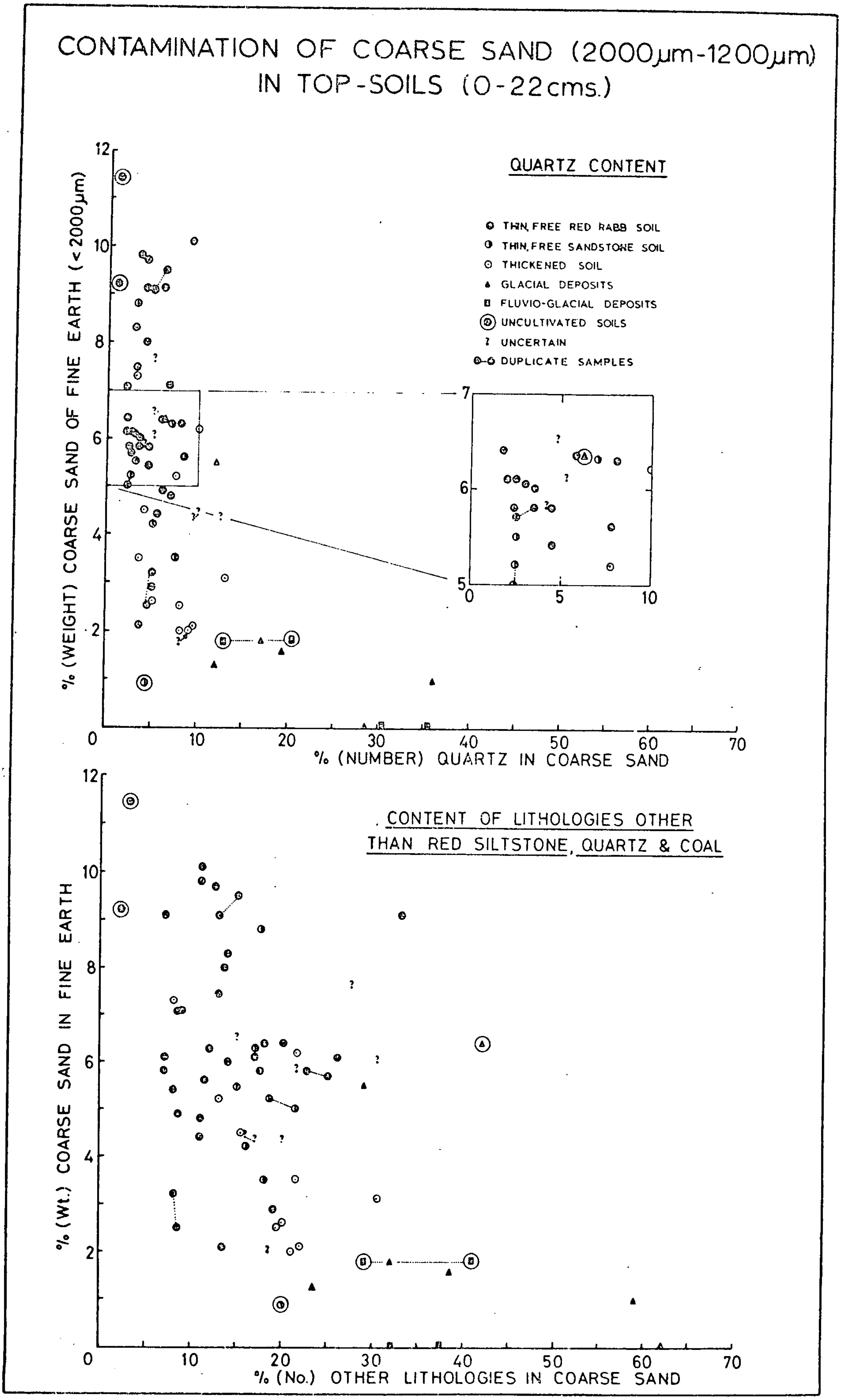
In sharp contrast to red siltstone, the "absolute" quartz content is not very effective in distinguishing the soil types (Fig 5e). Indeed, the ranges of "absolute" quartz content are of the same order for all samples, except water-sorted glacial material (as noted before, deficient in total coarse sand content). The possibility exists, therefore, that the quartz has a common origin.

It is only when the "relative" contents of quartz are examined that distinctions can be drawn between soil material types (Fig 5d). The proportions tend, as a general rule, to be complementary to the major constituent - red siltstone. Thus, glacial materials display the highest percentages, with intermediate values for "thickened" soils, and the lowest values for the plateau soils.

The vertical axis assumes greater importance in these graphs, suggesting that the weight percentage of overall coarsest sand content in the Fine Earth may, in itself, be a useful criterion of origin of the soil material. Thus, only a few of the thin plateau soils have coarsest sand contents less than 4% (Fig 5d). Moreover, they have "relative" quartz contents rarely exceeding 10%.

On the "absolute" quartz content graphs (Fig 5e) a boundary can be drawn around the entire field of plots of thin plateau soils which

Fig 5d



CONTAMINATION OF COARSE SAND (2000µm-1200µm) IN TOP-SOILS (0-22cms.)

QUARTZ CONTENT

CONTENT OF LITHOLOGIES OTHER THAN RED SILTSTONE, QUARTZ & COAL corresponds to a maximum "relative" quartz content of about 9%. This boundary is reproduced in subsequent graphs to serve as a reference line in distinguishing soil material types.

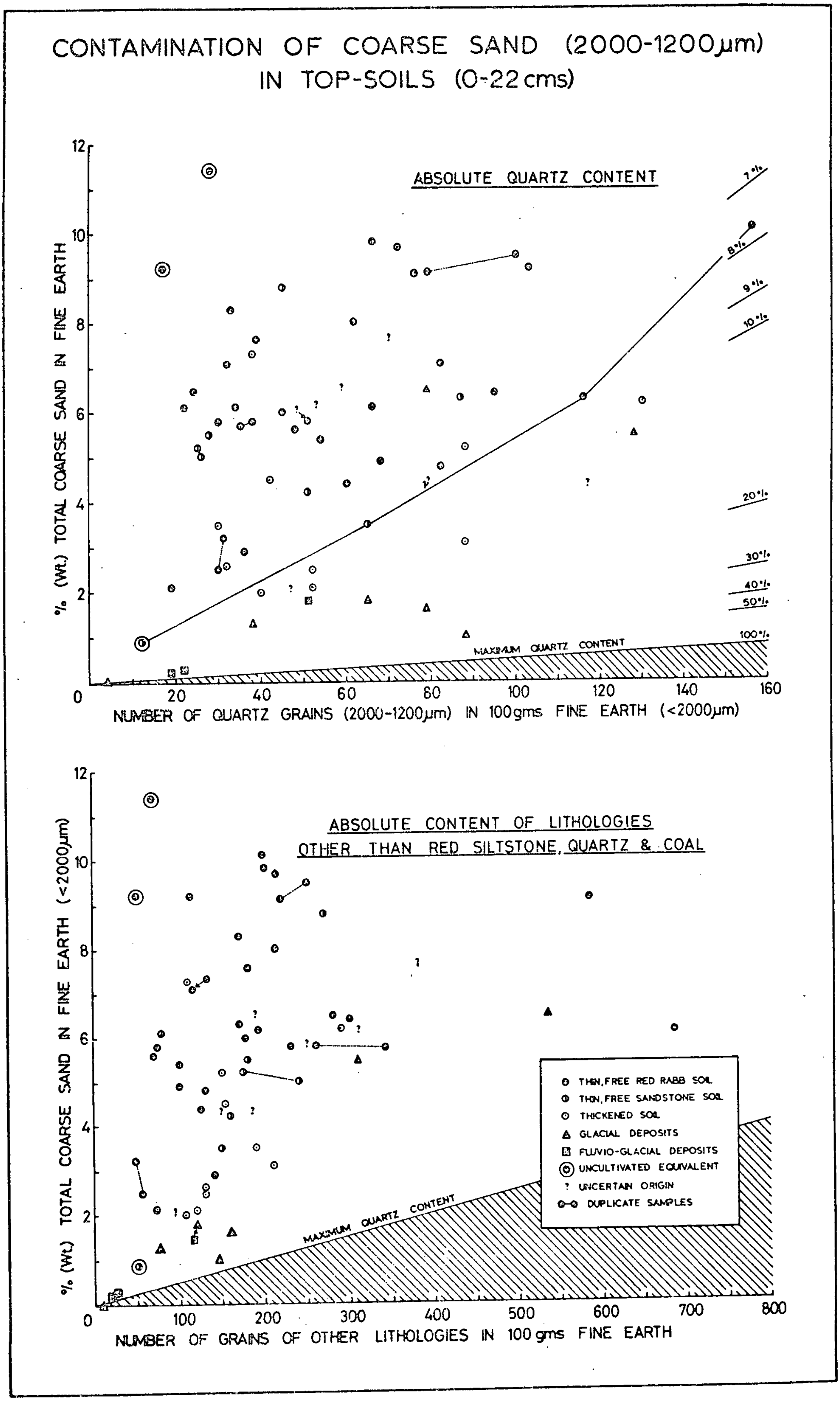
Predictably, the group of "other lithologies" is much weaker as a basis for classification (Figs 5d and 5e). Such a group includes not only truly foreign material from outside the study area, but also local variants of bedrock that cannot be allocated to the "red siltstone" class. Hence, there is considerable variability in material of glacial origin, in soils formed in colluvium, and in some cases in the plateau soils.

The y-axis emerges as more powerful in separating the soil material types than the lithological composition axes. "Relative" contents of "other lithologies" (Fig 5d) show an increase in the "thickened" and glacial materials, but in "absolute" terms (Fig 5e) the situation is reversed. The thin plateau soils exhibit, in fact, greater contamination by the "other lithologies" in most cases, probably reflecting the influence of local lithological variants in the Devonian red siltstones, and certainly so in the extreme case of P 119 (appendix 5).

5.4.5 Quartz as a Contaminant

The fore-going results showed that quartz was the clearest indicator of contamination from external sources, and that it was more important to consider "absolute" contents rather than "relative" contents. In this set of six studies, small areas have been selected and interpreted in the light of their "absolute" quartz content distribution. As indicated earlier (section 5.4.1), the "relative" contents can be determined from these graphs, and a reference line at about 9%

Fig 5e



CONTAMINATION OF COARSE SAND (2000-1200μm) IN TOP-SOILS (0-22 cms) "relative" quartz content is included as the boundary for the thin plateau soils (see Figure 5e).

Pearson Farm, St Brides Ph (Fig 1a)

Samples P 101 and P 110 belong to a problematical plateau area (Fig 5f) in which the soil material is of uncertain origin. P 104 and P 105 especially, are anomalous in that they are very light-textured even at 50 cms depth.

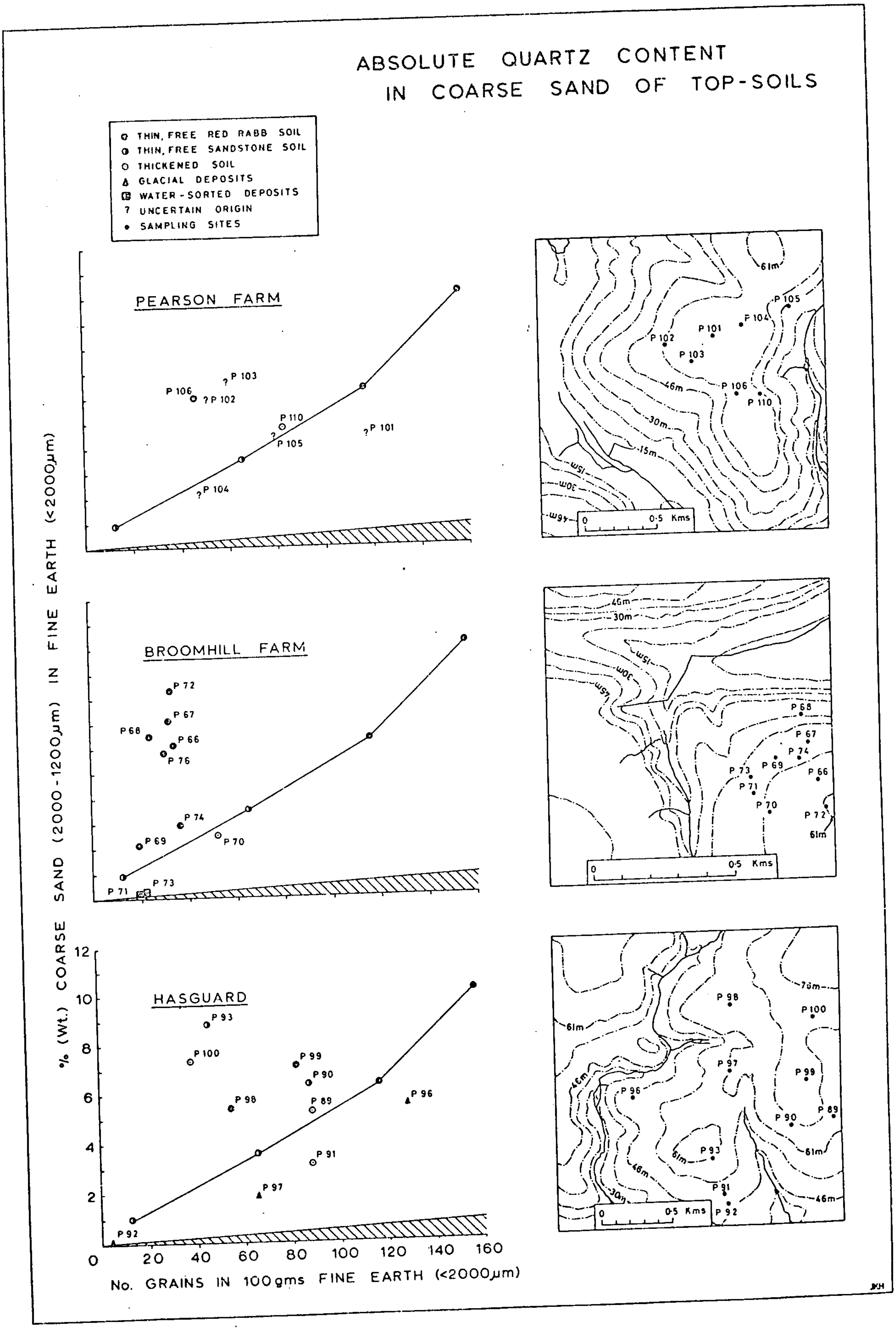
The graph (Fig 5f) only partly bears this out. P 104, P 105, but also P 110 and P 101, plot near or outside the boundary line. The "absolute" quartz content, particularly in the three latter samples, is higher than at P 106 (unquestionably of bedrock derivation) and P 102 and P 103 (probably derived from bedrock).

A possible explanation is that the whole area was originally covered by a thin till sheet - the source of quartz. Soils along the western edge of the plateau - P 102, P 103 and P 106 - may have received less glacial material, or may have been eroded preferentially by slope processes, resulting in a reduced "relative" quartz content from the incorporation of more bedrock fragments.

P 101, in keeping with such a hypothesis, bears the highest "absolute" quartz content by its location in the centre of the plateau where the till sheet would have been least affected by erosion. P 104, P 105, and P 100 110? may have experienced water-sorting. P 104 in particular, may be related to the channel draining north-westwards in which P94, with strongly sorted sediments, is situated.

The degree of derivation from bedrock is clearly indicated by

Fig 5f



ABSOLUTE QUARTZ CONTENT IN COARSE SAND OF TOP-SOILS the "absolute" red siltstone contents (Fig 5c) - P 102, P 103 and P 106 together with P 110 fall within the thin plateau soils group, P 101 and P 105 occupy transitional positions, while P 104 with a very low red siltstone content plots with materials of glacial origin.

No evidence is given by the Geological Survey (Cantrill et al, 1916) of till in the Pearson Farm area, although John (1972) has identified a Kame Terrace in the adjoining Gann Valley to the west (Fig 1a), with which there may be a genetic connection.

Broomhill Farm, Dale Ph (Fig 1a)

In contrast to the soils at Pearson Farm, those at Broomhill Farm have low "absolute" quartz contents, suggesting a lesser overall contamination by glacial deposits. In this case the distinction between soil material types is based on the overall coarse sand content.

The thin plateau soils (P66, P67, P68, P72 and P76) have high "absolute" red siltstone contents (Fig 5c) and, therefore, high overall coarse sand contents. On the other hand, P70, P71 and P73 are associated with the channel trending northwards,and the latter two in particular have very low total coarse sand contents as a result of sorting. P70, P69 and P74 plot closely together with respect to both their "absolute" quartz contents (Fig 5f) and their "absolute" red siltstone contents (Fig 5c), although they differ considerably in the field (Horbaczewski, 1975 - Appendix 3). Some of the channel deposits may be associated with the Dale till sheet to the south.

It is interesting to observe that no systematic trend in the overall coarse sand content is evident in the topographical transect - P72 - P66 -

P67 - P68.

Hasguard Farm, Hasguard Ph (Fig 1a)

Samples from this area (Fig 5f) include, among others, those of the Winsle till sheet - Red Rabb transect (P91 - P93). No other glacial deposit is recorded for this locality by the Geological Survey (Cantrill et al, 1916). However, soil profile morphology suggests the presence of a thin unsorted glacial deposit at P97 (no more than 35 cms thick) and P96 (about 30-40 cms thick).

"Absolute" quartz contents (Fig 5f) support the existence of glacial deposits, with a range of values closer to those at Pearson Farm than at Broomhill Farm. P91, P96 and P97 plot as glacial - particularly P96 with a very high value. All three have "absolute" red siltstone contents below 700 grains per 100gms Fine Earth (Fig 5c), indicating weak derivation from underlying bedrock.

On the other hand, P89, P90, P98 and P99, displaying moderately high "absolute" quartz contents (Fig 5f), are sufficiently thin to incorporate fragments of bedrock and thus register low "relative" contents through dilution. This effect is reflected in their higher "absolute" red siltstone contents (Fig 5c) placing them within the thin, plateau soils category.

Bearing in mind the surrounding glacial deposits - the Talbenny till sheet to the north, the Winsle till sheet to the south, and the sediments in a hump-backed channel, presumably of glacial origin, to the west - it is very probable that the area was covered by glacial deposits. However, these must have been thin and patchy to produce, on erosion, the present tenuous and complex distribution. Indeed, some sites, such as P93 and P 100, may have been little affected or none at all by the most recent glaciation.

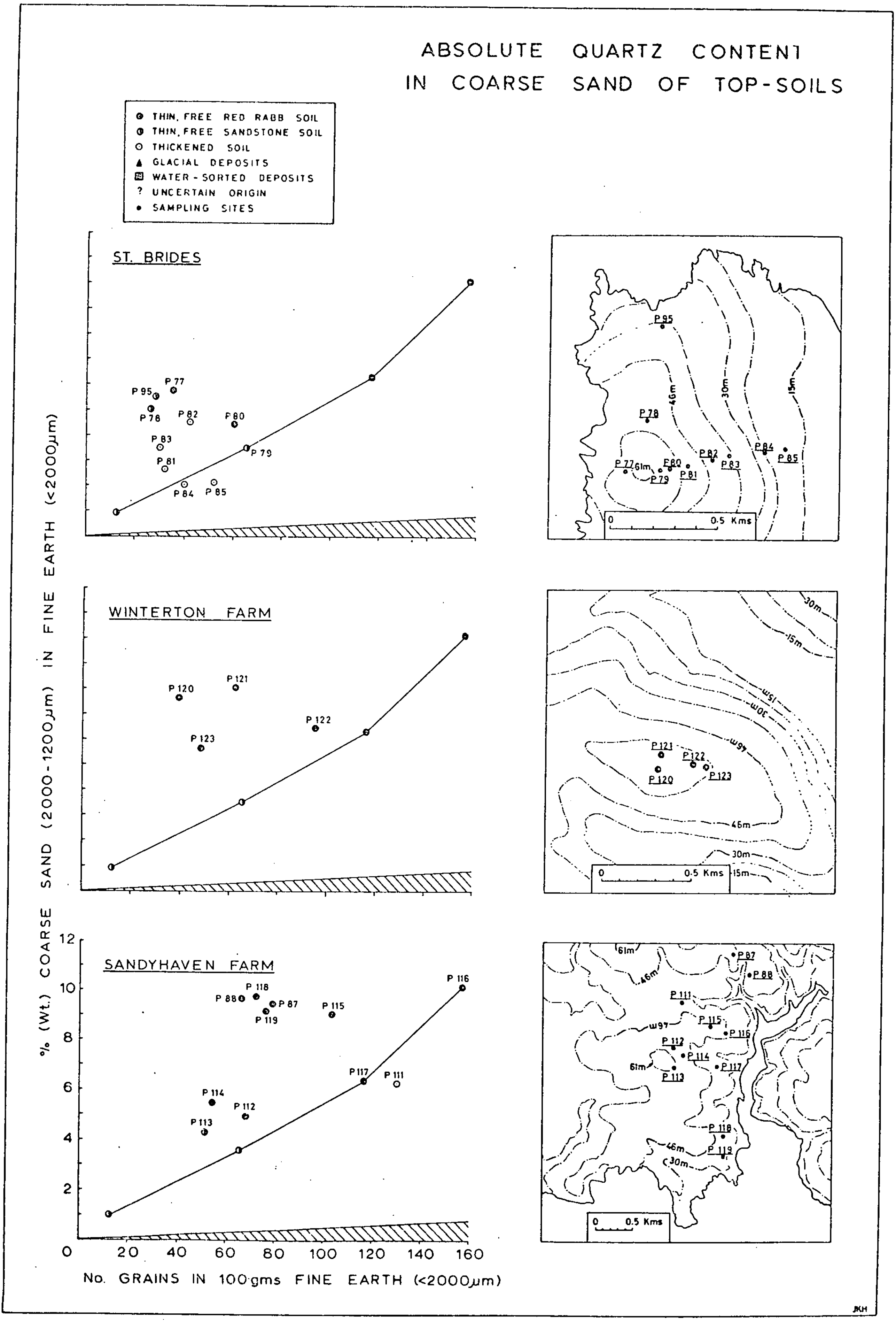
St Brides (Fig 1a)

The samples along this topographic transect (Fig 5g, see also Fig 6k for slope profile) show little systematic variation with the slope and reveal generally low "absolute" quartz levels. As the slope terminates in the Kame Terrace deposits of the Gann Valley (John, 1972), these results are rather surprising and may indicate either slight glaciation of the locality or intensive erosion. The nearest unsorted glacial deposits are found just a few hundred metres south of the transect; the nearest sorted material lies in the Kame Terrace to the east. In fact, the two lowest sampling sites - P84 and P85 - may be located in these sediments.

"Absolute" red siltstone contents fluctuate somewhat erratically along the transect (Fig 5c), but there is an overall trend from moderately high values (all expressed as number of grains per 100gms Fine Earth : P77 - 870, P78 - 780) to the low values at P84 and P85 (360 and 370 respectively).

More detailed studies would be necessary to ascertain whether the decline in coarse sand is due to depositional forces of the glacial environment, weathering intensity, or slope processes. It is suggested that P84 and P85 are probably due to the first and possibly the third; sites on the upper slopes - P77-P80 - influenced by the second; and the downslope samples - P81- P83 - affected by the third.

Fig 5g



ABSOLUTE QUARTZ CONTENT IN COARSE SAND OF TOP-SOILS

Winterton Farm, Marloes Ph (Fig 1a)

The soils at Winterton Farm (fig 5g) - P 120-P 123 - occupy a level hill-top a few hundred metres south-west of the Kame Terrace mentioned above. The soils are derived from bedrock with high levels of "absolute" red siltstone (Fig 5c) and have moderate levels of "absolute" quartz. There is no field evidence of direct glaciation within the locality, although this may have been removed by erosion. Alternatively there is the possibility of aeolian contamination in this particular case (see section 6.4.5).

Sandy Haven Farm, Sandy Haven Ph (Fig 1a)

The soils in this south-eastern extremity of the study area have very high coarse sand contents dominated by red siltstone (Fig 5c). Field evidence shows no sign of glaciation, yet "absolute" contents of quartz are high (Fig 5g). Whether this quartz represents relict glacial material, or whether it is of aeolian origin from material to the south (now under water in the drowned "ria" system of Milford Haven) is uncertain.

P 111 is anomalous, as it is developed in a soft sandstone and therefore has a low total content of rock fragments of coarse sand size, as they disintegrate rapidly to the finer sand constituent grains, but what it has is mostly composed of quartz (see section 6.4.5).

5.5 COAL IN THE COARSEST SAND FRACTION (2,000µm to 1,200µm)

In the course of field work, fragments of coal were occasionally noticed in the soils of the area. Most commonly they were of fine gravel size (2 to 6 mm) although pieces up to 10 mm across were found at Broomhill Farm, Dale. On analysis, it became apparent that most soils had significant amounts of coal fragments in the sand fractions, and in many cases the "absolute" content of coal exceeded that of quartz! Clearly, the coal may represent an important genetic indicator, and its anomalous distribution warrants a separate discussion.

It should be stated that the morphology of the coal is such as to preclude any confusion with charcoal. The grains are black and very lustrous after washing. They are generally angular and often possess conchoidally-fractured faces, though many do not appear fresh-looking. Coal is encountered in all of the size fractions - even the finest sands contain a few grains, though these may be recent splinters from larger fragments.

As they are two obvious contaminants, a relationship was expected between coal and quartz "absolute" levels. The absence of such a relationship could not be more emphatic (Fig 5h).

It was found in all cases that the "absolute" coal content decreased down the soil profile and that it was minimal or nil in uncultivated soils. Accordingly, groupings of top-soils, sub-soils and uncultivated soils were selected for plotting on the "relative" and "absolute" graphs (Fig 5j).

The distribution of these groups is striking, especially on the "absolute" graph. In fact, they are almost mutually exclusive. There are only three out of 14 sub-soils with more than ten grains

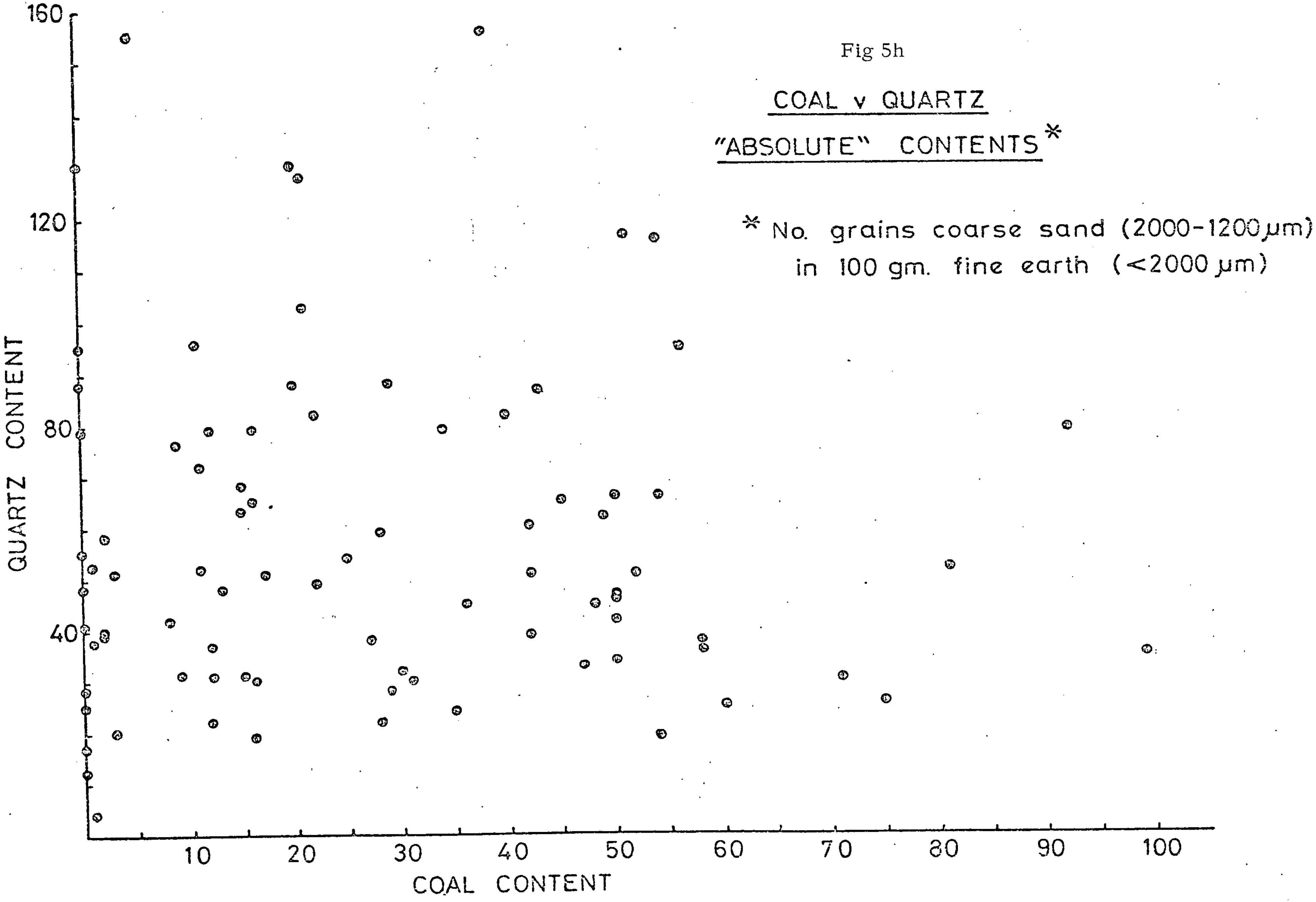


Fig 5h

COAL v QUARTZ

"ABSOLUTE" CONTENTS*

* No. grains coarse sand (2000-1200 µm) in 100 gm. fine earth (<2000 µm)

of coal per 100 gms of Fine Earth, and five out of 68 top-soils with less than ten grains per 100 gms Fine Earth (see Appendix 5 for raw data). Only in one case - P94 - does an uncultivated soil contain any coal, and then it amounts to only two grains per 100 gms Fine Earth. It is, perhaps, significant that the sub-soils with "absolute" coal contents greater than ten grains per 100 gms Fine Earth - P83, P91, P70 and P85 - occur at pediment footslope positions (terminology Ruhe, 1960) and are, therefore, probably cumulative soils (i.e., the present sub-soil originally having been a top-soil that was buried beneath slope wash material).

Sub-soils on the plateau sites - P60, P61, and P58 - fall on the vertical axis of the graph, with zero coal contents, even though they contain appreciable amounts of quartz, and both quartz and coal in the overlying top-soils.

Any explanation for the origin of the coal has to account for the following:-

(i) The concentration of coal in top-soils, with very reduced or zero contents in the sub-soils, even though quartz persists.

(ii) The apparent absence of coal in uncultivated soils.

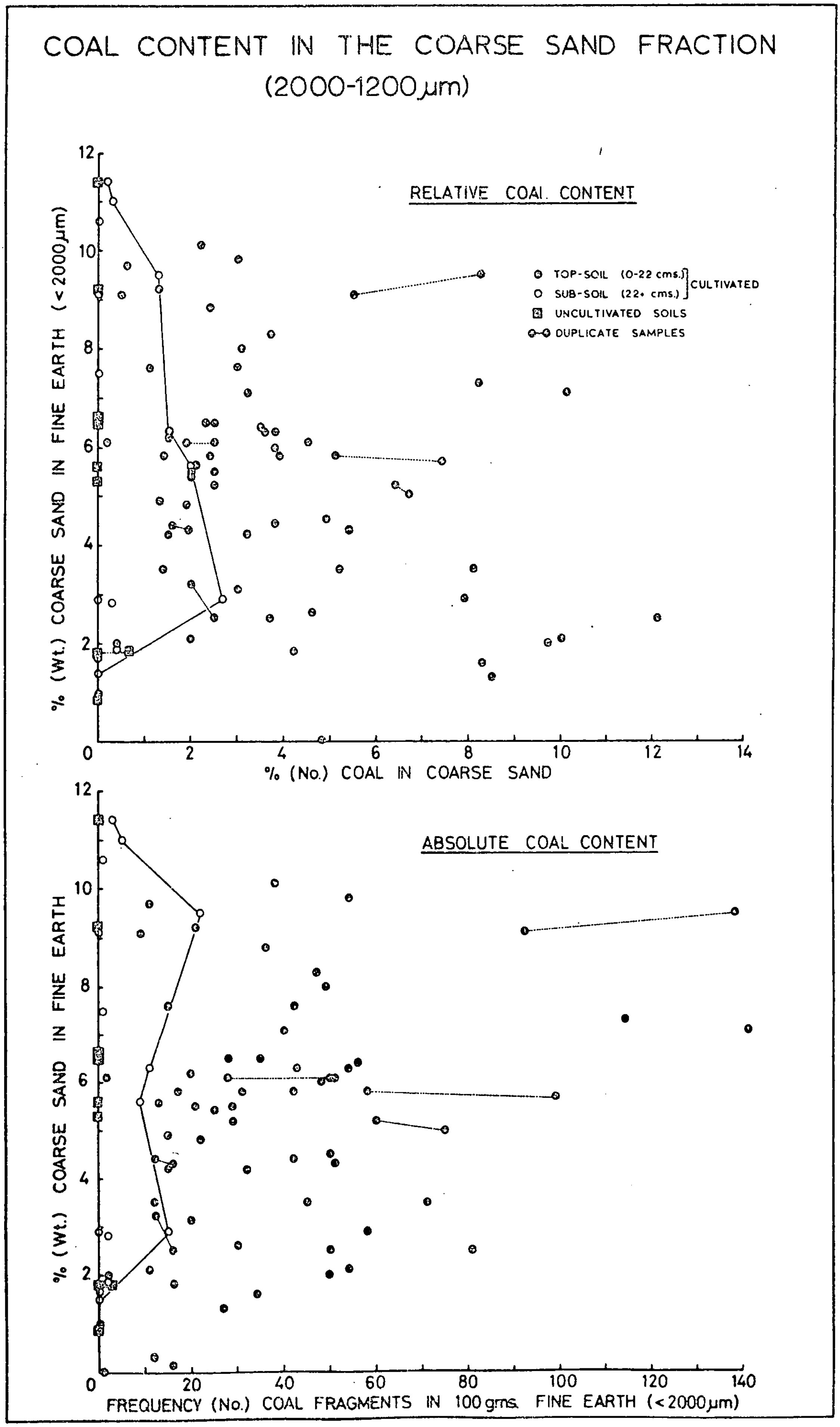
(iii) The very high variability of "absolute" coal contents in transects and small areas.

(iv) The appearance and size distribution of the coal fragments.

Glacial Origin

In view of the proximity of coal outcrops to the north of the study

Fig 5j


COAL CONTENT IN THE COARSE SAND FRACTION
(2000-1200 µm)
RELATIVE COAL CONTENT
TOP-SOIL (0-22 cms.)
SUB-SOIL (22+ cms.)
CULTIVATED
UNCULTIVATED SOILS
DUPLICATE SAMPLES
% (Wt.) COARSE SAND IN FINE EARTH (< 2000 µm)
0 2 4 6 8 10 12
0 2 4 6 8 10 12 14
% (No.) COAL IN COARSE SAND
ABSOLUTE COAL CONTENT
% (Wt.) COARSE SAND IN FINE EARTH
0 2 4 6 8 10 12
0 20 40 60 80 100 120 140
FREQUENCY (No.) COAL FRAGMENTS IN 100 gms. FINE EARTH (< 2000 µm)

area (Fig 1b) and their existence in the sea-bed to the north-west in the path of the ice (Dobson et al, 1973), a glacial origin for the coal appears as an attractive hypothesis. But it is difficult to uphold.

Although John (1972) reports the presence of coal fragments in the Kame Terrace at Mullock Bridge, none have been encountered in any other material of glacial derivation within the study area. On the contrary, the highest "absolute" coal contents are associated with soils that show least signs of glacial influences (for example, P58, P67, P72, P77, P118, P122 - Appendix 5).

Even if it is assumed that the coal is of glacial origin, some mode of redistribution has to be invoked for its presence in the remote Sandy Haven soils, unless it is a relic of a former till sheet that has since been eroded (see section 5.4.5 - Sandy Haven Farm).

In view of the variability of unsorted glacial materials, the lack of correlation between "absolute" quartz contents and "absolute" coal contents is to be expected (Fig 5h). But it is not clear why a number of samples possess no coal at all, while there are none that has no quartz.

Aeolian Origin

Evidence for widespread aeolian activity under periglacial conditions is presented later (section 6.7). It is sufficient to say that, given a source, such as coal outcrops or comminuted material in till and outwash deposits, the periglacial conditions would have been very favourable for aeolian transportation.

It could be argued then that coal, with its lower density and higher angularity in comparison with quartz, would be aerodynamically related more closely to a quartz grain size finer than 2,000μm to 1,200μm, and therefore would not display a strong correlation with quartz of its own size (Fig 5h).

Under particularly extreme conditions it is possible that grains of coal up to one centimetre across would be susceptible to wind transportation. The concentration of coal in the surface horizons of the soils is in good accord with such a hypothesis.

Anthropogenic Origin

The high "absolute" contents of coal - higher than those of quartz in many cases (Appendix 5) - raise doubts about the ability of glacial deposits to furnish such amounts, either directly or through aeolian action. An alternative hypothesis is that the coal was introduced, deliberately or inadvertently, in soil management practices. Coal, by itself, is not beneficial to the soil and is unlikely to have been applied as a fertiliser, but it may have been a constituent of some others:-

1. Farm-yard manure to which assorted waste, including coal ash, had been added.
2. Lime, particularly burnt lime, obtained in the past from the small, local coastal kilns.
3. Beach sand, used in parts of Pembrokeshire in the past as a liming agent because of its high shell content.

In all these cases the fertiliser would not have been applied, generally speaking, deeper than the plough layer and hence would not have penetrated to the sub-soil. Virgin soils would not have been treated at all. High variability of "absolute" coal contents would be understandable in view of the difficulties of achieving a uniform application. Also, variability would be expected to be highest between fields rather than within fields.

The appearance and size distribution of the coal fragments would depend on the nature of the fertiliser. In both the farm-yard manure and the burnt lime (MAFF, 1973, pp 21-22) small pieces of unburnt coal would occur and would be the only constituent, albeit minor, to persist in the soil. In the case of beach sand, the coal would also be a minor constituent - probably a surface swash deposit - but would remain in the soil together with the associated quartz and rock fragments. Again, by reason of its lower density, coal grains would tend to be larger than the associated quartz and rock grains.

On balance, it would seem that burnt lime, prepared locally up to the nineteenth century (Dresser, 1959), would have been the most common form of soil conditioner in the study area. George Owen, at the beginning of the seventeenth century, reports the application of calcareous dune sands at Freshwater West (on the opposite shore of Milford Haven), and shelly sea-sand was used as a source of lime for a long time in the St David's Peninsula, north Pembrokeshire (Davies, 1939, p 115). However, there is no documentary evidence for sanding inside the study area.

It is likely, though not certain, that local outcrops of limestone would have been exploited in preference to the arduous collection of beach sand. One outcrop occurred, in fact within the study area at

Goultrop (Owen, 1892, p 64. See Figure 1a for location), while thicker limestones were to be found just across the Haven to the south of the area (Cantrill _et al_, 1916, p 166. See also geological map - Fig 1b).

CHAPTER 6

GENESIS OF THE SOIL SAND FRACTION - SIZE DISTRIBUTION

6.1 INTRODUCTION

The soil sand fraction (2,000 - 50μm) was chosen for detailed size analysis, not only in response to Blatt's exhortation (1967, p 1034)

> "The non-phylloscilicate fraction of horizons in residual soils is an extremely significant component of sediments which has not received the attention it deserves from sedimentologists"

but also for more mundane operational reasons.

Possibly of most importance is the fact that the sand size distribution can be measured easily by the single technique of sieving, which also allows for the retention of the separated size fractions for further analysis. The accuracy and precision of the method is good, provided the sieves are not overloaded (McManus, 1965), and the procedure is standardised. The determination of the silt and clay size distributions requires a different technique, and problems of continuity with the sieve technique arise.

In the sand analysis, an upper limit of 2mm has been adopted, partly to comply with the convention of size classes (Committee Report, 1967), but also for sampling reasons : samples much larger than the standard weight of 1kg would have become necessary to represent adequately larger grains (Avery and Bascombe, 1974, p 3; Dennison, 1962).

On the theoretical side, one of the prime considerations for selecting the sand fraction was that for the red siltstones this size range represents a transient phase before the rock fragments disintegrate to their constituent silt and clay grades. It was hoped that, in a manner analogous to sediments (Visher, 1969), the size distribution of the weathering rock fragments would indicate the type of weathering processes, and even mechanisms in operation.

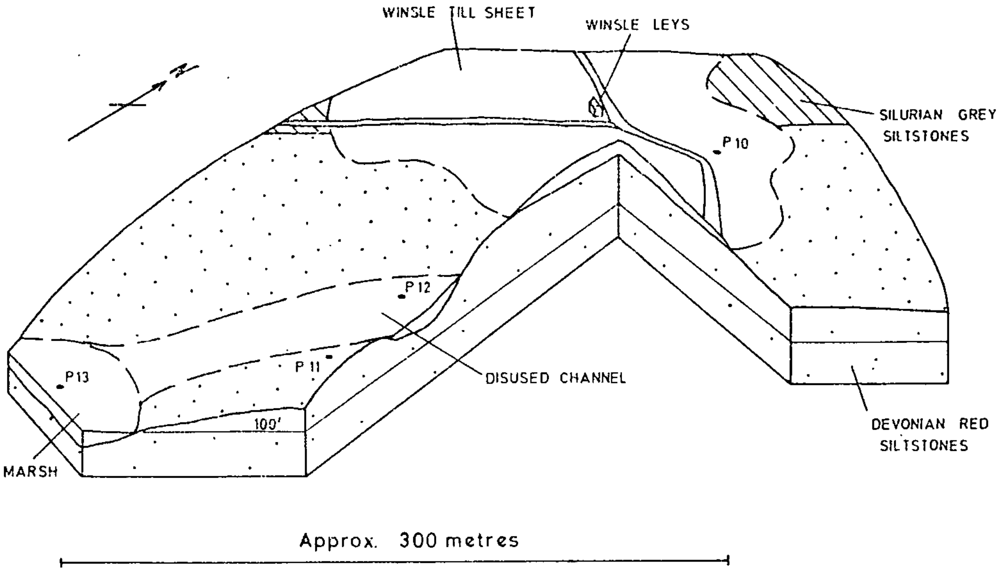
For such a study of weathering, it was desirable to minimise the effects of pedogenic translocation, and this consideration also favoured the sand fraction over the silt and clay.

6.2 GRAVEL, SAND, SILT, AND CLAY FRACTIONS

Initially, the primary textural parameters generally used by soil scientists (gravel, sand, silt, and clay) were tested for sensitivity in a study of the genesis of soil material at the edge of the Winsle till sheet. Sites were selected on different geomorphic units (Fig 6a), and soil profiles were sampled by horizons, rather than at pre-determined levels, to avoid problems of sampling across horizon boundaries. The laboratory analysis (Appendix 1) included the textural classes of the Fine Earth fraction (2,000 - 60µm, 60 - 2µm, <2µm) and also the fine gravel fraction (6 - 2mm/6,000 - 2,000 µm).

The results show that the strongest variations were expressed in the fine gravel content (Fig 6a). A marked concentration of gravel at less than 20 cms depth in P 12 corresponded to a similar horizon at about 45 cms depth in the till sheet at P 10, and a thin sharp layer at

SOIL TEXTURAL RELATIONSHIPS AT WINSLE LEYS, HASGUARD

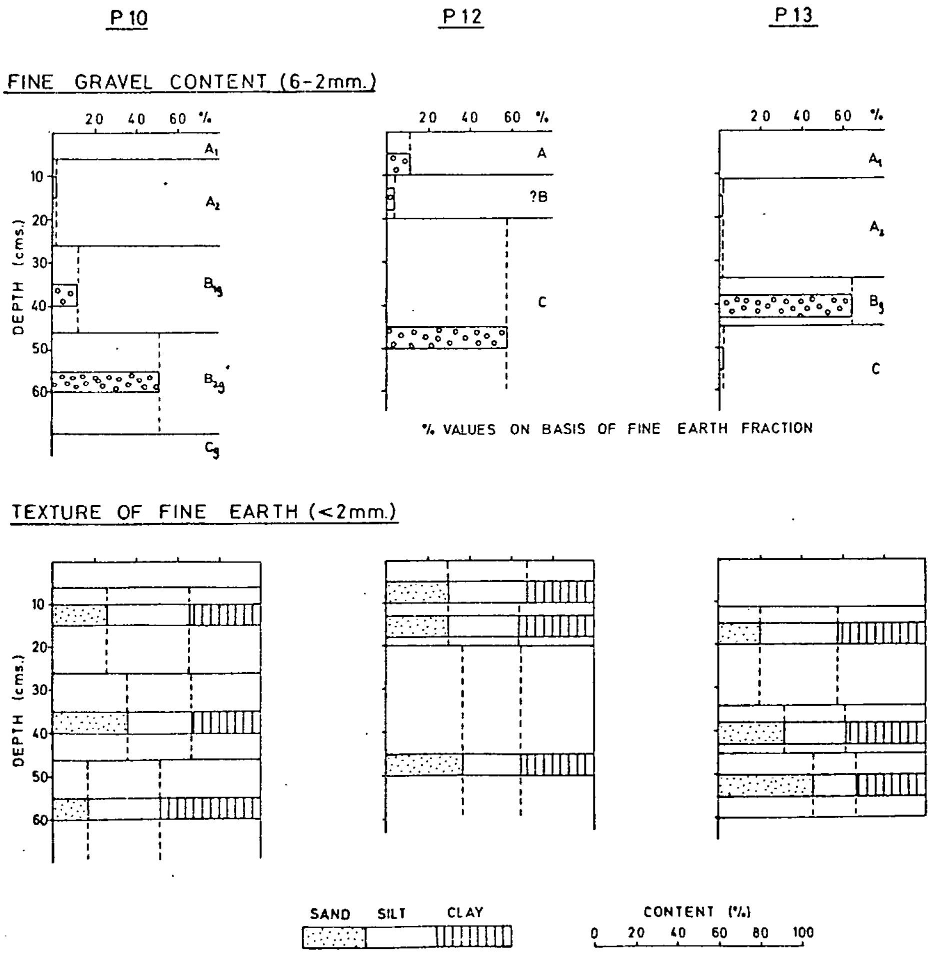


SOIL DEPTH TO BEDROCK

P 10	P 11	P 12	P 13	
86	2	63+	60+	cms.

SITE HEIGHT (O.D.)

P 10	P 11	P 12	P 13	
41±2	35±2	32±2	30±2	metres



about 35cms depth in the low-lying marshy region (P 13). The position of P 12 in a topographical depression leading from the till sheet suggests the existence of a relict channel formerly draining the glacial deposits of the till sheet.

High energy melt-waters or surface run-off would account for the concentration of coarser material under the action of winnowing, resulting in a thick channel lag deposit (P 12) with, possibly, a small temporary extension to the generally lower energy conditions of the low-lying plain (P 13). The stone-free uppermost horizons of both P 12 and P 13 may be due to the accumulation of finer products from soil erosion of the surrounding areas, such as represented by P 11, where bedrock is barely covered with a grass mat.

The sorting action of running water is clearly responsible for the concentration of fine gravel into a layer; however, its presence in the glacial deposit itself (P 10) suggests that this action may have been contemporaneous with the deposition of the till - the till perhaps being ablational rather than lodgement in type. The immediate effects of water on size-sorting in a glacial environment have similarly been noted by Buller and McManus (1973).

The distribution of the Fine Earth fractions accords well with this explanation, representing, in part, the winnowed material. Thus the sand fraction falling, in this case, below the critical size of about 2mm for a lag deposit, tends to increase with respect to the silt and clay, from the till (P 10), through the channel (P 12) to the receiving area (P 13). However, the energy of the water had not declined sufficiently to allow much deposition of the silt and clay fractions which were presumably transported further downstream.

Although the fine gravel has acted as a good indicator in this case, it is only thanks to the strong sorting action of surface drainage which is clearly highly localised. For the bulk of soils, where such processes are not in operation, finer textural parameters have to be used.

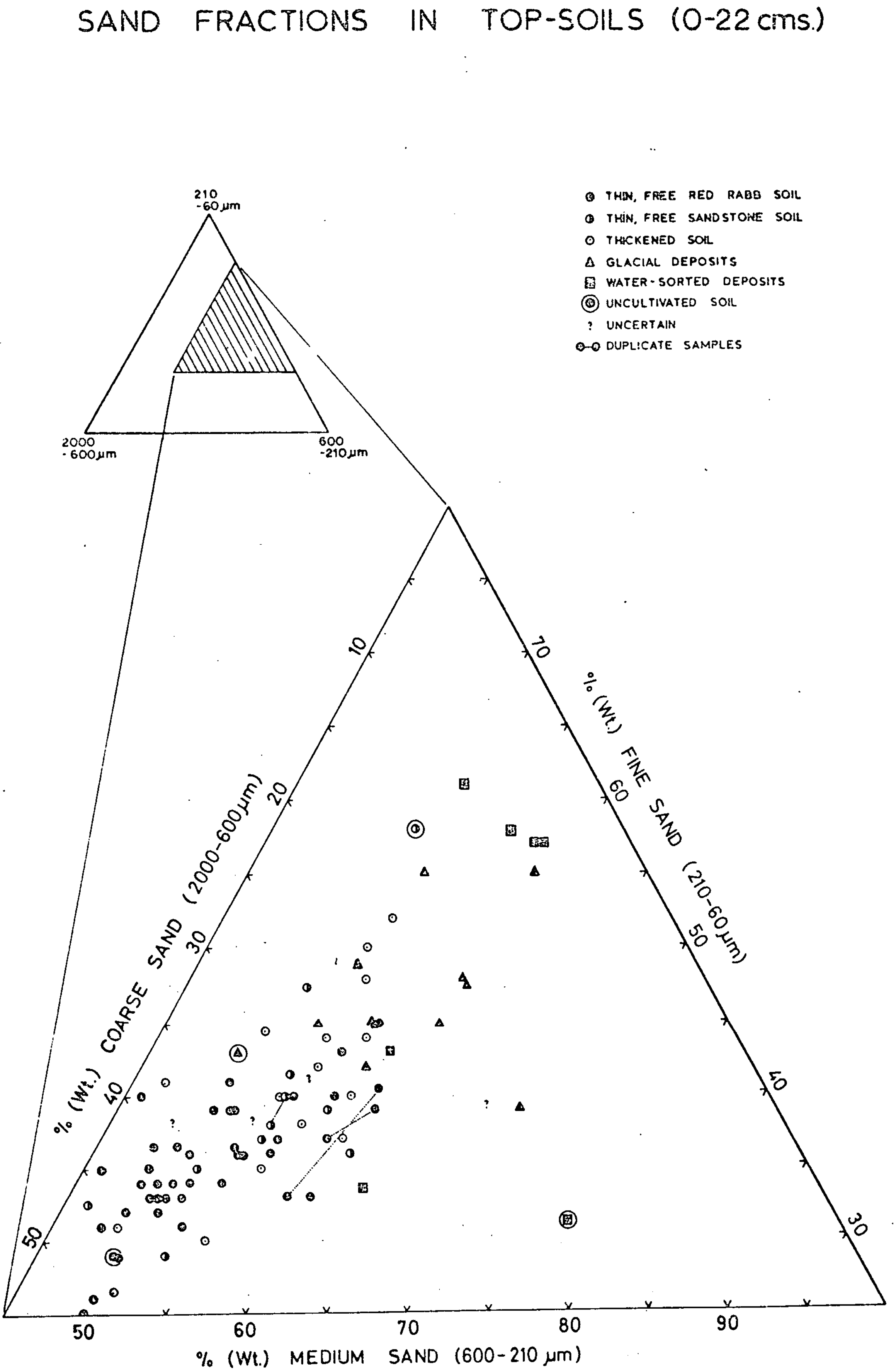
6.3 COARSE, MEDIUM, AND FINE SAND FRACTIONS

Avery (1973) suggests three size classes for detailed studies of the soil sand fraction - coarse sand (2,000 - 600µm), medium sand (600 - 200µm), and fine sand (200 - 60µm). These have already been mentioned in the context of lithological composition (see section 5.3) where only a semi-quantitative analysis was practicable. Fully quantified results can be obtained from a study of the weight-size distributions.

The volume of early data (on samples shown in section 5.3) has been augmented by re-calculating later and more detailed analyses (section 6.4). Results have been plotted on a triangular graph (Fig 6b; see Appendix 5 for raw data), with symbols assigned on the basis of the field classification of soil material types. Where the origin of the soil material was uncertain, an interrogation mark has been employed; uncultivated soils have been distinguished, although there are too few for meaningful interpretation; so-called "duplicate" samples have been taken from different levels but within the plough layer which has been assumed to be homogeneous.

Two significant features are apparent in the graph:-

Fig 6b


SAND FRACTIONS IN TOP-SOILS (0-22 cms.)
210 -60 µm
2000 - 600 µm
600 -210 µm
THIN, FREE RED RABB SOIL
THIN, FREE SANDSTONE SOIL
THICKENED SOIL
GLACIAL DEPOSITS
WATER-SORTED DEPOSITS
UNCULTIVATED SOIL
? UNCERTAIN
DUPLICATE SAMPLES
% (Wt.) COARSE SAND (2000-600 µm)
10
20
30
40
50
% (Wt.) FINE SAND (210-60 µm)
70
60
50
40
30
% (Wt.) MEDIUM SAND (600-210 µm)
50
60
70
80
90

(i) There is a general trend of data points from a position midway along the fine sand-medium sand axis towards the coarse sand apex.

(ii) There is a rough differentiation of soil material types along this trend (see also Figure 6c).

Soils with the highest coarse sand contents are those derived from bedrock - whether directly as the thin, plateau soils, or indirectly as the slope-thickened types. These groups display the greatest variation in coarse sand contents, with relatively small differences in the proportion of fine to medium sand.

From the lithological composition analyses (section 5.3), it can be recalled that the coarse sand consisted dominantly of red siltstone (especially in the case of the thin, plateau soils), and that the bulk of the medium and fine sand fractions was composed of foreign quartz. Thus the fixed proportion in weight of medium to fine sand in these samples represents a property of the contaminant and suggests a common origin.

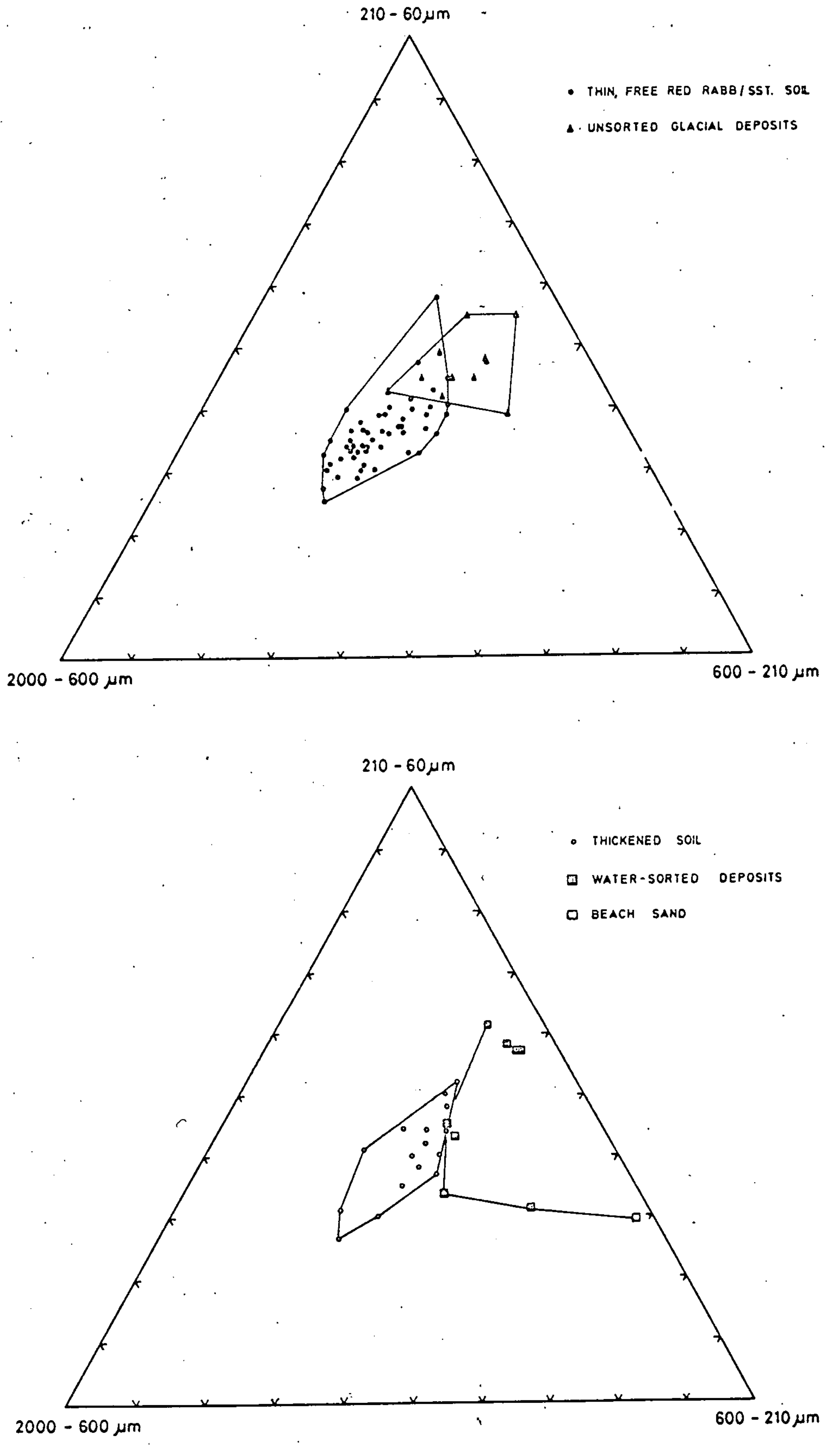
Furthermore, if the effect of the quartz contamination is subtracted, then it becomes evident that the thin, plateau soils would cluster at the coarse sand apex with only a slight spread along the medium sand-coarse sand axis, but with almost no contribution towards the fine sand end-member. The implications of this are explored in the succeeding section (6.4).

The distinction between the thin soils and the slope-thickened soils is not clear-cut (Fig 6b), but there is generally a lower content of coarse sand in the latter (Fig 6c), supporting the common finding that

Fig 6c

SAND FRACTIONS IN TOP-SOILS (0-22 cms.)

FIELDS OF SAND DISTRIBUTIONS OF DIFFERENT SOIL MATERIALS



finer particles are preferentially transported by slope-wash.

Sandstone variants of the plateau soils and uncultivated soils are too few in number for interpretation.

Unsorted and water-sorted glacial materials do not exhibit the same disposition towards the coarse sand end-member (Fig 6c). From the relatively small number of results available, it also appears that the proportion of medium sand to fine sand can vary considerably, particularly in the water-sorted deposits. It should be noted that wind-sorting may have dominated in the formation of deposits at P71 and P73 (Fig 6f).

Nevertheless, regardless of the agent, the action of sorting is to concentrate material of a small size range. Thus, such material should plot close to the axes joining fine sand to medium sand, and medium sand to coarse sand. In practice, there are deviations from this ideal (Fig 6c), possibly from the slumping of soil material into the small drainage channels or from translocation of fines within the soil, contrasting with the strong sorting of beach sand containing less than 5% coarse sand (Fig 6f).

Studies

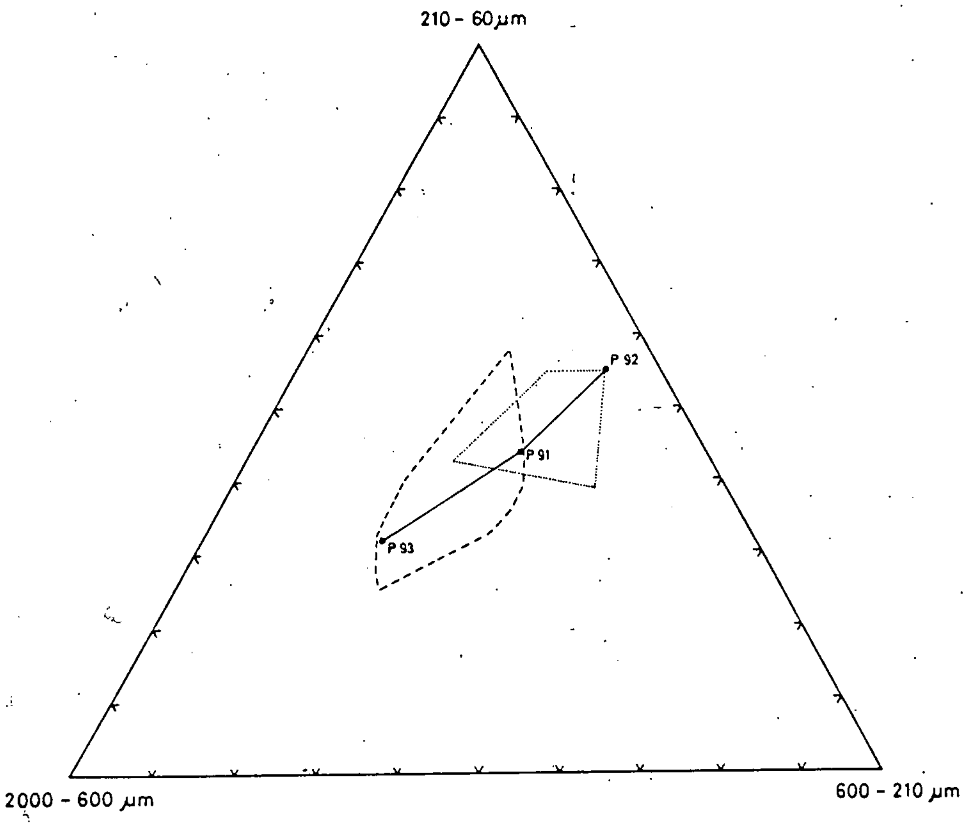
The "fields" of the soil material types delineated on the triangular graph have been obtained simply by constructing a convex envelope about the appropriate data points. In order to check the accuracy of these, and also to emphasise some of the trends concealed in Figures 6b and 6c, several studies of soil changes in small areas and along transects have been included.

Both of the till sheet transects (Fig 6d) demonstrate strong trends

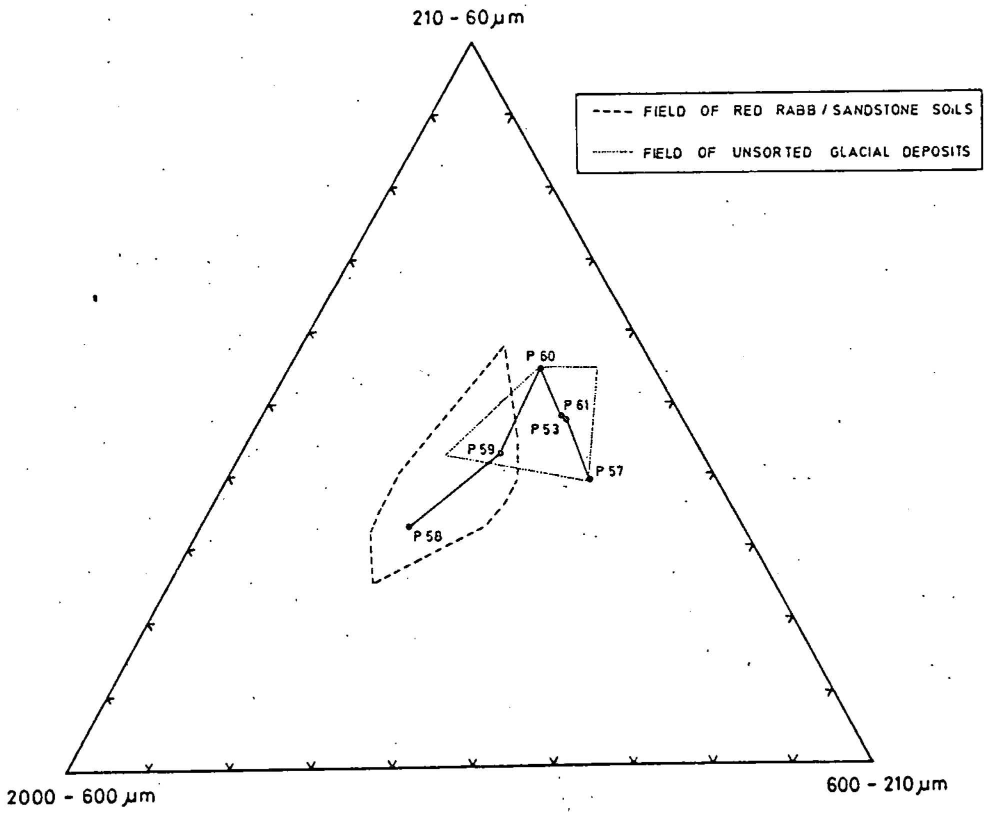
Fig 6d

SAND FRACTIONS IN TOP-SOILS (0-22 cms.)

TRANSECT ACROSS EDGE OF WINSLE SHEET



TRANSECT ACROSS EDGE OF DALE SHEET



from high coarse sand levels over bedrock to much lower contents in the till. In these cases, the envelope of the red rabb/sandstone soils (generally referred to as thin, plateau soils) seems to be well placed. P91 is, in fact, transitional in nature between till and bedrock soils, while the results for the Dale Sheet are in agreement with the boundary, mapped in the course of field survey, between P59 and P60.

The soils of Sandy Haven Farm (Fig 6e) plot at the lower end of the red rabb/sandstone "field", emphasising their very high coarse sand content, mostly attributable to fragments of red siltstone. There is some suspicion that these soils may have lost finer material through erosion as there is evidence of bedrock disturbance and upheaval in ploughing (see plate 5). Indeed, the coarse sand content may be a useful parameter for monitoring such changes.

Only one of the soils at Pearson Farm (Fig 6e) plots outside the "field" of the thin, plateau soils - P104 (see also Figure 6m for detailed size distribution). The remaining sites, classified as of uncertain origin in the course of survey, do not betray glacial influences.

Broomhill Farm samples, all taken from a single field, display strong differences in coarse sand content (Fig 6f; see also Appendix 3 for location map). It is interesting to note that the proportion of medium sand to fine sand varies only slightly, however, again suggesting a common origin for the contaminant quartz (see also Figure 5f). P70, regarded as transitional from field survey and red siltstone content (Fig 5c), falls close to the thin soils P69 and P74 on the triangular graph (Fig 6f). On the other hand, P71 and P73 are suggestive of powerful sorting (see also Figure 6j for more detailed size distribu-

Fig 6e

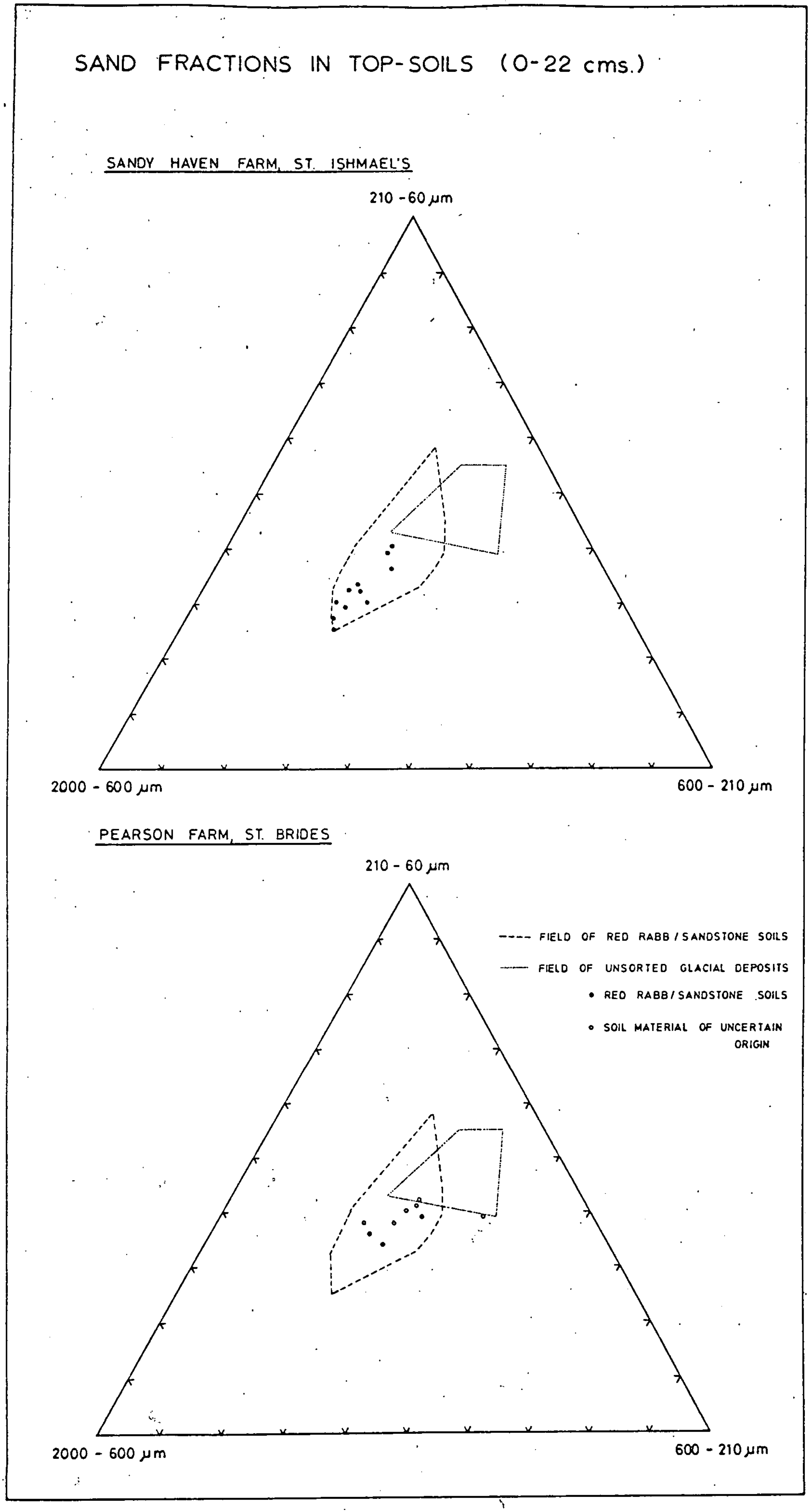
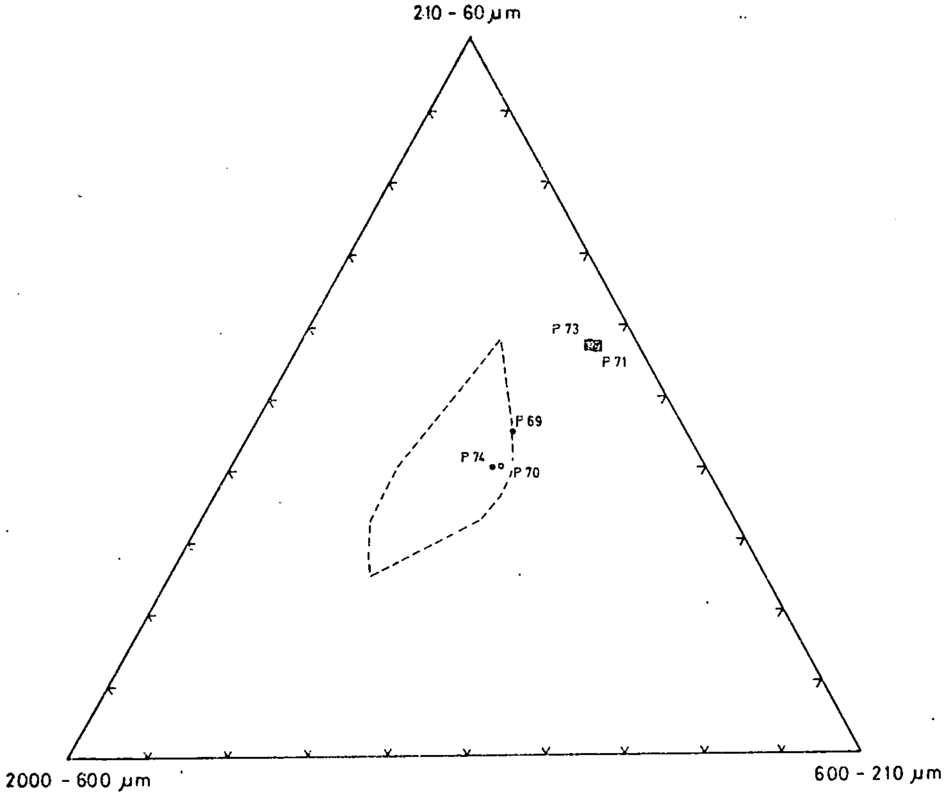

SAND FRACTIONS IN TOP-SOILS (0-22 cms.)
SANDY HAVEN FARM, ST. ISHMAEL'S
210 - 60 µm
2000 - 600 µm
600 - 210 µm
PEARSON FARM, ST. BRIDES
210 - 60 µm
2000 - 600 µm
600 - 210 µm
---- FIELD OF RED RABB / SANDSTONE SOILS
—·— FIELD OF UNSORTED GLACIAL DEPOSITS
• RED RABB / SANDSTONE SOILS
∘ SOIL MATERIAL OF UNCERTAIN ORIGIN

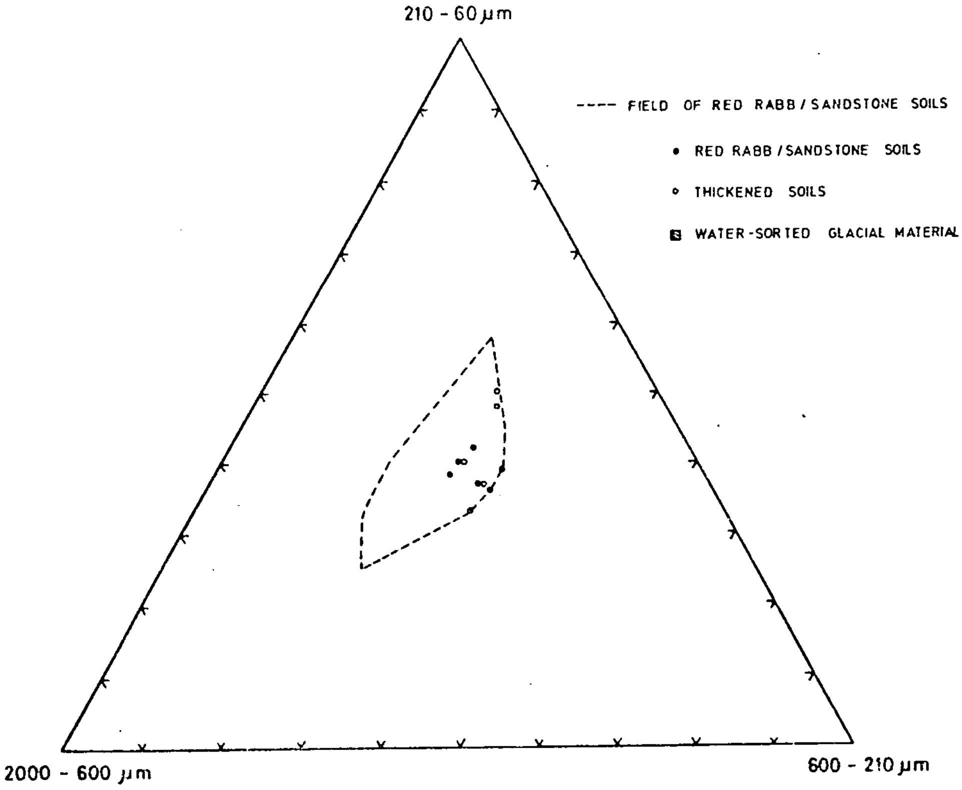
Fig 6f

SAND FRACTIONS IN TOP-SOILS (0-22 cms.)

BROOMHILL FARM, DALE



TOPOGRAPHICAL TRANSECT, ST. BRIDES



tions).

In contrast, the effect of topography on sand proportions appears to have been slight (Fig 6f, also Fig 6k). This is not to say that there is no differentiation, but that the scale of resolution with three sand fractions is too coarse to register such changes.

6.4 DETAILED SIZE DISTRIBUTION OF SAND FRACTION

6.4.1 Introduction

Detailed size distribution analyses have been frequently used by sedimentologists in elucidating the fundamental mechanisms of deposition, whether from an aeolian medium (Bagnold, 1941), an aqueous medium (Visher, 1969) or a glacial medium (Buller and McManus, 1973; Dreimanis and Vagners, 1971). The effects of crushing and grinding on size distribution of various materials have been studied by geologists and engineers alike (Kittleman, 1964; Agar and Charles, 1961).

In contrast, few studies are available of detailed size distributions of weathering and soil formation mechanisms. Such work that has been published is almost invariably concerned with granites, or granitic rocks (Krumbein and Tisdel, 1940; Ruxton and Berry, 1957; McEwen, Fessenden and Rogers, 1959; Wolff, 1967; Lumb, 1962; Lo and Roy, 1969; Gillespie and Protz, 1969; Verague, 1973). Harriss and Adams (1966) and Wolff (1967) have shown that the relative stability of minerals in granite ranges from plagioclase feldspar, biotite, K feldspar to quartz; the last being the most resistant. The process of decomposition, therefore, involves a preferential "rotting" of the minerals, with consequent disintegration and accumulation of resistant quartz grains (Ruxton and Berry, 1957).

Size distributions of soils derived from sedimentary rocks are relatively rare in the literature. Carroll (1952) has applied moment measures to residual soils formed under tropical conditons on sandstones as well as granitic rocks, and found a negative skewness in the former and a positive skewness in the latter. Little mention is made of mechanisms of disintegration. Walker (1964), in a study of hillslope processes, describes a bi-modal size distribution of talus deposits representing the initial breakdown of the sandstone rock to a mixture of fragments and single grains where there has been a minimum of sedimentary transport.

Very little attention has been directed at the disintegration of siltstones and shales. Stewart, Adams and Abdulla (1970) conclude that sand-sized fragments of Silurian shale in mid-Wales weather to produce the residual silt and clay in fixed proportions reflecting their proportions in the parent rock. The silt is relatively resistant, representing the original "primary particles" (detrital grains). Furthermore, they consider that "the sand-sized particles are probably fragments of shale produced by mechanical breakdown", presumably referring to frost-shattering and scree formation. Later work (Adams, Evans and Abdulla, 1971) suggested that acid dissolution of the iron-rich chlorite, probably diagenetic in origin and acting as a rock cement, results in the textural ~~degration~~ degradation of the shale (see also Evans and Adams, 1975a,b; and Evans, 1972).

6.4.2 Laboratory Procedure

The laboratory procedure is given in Appendix 1. However, several limitations became apparent in the course of size distribution analysis and are briefly discussed here.

(i) Separation of the Fine Earth Fraction

The separation of the Fine Earth fraction from coarser material by sieving through a 2mm aperture sieve (BS No 8) was found to be incomplete. Sand-sized grains (i.e., less than 2mm in diameter) were often retained on the sieve as their size was effectively increased by clay coatings. As the coarsest sand grains are particularly prone to this, there is a danger of artificial sorting causing a deficiency of these sizes in the Fine Earth fraction.

The use of a pestle or rubber policeman to "rub down" the samples can cause fracturing of grains and hence modification of the size distribution. The remedy was found to lie in the use of a sieve with a larger aperture of 2·4mm (BS No 7) to avoid the loss of coated sand grains. The excess size fraction (2·4 to 2·0 mm in diameter) was determined in the course of analysis and its weight subtracted in subsequent calculations.

(ii) Operational Variation

As a check on operational variations, Fine Earth samples were split on rifflers to produce two duplicate sub-samples which were sieved separately and distinguished on final size-distribution graphs. The levels of variation can be seen from the separation of values for particular size classes between the duplicate samples. As expected, these are generally largest at the extremes of the sand fraction. At the coarse sand end there is the problem of a small number of grains and hence greater variability. On the other hand, the enormous numbers of grains in the finest sands increase the danger of overloading and incomplete separation (McManus, 1965). For this reason a standardised procedure, of sieving for five minutes on an automatic shaker, was adopted.

(iii) Sieve Intervals

The accuracy of discrete size classes in describing continuous size distributions clearly improves as the class interval is reduced. Hails, Seward-Thompson and Cummings (1973) have shown that significant differences in moment measures can occur between calculations based on 0·5 Ø and 0·25 Ø interval data, and advocate the use of the latter. (For explanation of the Ø-scale, see Krumbein, 1938.)

In this study the smallest sieve interval available over most of the required size distribution was 0·5 Ø units. However, some irregular intervals were found over the coarse sand range, necessitating a correction procedure in subsequent calculations. (For conversion tables between the Ø-scale and the metric size scale, see Appendix 7, taken from H G Page, 1955.)

6.4.3 Presentation of Results

One of the first requirements in presenting size-distribution data is to specify which weighting process is employed, since - for example - number-size and weight-size distributions are in general very different

(Irani and Callis, 1963, p 25). The general convention of using weight-size as a basis for presentation is adopted here, as this is the manner in which data are collected from sieve analysis and generally reported in the literature. While serving as a convenient reference base, it should be stressed that it is not necessarily the most apt. In the case of some weathering mechanisms it may be more appropriate to use a weighting based on surface area (see section 6.6).

Weights of sieve fractions can be left as raw data in the form of tables, but are usually presented in one of three ways (McBride, 1971) :

(i) Graphical - Plotting data as histograms, frequency distributions curves and using visual interpretation (Krumbein and Pettijohn, 1938).

(ii) Computational -

  (a) using moment statistics - mean, standard deviation, skewness, kurtosis (Inman, 1952).

  (b) using multivariate techniques directly on raw data (Klovan, 1966).

(iii) Graphic-Computational - Using graphically-derived parameters.

Apart from the rather sophisticated multivariate techniques, the computational methods demand the fulfilment of certain pre-requisites. In particular, they demand unimodality and entire size distributions (Jones, 1970). While these conditions are often satisfied by aeolian or aqueous sediments, they are rarely met by glacial deposits and soils.

Dreimanis and Vagners (1971), in size distribution studies of till, have used samples of one cubic metre in order to have statistically significant representation of the larger rock fragments. Avery and Bascomb (1974, p 3) quote the following minimum sample sizes for estimating stone contents:-

Effective Stone Diameter	Minimum Sample Weight
20mm	1·1kgs
60mm	30kgs
260mm	1,000kgs

In fact, many of the rock fragments in the red siltstone soils were up to 100mm across.

Clearly, such sampling is not possible in these soils, so that a cut-off point on the size scale has to be selected, beyond which any material is rejected from the analysis. In this way an artificial truncation of the size distribution is created, with possible consequent modifications of the measured size distribution (Tanner, 1964). Moreover, it is rarely certain where the truncation has occurred. At best it just "clips the tail" of a distribution. At worst it excludes the greater part, including the mode.

In this study, attention has been directed to the sand fractions only, but the silt and clay have been allowed for by determining the sand fractions as weight percentages of the whole Fine Earth. This suppression of certain size classes (i.e., silt and clay) without absolute truncation has been called Type II censoring by Tanner (1964) and generally speaking does not need to hinder analysis providing the assumption of true normality can be made.

However, in the course of analysis, the polymodality of the sand fraction alone became evident, quite apart from possible additional modes removed above the cut-off point. Together with the truncation effects already mentioned, it is apparent that the application of computational and graphic-computational statistics to the size distribution of the soil sand fraction is inappropriate. A graphical presentation was chosen as the clearest and simplest manner of displaying the data.

6.4.4 Graphical Presentation

Various graphical methods of presentation are available (Harriss, 1971). They fall broadly into three groups:-

(i) Histograms;

(ii) Frequency distribution curves and cumulative frequency distribution curves;

(iii) Graphical transformations.

The use of histograms is subject to severe limitations. The size intervals have to be regular, as areas and not heights are proportional to the weight percentages recorded. Also, the size and position of the intervals themselves can affect the shape of the distribution. In the extreme case, with an infinite number of intervals, the diagram will disappear.

To circumvent this problem, the absolute frequency distribution can be derived; either by calculation or graphically (Krumbein and Pettijohn, 1938; Bagnold, 1941). Alternatively, and especially in the case of irregular size classes, a cumulative frequency graph can be used. Not only is this a unique representation of the data, but it also lends itself to graphic-computational measures, such as percentiles and other descriptive statistics. Unfortunately, cumulative curves are difficult to interpret visually. Modes are represented by changes of slope, which are not always readily apparent. Moreover, these gradients are severely affected by truncation (Tanner, 1964) and are prone to errors in drawing.

Certain graph papers are available which presuppose a particular size distribution. If this condition is met, the experimental data should plot on such graphs as a regular feature - always a straight line. Thus the log-probability graph reduces log-normal distributions to straight lines. Similarly, crushed materials tend to follow Rosin's distribution (Kittleman, 1964). More complex transformations include the log hydrodynamic probability charts (Brezina, 1963). The problem with soils is that a "model" distribution can very rarely be applied, let alone assumed.

For the purposes of this study, presentation of the results as frequency distributions was considered the most suitable. However, weights of material from irregular sieve intervals had to be standardised first. One method is to divide the percentage weight for each size class - $\Delta\rho$ - by the interval (expressed in $\emptyset$ units) of the size class - ΔR (Bagnold, 1941, p 112). The introduction of a factor of two into the denominator -

$$\frac{\Delta\rho}{2\,\Delta R}$$

is simply to avoid unnecessary calculations where $\Delta R = 0{\cdot}5\ \emptyset$ units, as is the case for most of the sieve intervals.

Variations in sieve intervals are thus corrected, but at the cost of changing the values along the y-axis. These now represent the change of diameter over the same interval. As Bagnold (1941, p 113) points out, this value now represents the first differential of percentage weight against grain size and is, in fact, the first differential coefficient of the corresponding cumulative diagram. Hence the height of the peak is equivalent to the steepest slope of the cumulative curve, and its position is that of the predominant diameter.

In the final analysis, frequency polygons were constructed instead of frequency curves. These avoid the more subjective placing of curved lines and emphasise the fact that information is available only for changes in weight of material over a sieve interval and not over a continuous set of points (see Figure 6g).

To draw the polygon, points representing changes of weight were placed in the centres of their respective classes and connected. Where duplicate analysis coincided, one of the symbols is displaced to the side. Otherwise, the variation between duplicates is shown by their vertical separation and the straight connecting lines are taken mid-way between the points. Histogram-type columns are omitted for clarity.

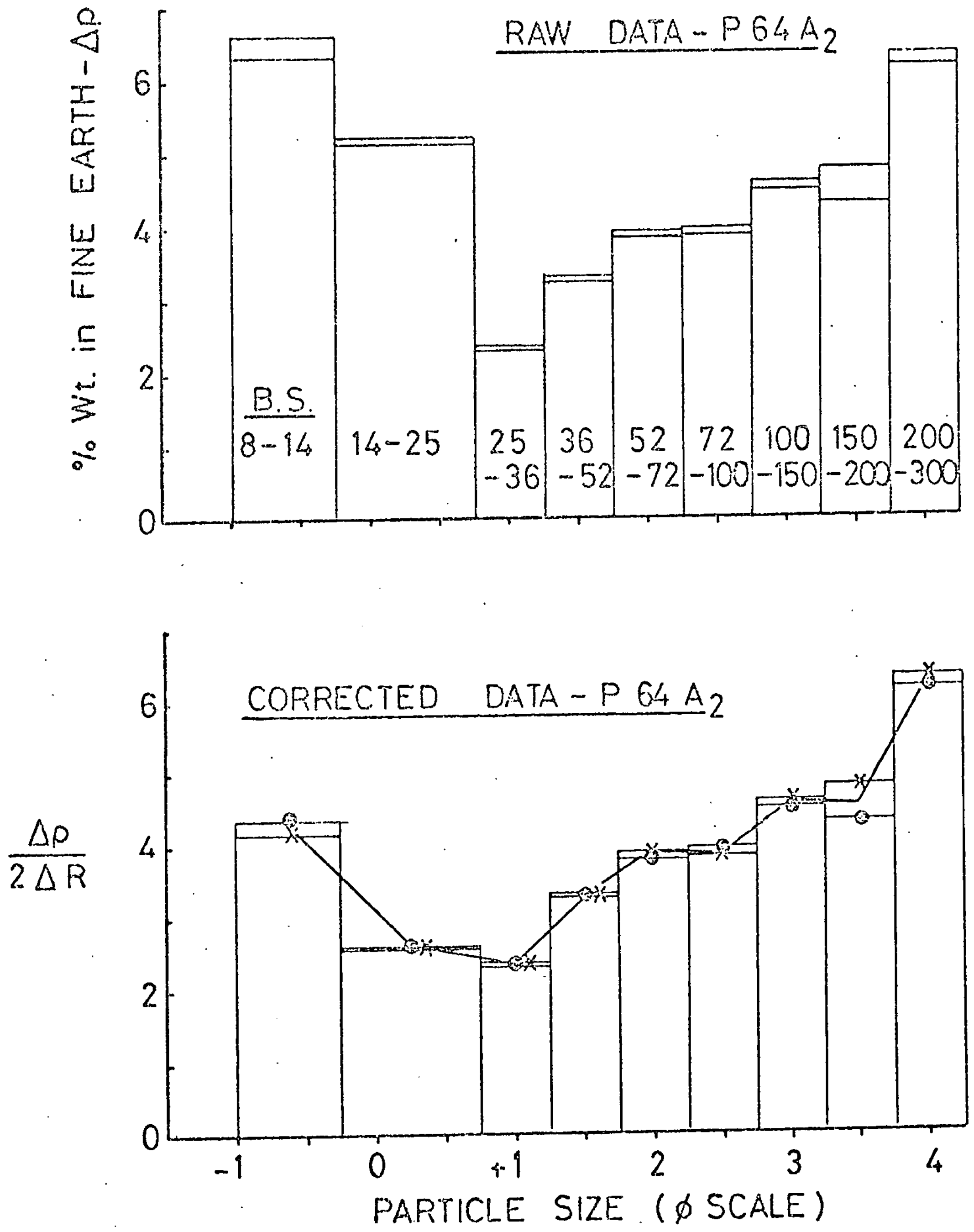
6.4.5 Results

The location of sampling sites for the sand size distribution analyses is the same as for the sand composition analyses and is shown in Figure 5b. In order to facilitate discussion, the results have been grouped on a basis relevant to genesis.

Fig 6g

CORRECTION OF DATA FROM IRREGULAR SIEVE INTERVALS

B.S. British Standards sieve numbers
ΔR Sieve Interval (in ø units)



Virgin Soils (Fig 6h)

The occurrence of virgin soils is restricted to a narrow zone along the coastal cliff-tops lying just beyond the outermost field boundary walls, and the five samples shown come from such positions. P4 is slightly unusual, in that it is sited on a slope (about 10° - 15°) within a small valley set back a little from the cliffs, and may represent soliflucted material. The other soils occur on level sites (<5°).

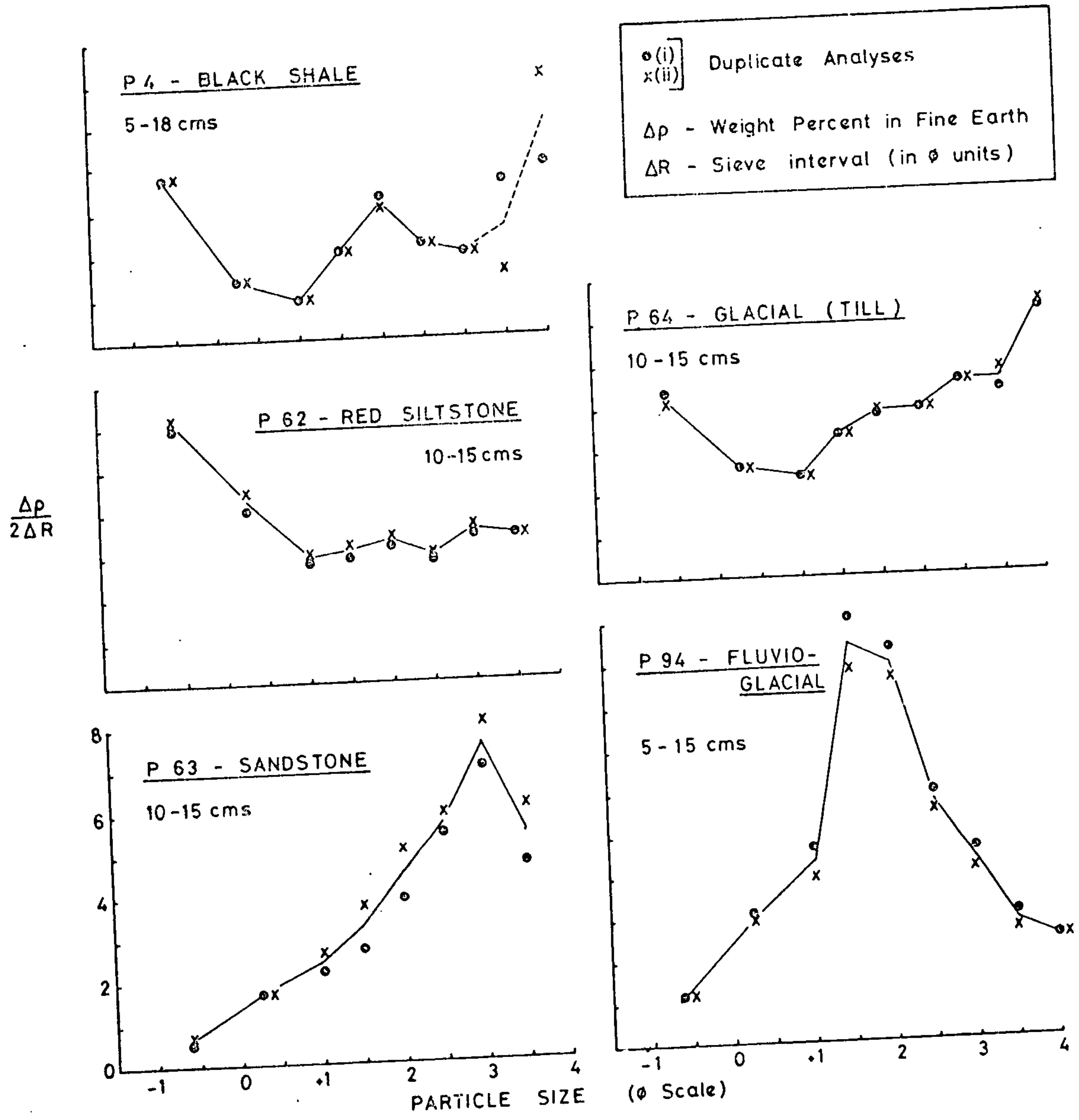
P64 and P94 possess size distributions largely determined by their mode of depositon. P64 is typically unsorted, but the increase in the finer sand fractions underlines the role of abrasion and crushing leading to high silt and clay contents. The increase in the coarse sand fraction is caused by the presence of rock fragments which gradually disappear from finer sand fractions to be replaced by mineral grains, and in particular quartz, as has been observed in other glacial deposits (Dreimanis and Vagners, 1969, 1971; Beaumont, 1971; Slatt, 1972; Buller and McManus, 1973).

On the other hand, strong sorting at P94 has resulted in a concentration of grains (mostly quartz) between +1 Ø and +3 Ø (500µm - 125µm). This stone-free sandy deposit was found in a channel, visible on air photographs, tracing a course from an area of (suspected) glacial till at Pearson Farm, and may possibly represent till material transported and resorted by melt-waters.

Although it is not evident from the sand size distribution, the sample had a considerable content of silt and clay (about 60% of the Fine Earth by weight) which is not in keeping with the strong sorting of the sand. Slope, soil-forming and weathering processes may be respons-

Fig 6h

PARTICLE SIZE DISTRIBUTION OF SAND FRACTION IN VIRGIN SOILS



ible for this finer material.

P4 appears to be polymodal with one peak suspected to be lying beyond -1 0 (2mm) due to fragments of black shale, another at about +2 0 (250 µm) due to clear rounded quartz grains, and a third, lying beyond the fine sand, possibly representing an influx of silt from weathering or aeolian activity.

The red siltstone profile - P62 - is remarkably pure at the coarse sand end, so that the size distribution is that of the siltstone rock fragments down to about +1 0 (500µm). Below this size there is a gradual increase in the relative quartz content towards the fine sand at 4 0 (63 µm), where there is almost no siltstone present at all. Thus the sand fraction is lithologically strongly bi-modal, although this is not readily apparent in the overall size distribution.

P63, only a hundred metres from P62, is a sandstone variant of the thin plateau soil. The influence of the parent rock can be seen clearly in the strong peak at +3 0 (125 µm), which probably approximates to the size of the original detrital grains in the sandstone and represents their accumulation as a residual product of weathering.

Broomhill Farm (Fig 6j)

Most of the size distributions display polymodality, although the only mode fully within the sand fraction falls at about 2·0 0 to 2·5 0 (250µm to 180µm). In some cases this peak is very clearly defined - P66, P67, P68, P69, P72 and P74. These are typical thin, upland soils. P76, though no different in field appearance, has a less pronounced mode in the medium sand for which no explanation is available.

Fig 6j

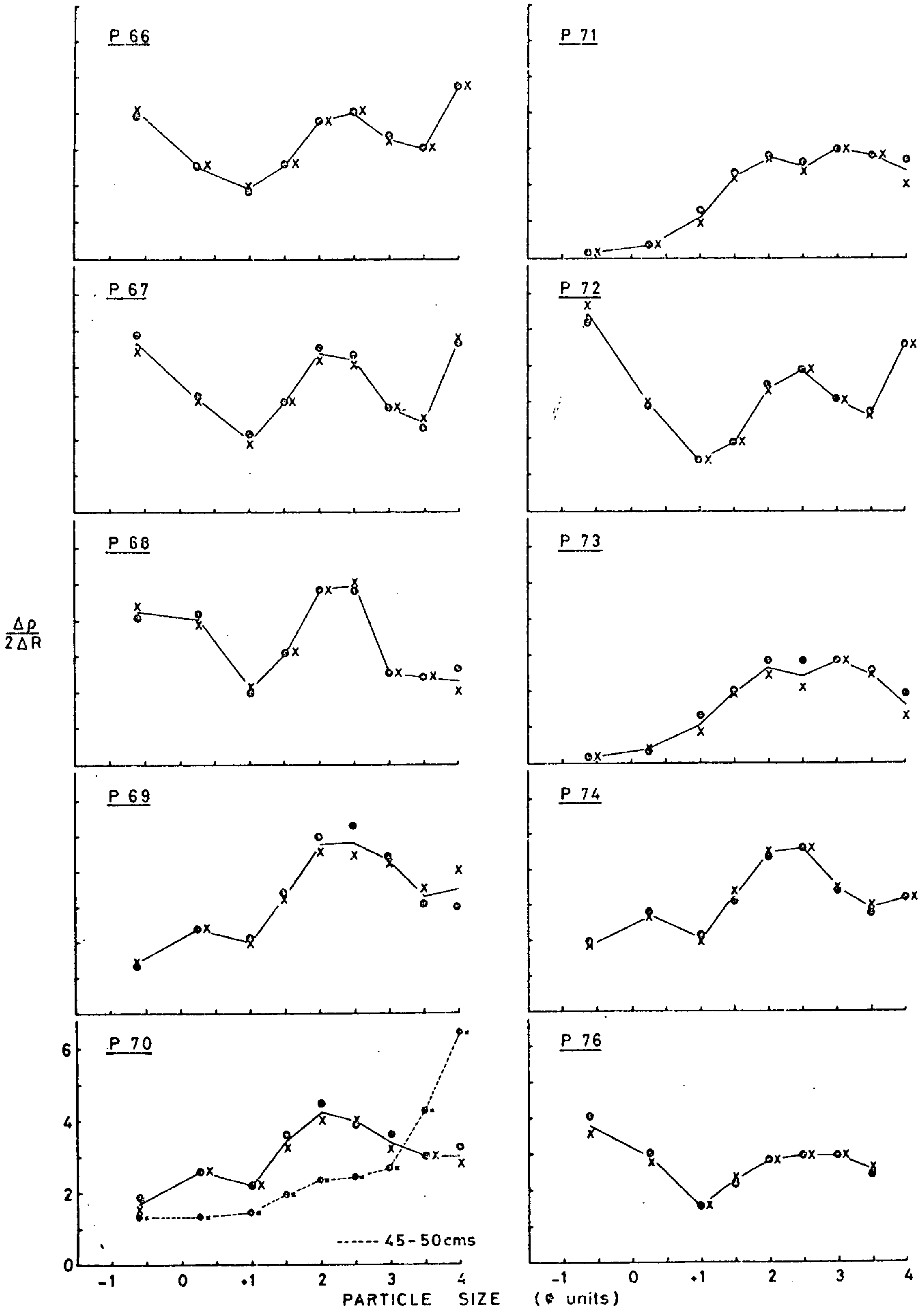
PARTICLE SIZE DISTRIBUTION OF SAND FRACTION AT BROOMHILL FARM

o (i)
x (ii) Duplicate Analyses

Δp - Weight Percent in Fine Earth

ΔR - Sieve interval (in φ units)

Top-soil samples taken at 5-15 cms depth.



The relatively high coarse sand contents of these soils are due to red siltstone rock fragments.

P71 and P73, located in a channel-like depression, are almost completely deficient in coarse sand (see also Fig 6f). The sorting in these soils is unusual : only one, rather broad mode is evident - in both cases spread over the medium sand range from about +2 Ø to +3 Ø (250µm to 125µm). They do contain stones, but these are of varied lithologies and not as abundant as in the bedrock-derived soils. Furthermore, they disclose a high content of silt and clay (over 80% of the Fine Earth in both cases) which militates against a purely fluvial origin.

The alternative is an aeolian origin, which would account for the good sorting of the medium and fine sands, with the remaining material representing unsorted "host" soil. A possible source for the aeolian contaminant may have been the Dale Till Sheet, just a few hundred metres to the west and to the south. Indeed, it is almost certain that material blown around under the harsh periglacial conditions of the late Glacial would have accumulated in topographical depressions.

Whatever the explanation, the soils are not derived from the underlying bedrock, as they lack the high coarse sand contents of red siltstone. In this respect, P70 appears to be an intergrade between the channel soils (P71, P73) and the upland soils (P69, P72, P74) as some degree of bedrock influence is indicated by the higher coarse sand contents in spite of its "low" topographical position. It is interesting to note that the moderately-expressed mode at about 2·0 Ø (250µm) in the top-soil (5-15cms) is considerably reduced in the sub-soil (45-50cms), but a sharp increase is registered in the finest sand leading to the silt fractions. The medium-sand contaminant is confined to surface soil horizons, and favours an aeolian origin, though it is more likely that some water-sorting and soil slumping has also occurred, producing a complex size distribution.

St Brides Topographical Transect (Fig 6k)

The effect of slope on the size distribution of the sand fraction of the soils was determined in order to assess the significance of this factor. In spite of the inevitable lithological variations in the underlying Devonian geology, several trends, albeit weak, were apparent in the size distributions:-

(i) The coarsest sand content decreased donwslope, although the lowest values at P84 and P85 may have resulted from fluvial sorting.

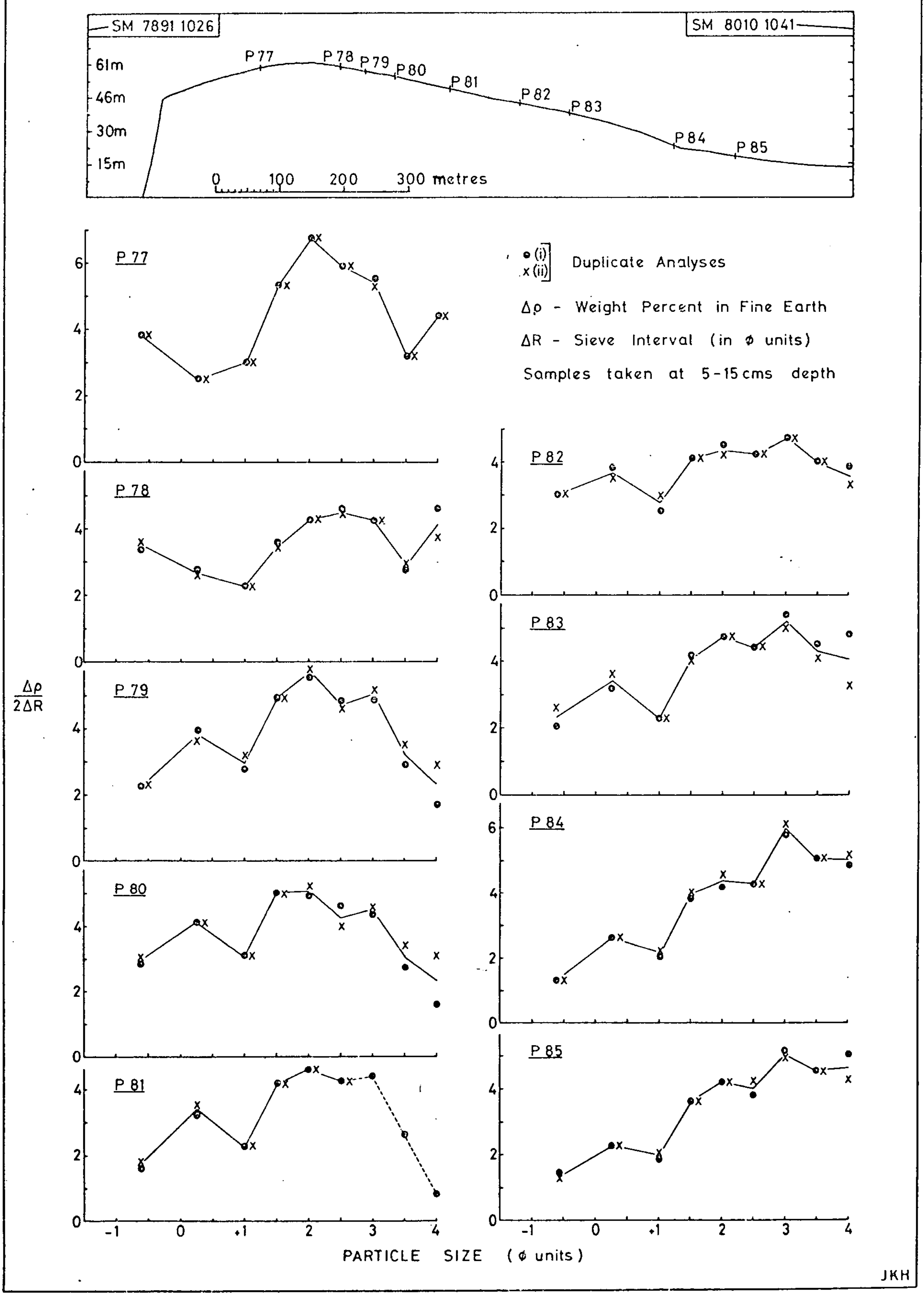
(ii) There was a concomitant trend towards higher contents of the finer sands, possibly extending to the silt fractions. (It should be remembered that the basis for sand contents is the entire Fine Earth, so that increases in fine sand content are not a necessary consequence of decreasing coarse sand content.)

(iii) A feature common to all the soils was an increase in medium sand over a size range of about +1·0 Ø to about +3·5 Ø (500μm to 88μm). This mode is composed predominantly of quartz, varying in form from clear, angular fragments to frosted and rounded grains, contrasting with the coarser sand of rock fragments.

With the possible exceptions of P84 and P85, the changes at the ends of the sand size distribution are probably a result of differential

Fig 6k

PARTICLE SIZE DISTRIBUTION OF SAND FRACTION IN ST. BRIDES TOPOGRAPHICAL SECTION



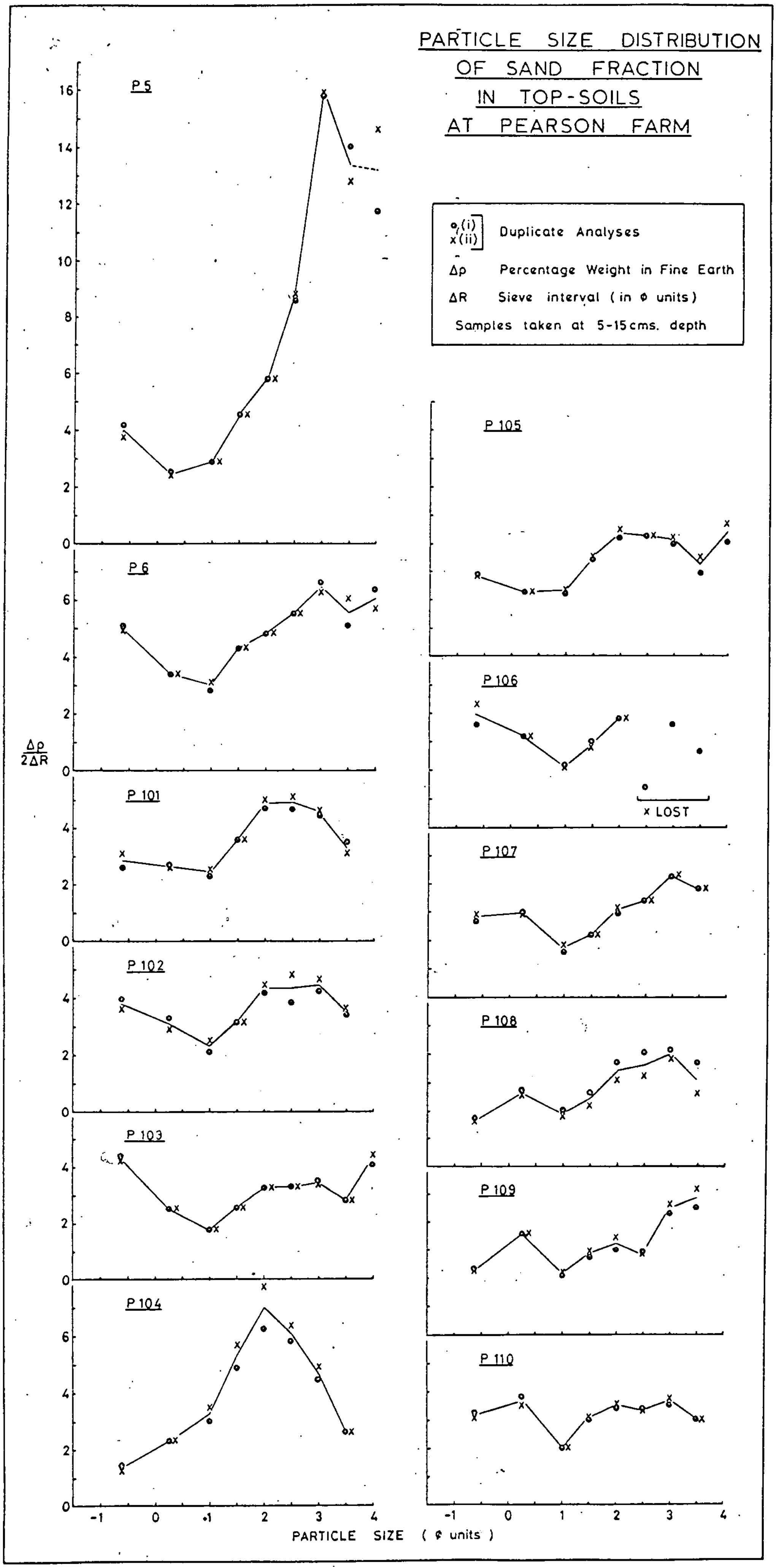
movement of material by slope-wash and raindrop splash. Ekern (1950) has shown experimentally that the size range most suceptible to raindrop impact is 400μm to 50μm (about +1Ø to +4Ø). Particles greater than 400μm were found to be much less mobile on gradients, owing to the comparatively greater energy required to disturb them, while grains smaller than 50μm were found to compact quickly with a rapid sealing of the surface, the accumulation of water and a consequent reduction in raindrop impact energy.

As far as slope-wash is concerned, soil surface texture is important in affecting run-off and infiltration, especially in view of the fact that water-stable aggregates (suggested as a good criterion of soil erodibility - Bryan, 1968) may, in fact, disintegrate to the textural separates under high-velocity rainfall. The combination of raindrop splash and slope-wash leads to the formation of a stony surface soil layer in upslope zones and the accumulation of fine material down-slope.

Pearson Farm (Fig 6m)

The origin of some of the soils (P 101 - P 105) in the Pearson Farm area (Fig 5f for map) is problematical. Coarse sand composition analyses (Fig 5c) separate P 102 and P 103 as bedrock-derived soils from P 101, P 104 and P 105, which plot near or inside the glacial/fluvioglacial "field". These differences are not so apparent when the coarsest sand content is examined from the size distribution graphs alone (Fig 6k) - only P 104 is truly anomalous. The others betray just slight variations in the maximum value of the medium sand peak, and the coarse sand end.

Fig 6m


PARTICLE SIZE DISTRIBUTION
OF SAND FRACTION
IN TOP-SOILS
AT PEARSON FARM
o (i)
x (ii)
Duplicate Analyses
Δp Percentage Weight in Fine Earth
ΔR Sieve interval (in φ units)
Samples taken at 5-15 cms. depth
P 5
P 6
P 101
P 102
P 103
P 104
P 105
P 106
x LOST
P 107
P 108
P 109
P 110
Δp / 2ΔR
0
2
4
6
8
10
12
14
16
-1
0
1
2
3
4
PARTICLE SIZE (φ units)

It is particularly difficult to classify P 101, P 104 and P 105. From field survey, P 101 may be regarded as a till with a sandy top-soil and a stonier sub-soil of varied lithology. P 105 is stonier, but has a considerable proportion of sand and silt (sandy silt loam) and is easy to work even at a depth of over half a metre. P 104 is lighter still (also sandy silt loam) and has only rare stones at depth.

The very well-defined peak in P 104 at about +2·0 Ø (250µm) suggests powerful sorting by water. The position, breadth and height of the peak indicate that the energy of the postulated drainage, following a channel-like depression to P94, was lower than at the latter site, where the peak lies at about 1·5 Ø to 2·0 Ø (360µm to 250µm) (see Figure 6h).

Water-sorting is clearly evident in the fluvioglacial material at P5 and P6 (Fig 6m). P5 is taken from soil overlying a disused sand pit at Orlandon, St Brides (see Figure 5b for location relative to other sites at Pearson Farm). The action of ploughing has been to incorporate the fine, very well sorted sand (with a mode of about +3·0 Ø - 125µm) into the red siltstone transported cover soil. Except for the red siltstone concentration at the coarse sand end, the original size distribution of the soil has been swamped by this influx of sand. P6 has been similarly affected, but to a lesser degree.

Samples P 106 to P 110 all come from one field that is bisected by the boundary between the red siltstones of the Devonian and the grey interbedded siltstones and sandstones of the Silurian; P 106 and P 110 representing the former, and P 107 - P 109 the latter. The field appearance of these soils indicates derivation from sub-adjacent bedrock and, apart from colour, the similarity of the two soils is very great. Size distributions, likewise, show few significant differences between these soils formed over the two geological formations, vindicating the hypothesis that the medium sand contaminant (also present at P 107 - P 109) is of a common origin.

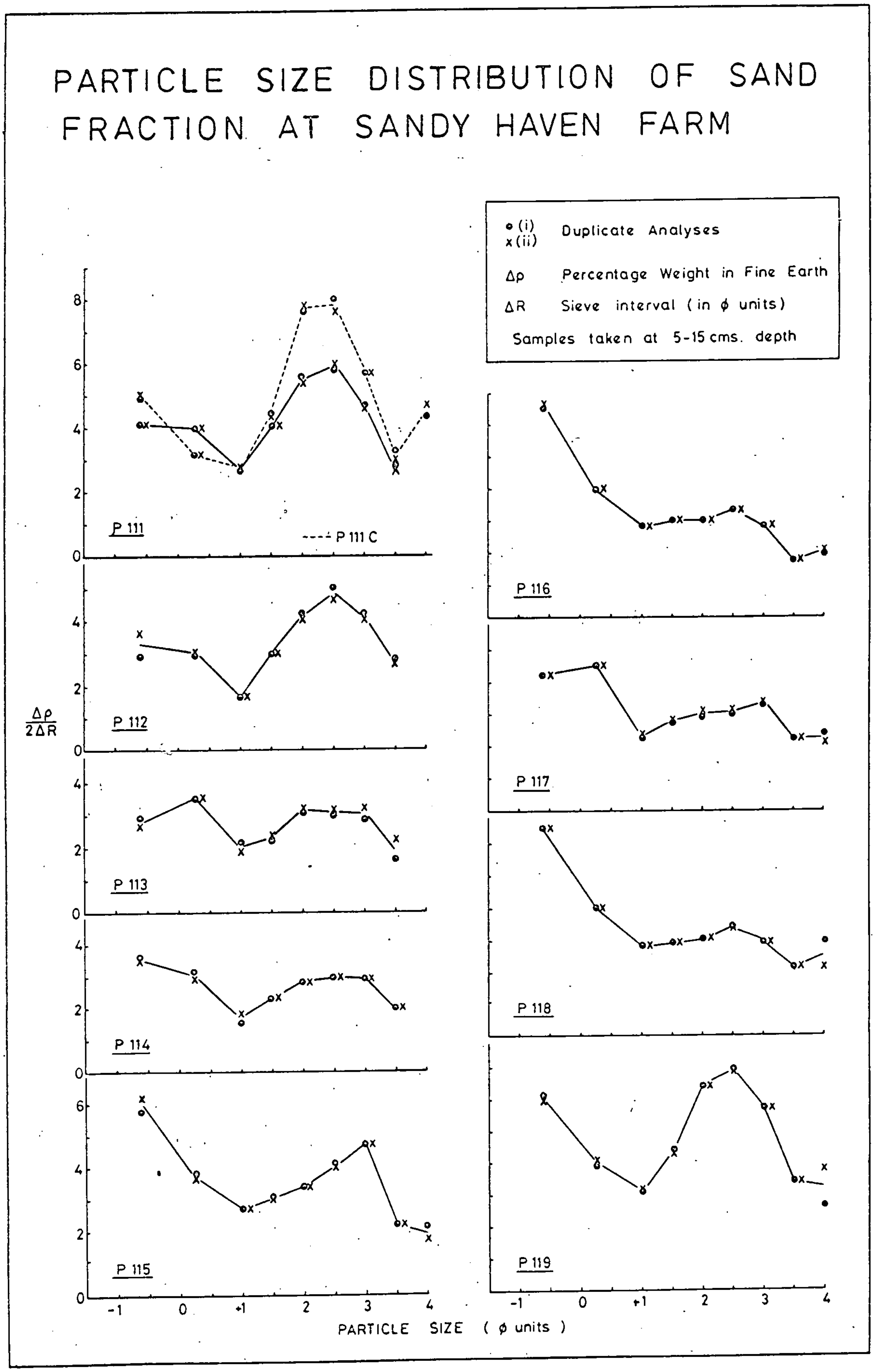
Sandy Haven Farm (Fig 6n)

The thin bedrock soils of this south-eastern part of the study area (P 111 - P 119) are characterised by very high levels of coarse sand content represented predominantly by red siltstone fragments. The medium sand modes resemble those of other soils in the study area, although they appear to be less pronounced, with two exceptions - P 111 and P 119.

On the basis of coarse sand composition analysis, P 111 is ambiguous, plotting outside the boundary of the thin, upland soils group owing to its high absolute quartz content (Fig 5g), yet also possessing a considerable amount of apparently bedrock-derived red siltstone (Fig 5c). In the field it was found to be a deeper soil than those generally encountered, overlying a soft sandstone. Size distributions for both the top-soil and sub-soil have a very pronounced peak, at about $+2{\cdot}0\phi$ to $+3{\cdot}0\phi$ ($250\mu m$ to $125\mu m$), which is particularly strong at the deeper level (35 - 40cms).

The vigorous size sorting may simply be due to the accumulation of residual material from the disintegration of the sandstone. On the other hand, it may represent strong fluvial sorting along a line of former surface drainage, such as the palaeorills described by Kirkby

Fig 6n



PARTICLE SIZE DISTRIBUTION OF SAND FRACTION AT SANDY HAVEN FARM

(1969) and Huggett (1974). In either case, the decrease of the peak towards the soil surface may be attributed to the "diluting" effect of mass-transported soil material from other sources under gravity.

P 119, with a similar peak between +2·0 Ø and +3·0 Ø (250µm to 125µm) was rich in fragments of soft green sandstone even though the sub-adjacent lithology was red siltstone. Fluvial sorting cannot be invoked in the geomorphological setting, and in this case the likeliest explanation is that residual weathering products from a highly localised, nearby (probably within a distance of a metre) sandstone bedding unit have been incorporated through mass soil movement under gravity and cultivation.

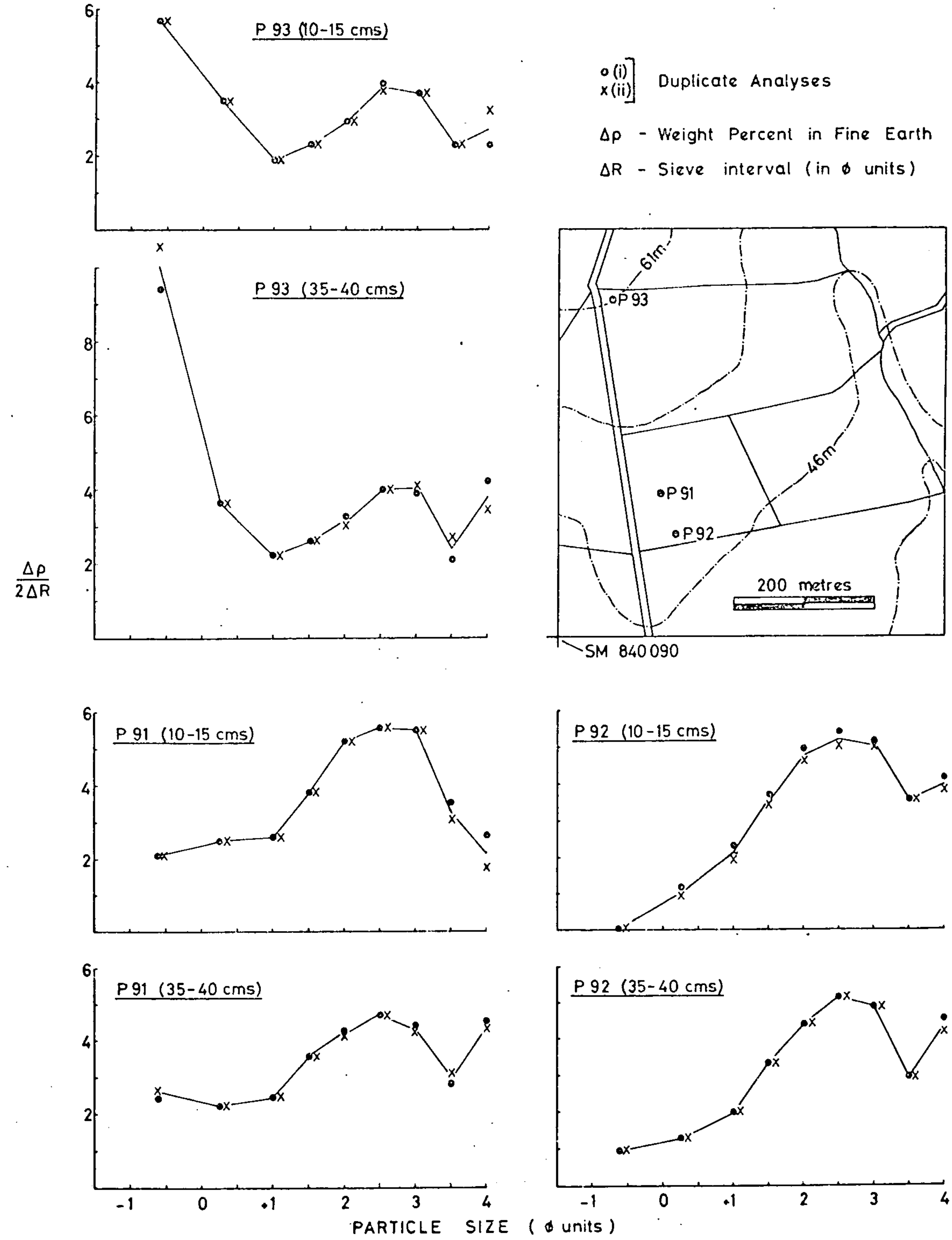
Winsle Sheet - Red Rabb Section (Fig 6p)

The rapid decline in coarse sand content and a complementary increase in the medium-fine sand peak characterises the trend from bedrock soils, as at P93, through the transitional phase, at P91, to glacial material - P92. These trends are closely followed in the subsoils (35 - 40cms depth); though P93 shows emphatically the greater proximity and influence of bedrock in a very high content of coarse sand-sized rock fragments. Air photographs reveal the presence of a sharp boundary between P91 and P92, which is borne out by the sharp differences in absolute quartz contents at the two sites (Fig 5f).

All of the samples possess the generally near-ubiquitous peak in the medium-fine sand range, but at P91 and P92 it is broad and spans the size scale from about +2·0 Ø to +3·0 Ø (250µm to 125µm) whereas at P93 it is smaller and narrower with a range of values from about +2·5 Ø

Fig 6p

PARTICLE SIZE DISTRIBUTION OF SAND FRACTION IN WINSLE SHEET - RED RABB SECTION



to +3·0 Ø (180μm to 125μm). The occurrence of this peak at P93, with almost no change in shape or magnitude at the deeper level appears to militate against an aeolian origin. However, it is sufficiently dissimilar to the peaks in P91 and P92 to preclude a glacial origin (apart from the evidence from other sources - such as air-photo interpretation, coarse sand lithology and field survey). No satisfactory explanation can be offered, but an "aeolian" hypothesis for the peak at P93 is preferred, as the depth criterion for wind-blown material (generally only present in the upper 25cms of the plateau regolith) may not be applicable owing to deep ploughing or similar cultivation.

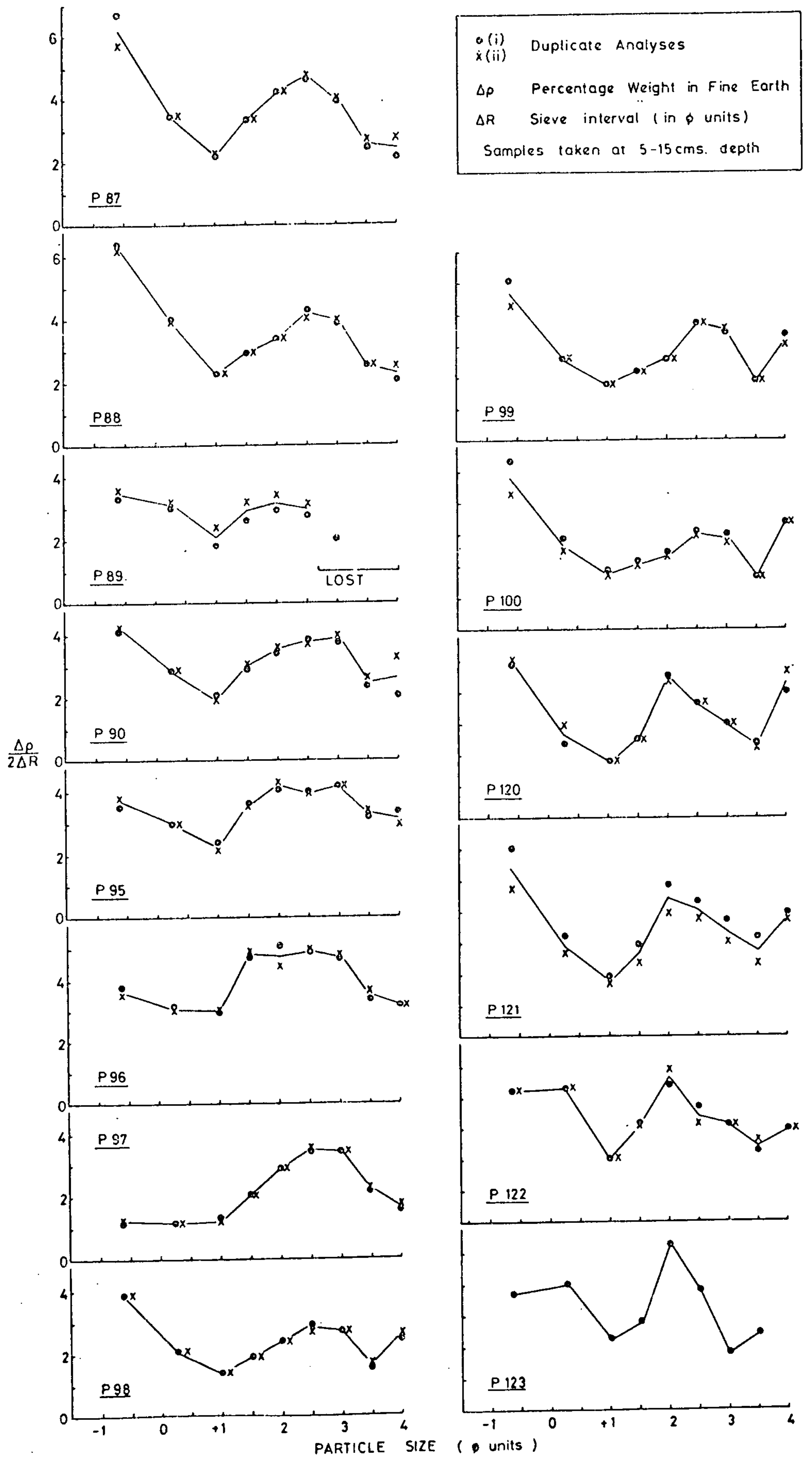
Remaining Soils (Fig 6q)

The remaining soils (P87 - P90, P95 - P100, P120 - P123) are drawn from diverse parts of Hasguard and St Brides Parishes, but are all from upland plateau situations.

Most of the samples have typically high contents of coarse sand (dominantly composed of red siltstone - Fig 5c). The lowest values are seen in P96 and P97 (Fig 6q). Both of these plot outside the "field" of the thin upland soils on the basis of their absolute quartz contents (Fig 5f) - P96, in particular, having a very high content. Field evidence also reveals that these soils are formed in extremely thin glacial deposits (not more than 35cms thick at P97) overlying Devonian bedrock. In such a situation it is unlikely that the superficial material will be uninfluenced by the subadjacent geology, and various properties, including size distributions, will tend to be intermediate in character.

Fig 6q

PARTICLE SIZE DISTRIBUTION OF SAND FRACTION IN TOP-SOILS



The four samples from Winterton Farm (P 120 - P 123) are distinguished by their exceptionally sharp peaks at about +2·0 Ø (250μm). In spite of high absolute quartz contents, the soils plot well within the thin upland soils group (Fig 5g) as a result of their high overall coarse sand contents. Field survey provides no evidence of glaciation in the locality - indeed, the soils appear to be classically derived from bedrock.

The consistent occurrence and definition of this peak from the four sites in one field is noteworthy. Such a large grain size cannot travel far by saltation or ground creep over an irregular surface of frost-shattered rock debris, where entrapment is rapid. A close source is therefore required, and the fluvioglacial deposits a few hundred metres to the east are ideal in this respect. Alternatively, the ancient practice of "sanding" (the application of shelly beach sand as a source of lime) may be responsible, although there is no documentary evidence for it in this part of Pembrokeshire (see section 5.5 and the discussion on the Anthropogenic Origin of Coal).

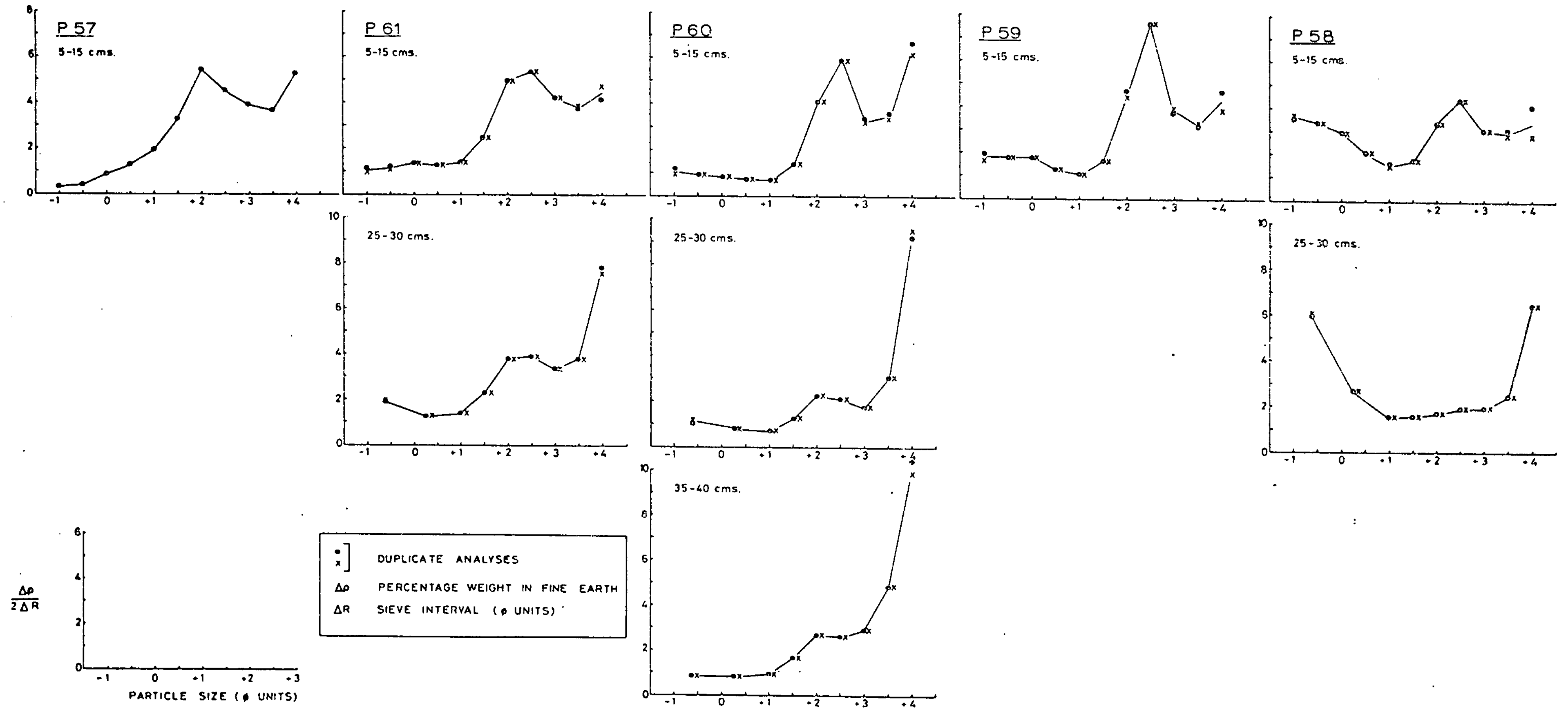
Dale Sheet - Red Rabb Transect (Fig 6r)

With the later acquisition of a full set of sieves at regular intervals of 0·5 Ø, it became possible to check the correction procedure for the irregular sieve intervals (Fig 6q) by additional analyses.

The sequence of sites shown (P57 - P61 - P60 - P 59 - P58) is that of a sampling line from the Till Sheet to the thin red rabb (red siltstone soil) in Dale Parish (location map - Fig 5b). On the strength of field work and coarse sand composition analysis (Fig 5c), the bound-

Fig 6r

PARTICLE SIZE DISTRIBUTION OF SAND FRACTION IN DALE SHEET — RED RABB TRANSECT



ary separating the two soils materials had been plotted between P60 and P59.

The same trends that had been observed in the "corrected" graphs are exhibited in these analyses. In passing from the till sheet to the bedrock soil a powerful increase in red siltstone fragments is experienced, giving rise to high coarse sand contents, as at P58 and, to a lesser extent, at P59. Unfortunately, size distribution data are not available for P59 (25-30cms), but from soil profile affinity it is more likely to resemble P58 rather than P60. The same trend is expressed, albeit not so strongly, in the top-soil samples.

All the top-soils also present the medium-fine sand peak, composed dominantly of quartz grains. While its magnitude varies only slightly, its position changes from about +2·0 Ø (250µm) at P57, through a broad peak at P61 at around +2·0 Ø to +3·0 Ø (250µm to 125µm), to a sharp peak at P60 and P 59 at about 2·5 Ø (175µm). These modes are strongly reduced in the sub-soils; P58 (25-30cms) appears to have suffered little or no contamination at all, in contrast to the top-soil (5-15cms). Such results can be interpreted in terms of aeolian contamination. The shift in position of the peak to finer sizes away from the till sheet may indicate a transition from glacially-transported to wind-transported material. While the depth of penetration of wind-blown deposits into a regolith appears to be variable, it is evident that at P58 this did not exceed 25cms, above which ploughing has subsequently homogenised the top-soil.

6.5 SIZE DISTRIBUTION OF SAND AND GRAVEL FRACTIONS AT P75

In order to confirm the suspected size distribution of the gravel fractions of the thin upland soils, an extended sieve analysis was carried out up to a size of about -3·67 Ø (12·7mms) on P75, Dale Parish. Irregular sieve intervals were corrected by the same procedure as used in previous analyses (see section 6.4.4). Where the size distribution has been contaminated by foreign material, several counts were made on sub-samples of at least a hundred grains to obtain the relative proportions of contaminant to red siltstone, and hence to derive the size distribution of the latter only (Fig 6 s).

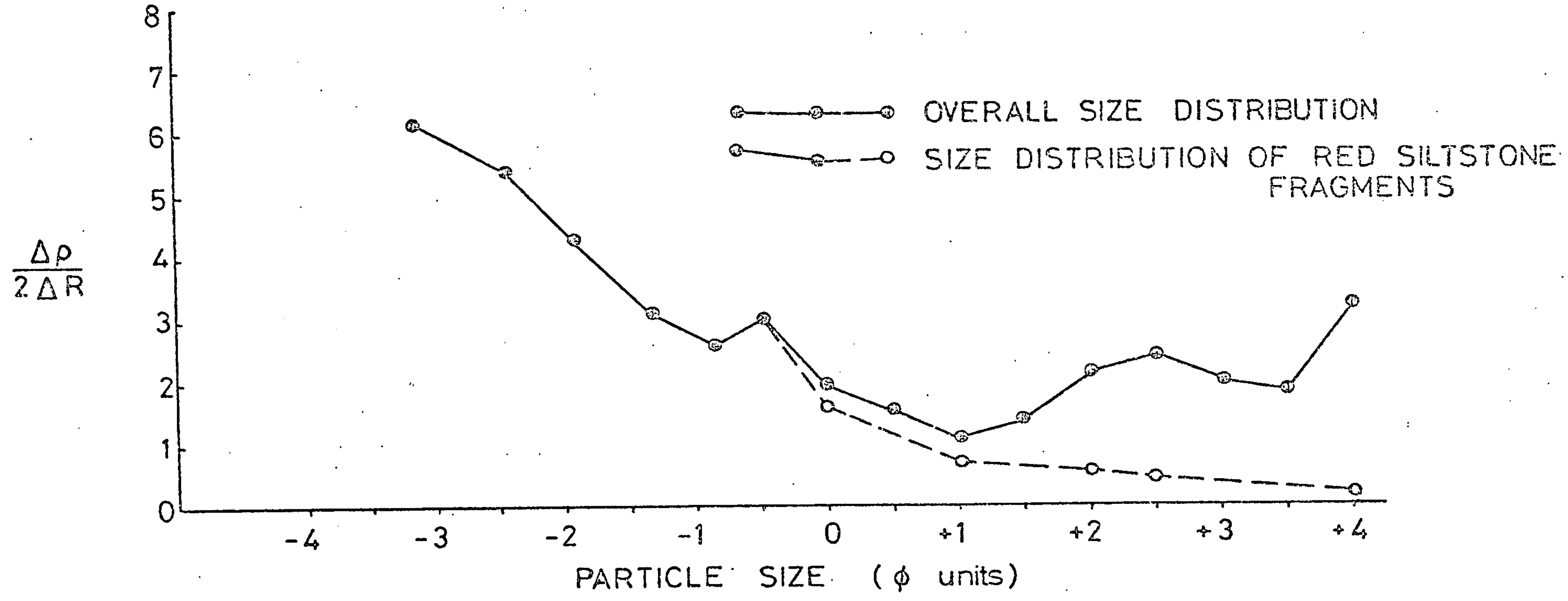
The sieve fraction of the largest fragments (-3·67 Ø to -2·67 Ø, equivalent to 12·7 mms to 6·36 mms) was found to number 132 grains and this was felt to be the maximum size that was adequately represented in a soil sample weighing just over 1,000gms. In the calculations, sieve fractions were expressed as percentage weights of the total soil sample (including silt and clay) up to a size of -3·67 Ø (12·7 mms).

As expected, the mode of the red siltstone fragments has not been achieved even in this extended sieve analysis (Fig 6s). Even in closely-jointed red siltstones, fragments up to 5 cms across (-5·65 Ø) are common, and adequate sampling would require enormous amounts of soil material (Avery and Bascomb, 1974, p 3; see also section 6.4.3). Nevertheless, a field assessment of the modal size was possible and suggested an order of magnitude of 5 to 10cms (-5·65 Ø to -6·65Ø).

The size distribution (Fig 6s) of the rock fragments shows a gradual decline to -1 Ø (2 mm or 2,000µm) as fracturing occurs along

Fig 6s

SIZE DISTRIBUTION OF SAND AND GRAVEL FRACTIONS AT P75



planes of weakness at such a distance of separation - the closely-spaced bedding planes and the more widely-spaced joints. At about -1 Ø to -0·5 Ø (2,000μm to 1,400μm) there appears to be an accumulation of red siltstone fragments. When examined under a lens, they are seen to have the form of flattened ellipsoids, with thicknesses of the order of a millimetre, corresponding to the thickness of the sedimentary laminations in some of the siltstones.

The rounding of the edges of these fragments and their sudden increase suggests a change in the fundamental mode of weathering. Over the range -1·0 Ø to -0·5 Ø (2,000μm to 1,400μm), planes of mechanical weakness become rare, and therefore these fragments approximate to the smallest units obtainable by mechanical splitting (as occurs in frost weathering, for example), although invariably a little material smaller than this is produced in the process.

Below this size range surface mechanisms of weathering take over, resulting in the rounding of edges and increasing in effect as the ratio of the surface area to size increases towards the finer grades. This is clearly seen in the lower line of the graph (Fig 6s) tracing the size distribution of the red siltstone fragments only.

This graph also demonstrates the size distribution of the contaminant which becomes apparent at a size of about -0·5 Ø (1,400μm), increases rapidly below +1·0 Ø (500μm), and reaches a peak at about +2·5 Ø (175μm). The "masking" effect of the contaminant in the overall size distribution is particularly evident in its modification of the rapid decline of rock fragments below -0·5 Ø to a much gentler decrease. This effect needs to be borne in mind in the interpretation of size distributions where such a lithological separation was not practicable.

The sudden upturn in the fine sands +3·5 Ø (88 μm) probably represents the incursion of the weathered products of the siltstone - very fine sand and coarse silt beyond the end of the distribution.

6.6 SURFACE MORPHOLOGY OF SAND-SIZED RED SILTSTONE

Evidence for surface weathering was also found in the morphology of red siltstone fragments taken from the soils. Differences in the degree of rounding and "surface texture" (granularity or roughness) could be observed between soil rock fragments and freshly crushed equivalents. The latter, prepared by mortar and pestle, is thought to resemble fresh frost-shattered rock as far as surface texture is concerned, as fracturing would have occurred by the similar mechanism of tensile failure (Lo and Roy, 1969).

Some of the microfeatures described in the following section were apparent under a binocular light microscope (approximately x80). The application of the Scanning Electron Microscope to these surface features yielded much additional information. Not only was the magnification drastically improved (up to an operational maximum of x 10,000), but at the same time a very convenient broad depth of focus was maintained.

Procedure

Four samples were selected for viewing:-

SEM 1 - Crushed red siltstone
SEM 2 - Red siltstone from virgin soil - P62 A_2
SEM 3 - Red siltstone from cultivated soil - P75 Ap
SEM 4 - Red siltstone from cultivated soil - P75 Ap
(unwashed sample)

Samples were prepared as follows:-

About 20 fragments of red siltstone from one sieve fraction (420µm to 300µm/ +1·25 Ø to +1·75 Ø) were selected to represent the range of surface textures seen under the binocular microscope, mounted with double-sided sellotape on stubs, and gold-plated.

SEM 1 had been obtained by crushing a sample of red siltstone in a mortar, and was unwashed. SEM 2 and SEM 3 had been thoroughly washed by shaking overnight in the pre-treatment for the sieve analyses. SEM 4 was taken as an unwashed equivalent of SEM 3 and comprised larger fragments of red siltstone which were not gold-plated but mounted directly on a bed of silver.

Errors Possible due to Experimental Procedure

(i) Misrepresentation is possibly the greatest source of error. Given the limitations of time and finances for viewing, sub-samples of only 20 rock fragments per stub were prepared, and these were often reduced to half that number as a result of "charging-up" - a condition in which the object acquires an electric charge and cannot be viewed properly under the electron microscope. However, as noted earlier, general observations made of numerous rock fragments under the light microscope corroborate the evidence of the few fragments seen under the Scanning Electron Microscope.

(ii) Some of the surface features may be attributed to the overnight washing in an end-over-end shaker, particularly as the effects of the water may have been enhanced by the presence of the sodium hexametaphosphate (Calgon) used as a deflocculant.

The evidence, however, suggests that such action is slight. Unwashed samples, under the binocular microscope, exhibit the same granular surface texture and rounding of "soil" fragments, in contrast to the relatively smooth facets and high angularity of crushed rock. These features were detectable in SEM 4, but the inevitable coating of loose soil clays obscured any detail.

Furthermore, the overnight shaking has failed to remove some very protuberant silt grains, of both quartz and mica, which would have been dislodged in a particularly vigorous washing, although a few very fresh-looking cavities may indicate such a loss. (Laboratory experiments have also shown that the red siltstones are very resistant to strong acids and reducing agents.)

Results

The sharpest contrasts are found between the "soil" rock fragments (SEM 2 and SEM 3) and the crushed rock fragments (SEM 1).

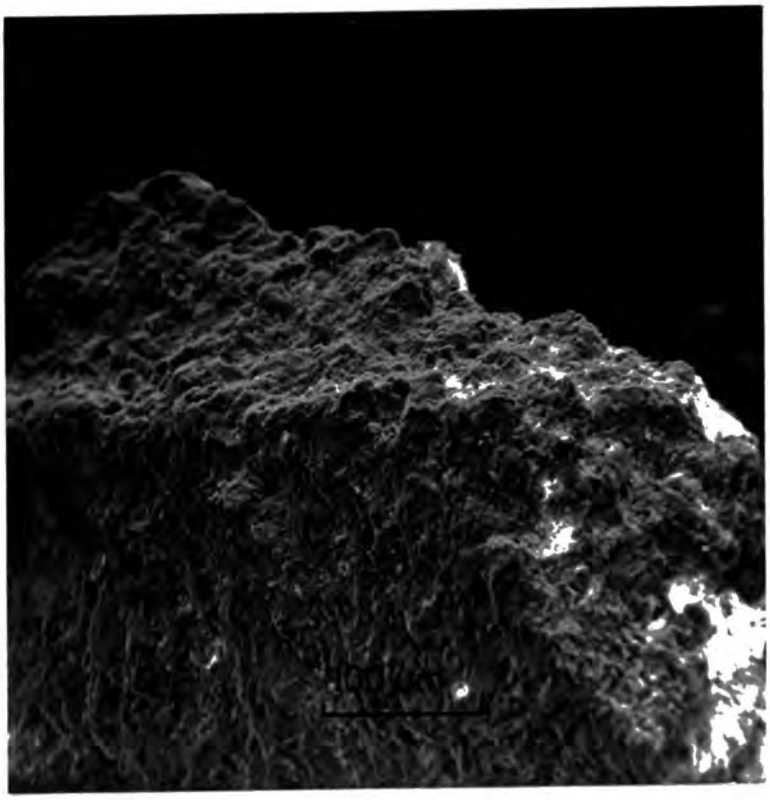
SEM 1 (Plates 13 and 21) displays a high angularity typical of crushed material. From plate 13B it is evident that the silt grains (of the order of 20-30μm across) are mechanically more resistant than the matrix and hence form a serrated edge. This is the only situation in which these grains protrude in the crushed material. Elsewhere, on the facets, there are only minor irregularities, and it is difficult to distinguish individual silt grains (Plate 21 A and B).

The remaining photographs (Plates 14-20) all demonstrate, to varying degrees, the greater roundness of the fragments with only occasional subdued edges (for example, Plates 14, 15 and 18). The surface texture in most cases is very granular, and individual silt grains are clearly visible, even on the flatter surfaces. Closer inspection reveals that these grains (mostly 50µm to 20µm across) project from a much finer matrix and that they possess clean faces (for example Plates 14B, 15B, 16B) in contrast to the matrix-coated silt grains in the crushed rock (Plate 13B).

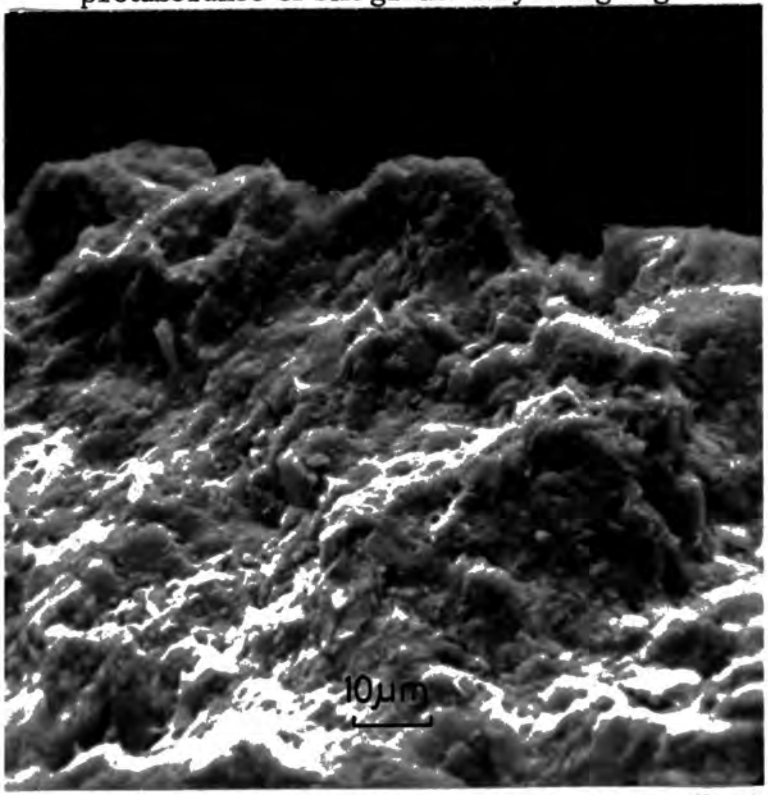
Both quartz and mica grains of silt have been identified. A particularly good example of a quartz silt grain, with conchoidally-fractured faces, is shown in Figure 16B. The matrix is cut back deeply and the grain appears to be on the verge of dropping out. Mica grains (identified as muscovite from petrological thin sections) appear to be more resistant to chemical weathering than the matrix (Plates 19B and 19C), but are prone to mechanical disintegration where their orientation with respect to the surface is unfavourable (Plate 20B). The grains then weather by loss of cleavage flakes.

When a resistant silt grain is sufficiently exposed, it will drop out leaving a small cavity which, when fresh, is characterised by a slightly raised rim. Such a cavity is thought to be present in Plate 18B (evacuated by a grain at least 20µm in diameter), and possibly in Plate 17B (with a cavity about 50µm across). With the continuation of weathering, these rims, composed only of the matrix, are lowered to the overall surface, and the cavities become inconspicuous and finally

SEM 1

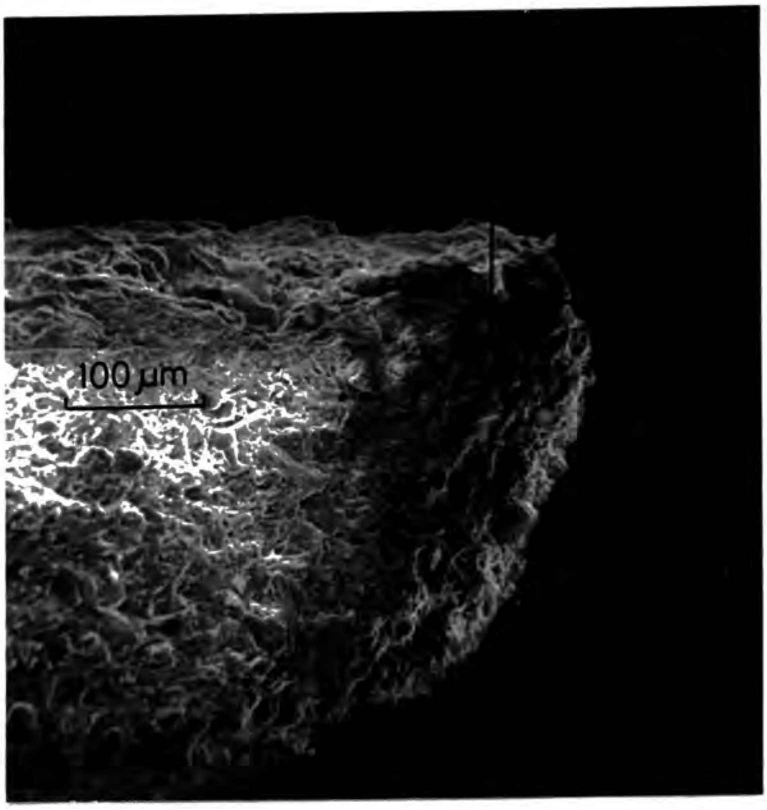


A. Crushed red siltstone. Note high angularity and protuberance of silt grains only along edges.

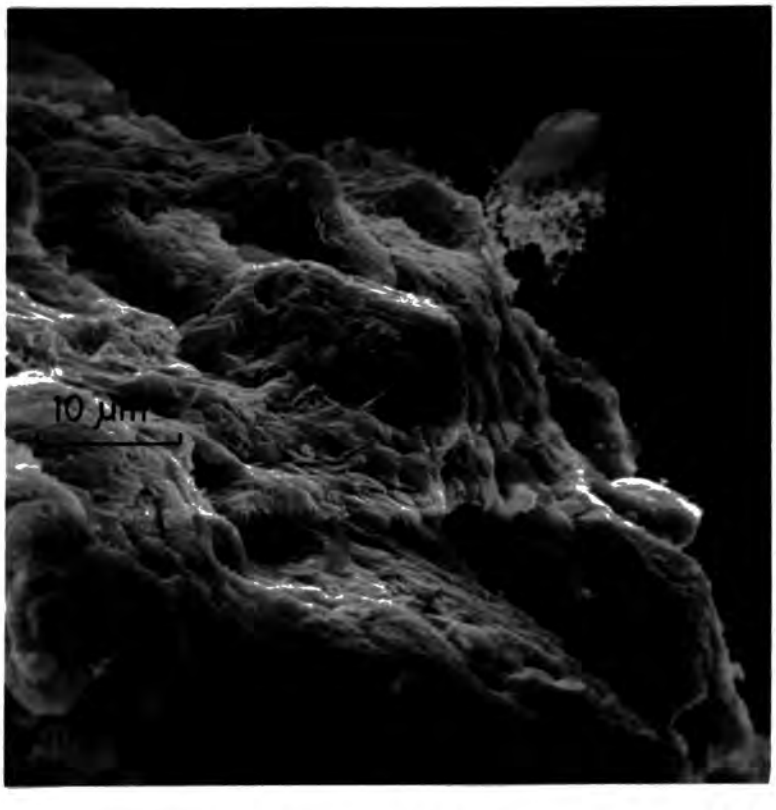


B. Silt grains along upper edge show matrix adhering to their sides.

SEM 3

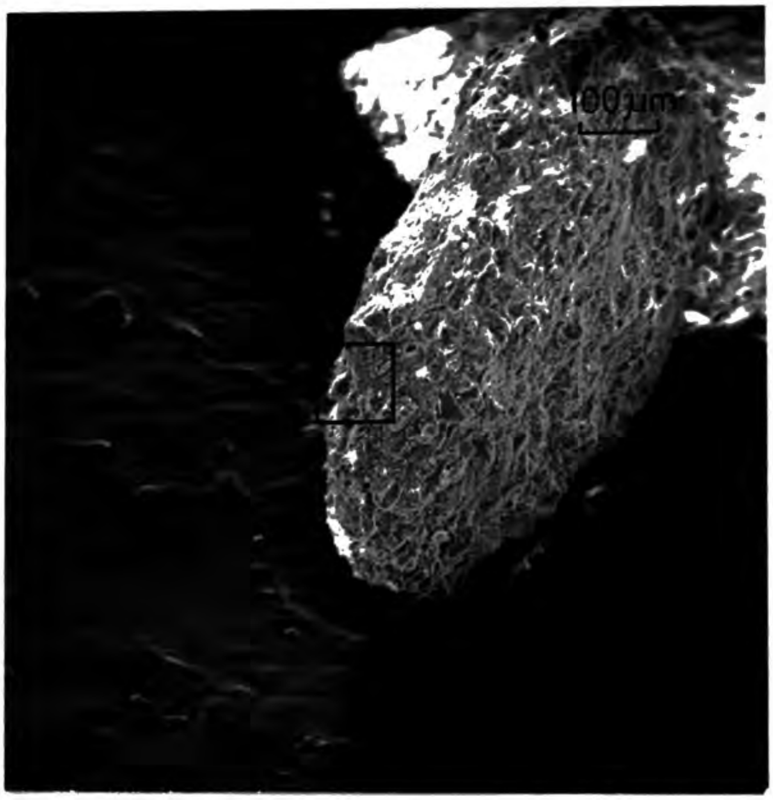


A. Red siltstone fragment from soil showing roundness of form and protuberant silt grains.

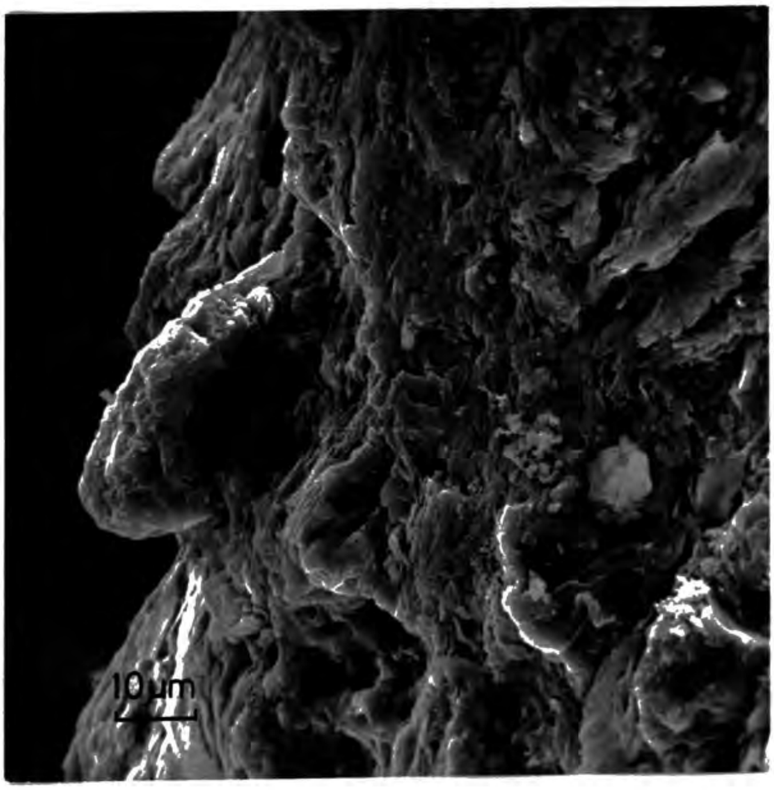


B. Silt grains projecting clearly from matrix which has been etched away.

SEM 3

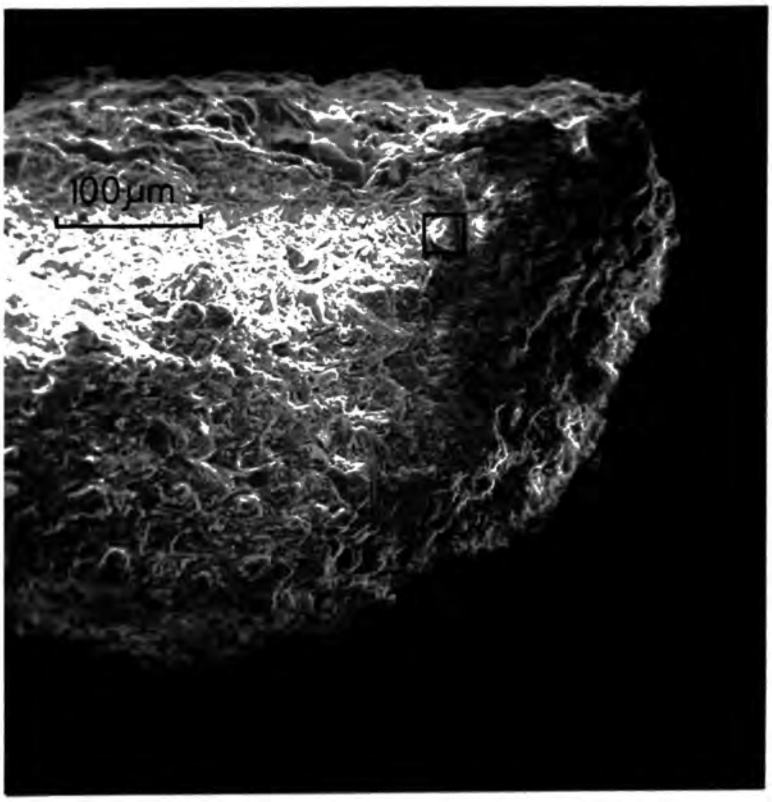


A. A well-rounded fragment of red siltstone showing a strongly "granular" surface morphology.

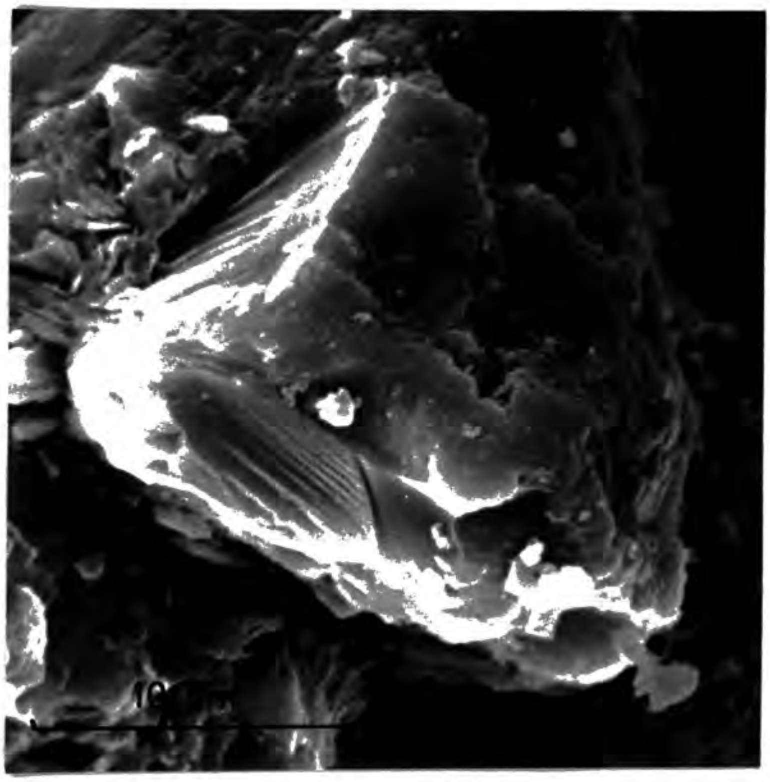


B. Detail of protuberant silt grain (probably of quartz).

SEM 3



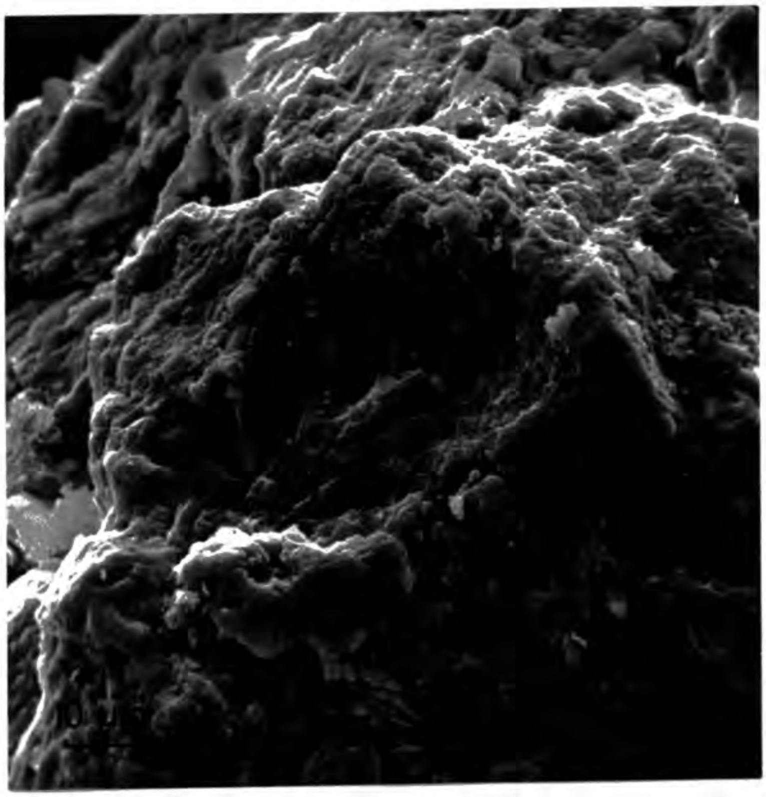
A. Highly "granular" surface morphology. (Same rock fragment as in Plate 14).



B. Extremely protuberant silt grain with conchoidal fractures on two faces and corrosion on third. Probably quartz.

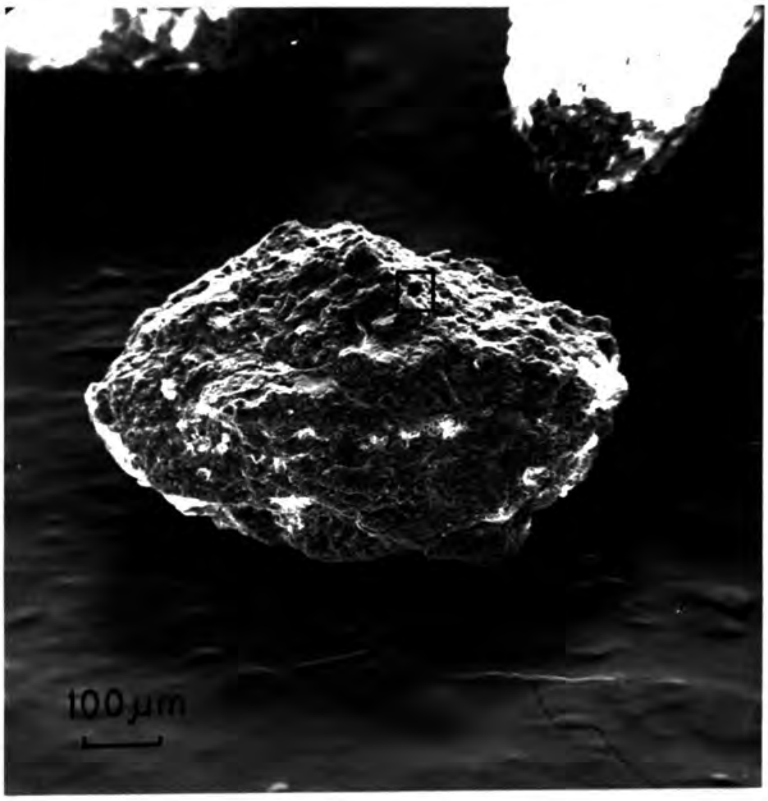
SEM 3

A. Red siltstone fragment from soil showing depression caused by loss of silt grain.

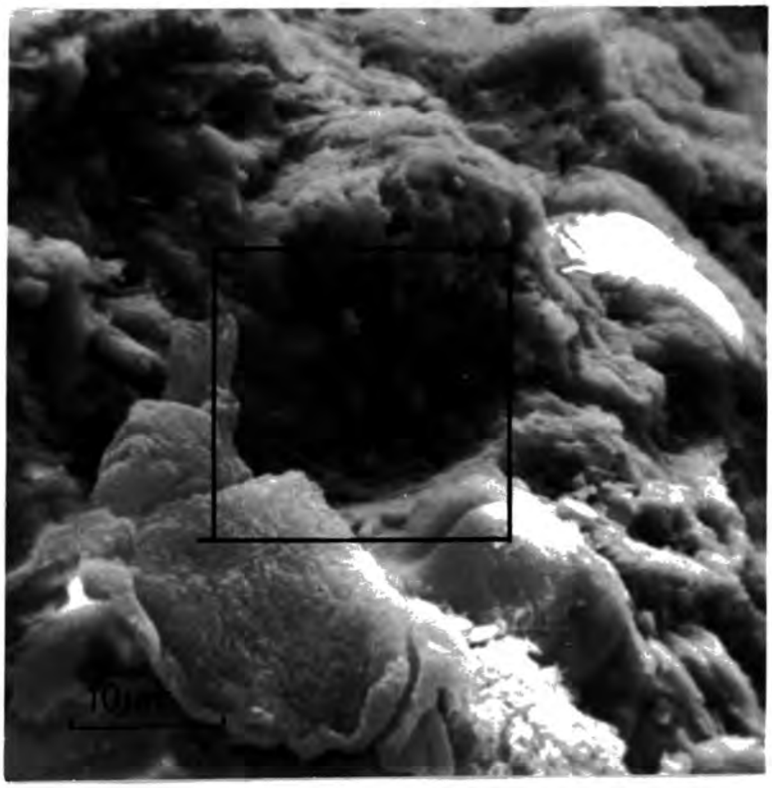


B. Note raised rim of hole indicating recent loss of silt grain. Size of depression corresponds to grain of coarse silt or fine sand size.

SEM 2

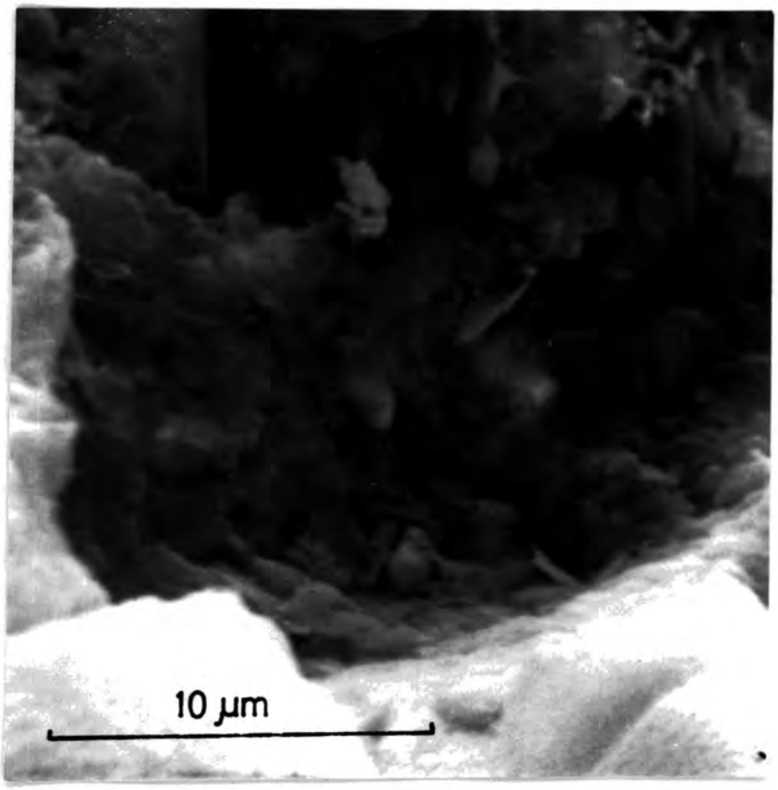


A. Well-rounded fragment of soil red siltstone with very clear socket caused by loss of silt grain.



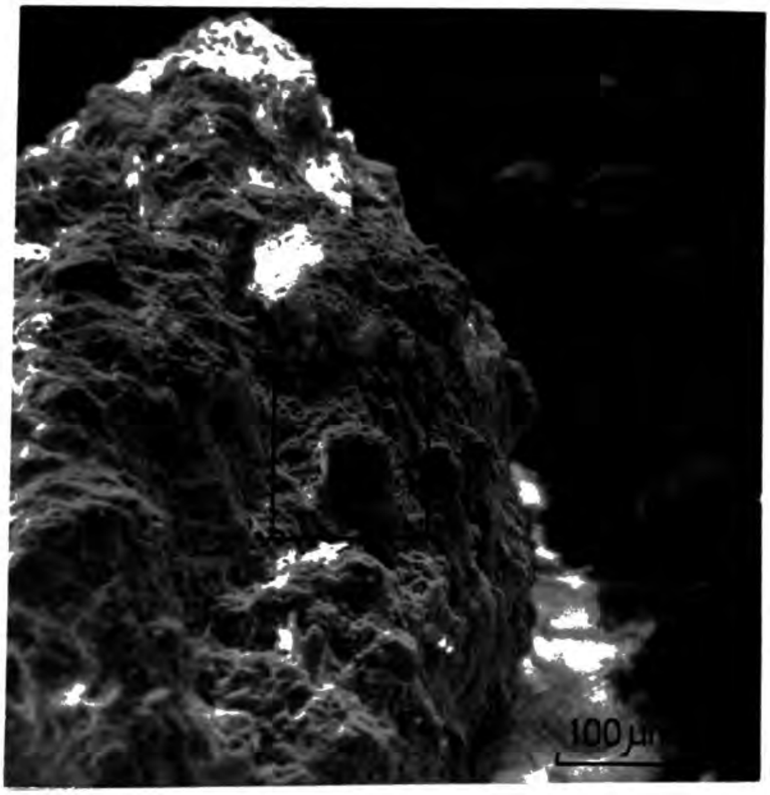
B. Deep concavity with sharp edges suggests recent formation. Material in foreground with curled-up edges interpreted as artefact.

SEM 2 (Continued)

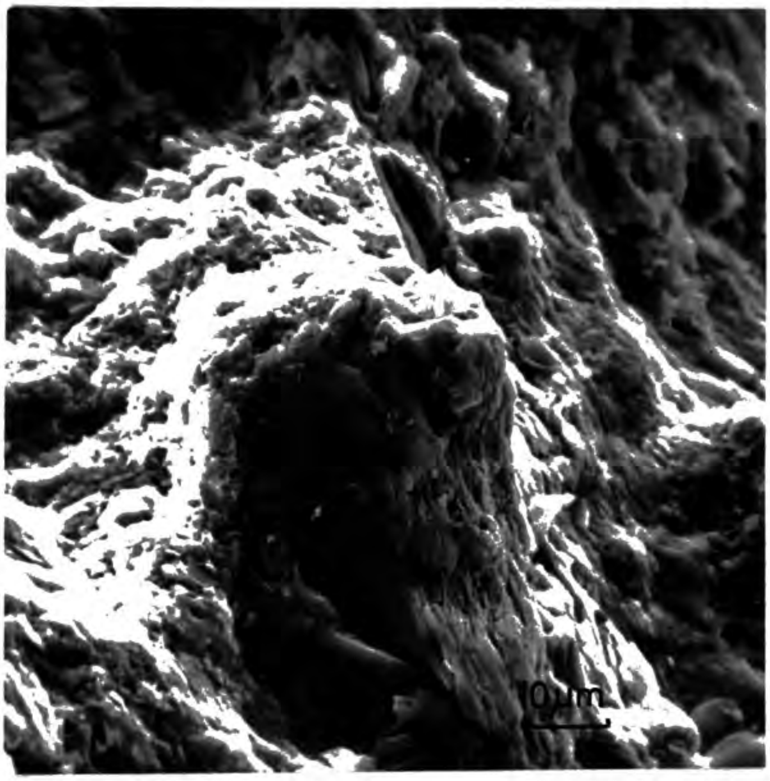


C. Detail of inner lining of hole showing the fineness of grain of the matrix material.

SEM 3



A. Very "granular" fragment of red siltstone from soil.

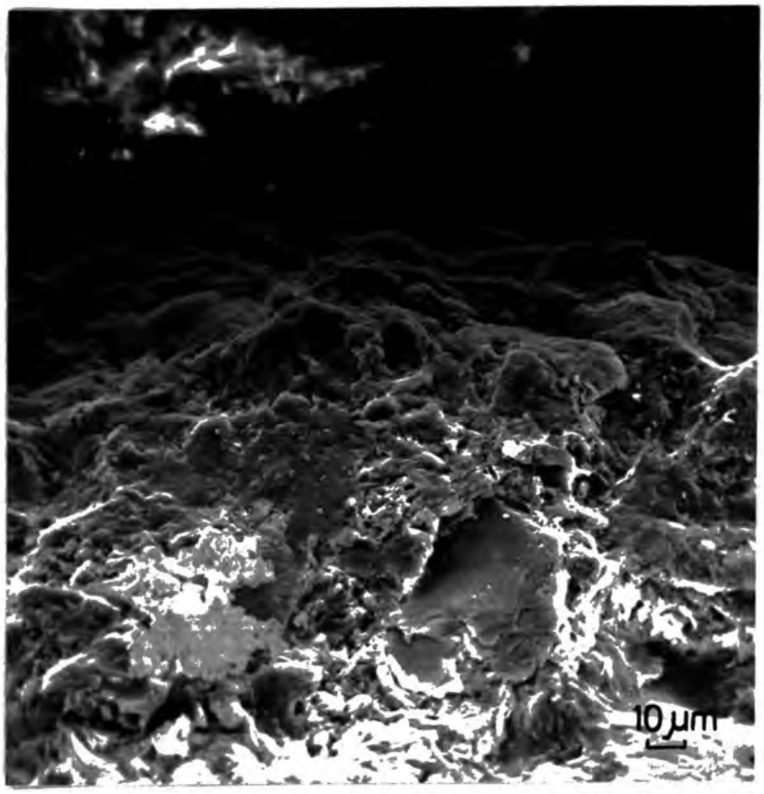


B. Silt-sized grain of mica, with cleavage planes normal to surface of rock fragments imparting greater mechanical strength. Matrix more susceptible to weathering than the mica grain.

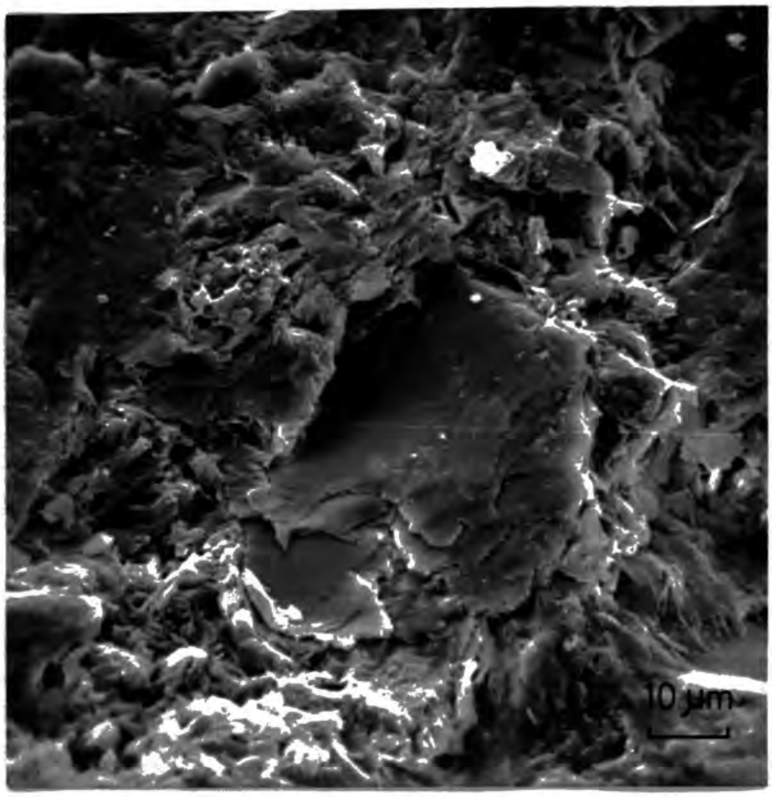
SEM 3 (Continued)

C. Detail of mica cleavage planes showing perhaps traces of matrix material still adhering.

SEM 3

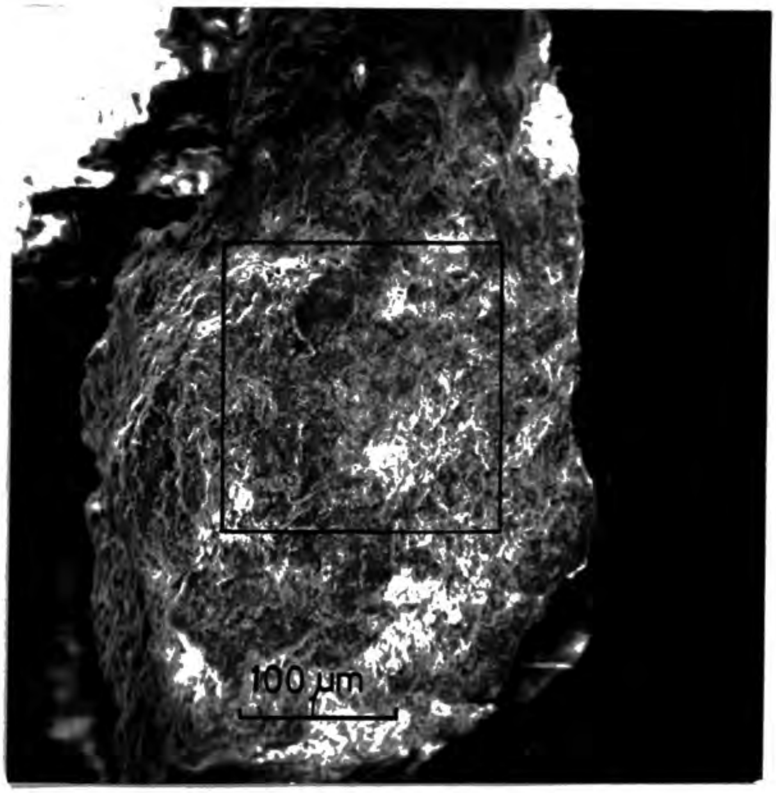


A. Mica silt grain with cleavage planes lying parallel to rock fragment surface.

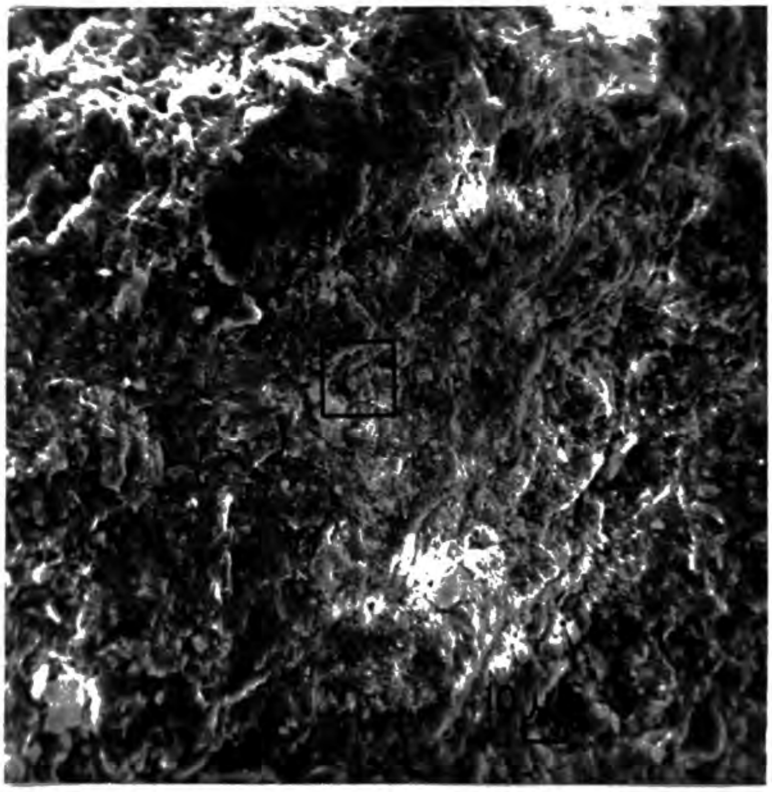


B. Disintegration of mica grain by flaking along cleavage planes appears to be more rapid than weathering of matrix, hence undercutting.

SEM 1



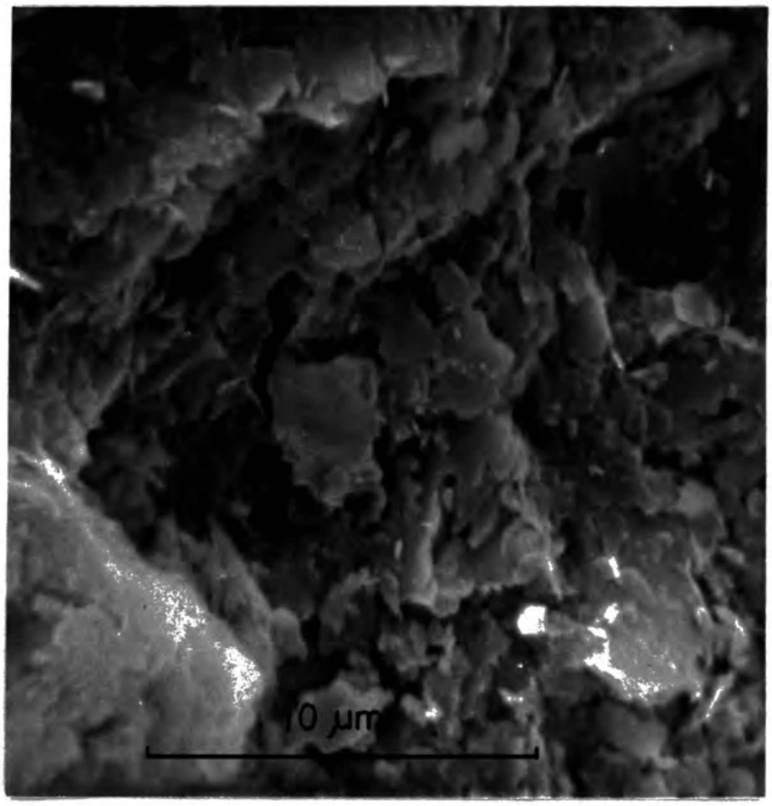
A. Fragment of crushed red siltstone. Angular with weak "granularity".



B. Component silt grains are indistinguishable in cleanly-fractured surfaces.

Plate 21

SEM 1 (Continued)



C. Detail of crushed red siltstone surface showing fine-grained matrix material - apparently flakes of clay minerals.

disappear.

The matrix material (equivalent to a cement in function) is very difficult to identify because of its fineness and diagenetic alteration. High magnifications (x 5,000) indicate the presence of small mica platelets (about 1μm to 2μm across) on the surface of both the crushed red siltstone (Plate 21C) and on the inside of a cavity from SEM 2 (Plate 18C). It is likely that these have been re-crystallised to some extent under geological compaction, if only at their edges. The effect is to trap the silt grains in a fine mesh. The finer grain and, hence, higher specific surface of the matrix means that it is more susceptible to chemical weathering, even though it may have a similar mineralogical composition to the grains.

Some re-crystallisation at the edges of the silt grains may also have occurred, especially along mica cleavages (Plate 19C), but it does not appear to be very strong. Some corrosion is also apparent on one face of a quartz silt grain (Plate 16B), although the other faces are very fresh.

6.7 DISCUSSION

6.7.1 Introduction

The polymodality of the plateau bedrock-derived soils is evident from the size distribution analyses. The first mode, due to mechanical breakage of the red siltstone (whether in the past by frost-shattering or currently by cultivation), is inferred from field observations to lie approximately in the size range 5-10 cms (-5·65 Ø to -6·65 Ø). The next mode falls entirely within the sand fraction and peaks consistently, if not always clearly, between 250µm and 125µm (+2·0 Ø to +3·0 Ø), and is seen (Fig 6s) to be composed dominantly of "foreign" quartz. An increase towards a third mode is detectable in most cases at the fine sand end, and by analogy with sand derived from sandstones (P63 - Fig 6h, P111 - Fig 6n), probably represents the silt residue from the weathering of the siltstones. A fourth mode is to be expected in the clay fraction developed from the disintegration and decomposition of the matrix material of the siltstones.

The origin of the quartz mode is almost certainly aeolian. It is present in uncultivated soils, hence eliminating an anthropogenic origin; it occurs in soils which from all the available evidence have not been contaminated by direct glaciation; it is ubiquitous in top-soils, but shows a rapid decline, if not extinction, below a depth of about 25 cms.

Detailed size distributions of loess in the soils of North Norfolk (Catt et al, 1971) revealed a large peak at approximately 40µm (+4·5 Ø) and a subsidiary peak in the sand fraction, which when deemed to be unequivocally of aeolian origin had a modal range from 500µm to 125µm (+1·0 Ø to +3·0 Ø) with a peak at 250µm (+2·0 Ø). The authors concluded that the silt was from a common source but that the same could not be said for the sand. However, this is hardly surprising. Silt, carried in suspension, can be far-travelled, well-mixed and spread uniformly, whereas sand moving by saltation is more localised and hence geographically more variable in its properties.

Franzmeier (1970) found that the aeolian sorting of proglacial material led to a break in the size scale over a range of 80µm to 40µm

(+3·64 Ø to +4·64 Ø) owing to differences in the mode of transport; between the two limits the two sediments were found to be more than 94% exclusive of each other.

While it is possible to have a wind-blown deposit consisting only of the material carried in suspension with no contribution from saltation (as has happened in the loess deposit at Pegwell Bay, Kent - Catt et al, 1971), the converse is very unlikely. Thus, if the study area has been affected by wind-blown material carried by saltation, then it has almost certainly been strongly affected by material carried in suspension, given the widespread distribution of glacial material in the region exposed over a long period of periglacial conditions (John, 1973). Consequently, it is very probable that a part, perhaps a considerable part, of the silt fraction of the soils in the study area is derived not so much from the weathering of the bedrock as from aeolian activity.

If the effects of the aeolian contamination are subtracted from the size distributions, the contents over the middle and fine sand ranges drop dramatically (P58 - Fig 6r, P75 - Fig 6s). The question is whether this rapid decline below a size of about 2mm (-1·0 Ø) is inherited from weathering processes in the past or whether it is a characteristic of on-going processes.

Of processes operating in the past, the most significant would have been mechanical weathering of rocks under periglacial freeze-thaw conditions. Frost-shattering of rocks has been shown, from experimental work (Tricart, 1956), to operate at three scales (Wiman, 1963), although Martini (1967) questions their independence, arguing that one type facilitates the activity of another.

(i) Block Macro-gelivation - resulting in large fragments, from the exploitation of cleavage, jointing, and bedding-planes.

(ii) Granular Macro-gelivation - resulting in mineral grains, by the attack of weathering on a weak cement.

(iii) Micro-gelivation - without an obvious dependence on structure or texture.

Field observations of the red siltstone rock fragments suggest that the first type of action was the most important in the study area - closeness of the jointing and micaceous bedding-planes restricting the maximum size to about 10cms. Fragments tended to be angular and elongated, sometimes flaggy. Similar dimensions are reported for the coarser congelifractates in the Palaeozoic shales of Central Wales (Young, 1972, p 241) and the screes of Cambrian shale in Merioneth, Wales (Ball, 1966).

Experimental work (Wiman, 1963; Potts, 1970) had borne out these observations. The bulk, by weight, of weathered products from materials with closely-spaced shatter planes, such as slate and shale, was found to be larger than 2mm (-1·0 Ø) and surprisingly little material was produced in the size fractions smaller than 500µm (+1.0 Ø). Owing to their structure, similar results are to be expected from the red siltstones of the study area.

Therefore, neither an aeolian origin nor a derivation from frost-shattering can be invoked for the formation of the clay fraction of the thin plateau soils. The former is substantiated by the close correspondence of the soil clay fraction to the clay minerals of the underlying rock (Figs 4c - 4e) even where contamination of the sand fraction has occurred. The reason is that there is a minimum size of about 15μm (+6·06 Ø) below which material is picked up by the wind with difficulty (Allen, 1970, p 104). The latter stems from the experimental work cited, but is also supported by the evidence of surface morphology of the rock fragments (section 6.6) which suggests that weathering by granular disaggregation is in progress - the grains contributing to the silt fraction, and the matrix producing the clay fraction. If this hypothesis is correct, then some important implications are posed for size distribution analysis of such "weathering systems".

6.7.2 Size Distribution of "Weathering Systems"

Size distributions of sediments are usually measured and presented (as they have been in this study) on logarithmic scales, because the mechanical laws of settling and crushing (mechanisms prevalent in sedimentology) are related geometrically to the grain diameter. The scale generally used is that of a logarithm to the base 2, formalised and defined as the Ø-scale by Krumbein (1938, 1964) :-

$\emptyset = -\log_2 d$ $\qquad$ d = diameter of grain in metric units

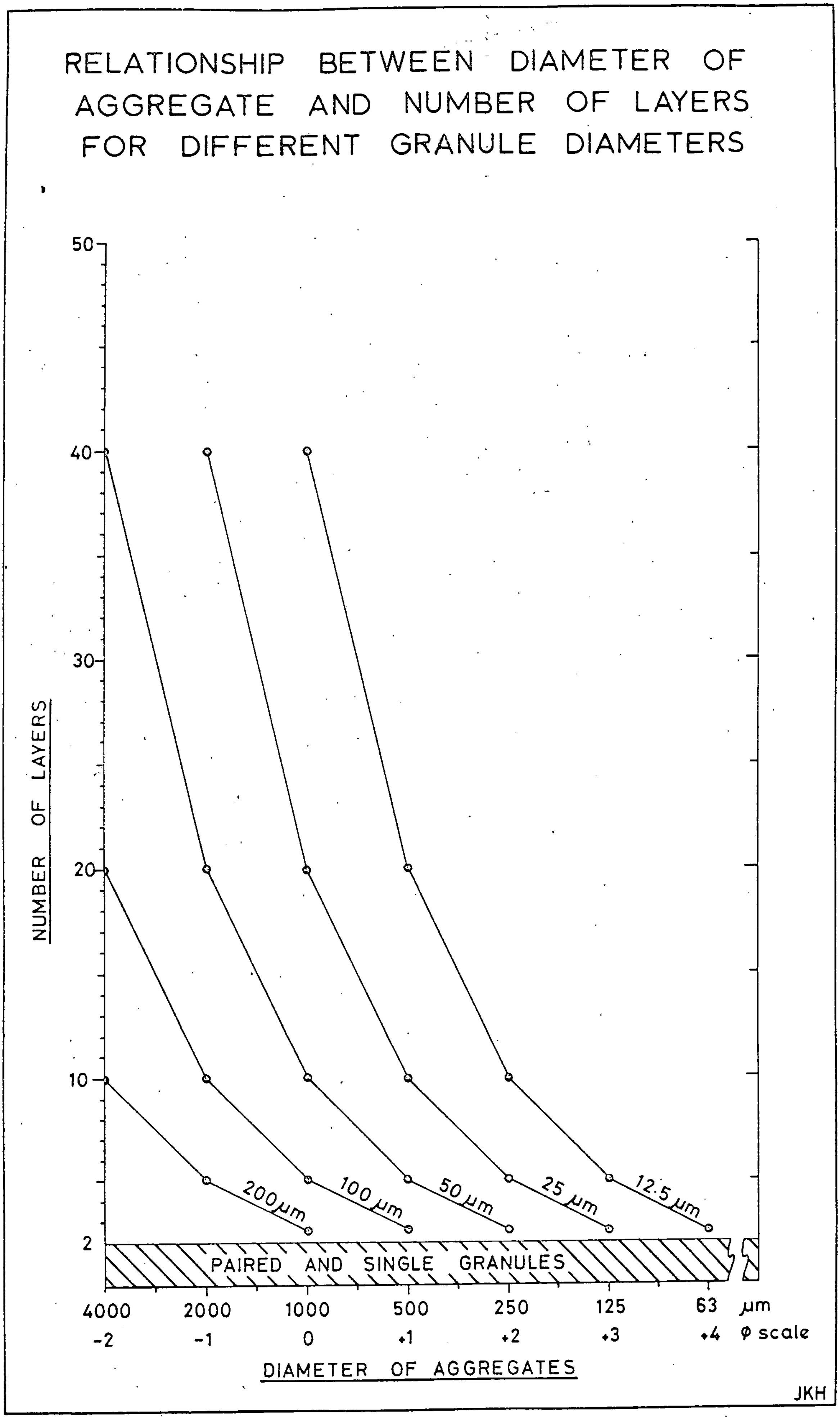
(For the sake of convenience, 1mm was taken as the reference size for Ø =0). As most of sedimentology is concerned with finer material, the negative sign was introduced to produce a positive Ø notation for the smaller sizes. Thus, +1·0 represents 0·5mm (500μm); +2·0 Ø represents 0·25mm (250μm); -1·0 Ø represents coarser material of 2mm (2,000μm); -2·0 Ø represents 4mm (4,000μm). Thus every Ø unit indicates a factor of 2 (doubling or halving) of grain diameter. (For a discussion of the advantages of the Ø-scale, see Tanner, 1969; Ø to mm transformations are given by Page, 1955, in Appendix 7.)

As granular disaggregation is a surface process and is, therefore, arithmetically related to the grain diameter, a rock fragment of 2mm diameter will take twice as long to disaggregate entirely than one of 1mm diameter under the same conditions.

This is best understood, and indeed quantified, by the concept of weathering by the removal of "layers" of granules (original detrital grains) from a multigranular aggregate (rock fragment) (see Horbaczewski, 1974 - Appendix 6). It is particularly useful in a discussion of weathering rates and the Ø-scale.

The absolute weathering rate can be defined as the time required to remove 'n' layers of granules from an aggregate. It is, in fact, independent of aggregate size, as the same amount of time is required to remove 'n' layers of granules from a small aggregate as from a larger one. However, on the Ø-scale, the effect of removing 'n' layers becomes progressively more drastic in terms of the reduction in size (and weight) of the aggregates (Fig 6t).

With a granule of 50μm in diameter, 20 layers need to be removed for an aggregate to cross the size range 4,000μm to 2,000μm (-2·0 Ø to -1·0 Ø); 10 layers to cross from 2,000μm to 1,000μm (-1·0 Ø to 0 Ø); and only five layers to cross from 1,000μm to 500μm (0 Ø to +1·0 Ø). This is generally understood intuitively as, Fig 6t


RELATIONSHIP BETWEEN DIAMETER OF AGGREGATE AND NUMBER OF LAYERS FOR DIFFERENT GRANULE DIAMETERS
NUMBER OF LAYERS
50
40
30
20
10
2
200 µm
100 µm
50 µm
25 µm
12.5 µm
PAIRED AND SINGLE GRANULES
4000
2000
1000
500
250
125
63
µm
-2
-1
0
+1
+2
+3
+4
φ scale
DIAMETER OF AGGREGATES
JKH

for example, in Bagnold's words (1941, p 7) :-

> "As rocks are degraded by the action of water and weather into smaller and smaller particles, fragments which are either soft, brittle or easily soluble pass rapidly down the scale of size. These have but a short life as sand grains, and do not contribute much material to the existing sand of the Earth's surface."

It would seem, therefore, that a more "natural" scale for use on material that is weathering by granular disaggregation (or any other surface process) would be based on arithmetic rather than geometric size intervals. If the Ø-scale is used, a bias is introduced against smaller rock fragments.

Given an initial log-normal distribution of aggregates, the effects of surface weathering would cause the mode to "migrate" to the coarser end of the distribution with the development, perhaps, of a positive skewness. In the absence of experimental verification, such an assertion is clearly speculative.

In this context, it is interesting to note the report (Carroll, 1952) of a negatively skewed distribution for the sand fraction of soils from sedimentary rocks (a generalisation from a study of fine-grained sandstones). On closer examination, however, it becomes apparent that the negative skewness was a feature of the size distribution of the original sand grains in the rock, and was not concerned with the size distribution of the rock fragments in the soil.

Similarly, the sand fractions of soils in the study area only register the terminal products of granular disaggregation if the original detrital grains are of sand size. Such examples are found at P63 (Fig 6h), P111 (Fig 6n), and perhaps P119 (Fig 6n). It is relevant to note that a calculation of the skewness of the sand fraction (2,000µm - 50µm) would be based on an incomplete size distribution (as many of Carroll's were) and would also tend to be negative, through the inclusion of the "rock fragments' tail" to the well-sorted log-normal distribution of the weathered residual sand grains.

When the size distribution of siltstones is considered, the terminal products of weathering fall beyond the fine sand limit effectively displacing the same relationship of rock fragments to component grains towards the finer grades. The sand fraction in such cases, therefore, exhibits the size distribution of rock fragments only, and even then it is grossly incomplete, omitting fragments greater than 2mm. The complete size distribution of such a "weathering system" would need to include at least three modes - that of the rock fragments, the silt detrital grains and the clay matrix material.

6.7.3 Towards an Absolute Weathering Rate

If the evidence is accepted for the formation of silt and clay fractions from the granular disintegration, under chemical weathering, of the red siltstone fragments, then it is possible to obtain a crude measure of the absolute weathering rate by the use of a weathering model (Horbaczewski, 1974 - Appendix 6).

The weight of silt and clay released on the removal of one layer of grains from the rock fragments of each sieve fraction is calculated using Table 1 (in Appendix 6). The total weight is then divided into the actual weight of silt and clay present in the soils and hence an estimate of the number of layers lost is derived. Minimum and maximum values result from a consideration of both extremes of sieve intervals - a minimum value related to the larger limit where the proportional effect is smaller, and a maximum corresponding to the lower size limit.

In order to apply the model to residual soils, the size distribution must apply solely to the rock and its weathering products - soils must be uncontaminated. Unfortunately, only one of the soil samples satisfy this condition - P58 (25-30cms) - (Fig 6r).

Furthermore, several assumptions need to be made:-

(i) As the original unweathered size distribution is unknown, the present-day distribution has to be used as a base for calculations. It is appreciated that considerable changes may have occurred in the finer sand-sized rock fragments by the very mode of weathering. Thus the result, in terms of numbers of layers, is likely to be an overestimate. Nevertheless, gross errors should not result, as high initial fine sand contents are not to be expected from frost-shattering (Wiman, 1963; Potts, 1970)

(ii) It is also a requirement of the model that there should be no weight loss due to true solution and removal by leaching; neither should there be any preferential movement of material by slope processes. In the first case some solution is bound to occur, and thus an underestimate is to be expected. Secondly, the selection of a sub-soil sample from a plateau location has minimised any possible particle size sorting.

Finally, some of the limitations of the model should be restated:-

(i) The Devonian siltstones were formed from material that had sedimented slowly from a relatively still suspension. Grains of silt, therefore, tended to be suspended in a finer matrix - the cement. Though the grains are fairly dense in concentration, they are not often contiguous, and cannot be said to be in a state of packing, whether open or close. Calculations based on such an assumption will result in a disparity between the predicted and actual number of "layers" lost, favouring an overestimate.

(ii) The silt grain size is taken as 40µm, which from microscopic examination of the rock fragments seems to be a reasonable figure. Where the grain size is smaller, it will serve to compensate, by underestimating, the previous deviation from a state of packing.

The results of the calculations (Table 6(i)) indicate that the removal of about 3·5 to four layers is sufficient to account for the formation of the silt and clay fractions. Bearing in mind the limitations listed above, this figure should be treated as an order of magnitude.

Nevertheless, the implications are far-reaching. The considerable amounts of silt and clay in the soil (approximately 65% by weight of the Fine Earth) can result from the loss of a relatively small number of layers from rock fragments in a significant (in terms of surface area) part of the size distribution. Furthermore, and more importantly, an absolute rate of weathering can be determined.

Assuming that the onset of granular disaggregation can be ascribed to the increase in chemical weathering with the post-Glacial climatic amelioration (about 10,000 years BP) the rate of weathering is approximately 3·5 to four layers per 10,000 years or about one layer per 2,500 to 3,000 years. This, it should be emphasised, is an order of magnitude for the weathering rate in the sub-soil at P58.

TABLE 6(i)

Calculation of Absolute Weathering Rate

SAMPLE P58 (25 - 30 cms)

	Weight (gms)	
	(i)	(ii)
Total Fine Earth (<2,000µm)	70·93	72·89
Sand Fraction (2,000µm - 50µm)	22·93	23·70
Silt and Clay (<50µm)	48·00	49·19

Sand Fraction Size (µm)	Original Weight (gms) (i)	Original Weight (gms) (ii)
2,000 - 1,200	6·51	6·83
1,200 - 600	3·81	3·90
600 - 420	1·08	1·10
420 - 300	1·11	1·15
300 - 250	0·71	0·74
250 - 210	0·51	0·52
210 - 150	1·39	1·40
150 - 105	1·40	1·48
105 - 75	1·76	1·80
75 - 63	1·81	1·98
63 - 53	2·84	2·80

Calculation : Original weight x fractional loss on removal of one layer (see Table 1 in Appendix 6)

Sand Fraction (µm)	Original Weight (gms) (i) Min	 (i) Max	 (ii) Min	 (ii) Max
2,000 - 1,200	0·72	1·17	0·75	1·20
1,200 - 600	0·70	1·30	0·72	1·33
600 - 420	0·38	0·51	0·38	0·52
420 - 300	0·52	0·67	0·54	0·69
300 - 250	0·43	0·49	0·45	0·51
250 - 210	0·35	0·40	0·36	0·41
210 - 150	1·08	1·25	1·09	1·26
150 - 105	1·26	1·40	1·33	1·48
105 - 75	1·76	1·76	1·80	1·80
75 - 63	1·81	1·81	1·98	1·98
63 - 53	2·84	2·84	2·80	2·80
	11·85	13·60	12·20	13·98

$$\text{No of Layers} = \frac{\text{Weight of Silt and Clay Fractions}}{\text{Original Weight x Fractional Loss}}$$

= 4·05 3·53 4·03 3·52

CHAPTER 7

ENVIRONMENTAL RECONSTRUCTION

> "The geologist's first task, after careful observation and description, should be to interpret his observations in terms of mechanisms. A number of such interpretations of related strata suggest larger-scale interpretations in terms of processes, and a final synthesis of all the observations and interpretations might suggest an interpretation in terms of environments . . . ."
>
> (Blatt, Middleton and Murray, 1972, p 33)

Insofar as this advice also applies to the pedologist, three environments of soil genesis in the study area should be considered:-

- (i) Glacial
- (ii) Periglacial
- (iii) Post-glacial.

Strictly speaking, the first two encompass the processes of "parent material" formation (Nikiforoff, 1949), while the third is concerned with soil genesis, but the arbitrariness of such a distinction will soon become apparent.

(i) Glacial Environment

Glacial deposits, both unsorted and water-sorted, occupy extensive tracts of the study area and in consequence have an important function as soil "parent materials". In general these surficial sediments are easily recognisable, but in some cases the glacial influence may be cryptic as a result of partial erosion. A reconstruction of the original environment of glaciation helps considerably in identifying such areas and is, therefore, of relevance in a study of soil genesis.

From their overall distribution and appearance, the tills in the study area appear to belong to one glaciation. There is no evidence, for example, of two glacial deposits clearly separated by a major stratigraphical break; on the other hand, neither is there any conclusive proof of a single glaciation. Indeed, from regional considerations (George, 1970) it is very possible that the Marloes peninsula was directly affected by both of the most recent glaciations - the Saalian (Riss, Wolstonian) and the Weichselian (Würm, Devensian).

In the absence of stratigraphical evidence, dating of the glacial material in the study area becomes problematical. It is generally acknowledged (George, 1970) that the earlier Saale Glaciation was more widespread than the Weichselian, and would therefore be more favoured as the source of the glacial deposits.

Yet their freshness, and association with meltwater sediments that are undisturbed, and their relationship with periglacial features suggests that they belong to the Weichselian Glaciation. If that were the case, then the preceding Eemian interglacial period must have witnessed extensive erosion that has left no trace of the older drift material (John, 1971). Such a hypothesis (John, 1971, 1972) has been supported by recent work (Garrard and Dobson, 1974; John, 1974).

Even if the Weichselian age is accepted, there still remains the problem of defining precisely the maximum limit of this advance. Bowen (1973a, b) places it against the cliffs along the northern coastline of the study area; John (1971) allows it to traverse the Marloes peninsula entirely and to reach Milford Haven; Garrard and Dobson (1974) depict it as encroaching over a narrow zone about 1km wide along the northern edge.

None of these postulated limits are very satisfactory. Bowen's hypothesis is incompatible with Weichselian deposits in the study area and has to be discarded if the latter dating is accepted. John's (1971) case is weakened by the apparent absence of glacial material over much of the southern part of the peninsula. Garrard and Dobson omit to include the Dale till sheet within their glacial limit.

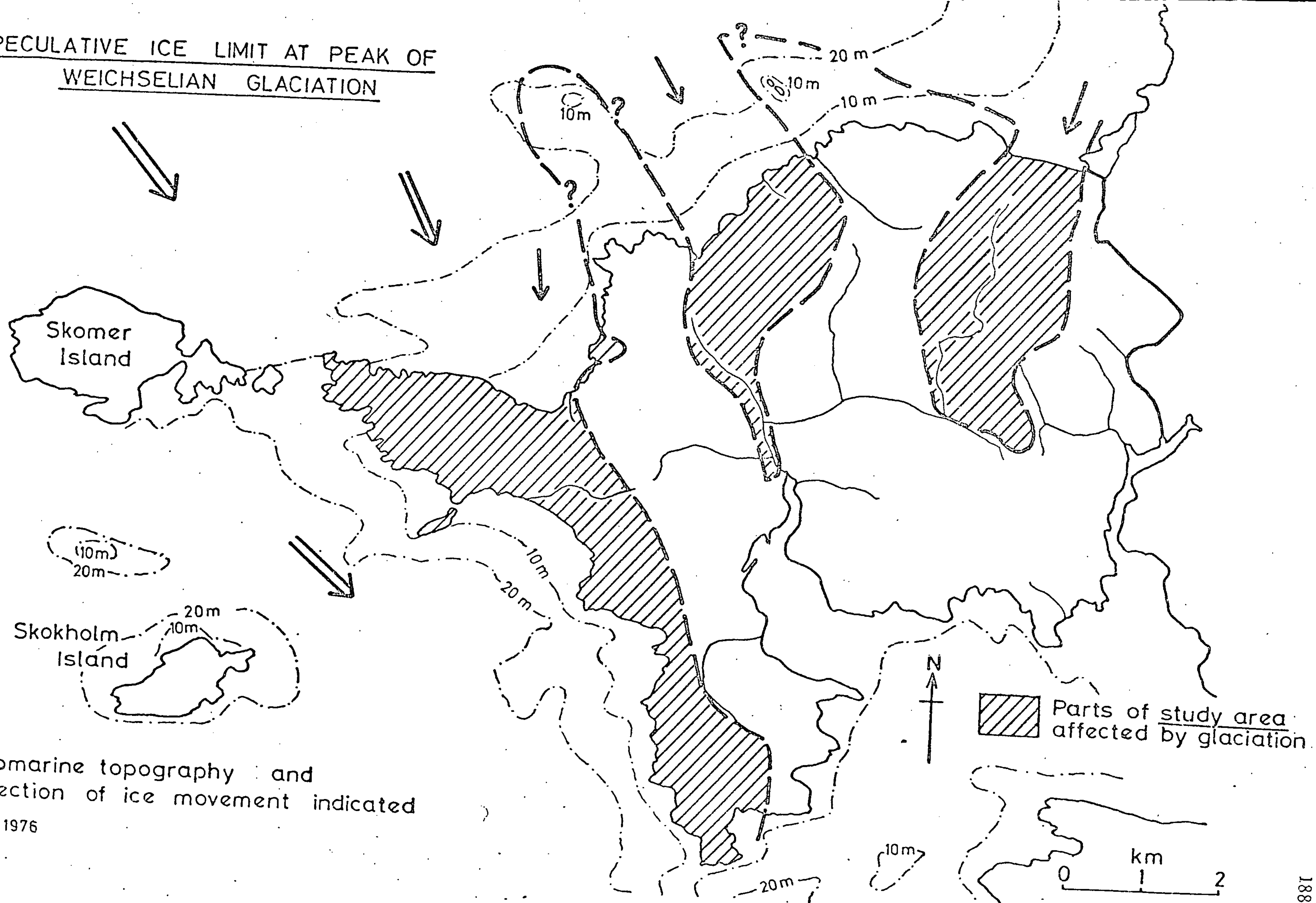
What still seems to be generally agreed is that the area was marginal during the last glaciation. The Irish Sea ice would have had little erosive power and little "energy" to climb onto the peninsula. This appears to be borne out by the thinness of the till sheets, evidence of ice-contact stratified deposits and the indications of temporary drainage impedance by "dead" ice. The tills at Dale, especially, reveal the action of water-sorting and may correspond to the upper part of the formation found in the Irish Sea basin and interpreted as a "melt-out" rather than "lodgement" till (Garrard and Dobson, 1974; see also Boulton, 1972).

It could also be argued that post-Glacial erosion has caused the reduction or even disappearance of some of the till cover. While it is indisputable that the study area was subjected to prolonged and intensive conditions favourable to such processes, there is little evidence of massive denudation. Inland valleys, such as the main east-west drainage line on the Marloes peninsula, do not betray the accumulation of much eroded material in their alluvial sediments, neither do the smaller channels draining till sheets. Quartz contents in the coarsest soil sand fraction - a possible indicator of residual glacial material - do not favour a hypothesis of large-scale erosion. Absolute quartz concentrations tend to be low even in soils close to areas affected by glaciation where they become high (section 5.4.5). Finally, there is no "residual" evidence of glaciation from larger erratics.

On balance, a hypothesis of partial glaciation of the study area seems most probable, thus agreeing broadly with Garrard and Dobson (1974). In detail, however, there are important differences. Glacial encroachment over the study area is thought to have taken the form of "tongues" along lines of least topographical resistance (see Figure 7a). This factor would have been particularly significant, bearing in mind the marginality of the area and the low energy of the ice. The sub-marine topography as well as the configuration of the present-day land-mass, and the prevailing direction of ice-movement from the north-west (modified locally by obstructions - Garrard and Dobson, 1974) have also to be taken into account.

The distribution of glacial deposits, both sorted and unsorted, conforms well to such an explanation. The maximum advance inland of the two "tongues" is defined by well-sorted glacial sediments taken as evidence of ice-contact or terminal melting. Thus the Gann valley is lined with a kame terrace (John, 1972) which is associated with till-like material around Pearson Farm at its northern end (see Pedogenetic Map - inside back cover). The easterly "tongue" abuts on the main east-west drainage line and there is good evidence of water-sorting of glacial material probably by melt-waters (section 6.2). It is in this

SPECULATIVE ICE LIMIT AT PEAK OF WEICHSELIAN GLACIATION



Submarine topography and direction of ice movement indicated

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locality that the accumulation of "dead" ice is suspected from the presence of a hump-backed channel (plate 3). That this was the very limit of glaciation is further suggested by the extreme thinness of the till sheets (section 3.5). South of the drainage line, thin red siltstone soils prevail, although a suspected till "outlier" at St Ishmael's village may represent a minor additional pulse, and anomalously high absolute quartz contents in the thin soils at Sandyhaven Farm (Fig 5g) may also be of glacial origin, although the exact connection is not clear.

To the west, the ice appears to have swept over the small peninsula of West Marloes (including also Skomer and Skokholm islands in its path, although these are not technically within the study area and have not been shaded in Figure 7a), and carried on southwards, shearing along the western edge of the Dale peninsula. A small pocket of impacted till is found on the coastline north of Marloes village, although its precise extent is uncertain. The greater part of the west Marloes peninsula is smeared with unsorted material, but there are also water-sorted glacial sediments occupying the small valley draining westwards into Marloes Sands (see P 15 - Plate 8), and these may be indicative of melting "stranded" ice in this locality. The relatively high level of these sediments (about 15m A OD) suggests some blocking of drainage to the south, possibly by an ice mass. Along the Dale peninsula, limited transgression of ice resulted in the deposition of a wedge of till with a thickness of several metres on the western cliff-line and a feather-edge a few hundred metres to the east.

(ii) Periglacial Environment

> "We cannot deny the role of ice in the shaping of the West Wales landscape, but we should recognise that periglacial, rather than glacial, processes have been operative for the greatest proportion of late Pleistocene time."
>
> (John, 1971, p 153)

As a consequence of the location of south-west Wales in the relatively warm oceanic approaches of Great Britain and because south-west Wales lies close to the southern limits of glaciation by the Irish Sea glacier, the periglacial period associated with this region is considered to have been prolonged in comparison with more northerly and inland areas. But it is also thought to have experienced relatively mild and humid conditions and, accordingly, should exhibit few features indicative of intense permafrost conditions (John, 1973).

Thus the induration of soils attributed to severe freeze-thaw action (Fitzpatrick, 1956), and reported from Cardiganshire (Stewart, 1961) and from the South Wales coalfield (Crampton, 1965) is missing in the study area. While considerable thicknesses of screes were forming in the uplands of northern and mid-Wales (Ball, 1966) and south Wales (Woodland and Evans, 1964) the plateau surfaces of the study area accumulated a frost-shattered regolith probably little thicker than its present thickness of 25-30cms. On the other hand, such differences may be attributed to terrain and moisture factors besides temperature.

Evidence of past freeze-thaw activity is present in the form of ice wedge casts reported from the kame terrace at Mullock Bridge (John, 1972), while features suggestive of cryoturbation have been encountered in coastal exposures near P94 at St Brides Haven. The occurrence of presumed pingo scars (still needing to be confirmed) in the study area (see section 2.4) indicates past permafrost conditions. As they appear to have formed diachronously with some overlapping, and as they are located in a low topographical position favouring moisture availability, it is likely that these represent "open-system" rather than "closed-system" pingos and as such are an indication of discontinuous permafrost (Washburn, 1973, pp 153-161; Flemal, 1976).

With relatively mild periglacial conditions, solifluction deposits are to be expected (John, 1973) and may be represented in the Head at West Dale Bay (Groom, 1956) which is attributed to the late Glacial period (Pollen Zone I to III, or earlier) (John, 1972). Soliflucted gravels on the flank of the kame terrace at Mullock Bridge may also be as late as Zone III in origin and may post-date or coincide with wind-blown silts (John, 1972). A fine example of soliflucted sediments, displaying a downslope orientation of shaly rock fragments is to be seen at P4 - Plate 7 - and will be returned to presently.

Evidence of a different kind and possibly indicating past periglacial conditions is found in the form of stone lines. Stone lines have been reported from many environments (Shaw, 1929; Parizek and Woodruff, 1957; Ruhe, 1959; Vogt, 1966; Curtis, 1975) and are subject to various interpretations (Wallace and Handy, 1961) : essentially those that have resulted from incorporation of coarse material at the base of a moving soil mass as in soil creep, or those that represent stone pavements buried by slope-wash. (In addition to geomorphological causes, a biological "sorting" action has been attributed to earthworms -

Webster, 1965.)

Ball (1967) interpreted stone lines in soils of Caernarvonshire, north Wales, as representing erosional stone pavements, developed in thaw periods with strong surface run-off and impeded drainage due to a frozen sub-soil, that were buried by periglacial and solifluction processes in the Late-Glacial period. The similarity of the soils in the study area to those described by Ball is close : the layer overlying the stone line is relatively fine in grain and remarkably stone-free - such a degree of sorting is unlikely to result from soil creep in these stony soils, but is to be expected from slope wash; moreover, the stone lines are found on sloping ground over both till and bedrock in locations with a potential up-slope source of fine material. They are absent on plateau surfaces. The lateral displacement of some of the stones from their source by as much as several metres militates against a biological agency, although it may contribute, in part, towards the formation of a stone line.

By far the most ubiquitous phenomenon that is probably indicative of past periglacial conditions, however, is the contamination of the soil sand fraction (and possibly also the silt fraction) by quartz. From its appearance it is clearly not derived from any of the rocks in the study area, and its size distribution suggests an aeolian origin.

Aeolian activity in a periglacial environment is almost inevitable, especially where broad outwash plains and exposed glacial deposits can act as sources (Washburn, 1973, p 228). With a sea-level reduced by as much as 100 metres below that at present (Donn et al, 1962) there would have been extensive tracts of glacial debris around the study area. Indeed, it is probable that much wind-blown material collected at the base of the cliffs only to be reworked later by the high-energy surf zone of the advancing Flandrian Sea. Relatively little was carried up onto the plateau surface, but it is the only record which has remained since the return of the sea.

A particularly interesting soil profile, indicating the possible sequence of events, is to be found near the coast north of Marloes village (P4 - Plate 7). The lowermost stony horizon, interpreted as a solifluction deposit, is overlain by a stone-free horizon of much finer material. Quartz contamination of the sand fraction is present in this upper layer but dies out at a depth of about 40 cms - the top of the stony horizon (see Table 5(i)). It is therefore suggested that in this case solifluction pre-dated the deposition of the finer material - possibly a slope wash deposit - which may itself have post-dated or coincided with an aeolian phase. Such a late dating is also supported by the findings at Mullock Bridge (John, 1972) where a thin loamy sand horizon, interpreted as an aeolian deposit, occurs near the top of a stratigraphical section and is ascribed to the late-Glacial.

Evidence for late-Glacial aeolian activity is also available on regional and national levels, although references are widely scattered (Washburn, 1973, pp 227-231). Loess-like deposits have been reported from sites along the Welsh coasts (George, 1932; Watson and Watson, 1967), though inland they are expressed in the form of a cryptic contamination of soils, as in Glamorgan (Crampton, 1961). Similar aeolian activity affected other parts of Britain (Perrin, 1956; Findlay, 1965; Clayden, 1971; Curtis, 1974).

One overriding problem of environmental reconstructions based on wind-blown deposits is that silt can be carried far from its original source and therefore its presence at a particular locality is not necessarily an indication of past periglacial conditions (Washburn, 1973, p 228). In contrast to the silt carried in suspension, sand is transported by the mechanism of saltation which does not allow for any great distance to be covered (see Franzmeier, 1970). Thus sand dunes are considered to be better environmental indicators than silt loess (Washburn, 1973, p 228). The "sand mode" of the contaminant in the soils of the study area is an indication of a close source and, if related to the "loamy sand" of Mullock Bridge, appears to be a product of the last periglacial episodes.

(iii) Post-Glacial Environment

The development of soils is closely related to changes in climate and vegetation. In general terms there is a sequence of phases during the temperate interglacial stage following a glaciation (West, 1970):-

(i) Climatic amelioration.

(ii) Expansion of a light-demanding flora.

(iii) Soil improvement to mull condition and expansion of shade-giving forest genera.

(iv) Soil deterioration to mor condition and/or expansion of late-arriving genera.

(v) Climatic deterioration, restriction of thermophilous genera, expansion of heathland.

The last phase leads into periglacial conditions and eventually to full glaciation. It should be noted that in the study area this simple procession of environmental changes would have been modified by the exposure of the peninsula to the open Atlantic ocean as well as by its proximity to a moderating marine influence (Edlin, 1960).

The climatic amelioration following the last Weichselian (Riss, Würm, Devensian) glaciation was marked by a rise in temperature at the Pollen Zone III/IV boundary. In coastal areas, as for example at Clarach near Aberystwyth, Wales, palynological and radiocarbon dating evidence has shown this to have been a very rapid increase (Taylor, 1973, p 311). The resultant vigorous organic activity set off pedogenetic processes, and thus the time-zero for soil formation in the strict biological sense can be considered to be the end of Zone III (Smith and Taylor, 1969).

Though a general picture of the evolution of the post-Glacial environment has been provided by the research following Godwin's (1956) pioneering work (for example, Pennington, 1969; Walker and West, 1970; Taylor, 1973), a detailed reconstruction for the study area is still not possible.

It is very likely that with the return of sea-level to approximately that of the present day, a flora would have become quickly established under the moderate coastal climate. The inherently fertile red siltstone regolith would have tended towards the formation of a brown earth soil - probably similar to the brown forest soil of "pH 6·0 or thereabouts" envisaged by Taylor (1960) for the Cardigan Bay coastal zone. This early Boreal (Zone V) development is succeeded by a change to warmer but wetter conditions which led to the formation of podzols and peaty soil in upland areas (over 300 metres) of Wales (Smith and Taylor, 1969; Crampton, 1968). However, soil evolution in the study area was probably little affected owing to the combination of a moderated climate and high natural soil fertility, and probably only tended towards a further gradual reduction in pH under the action of chemical weathering and leaching.

A decline in woodland in the Welsh uplands is reported at the end of the Atlantic climatic optimum (Zone VIIa) (Taylor, 1973), leading to an expansion of moorland and additional soil changes (Smith and Taylor, 1969). Also, at about this time the activity of Neolithic man is suspected in the vegetation changes at some localities (Smith, 1970).

In the study area, the soil was probably brought into cultivation at an early stage - certainly in the Bronze Age, if not earlier (Grimes, 1973). Clearance of the scrub or open woodland that constituted the natural "climax" vegetation probably led to the degradation of soils from brown earths to rankers. Since then the land has remained under continuous cultivation and although many of the soils resemble rankers, their chemical and physical properties are altered to suit agricultural requirements.

CHAPTER 8

CONCLUSIONS

(i) Soil genesis started in the study area at the beginning of the post-Glacial period (Pollen Zone III), i.e., 10,000 years BP. The factor of vegetation, important initially, has been replaced by Man.

(ii) The type of soil is strongly governed by its "parent material". Thinness and patchiness of surficial glacial deposits in the study area sometimes makes delineation of parent material classes difficult. Empirical criteria, based on the lithological composition of the coarsest sand fraction (2,000 µm - 1,200 µm) have been derived to define soils developed from bedrock and the degreee of contamination. "Absolute" rather than "relative" lithological contents were found to be more useful in this genetic study.

(iii) Another form of contamination has been discovered in top-soils by detailed size distribution analysis of the sand fraction; it appears to be ubiquitous and is ascribed to aeolian activity occurring principally under periglacial conditions of the late-Glacial.

(iv) Periglacial conditions were also responsible for the formation of a frost-shattered regolith on the plateau surfaces to a depth of about 25-30cms. Freeze-thaw activity ceased entirely in the study area with the return to the present sea-level and the consequent climatic moderation.

(v) Weathering of the rocks has therefore proceeded by chemical weathering. Other physical processes of weathering - wetting-drying, haloclasty and thermoclasty - have not been operative in the soil environment.

(vi) Chemical weathering has proceeded by attacking the intergranular matrix (cement) of the red siltstones, thereby releasing the "primary" detrital particles of silt and clay.

(vii) From theoretical considerations of the amounts of silt and clay produced an absolute rate of weathering can be estimated.

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(i) Soil Texture Analysis (Bouyoucos Determination)

Most of the top-soils and some of the sub-soils of profiles P1 to P56 were analysed for texture (sand, silt and clay content). Samples were split and all analyses were conducted on duplicate sub-samples, as indicated in Fig A, in order to monitor experimental precision. Where a difference in results greater than 2% was recorded, the analysis was repeated.

Size limits for the fractions were taken as (Avery, 1973):-

Sand	:	2,000 µm - 60 µm
Silt	:	60 µm - 2 µm
Clay	:	< 2 µm.

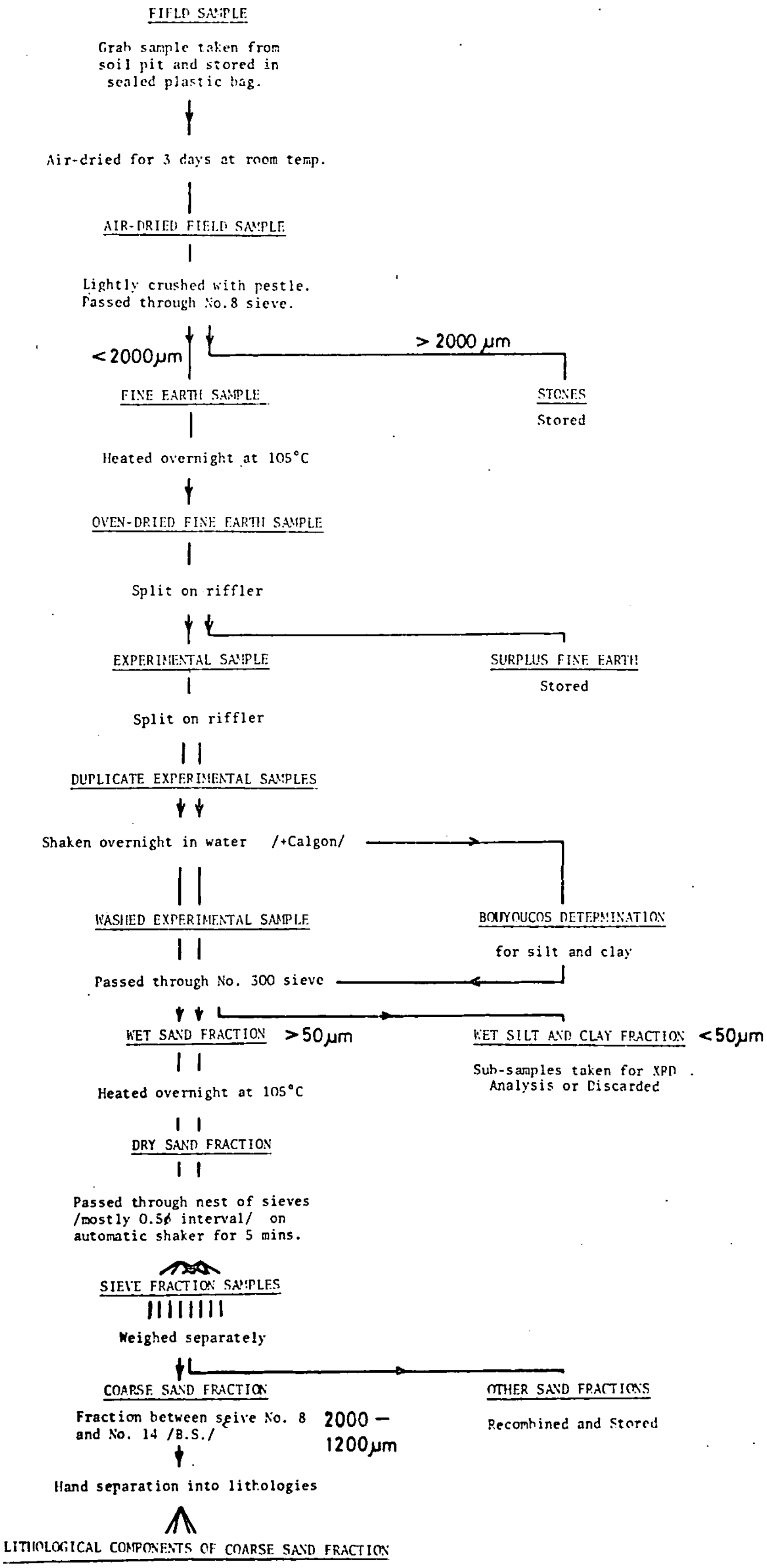
The method for obtaining the clay content was essentially that of Bouyoucos (1951). 50 gms of oven-dried Fine Earth (fraction less than 2,000 µm or 2mm) was dispersed in water after treatment with 5 cm^3 of N sodium hexametaphosphate (Calgon) and agitation in an end-over-end shaker overnight. The density of the suspension after two hours of settling was determined with the Bouyoucos hydrometer and the appropriate calculations made, allowing for temperature corrections, to obtain the clay content.

With most of the soil samples an initial weight of 50 gms ensured a concentration of about 25 to 35 gms of silt and clay per litre - concentrations at which the hydrometer method has been shown to be more efficient than the pipette method of analysis (Sternberg and Creager, 1961; see also Kaddah, 1974).

The sand content was determined by passing the suspension through

Fig A

FLOW SHEET OF EXPERIMENTAL PROCEDURE FOR SAND FRACTION ANALYSIS



JKH

a 60 μm sieve (British Standards sieve No 240 - 63 μm aperture). The retained sand fraction was dried, weighed, and the percentage by weight of the original oven-dried Fine Earth obtained.

The silt content was derived simply by subtraction of sand and clay percentages from the total of 100%.

Some analyses of fine gravel content (6,000 μm to 2,000 μm - 6mm to 2mm) were also carried out for some samples. Instead of obtaining an initial Fine Earth sample (<2,000 μm), the raw soil samples were passed through a coarser (6,000 μm) sieve. After the standard Bouyoucos determination, a 2,000 μm sieve was used to separate the fine gravel from the sand fraction. In the calculations the base for percentages was taken as the material under 2,000 μm and the fine gravel content was related to this "Fine Earth" base and thus could, theoretically, exceed 100%.

(ii) Sand Fraction Analysis

The sand fraction was analysed by the procedure outlined in Figure A and described in section 6.4.2. Sieves based on British Standards scales (1967) have been used throughout.

(iii) Moisture Content (M C)

10gms of air-dried "Fine Earth" were placed in a weighed nickel crucible and heated overnight at a temperature of 105 °C. The percentage moisture by weight lost by the oven-dried soil was calculated as a percentage of the air-dry soil.

(iv) Loss on Ignition (L OI)

The oven-dried sample from the moisture content determination was then placed in a furnace at a temperature of 800°C for 30 minutes. The resultant loss in weight was calculated as a percentage of the oven-dry soil.

NB: Loss on ignition is a crude method of estimating the content of organic matter, as there may also be loss of structural water from clay minerals at this temperature. It is, however, a much more rapid method than that of Walkley and Black (1934) for organic carbon (some results from this latter method are included in Horbaczewski, 1975 - Appendix 3). (For M C and L OI calculation, see Bascomb, 1974, p 14.)

(v) pH

pH, measured on a direct reading pH meter, was obtained for most of the soil samples. Readings were taken on a slurry of undried soil mixed with distilled water. Frequent checks with buffer solutions checked against instrument "drift". Results were expressed to one decimal place.

(vi) X-ray Diffraction Analysis

X-ray diffraction analysis was used to determine the broad mineralogy of soil samples. Sub-samples of the "Fine Earth" were ground up to a fine powder in a mortar and packed - untreated - into cavity mounts. They were scanned with Cu K α radiations from 2° 2θ

to 40° 2θ at a speed of 2° 2θ/minute. Peaks were converted to "d" (lattice) spacings using standard tables (Parrish and Mack, 1963) and were interpreted using ASTM mineralogical identification cards.

Used in this manner, the method is very crude and does not distinguish the detailed structure of the clay minerals, which requires the use of refined, orientated slide samples and numerous treatments (see Brown, 1961).

Texture Analysis of Top-Soils (0-22 cms)

All samples taken from a depth of 5-15 cms

Sand = 2,000 µm to 50 µm
Silt = 50 µm to 2 µm
Clay = < 2 µm

Sample	% Sand	% Silt	% Clay
P 2	42·9		29·4
P 3	32·7		29·4
P 8	28·8		28·0
P12	29·7		31·8
P13	20·2		42·5
P14	18·5		31·4
P15	58·1		18·3
P20	35·8		28·8
P22	33·0		36·4
P24	34·0		37·7
P25	38·4		29·9
P26	34·5		36·8
P28	40·2		35·0
P29	27·6		30·5
P30	44·2		24·4
P31	40·4		27·4
P32	40·6		30·4
P33	38·4		32·5
P34	38·8		32·7
P35	37·6		29·2
P36	37·4		39·8
P37	30·1		32·4
P38	34·2		31·6
P39	36·1		31·7
P40	37·0		30·0

Sample	% Sand	% Silt	% Clay
P41	32·8		30·1
P42	34·2		30·4
P43	30·8		35·1
P44	30·4		26·4
P45	37·0		29·6
P46	31·2		34·0
P47	42·1		24·4
P48	30·1		30·8
P51	32·4		24·5
P52	37·2		25·7
P53	41·2		20·4
P55	34·2		29·6
P56	30·9		26·6
P64	39·2		25·0

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ALUMINIUM AND MANGANESE TOXICITY TO BARLEY IN AN ACID SOIL

J. HORBACZEWSKI

Summary

A detailed study of a field with two soil types was made in order to find the cause of partial barley failure in summer 1973. Toxic amounts of plant-available aluminium and manganese were encountered in the soil with a poor barley stand, but were much reduced in the soil bearing a healthy crop. Differences between moisture regimes for the two soils are large and may have been critical in early growth stages of the plant. Liming was recommended to decrease the acidity of the poor soil and so reduce the pH-dependent, plant-available aluminium and manganese levels. Following this treatment there was an improvement in the succeeding year's barley (summer 1974).

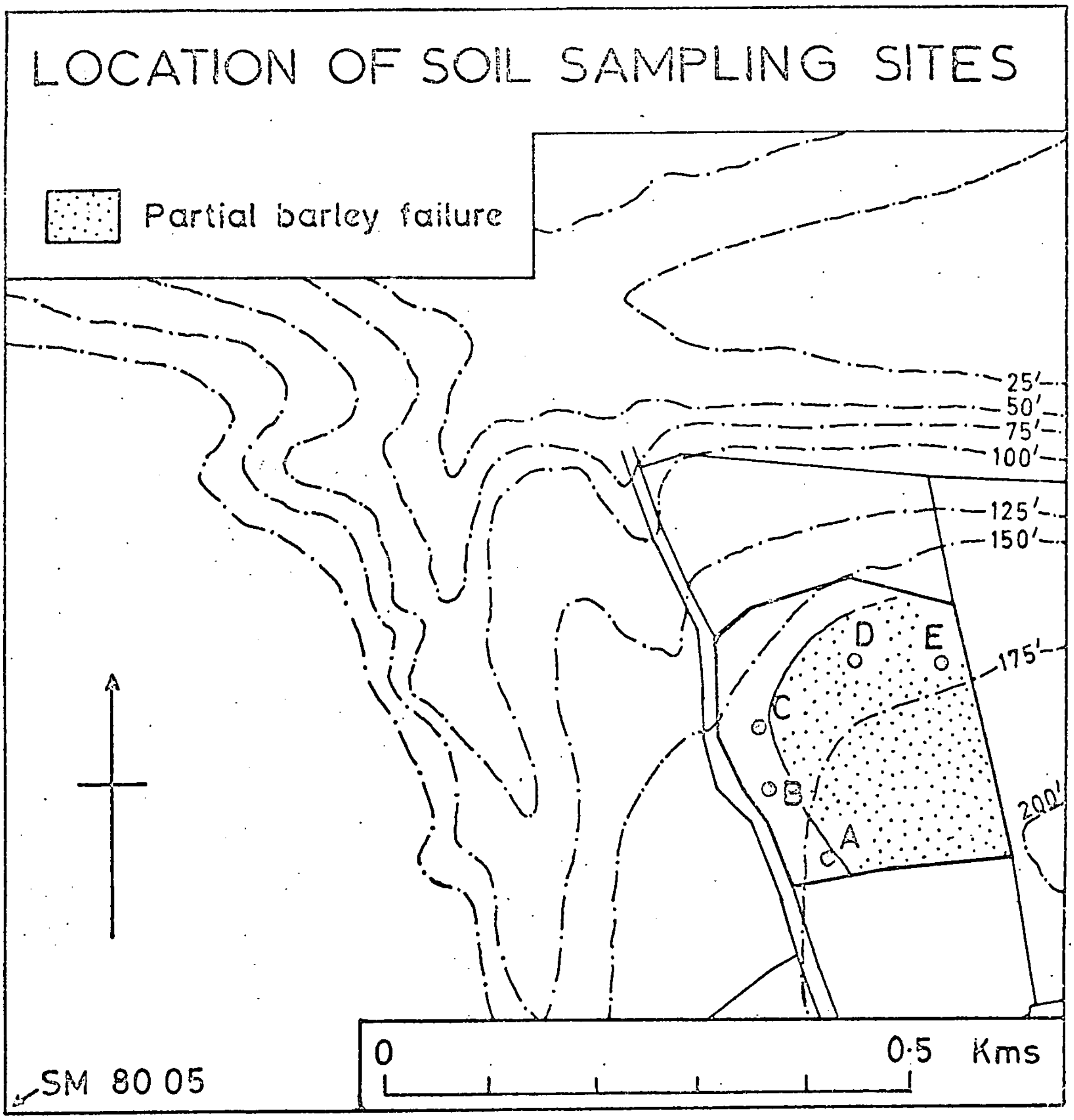
Introduction

This study was undertaken on Broomhill Farm in my research study area in South-west Dyfed (formerly Pembrokeshire). One of the fields, which had been enlarged through scrub removal several years previously, suffered partial barley failure. The objective was to determine the main detrimental cause and to suggest a remedy.

Barley performance was judged in the field (in September 1973) from the density and appearance of the stubble remaining after the harvest, and from the farmer's account. Partial failure (sparse and weak stubble) was confined to the higher ground on the eastern side of the field, while the lower reclaimed land had a good stand.

An inspection of five soil pits (see map) revealed that there were two different soils, strongly controlled by topography, in the one field. The first, with the generally poor barley stand (sites D and E), was a shallow stony soil developed on Devonian red siltstones. The reclaimed soil (sites A, B and C), on the other hand, was much deeper with fewer stones, higher organic matter and a better tilth. Grain-size distribution and composition analyses of the sand fraction indicate that the latter occupies an old stream channel with the water-sorted sediments probably derived from a till sheet several hundred yards to the south. Site A shows some characteristics transitional between the two soils both in genesis and crop performance.

Although there is no surface drainage at present there is evidence that the channel is still active in transmitting subsurface water. Aerial photographs (RAF 1959) reveal a darker tone, suggesting higher moisture contents, in the western half of the field although this may be partly caused by the higher organic matter levels. Abundant manganese staining in the lower horizons of the channel soil points to variable oxidation-reduction conditions usually caused by a fluctuating water-table. There are no signs of gleying but this is not unusual with these red soils. The iron, present as hematite, is particularly resistant to reduction and any gleying present is often masked by the strong red colouration. It may be that only recently has the water-table dropped sufficiently for the land to be suitable for reclamation. At the time of the survey in September 1973 there was no evidence of a water-table in any of the pits.



Brief field descriptions of the soil profiles were made and are included, in part, here. For the pruposes of this study only the samples taken from the plough layer, at a depth of 5-15 cm., have been used.

Results and Discussion

The initial pH determinations (Table 1) showed a considerable variation between the five soil samples, the extremes at pH 4.8 and pH 6.0 being associated with very poor and very good barley stands, respectively. Critical values for barley are quoted as pH 5.8 (Davies, Eagle and Finney, p.43) and pH 5.9 (M.A.F.F. p.16) but these are only rough guides as they are dependent on other soil properties.

Comparison of Selected Soil Properties

	A	B	C	D	E
Altitude (feet)	180±5	165±5	160±5	165±5	170±5
Drainage Regime	Freely dr. Transmitting Site	Imperfectly dr. Receiving Site	Imperfectly dr. Receiving Site	Freely dr. Transmitting Site	Freely dr. Shedding Site
Soil Depth to Bedrock (cms.	50+	38	55+	20	22
Minimum Depth of Manganese staining (cms)	-	38	34	-	-
Frequency + Nature of Stones in Top-soil	Abundant varied	Frequent varied	Few varied	Abundant Red siltstone	Abundant Red siltstone
Organic Matter in Top-soil (visual estimate)	Moderate	High	High	Moderate	Moderate

Soil acidity can affect crop yields in several ways, although the high hydrogen-ion concentration is itself only destructive at exceptionally low pH values. More important is the effect on the solubility, and hence availability to plants, of some metals. Concentration may become deficient or toxic. Early work (Hartwell and Pember 1918, Burgess and Pember 1923) showed that aluminium was released in toxic amounts in acid soils. Excessive manganese can also become available under these conditions but there is little or no correlation between these two metals (Hoyt and Nyborg 1972). For this reason tests have been carried out for both aluminium and manganese.

There are many extraction procedures which attempt to determine the amounts of the metals available to the plants. A discussion of these is not relevant here and the reader is referred to some excellent papers on the subject:- Leeper 1947, Sherman and Harmer 1943, Boken 1958, Hoyt and Nyborg 1971a, b, 1972.

All the determinations on manganese and aluminium display trends consistent with crop performance and pH (Table 1). Values for total manganese show wide differences which are more likely due to parent material variability than soil conditions. The Benzidine Test allowed for a clear and rapid visual estimate of the concentration of manganese forms readily available to plants (so-called "active manganese") but the limitations in its use should be noted (see Appendix). The results for plant-available aluminium and manganese follow the same trend but show much wider variation in the aluminium levels. They are discussed in more detail below (Table 3).

The physical tests in Table 1 demonstrate the expected contrast in field moisture contents, which are a reflection of the topo-drainage régime. The standard (inherent) moisture contents, however, do not differ appreciably, suggesting that the water-holding capacity is the same for the plough-layer of the two soils. Organic matter levels, as determined by the Walkley and Black (1934) method agree fairly well with the field evidence which clearly points to higher contents in the lower-lying reclaimed soils.

In order to determine concentrations of metals toxic or deficient to plants and for the sake of comparability, nutrient culture solutions have often been used. Published results from some studies are presented in Table 2. Differences between workers occur and more significantly between barley varieties in their susceptibility to aluminium, upper limits of toxic concentrations ranging from 1 to 4 ppm. Values above this are definitely harmful. Plant-available aluminium levels obtained in this study compare well, with good barley stands at 1.05 ppm and poor ones at 6.45 ppm. Very little data was found for critical manganese concentrations in nutrient culture solutions although Williams and Vlamis (1957) report maximum values for barley of 0.5 to 5.0 ppm., depending on the time of year (length of day and temperature).

As the extraction technique of Hoyt and Nyborg (1972) was used for plant-available aluminium and manganese determinations, it is possible to compare directly the results of this work with theirs (Table 3).

Manganese values show a definite trend with increasing pH in the Pembrokeshire soils but are more erratic in the Canadian ones. The relatively high manganese

TABLE 1 - LABORATORY RESULTS (expressed on weight of fresh soil basis)

SITE	A	B	C	D	E
Barley Stand	Good	V.Good	V.Good	Poor	V. Poor
pH	5.2	5.3	6.0	4.9	4.8
Active Mn Benzidine Test (Frequency of Blue Specks)	Abundant	Rare	Occasional	V. frequent	Abundant
Total Mn (ppm)	1000	250	750	1188	1560
Plant-Available Al (ppm)	1.05	0.25	<0.15	6.45	12.00
Plant-Available Mn (ppm)	0.35	0.10	0.05	3.85	8.40
Field Moisture Content % (Air-Dry)	15.45	22.85	26.95	8.30	9.80
Moisture Content % (Oven-Dry)	1.40	1.40	1.60	1.65	1.70
Carbon % (Walkley & Black)	2.30	7.3	>7.9	4.6	4.5

concentrations associated with good barley stands for the Canadian soils would suggest that this is not a limiting factor in the Pembroke crop. Differences in soils, climate and barley varieties will affect a detailed comparison, particularly in the absence of supporting data, but the order of magnitude is apparent - contents up to about 10 ppm. of plant-available manganese not being toxic to the Canadian barley.

Surprisingly similar results are obtained from a comparison of barley performance with pH and aluminium values. For both studies (Hoyt and Nyborg, and myself) the critical values for barley failure appear to be at pH 5.0 and plant-available aluminium concentrations of about 3 ppm.

Good performances are achieved above a pH of about 5.1 and an aluminium content of less than about 1.5 ppm, provided these are the only limiting factors.

TABLE 2 - PUBLISHED RESULTS FOR METAL TOXICITY TO BARLEY IN NUTRIENT CULTURE SOLUTIONS

Reference		Solution pH	Critical Ranges of Concentration Above which There are Marked Decreases in Yield of Barley AL ppm.
Ligon & Pierre (1932)		4.5	0.02 - 1.04
MacLean & Chiasson (1966)			
Barley Varieties	(Herta	4.8	0.5 - 1.0
	(Charlottetown 80	4.8	2.0 - 4.0
MacLeod & Jackson (1967)			
Barley Varieties	(Herta	4.3	0.7 - 1.5
	(Charlottetown 80	4.3	2.2 - 2.6
Reid, Fleming & Foy (1971)		4.8	<4.0

Conclusion

In field studies it is important to be aware that there are many factors affecting crop performance. In this particular case there is undoubtedly a strong influence exercised by the moisture regime, particularly at certain susceptible growth stages of the plant. There are also probably minor effects from the degree of stoniness, aeration, exposure to sun and wind and other nutrient imbalances. These variables are different for the two soils and would generally favour the lower-lying, deeper soil.

However, for an improvement in the crop it is the limiting factor that needs to be corrected. Following a diagnosis on the basis of pH, Al and Mn (Hoyt and Nyborg 1972) it was concluded that aluminium toxicity (and also perhaps manganese) was responsible for the barley failure. Liming was recommended to increase the pH and so convert the aluminium and manganese to forms not available to plants.

Epilogue

A recent letter (30 June 1974) from the farmer states:

"This field was ploughed in the late autumn 1973 and 30 cwt. of lime was spread on it in the spring of this year (1974). The barley crop up to date is looking much improved to last season's. There are a few patches in the field where the barley is still not quite so good, but I think that the crop would benefit from some rain as this has been a very dry season".

TABLE 3 - COMPARISON OF RESULTS WITH THOSE OF HOYT & NYBORG (1972, p.166)

FOR 0.02 M $CaCl_2$ EXTRACTABLE Al & Mn

Hoyt and Nyborg 1972				Horbaczewski 1974			
Barley Stand*	pH	Al ppm.	Mn ppm.	Barley Stand	pH	Al ppm.	Mn ppm.
Poor	4.5	21.3	26.0	Poor	4.9	6.45	3.85
Poor	4.1	20.6	48.1	Poor	4.8	12.00	8.40
Poor	4.8	10.7	5.1				
Poor	5.0	7.9	24.6				
Moderate	5.0	2.6	14.1				
Good	5.2	1.2	4.4	Good	5.2	1.05	0.35
Good	5.1	0.9	14.2	V. Good	5.3	0.25	0.10
Good	5.5	0.6	1.4	V. Good	6.0	<0.15	0.05

*Estimated from figures of relative percentage yield

Appendix: Experimental Methods

Samples from the top-soil of the five pits were taken and sealed in plastic bags. Subsequent chemical tests have been conducted on these fresh samples as air-drying has been found to affect the amount of easily extractable manganese (and possibly aluminium) (Sherman and Harmer 1943, Hammes and Berger 1960, Savant and Kibe 1969).

1) pH - was determined twice on a slurry of the fresh soil with distilled water.

2) Manganese - Active Form (Leeper 1947)

A solution of a benzidine salt is added to a small sample of the fresh soil in a test tube, which is then examined under a binocular microscope. The abundance of blue specks is a rough indication of the relative amounts of active manganese present.

N.B. 1. Benzidine is a carcinogenic.
2. Montmorillonite also gives a colour reaction (Page 1941, Solomon et al 1968)

3) Manganese - Total (Hesse 1971)
The method given by Hesse was used and the concentrations read on a spectrometer at 545 mμ

4) Plant-Available Manganese and Aluminium (Hoyt and Nyborg 1972)
This method employs simultaneous extraction of the metals and the concentrations can be determined by Atomic Absorption Spectroscopy.

5) Field Moisture Content
Calculated as the percentage loss in weight of fresh samples after air-drying for 4 days.

6) Inherent Moisture Content
Previously air-dried samples were oven-dried at 105°C overnight and the subsequent percentage loss in weight noted.

N.B. The field moisture content is a function of the prevailing soil moisture conditions at the time of sampling. The inherent moisture content is the capacity of the soil to retain moisture even after air-drying and is dependent on the clay mineralogy and organic matter content.

7) % Carbon (Walkley and Black 1934)
1gm of soil was oxidised by an excess of oxidising agents (20mls c. H_2SO_4 and 10mls 0.2M $K_2Cr_2O_7$). The solution was allowed to cool and excess oxidising agents titrated against 0.5N $FeSO_4$ using diphenylamine as an indicator.

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APPENDIX 4

Sand Textures of Top-Soils (0-22cms)

All samples taken between 5-15cms except where indicated otherwise.

Coarse sand = 2,000 µm - 600 µm
Medium sand = 600 µm - 200 µm
Fine sand = 200 µm - 60 µm

	% Coarse	% Medium	% Fine
P 2 (0-10cms)	24·0		40·5
P 2 (10-20cms)	33·5		33·0
P 3	29·0		44·5
P 12	22·0		43·0
P 13	7·0		58·0
P 14	22·0		45·0
P 24	35·5		36·5
P 25	18·0		45·0
P 26	29·5		40·0
P 28	34·0		39·0
P 29	8·5		61·0
P 30	25·0		47·5
P 31	28·0		39·0
P 32	24·0		41·5
P 33	29·0		41·5
P 34	22·5		45·0
P 37	25·5		45·0
P 38	36·5		41·0
P 39	35·0		36·0
P 40	33·0		36·0
P 41	32·5		37·0
P 42	40·0		36·5
P 43	47·5		29·5
P 44	42·0		32·0
P 45	25·5		44·0

	% Coarse	% Medium	% Fine
P 46	38·5		36·5
P 47	28·5		33·5
P 48	34·0		39·0
P 53	15·0		47·5
P 55	39·0		40·0
P 56	17·5		52·0
P 57	16·0		39·0
P 58	41·0		33·0
P 59	25·0		43·0
P 60	14·0		55·0
P 61	15·0		48·0
P 62	46·0		29·0
P 63	13·0		58·0
P 64	31·5		43·0
P 66	35·0		39·0
P 67	39·0		34·0
P 68	41·0		31·0
P 69	22·0		45·0
P 70	26·0		40·0
P 71	5·5		57·0
P 72	44·0		35·0
P 73	6·0		57·0
P 74	27·0		40·0
P 76	41·0		34·0
P 77 (5-10 cms)	29·0		37·0
P 77 (10-15 cms)	25·0		39·0
P 78 (5-10 cms)	32·0		38·0
P 78 (10-15 cms)	30·0		40·0
P 79	28·0		36·0
P 80	32·0		33·0
P 81	28·0		37·0
P 82	30·0		40·0
P 83	27·0		42·0

	% Coarse	% Medium	% Fine
P 84	20·0		50·0
P 85	21·0		48·0
P 87	41·0		33·0
P 88	46·0		31·0
P 89	40·0		30·0
P 90	38·0		35·0
P 91	23·0		44·0
P 92	7·0		55·0
P 93	46·0		32·0
P 94	17·0		31·0
P 95	33·0		37·0
P 96	30·0		38·0
P 97	21·0		49·0
P 98	42·0		34·0
P 99	41·0		35·0
P100	45·0		31·0
P101	28·0		41·0
P102	33·0		38·0
P103	38·0		38·0
P104	18·0		39·0
P105 (5-10 cms)	27·0		42·0
P105 (10-15 cms)	30·0		40·0
P106	37·0		34·0
P110	38·0		36·0
P111	34·0		35·0
P112	33·0		40·0
P113	42·0		33·0
P115	44·0		32·0
P116	50·0		25·0
P117	46·0		29·0
P118	49·0		26·0
P119	35·0		36·0
P120	40·0		33·0

	% Coarse	% Medium	% Fine
P121	40·0		34·0
P122	43·0		29·0
Beach Sand	2·5		29·5

APPENDIX 5

Lithological Composition of Coarsest Sand Fraction

(2,000 µm - 1,200 µm)

All samples taken between 5-15 cms except where indicated otherwise.

RS - Red Siltstone

Q - Quartz

C - Coal

O - "Other lithologies"

Weight - Percentage weight of coarsest sand (2,000-1,200 µm) in Fine Earth (<2,000 µm).

Absolute - Absolute Content (Number of grains in the coarsest sand fraction from 100gms Fine Earth - <2,000 µm).

Relative - Relative Content (Percentage of particular lithology in coarsest sand fraction - 2,000-1,200 µm only).

Appendix 5

Sample (Depth in cms)	Weight	Absolute				Relative			
		RS	Q	C	O	RS	Q	C	O
P 5	6·0	659	53	2	311	64	5	0	30
P 6	7·6	917	70	15	379	66	5	1	28
P57	1·0	12	88	-	144	5	36	-	59
P58	6·1	1838	66	50	684	70	3	2	25
(25-30)	9·1	1375	25	-	158	88	2	-	10
P59	2·5	549	30	16	55	84	5	2	9
(15-20)	3·2	505	31	12	48	85	5	2	8
P60	1·3	178	38	27	74	56	12	9	23
(28-32)	1·7	336	55	-	52	76	12	-	12
(35-40)	1·3	42	48	-	160	14	16	17	53
P61	1·6	139	79	34	157	34	19	8	39
(25-30)	2·9	233	95	-	245	41	16	-	43
P62 (0- 5)	11·4	2346	28	-	70	96	1	-	3
(10-15)	9·2	2094	17	-	47	97	1	-	2
P63	0·9	193	12	-	51	75	5	-	20
P64 (10-15)	6·4	653	79	-	535	52	6	-	42
(40-45)	5·1	337	130	-	602	32	12	-	56
P66	6·1	845	34	50	187	76	3	4	17
P67	7·1	1110	32	141	122	79	2	10	9
P68	6·5	1073	24	35	278	76	2	2	20
P69	2·1	392	19	54	73	73	4	10	13
P70	2·5	406	52	81	130	61	8	12	19
(40-45)	2·2	331	31	9	93	71	7	2	20
P71	0·2	8	19	16	20	13	30	25	32
P72	8·3	998	33	47	171	80	3	4	13
P73	0·3	5	22	12	23	8	35	19	38
P74	2·9	499	36	58	140	68	5	8	19
P76	5·8	1015	30	31	228	78	2	2	18
P77 (5-10)	5·7	868	35	99	338	65	3	7	25
(10-15)	5·8	780	38	58	257	69	3	5	23

Appendix 5

Sample (Depth in cms)	Weight	Absolute				Relative			
		RS	Q	C	O	RS	Q	C	O
P78 (5-10)	5·0	777	26	75	238	70	2	7	21
(15-20)	5·2	683	25	60	175	72	3	6	19
P79 (5-15)	3·5	596	65	45	152	70	8	5	17
(25-30)	11·0	1481	155	5	252	78	8	1	13
P80	4·4	887	60	42	125	80	5	4	11
P81	2·6	464	32	30	133	70	5	5	20
(30-35)	11·4	1700	20	3	165	90	1	0	9
P82	4·5	770	42	50	156	76	4	5	15
P83	3·5	591	30	71	188	67	3	8	22
(25-30)	9·5	1487	49	22	191	85	3	1	11
P84	2·0	360	40	2	107	71	8	0	21
(25-30)	10·6	1550	52	1	261	83	3	0	14
(40-45)	9·7	1500	41	-	226	85	2	-	13
P85	2·1	367	52	11	122	67	9	2	22
(25-30)	2·9	340	63	15	128	62	12	3	23
P87	9·5	1185	100	138	249	71	6	8	15
(18-23)	9·1	1280	79	92	218	77	5	5	13
P88	9·8	1479	66	54	201	82	4	3	11
P89	5·2	880	88	29	147	77	8	2	13
P90	6·3	885	87	43	207	72	7	4	17
P91	3·1	369	88	20	211	53	13	3	31
(35-40)	3·8	436	96	11	228	56	12	1	31
P92	0·04	1	4	1	9	5	29	5	61
(35-40)	1·5	7	188	-	101	2	64	-	34
P93	8·8	1171	45	36	269	77	3	2	18
(35-40)	13·9	2000	42	8	311	85	2	0	13
P94	1·8	230	51	3	117	57	13	1	29
P95	5·5	953	28	29	182	80	2	2	16
P96	5·5	619	128	21	311	57	12	2	29
P97	1·8	179	65	16	121	47	17	4	32

Sample (Depth in cms)	Weight	Absolute				Relative			
		RS	Q	C	O	RS	Q	C	O
P 98	5·8	927	51	42	75	84	5	3	7
P 99	7·1	1015	82	40	115	81	7	3	9
P100	7·3	1128	66	54	201	82	4	3	11
P101	4·3	589	117	51	186	63	12	5	20
P102	5·8	858	51	17	253	73	4	1	22
P103	6·5	957	59	28	187	78	5	2	15
P104	2·0	322	47	50	96	63	9	10	18
(42-47)	1·9	353	39	2	103	71	8	0	21
P105 (5-10)	4·4	569	79	12	126	72	10	2	16
(10-15)	4·3	613	79	16	148	72	9	2	17
(40-45)	2·8	528	58	2	153	72	8	0	20
P106	6·0	980	45	48	177	78	4	4	14
*P107	4·2	229	31	15	(652 +67)	23	3	1	(66 +7)
*P108	2·5	344	46	50	912	25	3	4	68
*P109	3·5	279	37	12	(520 +43)	31	4	1	(59 +5
P110	4·8	909	82	22	128	80	7	2	11
P111 (5-15)	6·2	894	130	20	288	67	10	2	21
(30-35)	7·4	1200	38	1	507	64	3	0	33
P112	4·9	949	68	15	98	84	6	1	9
P113	4·2	763	51	52	162	76	5	3	16
P114	5·4	1074	54	25	98	86	4	2	8
P115	9·2	1420	103	21	113	86	6	1	7
P116	10·1	1390	156	38	197	78	9	2	11
P117	6·3	1079	116	54	168	76	8	4	12
P118	9·7	1410	72	11	215	83	4	1	12
∞P119	9·1	1108	76	9	586	62	4	0	34
P120	7·6	1125	39	42	180	81	3	3	13
P121	8·0	1265	62	49	213	80	4	3	13
P122	6·4	1179	95	56	295	73	6	3	18
P123	5·6	1040	96	26	142	80	7	2	11

*"Other lithologies" includes grey siltstone/sandstone bedrock lithology.

∞"Other lithologies" includes highly micaceous variety of red siltstone.

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1974, v 16, (pp 21-27)

A WEATHERING MODEL

JAN HORBACZEWSKI

Summary

The effect of granule size on granular disaggregation of particulate material is calculated using a very simple mathematical model. This form of weathering is considered as removal of successive layers of granules from aggregate surfaces. Experimental results are interpreted using this "layer concept".

Definitions

Granule - Discrete grains, inert to weathering agents, forming bulk of material.

Cement - Substance, binding granules together, which is removed in suspension or solution on weathering releasing unaffected granules.

Aggregate - Material composed of granules bound by cement.

Granular Disaggregation - Removal of material, both granules and cement, from the surface of an aggregate by the weathering agent. Does not include disintegration of aggregate by splitting or spalling.

Model

A simplified equation allows the calculation of the weight loss incurred by removal of one layer of granules for different aggregate and granule sizes. Results are tabulated as percentage weight losses, in Table 1.

Calculations

Several assumptions need to be made at the outset.

1. All granules in a particular aggregate are equidimensional spheres of constant density. Aggregates themselves are spherical.
2. All granules are in contact with neighbours.
3. Cement has the same density as the granules and fills all the voids between them.

An additional important assumption concerns the arrangement of the granules. For granules in contact several classes of close-packing are possible. To avoid this problem and yet still obtain comparable results a hypothetical situation is created. Granules are imagined to be in a straight line along the diameter of the aggregate. The mathematical validity of this method for comparative purposes is that it expresses a limiting case ie. the minimum number of layers possible provided previous assumptions are retained.

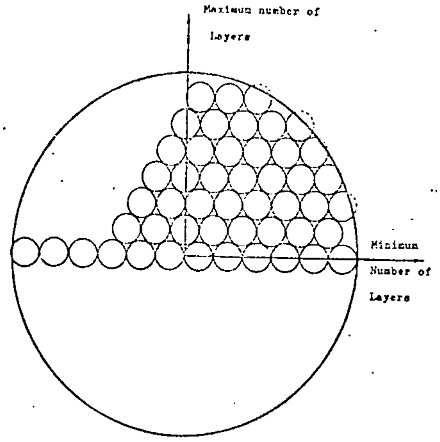

FIG. 1

Cross-section of an Aggregate with Rhombohedrally Packed Granules.

D = Diameter of Aggregate
d = Diameter of Granule

Fig.1. explains the relationships between layers, granules and aggregates. From this it can be seen that the number of layers can be defined as

$$n = \frac{D}{2d}$$

n = number of layers
D = diameter of aggregate
d = diameter of granule

The weight of a sperical aggregate is given by

$$\text{Weight} = \frac{4}{3}\pi p\left(\frac{D}{2}\right)^3 \qquad p = \text{density}$$

The removal of the outermost layer of granules and cement cause a weight reduction of the aggregate that can be expressed as

$$\%\ \text{weight loss} = \frac{p\frac{4}{3}\pi\left[\left(\frac{D}{2}\right)^3 - \left(\frac{D}{2} - d\right)^3\right]}{p\frac{4}{3}\pi\left(\frac{D}{2}\right)^3} \times 100$$

$$= \frac{\left(\frac{D}{2}\right)^3 - \left(\frac{D}{2} - d\right)^3}{\left(D/_2\right)^3} \times 100$$

Values for the removal of one layer of granules for different granule and aggregate sizes are tabulated (Table 1).
It should be noted that the density term has been eliminated allowing direct comparison with experimental results.

Experimental Testing

Experiments have been designed to approximate the conditions of the theoretical model, allowing an evaluation of its validity. Glass beads (generously provided by the Ballotini Manufacturing Company) and standard building cement have been used. Cemented samples were treated with dilute Hydrochloric acid as an experimental weathering agent. Results, expressed as percentage weight losses are presented in Table 2.

Method

Microscope inspection confirmed that the beads, with few exceptions, were smooth spheres. Considerable variations in size, however, necessitated repeated sieving. The clean beads from individual sieve fractions were mixed with a fixed weight ratio of cement and an excess of water. After thorough mixing the sample was allowed to settle and excess water removed. The samples were then allowed to set for a week under normal room conditions. The cemented blocks were carefully broken up in a mortar and seived. This operation separated the aggregates between the arbitrary sieve-limits as well as rounding the fragments, - and so approximating one of the assumptions of the theoretical model.

Aggregated from particular siev fractions were counted and wighed. Counting enabled an assessment of within-sieve size variation between samples for the same aggregate sizes. These samples were subsequently treated with a standard amount of dilute (25%) Hydrochloric acid for a fixed time. Products were carefully washed, air-dried and again sieved and counted.

Results showing percentage weight losses are presented in Table 2.

Table 3 reveals the same results calculated as the number of "model" layers removed. It is emphasised that these figures do not refer to the possible number of layers actually removed. They are an expression of the percentage weight loss in terms of the equivalent number of model layers.

At the end of the experiment aggregates of different bead sizes were set in plastic and sectioned. It was found that beads were mostly in contact with their neighbours and there were few cement clots of air pores to disturb the packing.

Interpretation

In attempting to re-create a theoretical model experimentally numerous concessions need to be made.

It is not possible to obtain equidimensional beads and aggregates on these experiments. Instead sieve-limits are set. For this reason Table 3 shows the range of "layers" removed. The other conditions can only be approximated. Nevertheless, the mechanism of material removal from aggregate surfaces has been achieved. Graphs, depicting the aggregate size distribution after treatment are bimodal - reduced aggregates and single beads. A further check is provided by counting, which shows only very slight increases of aggregate numbers after treatment, indicating rare splitting.

Where possible duplicate samples have been used and these give a rough idea of inherent experimental variations.

Conclusions

Although it has been possible to test only a small part of the theoretical model a few trends can be recognized.

The percentage weight loss for a particular aggregate size appears to be constant regardless of bead size. (Table 2) This is in spite of the fact that the numbers of "layers" removed increases from 0.5 for the largest beads to about 3 for the finest beads.

As expected, the percentage weight loss increases as the size of the aggregate decreases. This reflects the greatest surface area per unit weight, exposed to the weathering agent. However there is no significant increase in the number of "layers" removed. (Table 3). This evidence supports the model as the weathering rate, per se, does not alter simply because aggregates are smaller. Its effects are greater because the reaction surface is greater.

Finally, Table 4 shows the percentage weight losses of cement removed in solution. Results are remarkably similar for the same aggregate sizes irrespective of bead dimensions.

It appears, therefore that the cement, rather than the size of the beads, is the critical factor affecting weathering in this particular case.

Implications

The layer concept is very useful in the understanding of weathering by granular disaggregation for artificial systems. A logical extension is to the more complex case of natural sedimentary rock weathering and associated soil formation. This model will need to be modified accordingly and further experiments with this aim are now in progress.

Acknowledgements

I am very grateful to the Ballotini Manufacturing Comapny for the gift of the beads without which the experiments would not have been possible. I also wish to thank Mr. I.A.Bain, Dr. J.H. Stevens and Mr. J.S.Evans for critically reading the script.

Finally my thanks are due to Mr. G.Winn and Mr. J.Telford for suggestions and help with the experimental work.

Table 1 - Theoretical Percentage Weight Loss on Removal of one layer of Granules from an Aggregate.

DIAMETER OF AGGREGATE (MICRONS)	600	420	300	250	210	150	105	75	62	50	40	30	20	10	5
6360	46.58	34.78	25.78	21.74	18.63	13.66	9.63	7.14	5.90	4.66	3.73	2.80	1.86	0.93	0.62
4760	58.52	44.44	33.33	28.15	24.44	17.78	12.59	9.63	7.41	6.67	5.19	3.70	2.96	1.48	0.74
3180	75.87	60.20	46.52	40.05	34.58	25.62	18.66	13.43	11.19	9.20	7.21	5.47	3.73	1.99	1.00
2057	92.66	78.90	64.22	56.88	49.54	37.61	27.52	20.18	17.43	13.76	11.01	8.26	5.50	2.75	1.83
1200		97.22	87.50	80.09	72.69	57.87	43.98	32.87	27.78	23.15	18.52	14.35	9.72	5.09	2.31
600					97.31	87.41	72.59	57.78	50.00	42.22	34.81	27.04	18.52	9.63	4.81
420						97.62	87.47	73.43	65.01	55.72	46.98	37.04	25.92	13.61	6.91
300							97.33	87.54	79.82	70.33	60.53	48.66	34.72	18.69	9.50
250								93.85	87.18	78.46	68.72	55.90	40.51	22.05	11.28
210									95.00	88.00	78.00	66.00	49.00	27.00	14.00
150										96.21	89.81	78.44	60.66	34.83	18.72
105												91.95	75.84	46.31	25.50
75													89.44	59.93	34.61
62													95.64	68.79	40.94

Granule Diameter (microns).

1 millimetre = 1000 microns

Table 2 - Experimental Percentage Weight Losses from Aggregate After Treatment

AGGREGATE DIAMETER (MICRONS)	420 300	300 250	250 210	210 150	150 105	105 75	75 62
6360 4760	(i) 22.17 (ii) 30.72	35.27	26.58	INSUFFICIENT MATERIAL	30.36	(i) 27.97 (ii) 24.88	(i) 29.98 (ii) 32.51
4760 3180	(i) 31.62 (ii) 38.10	50.81	38.82		40.83	(i) 41.78 (ii) 40.79	(i) 42.60 (ii) [illegible] 39.55
3180 2057	(i) 51.18 (ii) 63.33	68.91	57.68		63.20	(i) 57.05 (ii) 64.53	(i) 57.54 (ii) 62.05

Bead Diameter (Microns).

Table 3 - Experimental Results Calculated as Numbers of Layers Removed

AGGREGATE DIAMETER (MICRONS)	420 300	300 250	250 210	210 150	150 105	105 75	75 62
6360 4760	(i) 0.50–0.66 (ii) 0.69–0.92	1.06–1.25	0.94–1.11	INSUFFICIENT MATERIAL	1.71–2.41	(i) 2.22–2.90 (ii) 1.98–2.58	(i) 3.11–4.05 (ii) 3.38–4.39
4760 3180	(i) 0.53–0.68 (ii) 0.63–0.82	1.09–1.27	0.97–[illegible] 1.17		1.59–2.19	(i) 2.24–3.11 (ii) 2.19–3.04	(i) 3.17–3.81 (ii) 2.94–3.53
3180 2057	(i) 0.65–0.80 (ii) 0.80–0.99	1.07–1.21	1.01–1.21 [illegible]		1.68–2.30	(i) 2.07–2.83 (ii) 2.34–3.20	(i) 2.85–3.30 (ii) 3.07–3.56

Bead Diameters (Microns).

Table 4 - Percentage Weight of Cement Removed in Solution after Treatment

AGGREGATE DIAMETER (MICRONS)	420 300	300 250	250 210	210 150	150 105	105 75	75 62
6360 4760	(i) 6.61 (ii) 7.90	9.04	7.74	NOT AVAILABLE	7.07	(i) 6.69 (ii) 4.42	(i) 6.40 (ii) 7.09
4760 3180	(i) 10.22 (ii) 11.22	12.70	10.49		11.41	(i) 10.26 (ii) 10.15	(i) 11.61 (ii) 10.41
3180 2057	(i) 15.61 (ii) 17.28	17.72	16.26		17.09	(i) 17.54 (ii) 17.11	(i) 16.45 (ii) 17.22

Bead Diameter (Microns), 1 millimetre = 1000 microns

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PHI-MILLIMETER CONVERSION TABLE[1]

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ABSTRACT

A phi-millimeter conversion table, computed with the use of seven-place logarithms, is presented. This table permits greater accuracy and is less tedious to use than previous methods of conversion.

INTRODUCTION

The phi symbol, ϕ, as originally adopted by Krumbein (1934; 1936b), is used to denote a grade scale in which all divisions are equal in range. This adapts the grade scale for plotting the data of mechanical analyses on arithmetic graph paper, thereby producing increased symmetry of the frequency curve and making possible direct arithmetic interpolation between phi grain diameters on the curve. To calculate many of the measures used in mechanical analyses, such as median diameter, quartiles, percentiles, and coefficients of sorting, skewness, and kurtosis, the phi units must be converted to millimeter sizes for use in the formulas involved or for easier comprehension of values. The slide rule or logarithms facilitate the algebraic computations in phi-millimeter conversions, but both processes are more or less tedious. Conversion charts now in use include those of Krumbein (1936a), Truesdell and Varnes (1950), and Inman (1952). Although these charts are sufficiently accurate for many uses, they require eye-straining observation and interpolations which result in only approximate values for intermediate grain-sizes.

The following table has proved very useful in conversions involved in mechanical analyses of sediments made as part of ground-water studies by the Navajo Project, U. S. Geological Survey. The table was computed with the use of seven-place logarithms (Hutton, 1830); hence it permits more accurate, faster, and easier conversions than most charts now available. Few groups of workers may require the complete table to cover the size-ranges their work involves, but the limits of the table were designed to encompass the major grain-sizes commonly employed by workers in various fields of analysis. Likewise, the figures are computed to three to five decimals to satisfy the requirements of those who desire that degree of accuracy.

Grain diameters smaller than one millimeter are represented by a positive phi value and are shown in the second column of the table; diameters larger than one millimeter are represented by a negative phi value and are shown in the third column.

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[1] Publication authorized by The Director, U. S. Geological Survey.

Phi-Millimeter Conversion Table

ϕ	$(+\phi)$ mm.	$(-\phi)$ mm.	ϕ	$(+\phi)$ mm.	$(-\phi)$ mm.	ϕ	$(+\phi)$ mm.	$(-\phi)$ mm.
0.00	1.0000	1.0000	0.50	0.7071	1.4142	1.00	0.5000	2.0000
01	0.9931	0070	51	7022	4241	01	4965	0139
02	9862	0140	52	6974	4340	02	4931	0279
03	9794	0210	53	6926	4439	03	4897	0420
04	9718	0285	54	6877	4540	04	4863	0562
05	9659	0355	55	6830	4641	05	4841	0705
06	9593	0425	56	6783	4743	06	4796	0849
07	9526	0498	57	6736	4845	07	4763	0994
08	9461	0570	58	6690	4948	08	4730	1140
09	9395	0644	59	6643	5052	09	4697	1287
0.10	9330	0718	0.60	6598	5157	1.10	4665	1435
11	9266	0792	61	6552	5263	11	4633	1585
12	9202	0867	62	6507	5369	12	4601	1735
13	9138	0943	63	6462	5476	13	4569	1886
14	9075	1019	64	6417	5583	14	4538	2038
15	9013	1096	65	6373	5692	15	4506	2191
16	8950	1173	66	6329	5801	16	4475	2346
17	8890	1251	67	6285	5911	17	4444	2501
18	8827	1329	68	6242	6021	18	4414	2658
19	8766	1408	69	6199	6133	19	4383	2815
0.20	8705	1487	0.70	6156	6245	1.20	4353	2974
21	8645	1567	71	6113	6358	21	4323	3134
22	8586	1647	72	6071	6472	22	4293	3295
23	8526	1728	73	6029	6586	23	4263	3457
24	8468	1810	74	5987	6702	24	4234	3620
25	8409	1892	75	5946	6818	25	4204	3784
26	8351	1975	76	5905	6935	26	4175	3950
27	8293	2058	77	5864	7053	27	4147	4116
28	8236	2142	78	5824	7171	28	4118	4284
29	8179	2226	79	5783	7291	29	4090	4453
0.30	8123	2311	0.80	5743	7411	1.30	4061	4623
31	8066	2397	81	5704	7532	31	4033	4794
32	8011	2483	82	5664	7654	32	4005	4967
33	7955	2570	83	5625	7777	33	3978	5140
34	7900	2658	84	5586	7901	34	3950	5315
35	7846	2746	85	5548	8025	35	3923	5491
36	7792	2834	86	5510	8150	36	3896	5669
37	7738	2924	87	5471	8276	37	3869	5847
38	7684	3014	88	5434	8404	38	3842	6027
39	7631	3104	89	5396	8532	39	3816	6208
0.40	7579	3195	0.90	5359	8661	1.40	3789	6390
41	7526	3287	91	5322	8790	41	3763	6574
42	7474	3379	92	5285	8921	42	3729	6759
43	7423	3472	93	5249	9053	43	3711	6945
44	7371	3566	94	5212	9185	44	3686	7132
45	7321	3660	95	5176	9319	45	3660	7321
46	7270	3755	96	5141	9453	46	3635	7511
47	7220	3851	97	5105	9588	47	3610	7702
48	7170	3948	98	5070	9725	48	3585	7895
49	7120	4044	99	5035	9862	49	3560	8089

Appendix 7

ϕ	$(+\phi)$ mm.	$(-\phi)$ mm.	ϕ	$(+\phi)$ mm.	$(-\phi)$ mm.	ϕ	$(+\phi)$ mm.	$(-\phi)$ mm.
1.50	0.3536	2.8284	2.00	0.2500	4.0000	2.50	0.1768	5.6569
51	3511	8481	01	2483	0278	51	1756	6962
52	3487	8679	02	2466	0558	52	1743	7358
53	3463	8879	03	2449	0840	53	1731	7757
54	3439	9079	04	2432	1125	54	1719	8159
55	3415	9282	05	2415	1411	55	1708	8563
56	3392	9485	06	2398	1699	56	1696	8971
57	3368	9690	07	2382	1989	57	1684	9381
58	3345	9897	08	2365	2281	58	1672	9794
59	3322	3.0105	09	2349	2575	59	1661	6.0210
1.60	3299	0314	2.10	2333	2871	2.60	1649	0629
61	3276	0525	11	2316	3169	61	1638	1050
62	3253	0737	12	2300	3469	62	1627	1475
63	3231	0951	13	2285	3772	63	1615	1903
64	3209	1166	14	2269	4076	64	1604	2333
65	3186	1383	15	2253	4383	65	1593	2767
66	3164	1602	16	2238	4691	66	1582	3203
67	3143	1821	17	2222	5002	67	1571	3643
68	3121	2043	18	2207	5315	68	1560	4086
69	3099	2266	19	2192	5631	69	1550	4532
1.70	3078	2490	2.20	2176	5948	2.70	1539	4980
71	3057	2716	21	2161	6268	71	1528	5432
72	3035	2944	22	2146	6589	72	1518	5887
73	3015	3173	23	2132	6913	73	1507	6346
74	2994	3404	24	2117	7240	74	1497	6807
75	2973	3636	25	2102	7568	75	1487	7272
76	2952	3870	26	2088	7899	76	1476	7740
77	2932	4105	27	2073	8232	77	1466	8211
78	2912	4343	28	2059	8568	78	1456	8685
79	2892	4581	29	2045	8906	79	1446	9163
1.80	2872	4822	2.30	2031	9246	2.80	1436	9644
81	2852	5064	31	2017	9588	81	1426	7.0128
82	2832	5308	32	2003	9933	82	1416	0616
83	2813	5554	33	1989	5.0281	83	1406	1107
84	2793	5801	34	1975	0631	84	1397	1602
85	2774	6050	35	1961	0983	85	1387	2100
86	2755	6301	36	1948	1337	86	1377	2602
87	2736	6553	37	1934	1694	87	1368	3107
88	2717	6808	38	1921	2054	88	1358	3615
89	2698	7064	39	1908	2416	89	1350	4110
1.90	2679	7321	2.40	1895	2780	2.90	1340	4643
91	2661	7581	41	1882	3147	91	1330	5162
92	2643	7842	42	1869	3517	92	1321	5685
93	2624	8106	43	1856	3889	93	1312	6211
94	2606	8371	44	1843	4264	94	1303	6741
95	2588	8637	45	1830	4642	95	1294	7275
96	2570	8906	46	1817	5022	96	1285	7812
97	2553	9177	47	1805	5404	97	1276	8354
98	2535	9449	48	1792	5790	98	1267	8899
99	2517	9724	49	1780	6178	99	1259	9447

φ	(+φ) mm.	(−φ) mm.	φ	(+φ) mm.	(−φ) mm.	φ	(+φ) mm.	(−φ mm.
3.00	0.1250	8.0000	3.50	0.0884	11.314	4.00	0.0625	16.009
01	1241	0556	51	0878	392	01	0621	111
02	1233	1117	52	0872	472	02	0616	223
03	1224	1681	53	0866	551	03	0612	336
04	1216	2249	54	0860	632	04	0608	450
05	1207	2821	55	0854	713	05	0604	564
06	1199	3397	56	0848	794	06	0600	679
07	1191	3977	57	0842	876	07	0595	795
08	1183	4561	58	0836	959	08	0591	912
09	1174	5150	59	0830	12.042	09	0587	17.030
3.10	1166	5742	3.60	0825	126	4.10	0583	148
11	1158	6338	61	0819	210	11	0579	268
12	1150	6939	62	0813	295	12	0575	388
13	1142	7544	63	0808	381	13	0571	509
14	1134	8152	64	0802	467	14	0567	630
15	1127	8766	65	0797	553	15	0563	753
16	1119	9383	66	0791	641	16	0559	877
17	1111	9.0005	67	0786	729	17	0556	18.001
18	1103	0631	68	0780	817	18	0552	126
19	1096	1261	69	0775	906	19	0548	252
3.20	1088	1896	3.70	0769	996	4.20	0544	379
21	1081	2535	71	0764	13.086	21	0540	507
22	1073	3179	72	0759	178	22	0537	635
23	1066	3827	73	0754	269	23	0533	765
24	1058	4479	74	0748	361	24	0529	896
25	1051	5137	75	0743	454	25	0526	19.027
26	1044	5798	76	0738	548	26	0522	160
27	1037	6465	77	0733	642	27	0518	293
28	1029	7136	78	0728	737	28	0515	427
29	1022	7811	79	0723	833	29	0511	562
3.30	1015	8492	3.80	0718	929	4.30	0508	698
31	1008	9177	81	0713	14.026	31	0504	835
32	1001	9866	82	0708	123	32	0501	973
33	0994	10.0561	83	0703	221	33	0497	20.112
34	0988	1261	84	0698	320	34	0494	252
35	0981	1965	85	0693	420	35	0490	393
36	0974	2674	86	0689	520	36	0487	535
37	0967	3388	87	0684	621	37	0484	678
38	0960	4107	88	0679	723	38	0480	821
39	0954	4831	89	0675	825	39	0477	966
3.40	0947	5561	3.90	0670	929	4.40	0474	21.112
41	0941	6295	91	0665	15.032	41	0470	259
42	0934	7034	92	0661	137	42	0467	407
43	0928	7779	93	0656	242	43	0464	556
44	0921	8528	94	0652	348	44	0461	706
45	0915	9283	95	0647	455	45	0458	857
46	0909	11.0043	96	0643	562	46	0454	22.009
47	0902	0809	97	0638	671	47	0451	162
48	0896	1579	98	0634	780	48	0448	316
49	0890	2356	99	0629	889	49	0445	471

PHI-MILLIMETER CONVERSION TABLE

φ	(+φ) mm.	(−φ) mm.	φ	(+φ) mm.	(−φ) mm.	φ	(+φ) mm.	(−φ) mm.
4.50	0.0442	22.627	5.00	0.0313	32.000	5.50	0.0221	45.255
51	0439	785	01	0310	223	51	0219	570
52	0436	943	02	0308	447	52	0218	886
53	0433	23.103	03	0306	672	53	0216	46.206
54	0430	264	04	0304	900	54	0215	527
55	0427	425	05	0302	33.128	55	0213	851
56	0424	588	06	0300	359	56	0212	47.177
57	0421	752	07	0298	591	57	0211	505
58	0418	918	08	0296	825	58	0209	835
59	0415	24.084	09	0294	34.060	59	0208	48.168
4.60	0412	251	5.10	0292	297	5.60	0206	503
61	0409	420	11	0290	535	61	0205	840
62	0407	590	12	0288	776	62	0203	49.180
63	0404	761	13	0286	35.017	63	0202	522
64	0401	933	14	0284	261	64	0201	867
65	0398	25.107	15	0282	506	65	0199	50.213
66	0396	281	16	0280	753	66	0198	563
67	0393	457	17	0278	36.002	67	0196	914
68	0390	634	18	0276	252	68	0195	51.268
69	0387	813	19	0274	504	69	0194	625
4.70	0385	992	5.20	0272	758	5.70	0192	984
71	0382	26.173	21	0270	37.014	71	0191	52.346
72	0379	355	22	0268	271	72	0190	710
73	0377	538	23	0266	531	73	0188	53.076
74	0374	723	24	0265	792	74	0187	446
75	0372	909	25	0263	38.055	75	0186	817
76	0369	27.096	26	0261	319	76	0185	54.192
77	0367	284	27	0259	586	77	0183	569
78	0364	474	28	0257	854	78	0182	948
79	0361	665	29	0256	39.124	79	0181	55.330
4.80	0359	858	5.30	0254	397	5.80	0179	715
81	0356	28.051	31	0252	671	81	0178	56.103
82	0354	246	32	0250	947	82	0177	493
83	0352	443	33	0249	40.224	83	0176	886
84	0349	641	34	0247	504	84	0175	57.282
85	0347	840	35	0245	786	85	0173	680
86	0344	29.041	36	0243	41.070	86	0172	58.081
87	0342	243	37	0242	355	87	0171	485
88	0340	446	38	0240	643	88	0170	892
89	0337	651	39	0238	933	89	0169	59.302
4.90	0335	857	5.40	0237	42.224	5.90	0167	714
91	0333	30.065	41	0235	518	91	0166	60.129
92	0330	274	42	0234	814	92	0165	548
93	0328	484	43	0232	43.111	93	0164	969
94	0326	696	44	0230	411	94	0163	61.393
95	0324	910	45	0229	713	95	0162	820
96	0321	31.125	46	0227	44.017	96	0161	62.250
97	0319	341	47	0226	426	97	0160	683
98	0317	559	48	0224	632	98	0158	63.119
99	0315	779	49	0223	942	99	0157	558

ϕ	$(+\phi)$ mm.	$(-\phi)$ mm.	ϕ	$(+\phi)$ mm.	$(-\phi)$ mm.	ϕ	$(+\phi)$ mm.	ϕ	$(+\phi)$ mm.
6.00	0.0156	64.000	6.50	0.0110	90.510	7.00	0.0078	7.50	0.0055
01	0155	445	51	0110	91.139	01	0078	51	0055
02	0154	893	52	0109	773	02	0077	52	0055
03	0153	65.345	53	0108	92.411	03	0077	53	0054
04	0152	799	54	0107	93.054	04	0076	54	0054
05	0151	66.257	55	0107	701	05	0076	55	0053
06	0150	718	56	0106	94.353	06	0075	56	0053
07	0149	67.182	57	0105	95.010	07	0074	57	0053
08	0148	649	58	0105	670	08	0074	58	0052
09	0147	68.120	59	0104	96.336	09	0073	59	0052
6.10	0146	594	6.60	0103	97.006	7.10	0073	7.60	0052
11	0145	69.071	61	0102	681	11	0072	61	0051
12	0144	551	62	0102	98.360	12	0072	62	0051
13	0143	70.035	63	0101	99.044	13	0071	63	0051
14	0142	522	64	0100	733	14	0071	64	0050
15	0141	71.012	65	0100	100.427	15	0070	65	0050
16	0140	506	66	0099		16	0070	66	0049
17	0139	72.004	67	0098		17	0069	67	0049
18	0138	505	68	0098		18	0069	68	0049
19	0137	73.009	69	0097		19	0069	69	0048
6.20	0136	517	6.70	0096		7.20	0068	7.70	0048
21	0135	74.028	71	0096		21	0068	71	0048
22	0134	543	72	0095		22	0067	72	0047
23	0133	75.061	73	0094		23	0067	73	0047
24	0132	584	74	0094		24	0066	74	0047
25	0131	76.109	75	0093		25	0066	75	0047
26	0130	639	76	0092		26	0065	76	0046
27	0130	77.172	77	0092		27	0065	77	0046
28	0129	708	78	0091		28	0064	78	0046
29	0128	78.249	79	0090		29	0064	79	0045
6.30	0127	793	6.80	0090		7.30	0064	7.80	0045
31	0126	79.341	81	0089		31	0063	81	0045
32	0125	893	82	0089		32	0063	82	0044
33	0124	80.449	83	0088		33	0062	83	0044
34	0123	81.008	84	0087		34	0062	84	0044
35	0123	572	85	0087		35	0061	85	0043
36	0122	82.139	86	0086		36	0061	86	0043
37	0121	711	87	0086		37	0061	87	0043
38	0120	83.286	88	0085		38	0060	88	0043
39	0119	865	89	0084		39	0060	89	0042
6.40	0118	84.449	6.90	0084		7.40	0059	7.90	0042
41	0118	85.036	91	0083		41	0059	91	0042
42	0117	627	92	0083		42	0058	92	0041
43	0116	86.223	93	0082		43	0058	93	0041
44	0115	823	94	0081		44	0058	94	0041
45	0114	87.427	95	0081		45	0057	95	0040
46	0114	88.035	96	0080		46	0057	96	0040
47	0113	647	97	0080		47	0056	97	0040
48	0112	89.264	98	0079		48	0056	98	0040
49	0111	884	99	0079		49	0056	99	0039

ϕ	$(+\phi)$ mm.	ϕ	$(+\phi)$ mm.	ϕ	$(+\phi)$ mm.	ϕ	$(+\phi)$ mm.
8.00	0.0039	8.50	0.0028	9.00	0.0020	9.50	0.0014
01	0039	51	0027	01	0019	51	0014
02	0039	52	0027	02	0019	52	0014
03	0038	53	0027	03	0019	53	0014
04	0038	54	0027	04	0019	54	0013
05	0038	55	0027	05	0019	55	0013
06	0038	56	0027	06	0019	56	0013
07	0037	57	0026	07	0019	57	0013
08	0037	58	0026	08	0019	58	0013
09	0037	59	0026	09	0018	59	0013
8.10	0036	8.60	0026	9.10	0018	9.60	0013
11	0036	61	0026	11	0018	61	0013
12	0036	62	0025	12	0018	62	0013
13	0036	63	0025	13	0018	63	0013
14	0035	64	0025	14	0018	64	0013
15	0035	65	0025	15	0018	65	0012
16	0035	66	0025	16	0018	66	0012
17	0035	67	0025	17	0017	67	0012
18	0035	68	0024	18	0017	68	0012
19	0034	69	0024	19	0017	69	0012
8.20	0034	8.70	0024	9.20	0017	9.70	0012
21	0034	71	0024	21	0017	71	0012
22	0034	72	0024	22	0017	72	0012
23	0033	73	0024	23	0017	73	0012
24	0033	74	0023	24	0017	74	0012
25	0033	75	0023	25	0016	75	0012
26	0033	76	0023	26	0016	76	0012
27	0032	77	0023	27	0016	77	0012
28	0032	78	0023	28	0016	78	0011
29	0032	79	0023	29	0016	79	0011
8.30	0032	8.80	0022	9.30	0016	9.80	0011
31	0032	81	0022	31	0016	81	0011
32	0031	82	0022	32	0016	82	0011
33	0031	83	0022	33	0016	83	0011
34	0031	84	0022	34	0015	84	0011
35	0031	85	0022	35	0015	85	0011
36	0030	86	0022	36	0015	86	0011
37	0030	87	0021	37	0015	87	0011
38	0030	88	0021	38	0015	88	0011
39	0030	89	0021	39	0015	89	0011
8.40	0030	8.90	0021	9.40	0015	9.90	0011
41	0029	91	0021	41	0015	91	0010
42	0029	92	0021	42	0015	92	0010
43	0029	93	0021	43	0015	93	0010
44	0029	94	0020	44	0014	94	0010
45	0029	95	0020	45	0014	95	0010
46	0028	96	0020	46	0014	96	0010
47	0028	97	0020	47	0014	97	0010
48	0028	98	0020	48	0014	98	00099
49	0028	99	0020	49	0014	99	00098
						10.00	00098

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Location and Field Classification of Soil Inspection Sites

Location

National Grid co-ordinates for 100km square - SM

"Topo-drainage" Classification

I - Moisture shedding sites
II - Moisture transmitting sites
III - Moisture receiving sites
IV - Sea-water affected sites

"Parent Material" Classification

r - Red siltstone (r/s - sandstone variant; th - thickened variant)
g - Grey siltstone/sandstone
sk - Skomer Volcanic Series
b - Black shales
u - Unsorted glacial material
w - Water-sorted glacial material
a - Alluvium
p - Peat
t - Talbenny Dolerite
h - Head

Uncertainty in classification is denoted by an interrogation mark.

Sample	Location	"Parent Material"	"Topo-drainage"
P 1	8210 1225	t	I
P 2	7930 1028	r	I
P 3	7988 1020	?w or r/th	II
P 4	7865 0889	b	II
P 5	8071 0963	w	II
P 6	8073 0971	w or r	II
P 7	8070 0944	w or g	III
P 8	8107 0952	g or w	II
P 9	8188 0913	g	I
P10	8422 0892	u	I
P11	8412 0873	r	I
P12	8411 0877	w or u	II
P13	8397 0870	a	III
P14	8116 0844	a	III
P15	7825 0765	w	III
P16	7670 0825	u	III
P17	7674 0818	u	III
P18	7671 0819	u	III
P19	7670 0816	u	III
P20	7754 0906	sk	I
P21	7761 0903	sk	I
P22	7910 0872	b	II
P23	7910 0872	b	II
P24	7910 0872	r	II
P25	8027 0527	u	I
P26	8039 0531	r	II
P27	8374 1250	t	I
P28	8053 1099	r	II
P29	8052 1109	w	III
P30	8091 1169	?u	I
P31	8179 1082	r/s	I
P32	8352 1180	u	I

Sample	Location	"Parent Material"	"Topo-drainage"
P33	8319 1173	r/s	I
P34	8335 1132	u	I
P35	8345 1222	t	I
P36	8294 0922	g	I
P37	8382 0956	u	I
P38	8435 1060	u	I
P39	8369 1049	r	I
P40	8255 1024	r	I
P41	8010 0884	r	I
P42	8170 0864	r	I
P43	8495 0702	r/th	I
P44	8524 0819	r	II
P45	8331 0874	r/th	II
P46	8259 0837	r	I
P47	8090 0806	w	I
P48	8424 0811	r	I
P49	8413 0729	r	I
P50	8363 0778	u	II
P51	7964 0751	g	I
P52	8069 0720	sk	II
P53	8079 0439	u	I
P54	8085 0391	u	II
P55	8162 0488	r	I
P56	8052 0669	w	II
P57	8069 0442	u	I
P58	8160 0444	r	I
P59	8135 0450	r	I
P60	8132 0449	u	I
P61	8115 0445	u	I
P62	8047 0318	r	I
P63	8028 0323	r/s	I
P64	8014 0379	u	I
*P65	7902 0628	?	?

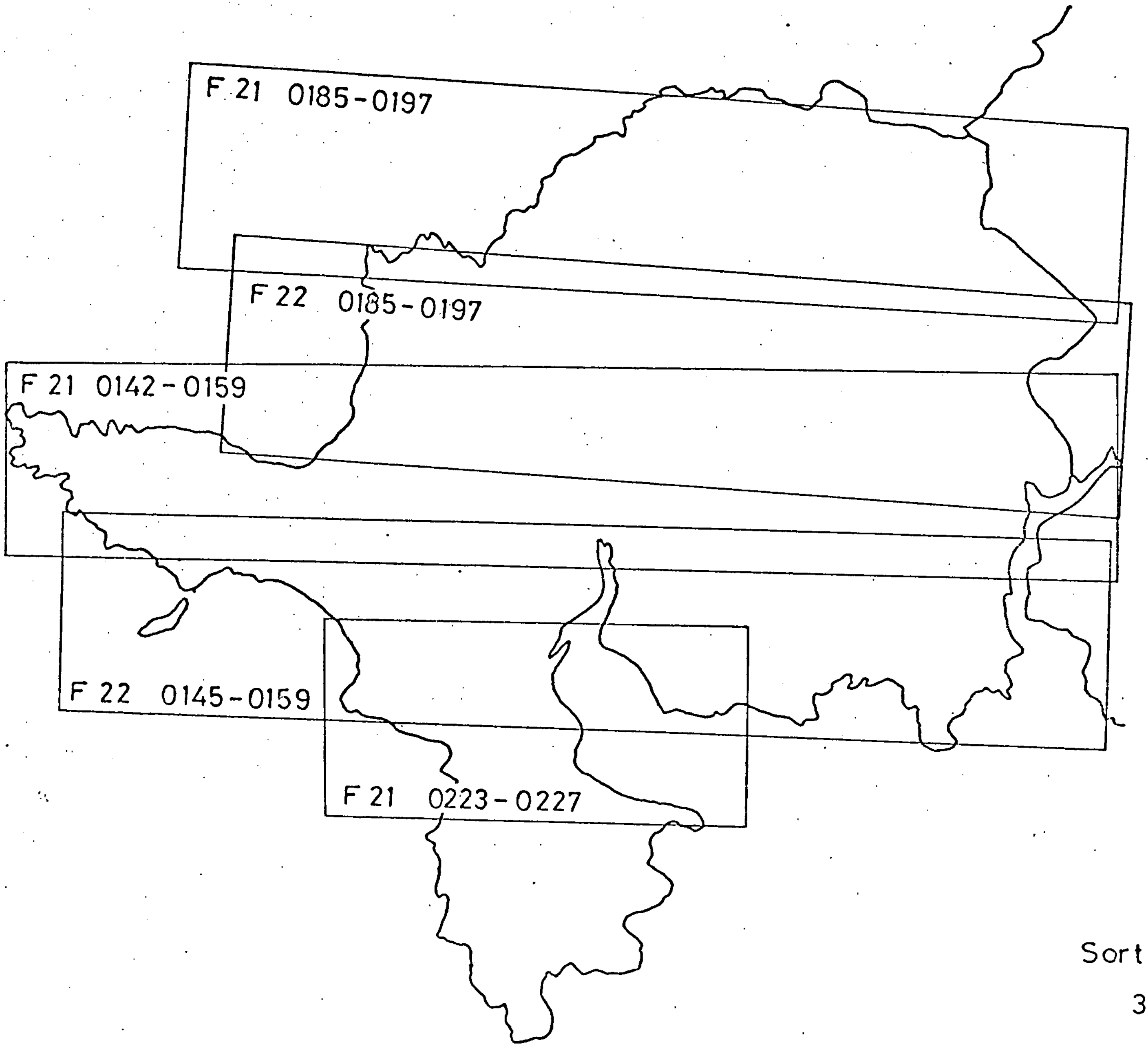
Sample	Location	"Parent Material"	"Topo-drainage"
P66	8093 0533	r	I
P67	8091 0545	r	I
P68	8089 0555	r	I
P69	8080 0541	r	I
P70	8077 0522	r/th	II
P71	8072 0629	?w	III
P72	8097 0523	r	I
P73	8070 0535	?w	III
P74	8088 0540	r	I
P75	8131 0524	r	I
P76	8115 0539	r	I
P77	7917 1029	r	I
P78	7927 1052	r/s	I
P79	7933 1030	r/s	I
P80	7938 1030	r	I
P81	7947 1032	r/th	II
P82	7957 1035	r/th	II
P83	7965 1036	r/th	II
P84	7981 1038	r/th	II
P85	7991 1039	w or r/th	II
P86	8031 1120	r/s	I
P87	8541 0940	r	I
P88	8562 0915	r	I
P89	8493 0970	r/th	I
P90	8466 0968	r/s	I
P91	8414 0920	g/th	I
P92	8417 0913	u	I
P93	8408 0946	r or r/s	I
P94	8024 1108	w	III
P95	7933 1092	r	I
P96	8355 0987	u	I
P97	8422 1003	u	I
P98	8423 1050	r	I

Sample	Location	"Parent Material"	"Topo-drainage"
P 99	8475 0999	r	I
P100	8480 1042	u or r/s	I
P101	8121 1031	?u	I
P102	8096 1026	?u	I
P103	8105 1016	r	I
P104	8142 1037	?u	I
P105	8174 1051	?u	I
P106	8133 0990	r	I
P107	8135 0966	g	I
P108	8148 0963	g	I
P109	8160 0970	g	I
P110	8157 0997	r	I
P111	8472 0871	r/th	I
P112	8460 0821	r	I
P113	8462 0794	r/s	I
P114	8473 0808	r	I
P115	8512 0846	r	I
P116	8530 0840	r	I
P117	8522 0794	r	I
P118	8529 0706	r	I
P119	8529 0680	r	I
P120	7987 0893	r	I
P121	7989 0901	r	I
P122	8006 0895	r	I
P123	8013 0894	r	I

* ? Earthen field boundary wall.

AIR PHOTOGRAPH

COVERAGE OF STUDY AREA



Sortie No. 58/RAF/2985
30 JUNE 1959

APPENDIX 10

SELECTED SOIL PROFILE DESCRIPTIONS

Soil Inspection Sites

P 2
P 5
P 8
P 9
P 10
P 11
P 12
P 13
P 21
P 22
P 23
P 24
P 25
P 26
P 27
P 36
P 37
P 39
P 41
P 53
P 81
P 82
P 83
P 101
P 102
P 103
P 104
P 105
P 122

See also:-

Plate 4 - P 62
Plate 5 - P 112
Plate 6 - P 86
Plate 7 - P 4
Plate 8 - P 15
Plate 9 - P 7
Plate 10 - P 14
Plate 11 - P 16

Sampling Periods

P 1 - P 27 : December 1972/January 1973
P 28 - P 56 : March/April 1973
P 57 - P 123 : August/September 1973

Appendix 10

P2 - Soil Profile Description

Location	7930 1028
Topo-drainage Class	Shedding (I)
"Parent Material"	Red Siltstone
Altitude	61 m ± 2 m (200' ± 5')
Slope and Aspect	5°, south
Land Use	Grass and clover + cereal stubble

0-11 cms	A_{1p}	Reddish brown (5YR 3/4) sandy clay, small hard peds, mod. moist, no mottles, mod. roots, rare fauna, mod. stones - small, up to 1 cm (pH 6·3). Boundary merging and regular.
11-19 cms	A_{2p}	Reddish brown (2·5YR 3/4) sandy clay, very small crumbs, compacted, mod. moist, no roots, no fauna, larger fragments red siltstone up to 2-3 cms (pH 6·3). Boundary sharp and regular.
19+ cms	C/R	Fragments of red siltstone "in situ" with finer intersticial matrix.

Horizon	Texture Analysis			Sand Fractions				MC	LOI
	Sand	Silt	Clay	F Gr	Co S	Med S	Fine S		
A_1	41·2	29·4	29·4	16·0	8·6	12·8	16·4	2·6	5·3
A_2	36·8	29·0	34·2	47·6	7·9	7·9	7·9	2·8	4·6

P5 - Soil Profile Description

Location	8071 0963
Topo-drainage Class	Transmitting (II)
"Parent Material"	Water-sorted glacial
Altitude	18 m ± 2 m (60' ± 5')
Slope and Aspect	5-10°, south-west
Land Use	Ploughed (pasture)

0-17 cms	Ap	(Inverted top-soil - grass-mat at 17 cms forming sharp boundary). Reddish brown (7·5YR 4/4) clay sand, loose, small crumbs, mod. moist, no mottles, OM low, roots mod. low fauna, stones abund. - red siltstone up to 1 cm across (pH 5·9).
17-21 cms	A_2	Same material as Ap but undisturbed. Boundary sharp and regular.
21-28/36 cms	B_s	Orange (7·5YR 5/6) sand, single grain, mod. compact, mod. moist, no OM, no roots, no stones (pH 7·0). Boundary sharp but irregular.
28/36-70 cms	C	Orange-yellow (10YR 5/6) sand, thin orange bands (7·5YR 5/6) at approx 4 cms spacing, well packed, mod. moist, no mottles, rare deep roots, no stones (pH 7·4)

Horizon	Texture Analysis			MC	LOI
	Sand	Silt	Clay		
Ap	69·8	23·1	7·1	1·2	5·1
B	86·6	9·2	4·2	0·6	0·0
C	90·5	9·5	0·0	0·0	0·0

P8 - Soil Profile Description

Location	8107 0952
Topo-drainage Class	Transmitting (II)
"Parent Material	Grey siltstone/sandstone or water-sorted glacial
Altitude	30 m ± 2 m (100' ± 5')
Slope and Aspect	10°, west
Land Use	Pasture

0-5 cms	A_{1p}	Brown (10YR 4/3) sandy silty clay, small stable crumbs, mod. moist, no mottles, OM mod, abund. roots, mod. fauna - earthworms, few stones. Boundary merging but regular.
5-21 cms	A_{2p}	Brown (10YR 4/3) silty clay, small crumbs, compacted, mod. moist, no mottles, OM low, few roots, few earthworms, mod. stones up to 1cm across (pH 5·7). Boundary merging but regular.
21-44 cms	B_w/C	Brown (slightly more yellow) (10YR 4/3). Much more stony horizon with most of stones aligned parallel to soil surface. (Mostly frags. of grey siltstone) (pH 5·7).
44-50+ cms	R	Finely jointed grey siltstone fragments "in situ"

Horizon	Soil Texture			Sand Fractions				MC	LOI
	Sand	Silt	Clay	F Gr	Co S	Med S	Fine S		
A_{2p}	23·9	38·1	28·0	6·4	5·8	6·4	14·8	4·4	6·1
C	26·4	41·2	32·4	21·6	8·3	3·8	13·2	2·2	3·7

P9 - Soil Profile Description

Location	8188 0913
Topo-drainage Class	Shedding (I)
"Parent Material"	Grey siltstone/sandstone (Silurian)
Altitude	27 m ± 2 m (90' ± 5')
Slope and Aspect	15°-20°, south
Land Use	Pasture

0-5 cms	A_1	Dark brown (10YR 4/3) silty clay loam, small crumbs, mod. plastic, mod. moist, no mottles, OM - high-mod., abund. roots, mod. fauna - earthworms, few stones. Boundary sharp and regular.
5-10 cms	A_2	Dark brown (10YR 4/3) silty clay, small crumbs, mod. plastic, mod. moist, no mottles, OM low, few roots, few worms, abund. stones - up to 1·5 cms (pH 7·0). Boundary merging and irregular.
10-20 cms	C	Horizon with abund. fragments of siltstone and mudstone up to 5 cms across, in finer matrix.
20+ cms	R	Yellowish-grey siltstone/mudstone - irregularly cleaved and finely jointed (fossiliferous).

Horizon	Soil Texture			MC	LOI
	Sand	Silt	Clay		
A_2	36·4	36·6	27·0	4·3	6·8

P 10 - Soil Profile Description

Location	8422 0892
Topo-drainage Class	Shedding (I)
"Parent Material"	Unsorted glacial till
Altitude	41 m ± 2 m (135' ± 5')
Slope and Aspect	5°, south-west
Land Use	Pasture

0-6 cms	A_1	Dark brown (10YR 3/4) sandy clay loam, small weak crumb, mod. plastic, mod. moist, no mottles, OM mod.-low, roots abund., stones very few. Boundary merging and regular.
6-26 cms	A_2	Dark brown (10YR 3/3) sandy silty clay. Compacted, mod. plastic, no mottles. OM low, roots few, fauna low - earthworms, stones few - up to 0·5 cms (pH 5·2) Boundary sharp but irregular.
26-46 cms	B_{1g}	Predominant colours - orange (7·5YR 5/8) clay and reddish grey (5YR 5/2) sand. Grey sand in form of vertical channels (of 1-2 cms width) in orange clay. Orange material - compact silty clay, mod. plastic, mod. moist, no mottles, OM low, no roots, no fauna, no stones (except at base) (pH 5·5). Red-grey material - slightly clay sand, single grain, very wet, no mottles, no OM, no roots, no fauna, no stones. Boundary sharp and irregular.
46-70 cms	B_{2g}	Reddish brown (2·5YR 4/4). Heavy clay, very plastic, very massive, mod.-very moist, no mottles, OM low, no roots, no fauna, stones at base (pH 5·9).
70-86 cms	C_g	Red clay with numerous pebbles of various lithologies (grey sandstone, red siltstone, quarts and others).
86+ cms	R	Finely jointed red siltstone "in situ".

Horizon	Soil Texture			MC	LOI
	Sand	Silt	Clay		
A_2	26·0	40·6	33·4	2·3	4·0
B_{1g}	35·7	31·6	32·7	0·8	0·2
B_{2g}	17·0	35·4	47·6	1·6	2·4

P11 - Soil Profile Description

Location	8412 0873
Topo-drainage Class	Shedding (I)
"Parent Material"	Red siltstone
Altitude	35 m ± 2 m (115' ± 5')
Slope and Aspect	5°, south
Land Use	Grass patch in field of cereal

0-2 cms	A_1	Reddish brown (2·5YR 4/2) sandy clay loam, small weak crumb, compact, mod. plastic, mod. moist, no mottles, OM mod., abund. roots, low fauna, small stones (red siltstone) up to 1cm across.
2 + cms	R	Solid bedrock - jointed red siltstone.

P 12 - Soil Profile Description

Location	8411 0877
Topo-drainage Class	Transmitting (II)
"Parent Material"	Water-sorted/?unsorted glacial material
Altitude	32 m ± 2 m (105' ± 5')
Slope and Aspect	5°, south
Land Use	Grass, and cereal stubble

0-10 cms	A_1	Reddish brown (5YR 4/3) sandy clay loam, small weak crumb, compact, mod, plastic, mod. moist, no mottles, OM low, freq. roots, few stones (up to 2 mm) (pH 5·3). Boundary merging but regular.
10-20 cms	A_2	Reddish brown (5YR 4/3) silty clay, compact, mod. moist, no mottles, no OM, few roots, no stones, freq. worms (pH 5·3). Boundary merging but regular.
20-63 + cms	C	Reddish brown (5YR 4/3) sandy silt clay, compact, mod. plastic, mod. moist, no mottles, no OM, roots absent, fauna rare - earthworms, abund. stones up to 5 cms across (green siltstone, sandstone, igneous and ?coal fragments).

Horizon	Soil Texture			Sand Fractions				MC	LOI
	Sand	Silt	Clay	F Gr	Co S	Med S	Fine S		
A_1	25·0	43·2	31·8	10·0	5·9	9·3	11·5	2·0	4·9
A_2	24·6	39·3	36·1	3·9	4·5	11·5	12·1	1·9	4·7
C	35·0	29·8	35·2	36·9	5·5	8·0	9·9	1·6	4·5

Appendix 10

P 13 - Soil Profile Description

Location	8397 0870
Topo-drainage Class	Receiving (III)
"Parent Material"	Alluvium
Altitude	30 m ± 2 m (100' ± 5')
Slope and Aspect	5°, south
Land Use	Waterlogged - grass and rushes

0-11 cms	A_1	Reddish brown (5YR 4/3) silty clay, weak crumb, mod. plastic, compacted, mod. moist, no mottles, OM mod., abund. roots, freq. earthworms, a few stones up to 1 cm. Boundary merging and regular.
11-34 cms	A_2	Reddish brown (5YR 4/3) silty clay, mod. - very plastic, mod. moist, OM mod., few roots, freq. worms, few stones up to 2 cm (pH 5·4). Boundary sharp and regular.
34-45 cms	C_{1g}	Grey-brown (7·5YR 5/2) clay sand, very moist - water-table, irreg. orange (7·5YR 5/6) mottles where larger pores and channels, OM low, no roots, few earthworms, freq. large stones (up to 10 cms) - volcanic, sandstone, trachyte (pH 5·7).
45-60+ cms	C_{2g}	Orange brown (7·5YR 5/6) clay sand, single grain, compact, mod. plastic, few mottles - greyish (7·5YR 5/2). No OM, no roots, no fauna (pH 6·0).

Horizon	Soil Texture			Sand Fractions				MC	LOI
	Sand	Silt	Clay	F Gr	Co S	Med S	Fine S		
A_2	15·0	42·5	42·5	1·5	1·4	7·0	11·5	2·0	3·8
C_{1g}	26·6	35·0	38·4	39·0	3·4	7·1	8·8	1·3	2·2
C_{2g}	44·2	22·7	33·1	2·2	2·6	21·4	20·4	1·0	1·3

P21 - Soil Profile Description

Location	7761 0903
Topo-drainage Class	Shedding (I)
"Parent Material"	Basic lava (Skomer Volcanic Series)
Altitude	55 m ± 3 m (180' ± 10')
Slope and Aspect	5°, south-west
Land Use	Pasture

0-11 cms	A_1	Dark brown (10YR 3/4) sandy clay loam, small crumb, loosely packed, mod. moist, no mottles, OM high, abund. roots, abund. fauna - worms, few stones. Boundary merging and regular.
11-11/15 cms	A_2/B_w	Brown (10YR 4/4) sandy loam, mod. compact, mod. moist, no mottles, OM mod., freq. roots, abund. stones up to 5 cms. Boundary very irregular but sharp.
11/15 + cms	R	Basic lava surface.

P22 - Soil Profile Description

Location	7910 0872
Topo-drainage Class	Transmitting (II)
"Parent Material"	Black shale (Ordovician)
Altitude	52 m ± 3 m (170' ± 10')
Slope and Aspect	5°, south
Land Use	Ploughed (grass)

0-21cms	Ap	Brown (5YR 3/4) sandy clay, mod. compact, plastic, mod. moist, no mottles, OM mod.-low, freq. roots, few worms, abund. stones (black shale) up to 2-3 cms (pH 6·7). Boundary sharp - inverted grass mat.
21-40 cms	A_2/B_w	Brown (5YR 3/4) sandy clay, mod. compact, plastic, mod. moist, no mottles, OM low, few roots, very few worms, abund. stones up to 3 cms (pH 6·7). Boundary merging and irregular.
40+ cms	C	Large pieces of black shale (up to 5 cms) more or less "in situ" with some finer intersticial matrix.

Horizon	Soil Texture			MC	LOI
	Sand	Silt	Clay		
A_p	27·1	36·5	36·4	2·2	6·8

P23 - Soil Profile Description

Location	7910 0872 (10 m south of P22)
Topo-drainage Class	Transmitting (II)
"Parent Material"	Black shale (Ordovician)
Altitude	52 m ± 3 m (170' ± 10')
Slope and Aspect	5°, south
Land Use	Ploughed (grass)

0-25 cms	A_p	Reddish brown (7·5YR 4/2) sandy clay, small crumb, mod. compact, plastic, mod. moist, no mottles, OM low - mod., freq. roots, rare fauna, abund. stones (red siltstone) up to 2 cms. Boundary sharp but irregular.
25-46 cms	B_g/C_1	Orange (7·5YR 7/8) with grey mottles (5YR 7/2) silty clay, sub-angular blocky, compact, plastic, mod. moist, mottled, no OM, no roots, no fauna, in places very stony (black shale). Boundary merging.
46+ cms	C_2	Grey (5Y 7/2) stiff clay with orange (7·5YR 7/8) mottles, mod. moist, very plastic. Abundant mottles, OM low, no roots, no fauna, no stones.

P24 - Soil Profile Description

Location	7910 0872 (1 m south of P23)
Topo-drainage Class	Transmitting (II)
"Parent Material"	Red siltstone (Devonian)
Altitude	52 m ± 3 m (170' ± 10')
Slope and Aspect	5°, south
Land Use	Ploughed (grass)

0-22 cms	A_p	Brown (5YR 3/4) sandy clay, small crumb, plastic, mod. moist, no mottles, OM mod., abund. roots, mod. fauna - worms, few stones - up to ½ cm (pH 6·0). Boundary sharp but irregular.
22-22/32 cms	C_1	Greenish-yellow (5Y 5/4) pebbly clay sand (variable in thickness from 0 to 10 cms northwards in pit). Single grain, loose, mod. - very moist, no mottles, no OM, no roots, no fauna, abund. stones up to 1·5 cms - black shale (pH 6·6). Boundary sharp and oblique.
22/32+ cms	C_2	Very finely jointed red siltstone fragments "in situ".

Horizon	Soil Texture			Sand Fractions				MC	LOI
	Sand	Silt	Clay	F Gr	CoS	Med S	Fine S		
A_p	24·5	37·8	37·7	26·8	8·8	7·0	9·0	1·8	7·2
C_1	42·5	27·2	30·3	57·8	10·7	4·5	3·6	1·1	3·9
C_2	46·0	24·2	29·8	63·8	11·7	4·2	3·3	1·0	4·9

P25 - Soil Profile Description

Location	8027 0527
Topo-drainage Class	Shedding (I)
"Parent Material"	Unsorted glacial till
Altitude	36 m ± 3 m (120' ± 10')
Slope and Aspect	5°, north-east
Land Use	Pasture

0-8 cms	A_{1p}	Brown (10YR 3/4) sandy clay to clay sand, single grain, mod. compact, non-plastic, mod. moist, no mottles, mod. OM, abund. roots, freq. worms, freq. stones up to 2 cms. Boundary very merging.
8-22 cms	A_{2p}	Fewer roots, otherwise similar to A_{1p} (pH 6·0). Boundary merging.
22-45 cms	C_1	Brown (10YR 3/4) sandy clay to clay sand, single grain, mod. compact, non-plastic, mod. moist, no mottles, low OM, few roots, few worms, abund. stones up to 3 cms. Boundary sharp and regular.
45-55+ cms	C_2	Yellowish brown (10YR 5/6) clay sand, single grain, mod. compact, mod. moist, no mottles, no OM, no roots, no fauna, abund. stones (varied) up to 2-3 cms across (pH 6·4).

Horizon	Soil Texture			Sand Fractions				MC	LOI
	Sand	Silt	Clay	F Gr	Co S	Med S	Fine S		
A_{2p}	34·7	35·4	29·9	7·7	6·4	13·1	15·9	2·0	7·2
C_2	41·1	25·5	33·4	22·9	7·2	11·4	14·0	1·0	3·7

P26 - Soil Profile Description

Location	8039 0531
Topo-drainage Class	Transmitting (II)
"Parent Material"	Red siltstone
Altitude	33 m ± 2 m (110' ± 5')
Slope and Aspect	5°, north-east
Land Use	Pasture

0-20 cms	A_p	Reddish brown (5YR 3/3) clay silt loam, small crumbs, loose, porous, little - mod. moist, no mottles, OM mod. - low, roots abund., fauna very freq. - worms, stones abund. (red siltstone only) up to 1 cm (pH 5·3). Boundary merging and irregular.
20-27 cms	C	Lighter reddish-brown (5YR 3/4) silty sand, single grain and small crumb, loose, porous, little - mod. moist, no mottles, OM low, few roots, freq. worms, abund. stones up to 3-4 cms (pH 5·3). Boundary irregular and merging.
27 + cms	R	Finely jointed red siltstone.

Horizon	Soil Texture			Sand Fractions				MC	LOI
	Sand	Silt	Clay	F Gr	Co S	Med S	Fine S		
A_p	41·0	22·2	36·8	18·4	8·2	8·6	11·2	6·2	9·7
C	35·1	34·1	30·8	34·5	10·7	6·1	8·2	3·9	9·4

P27 - Soil Profile Description

Location	8374 1250
Topo-drainage Class	Shedding (I)
"Parent Material"	Talbenny Dolerite
Altitude	91 m ± 2 m (300' ± 5')
Slope and Aspect	5°, south
Land Use	Grass and cereal stubble

0-16 cms	A_{1p}	Brown (10YR 3/4) silty clay loam, good crumb, loosely packed and porous, mod. moist, no mottles, OM mod., freq. roots, abund. worms, abund. stones up to 4 cms across (pH 5·5). Boundary merging and regular.
16-26 cms	A_{2p}/ B_w	Dark yellowish brown (10YR 4/4) sandy silt loam, mod. crumb, loosely packed, mod. moist, no mottles, no OM, no roots, no fauna, abund. stones - from 0·5 cm to 5 cms (Dolerite). Boundary irregular and sharp.
26+ cms	R	Dolerite - massive and very hard.

Horizon	Soil Texture			Sand Fractions				MC	LOI
	Sand	Silt	Clay	F Gr	CoS	Med S	Fine S		
A_1	33·8	33·1	33·1	20·0	10·4	5·9	14·2	5·0	6·3
A_2/B_w	20·8	48·8	30·4	29·2	7·8	4·4	10·2	7·0	5·9

P36 - Soil Profile Description

Location	8294 0922
Topo-drainage Class	Shedding (I)
"Parent Material"	Grey siltstone/sandstone (Silurian)
Altitude	30 m $\pm$ 2 m (100' $\pm$ 5')
Slope and Aspect	10°, south
Land Use	Pasture

0-10 cms	A_1	Dark brown (10YR 4/4) clay loam, small weak crumb, porous, mod. loose, mod. moist, no mottles, OM mod. high, abund. roots, fauna mod. - earthworms, stones very freq. - yellow sandstone/siltstone. Boundary merging and regular.
10-20 cms	A_2	Dark brown (10YR 4/4) clay loam, small weak crumb, mod. loose, mod. moist, no mottles, OM mod., roots less freq., fauna mod. - earthworms, freq. stones - yellow sandstone. Boundary merging.
20+ cms	B_w/C	Brown (10YR 3/4) loam, more compact with weathered stones of yellow sandstone. Little moist, no mottles, OM low, no roots, fauna rare.

Horizon	MC	LOI
A_2	2·1	7·5

P37 - Soil Profile Description

Location	8382 0956
Topo-drainage Class	Shedding (I)
"Parent Material"	Glacial till
Altitude	61 m ± 2 m (200' ± 5')
Slope and Aspect	Flat/none
Land Use	Grass

0-10 cms	A_1	Dark reddish-brown (5YR 3/4) silty clay loam, grass mat, mod. compact, small weak crumbs, mod. moist, no mottles, O M mod., abund. roots, freq. worms, few stones. (pH 7·4).
		Boundary merging and regular.
10-21 cms	A_2	Dark reddish brown (5YR 3/4) silty clay loam, mod. compact, weak crumb, mod. moist, no mottles, O M low - mod., mod. roots, mod. fauna, very few stones.
		Boundary merging and regular.
21-25 cms	B_w	Orange brown (7·5YR 4/4) sandy clay, single grain, compact, mod. to little moist, no mottles, O M low, no roots, no fauna, no stones.
		Boundary merging and regular.
25+ cms	C	Yellowish orange (7·5YR 5/6) sandy silt loam, compact, single grain, little - mod. moist, no mottles, no O M, no roots, no fauna, few stones.

Horizon	MC	LOI
A_2	0·9	5·0

Appendix 10

P39 - Soil Profile Description

Location	8369 1049
Topo-drainage Class	Shedding (I)
"Parent Material"	Red siltstone
Altitude	52 m ± 3 m (170' ± 10')
Slope and Aspect	10°-20°, east
Land Use	Last crop - turnips

0-20 cms	A_p	Dark reddish brown (5YR 3/4) silty clay loam, small weak crumbs (small hard sub-angular peds on surface), loosely packed, mod. moist, no mottles, OM mod., roots mods., fauna mod., abund. stones. Boundary irregular and sharp.
20-28/30 cms	C	Reddish brown (5YR 3/3) silty clay, more compact, mod. moist, no mottles, rare roots, rare fauna, abund. stones (all red siltstone). Boundary merging.
30+ cms	R	Fragments of red siltstone in rough alignment in finer matrix.

Horizon	M C	L O I
A_p	2·3	8·2

Appendix 10

P41 - Soil Profile Description

Location	8010 0884
Topo-drainage Class	Shedding (I)
"Parent Material"	Red siltstone
Altitude	52 m ± 6 m (170' ± 20')
Slope and Aspect	5°, south-east
Land Use	Pasture

0-12 cms	A_1	Reddish brown (2·5YR 3/4) silty loam, small weak crumb, loosely packed and porous, mod. to little moist, no mottles, OM mod. to high, roots abund., fauna abund. - earthworms, abund. stones (red siltstone). Boundary merging and regular.
12-20 cms	A_2	Reddish brown (2·5YR 3/4) silty loam, poor crumb but porous, freq. roots, fauna abund. - earthworms, abund. stones (red siltstone). Boundary merging and regular.
20-22 cms	C	Red (2·5YR 3/4 - 2/4) silty clay (gravelly), mod. to very compact, mod. to little plastic, mod. moist, no mottles, no OM, no roots, no fauna, abund. stones (red siltstone). Boundary sharp and irregular.
22+ cms	R	Red siltstone striking east-west.

Horizon	M C	L O I
A_2	0·4	9·9

P53 - Soil Profile Description

Location	8079 0439
Topo-drainage Class	Shedding (I)
"Parent Material"	Unsorted glacial till
Altitude 64 m	64 m ± 2 m (210' ± 5')
Slope and Aspect	5°-10°, north
Land Use	Ploughed

0-12 cms	A_{1p}	Dark brown (10YR 3/4) loam, good crumb, loose, mod. moist, no mottles, O M high - mod., abund. roots, mod. - freq. worms, stones abund. - rounded and very varied (pH 7·0). Boundary merging and regular.
12-16 cms	A_{2p}	Similar but fewer roots and weak crumb. Boundary merging and regular.
16-20 cms	A_2/C	Channels of A_{2p} material in top of C horizons.
20+ cms	C	Orange-brown (7·5YR 5/6) clay loam, mod. compact, mod. moist, no mottles, no OM, no roots, no fauna, abund. varied stones.

Horizon	M C	L O I
A_{2p}	1·7	9·3

P81 - Soil Profile Description

Location	7947 1032
Topo-drainage Class	Transmitting (II)
"Parent Material"	Red siltstone (colluvium)
Altitude	50 m ± 2 m (165' ± 5')
Slope and Aspect	10°-15°, east
Land Use	Potatoes

0-18 cms	A_p	Dark reddish brown (5YR 3/4) silty clay loam, hard irregular peds, dry, no mottles, O M low, roots abund., occ. worms, stones - green sandstone and red siltstone. Boundary sharp and regular.
18-40 cms	?A_2/C	Reddish brown (2·5YR 3/4) silty clay, mod. compact, mod. moist, no mottles, O M low, roots rare, worms rare, abund. red siltstone up to 2 cms. Boundary sharp but irregular.
40 + cms	R	Jointed red siltstone.

P82 - Soil Profile Description

Location	7957 1035
Topo-drainage Class	Transmitting (II)
"Parent Material"	Red siltstone (colluvium)
Altitude	42 m ± 2 m (140' ± 5')
Slope and Aspect	10°-15°, east
Land Use	Potatoes

0-20 cms	A_p	Reddish brown (2·5YR 3/4) silty clay loam, mod. compact, dry, no mottles, OM low - mod., roots freq., no worms, stones freq. (red siltstone, qtztic cong., green sst.).
20-30 cms	?A_2/C	Reddish brown (2·5YR 3/4) silty clay, compact, mod. moist, no mottles, OM low, no roots, no fauna, stones freq. - red siltstone, green sst. and green qtztic cong.
30+ cms	R	Blocks of qtztic cong. and frags. red siltstone, striking east-west.

Appendix 10

P83 - Soil Profile Description

Location	7965 1036
Topo-drainage Class	Transmitting (II)
"Parent Material"	Red siltstone (colluvium)
Altitude	38 m ± 2 m (125' ± 5')
Slope and Aspect	5°-10°, east
Land Use	Potatoes

0-20 cms	A_p	Reddish brown (2·5YR 3/4) stony silty clay loam, hard angular peds, mod. moist, no mottles, OM mod. - low, roots freq., occ. worms, freq. stones up to 2 cms. Boundary merging and regular.
20-34 cms	$?A_2/C$	Reddish brown (2·5YR 3/4) silty clay, more compact, mod. moist, no mottles, O M low, roots rare, fauna rare, occ. stones up to 5 cms. Boundary sharp and regular.
34+ cms	R	Soft green sst. - large blocky frags. up to 10 cms.

Appendix 10

P101 - Soil Profile Description

Location	8121 1031
Topo-drainage Class	Shedding (I)
"Parent Material"	? unsorted glacial/colluvium
Altitude	57 m ± 2 m (185' ± 5')
Slope and Aspect	5°, north
Land Use	Pasture

0-8 cms	A_1	Orange-brown (7·5YR 4/4) silty loam, small crumbs, mod. - loose tilth, mod. moist, no mottles, OM mod. - high, roots abund., occ. earthworms, stones rare. Boundary merging and regular.
8-23 cms	A_2	Orange-brown (7·5YR 3/4) silty loam, small crumbs, mod. compact, mod. moist, no mottles, occ. roots, occ. worms, freq. pebbles and cobbles of sandstone and basic volcanics. Boundary merging.
23+cms	C	Orange-brown (7·5YR 4/4) silty loam, compact, pebbles more common - mostly sandstone, with occasional red siltstone and some coal fragments.

P 102 - Soil Profile Description

Location	8096 1026
Topo-drainage Class	Shedding (I)
"Parent Material"	? unsorted glacial
Altitude	54 m ± 2 m (175' ± 5')
Slope and Aspect	5°, north
Land Use	Grass and cereal stubble

0-22 cms	A_p	Reddish brown (5YR 3/3) silt loam, small crumbs, mod. good tilth, mod. moist, no mottles, OM mod., abund. roots, freq. earthworms, freq. stones (yellow-weathering green sandstone and smaller rotted red siltstones). Boundary vague.
22-30+ cms	C	Similar to A_p but fewer roots and more stones - particularly green sandstone and red siltstone - in loamy matrix.

P 103 - Soil Profile Description

Location	8105 1016
Topo-drainage Class	Shedding (I)
"Parent Material"	Red siltstone
Altitude	55 m ± 2 m (180' ± 5')
Slope and Aspect	5°, south
Land Use	Pasture

0-20 cms	A_1	Reddish brown (5YR 3/4) silty clay loam, small crumb to irregular large peds, mod. compact, mod. moist, no mottles, OM mod., abund. roots, abund. earthworms, stones frequent - purple feldspathic fine sandstone. Boundary merging.
20-25 cms	A_2/C_1	Orange-red (7·5YR 3/4) silty clay, mod. compact, mod. moist, red mottles due to destroyed red siltstone fragments, OM low, no roots, no fauna, stones up to 1 cm (red siltstone). Boundary merging.
25+ cms	C_2	Larger fragments of red siltstone up to 4 cms "in situ".

Appendix 10

P 104 - Soil Profile Description

Location	8142 1037
Topo-drainage Class	Shedding (I)
"Parent Material"	? unsorted/water-sorted glacial material
Altitude	57 m ± 2 m (185' ± 5')
Slope and Aspect	5°, north
Land Use	Grass, and old potato crop

0-20 cms	A_p	Dark yellowish brown (10YR 4/4) clay loam, small crumbs, very good tilth, mod. moist, no mottles, OM mod., roots mod., occ. earthworms, no stones. Boundary fairly sharp.
20-45 cms	C_1	Dark yellowish brown (10YR 4/4) clay loam, slightly stony (coarse quartzitic sandstone) up to 5 cms, mod. crumbs, more compact, but still good tilth, mod. moist, no mottles, OM low, rare roots.
45-60+ cms	C_2	Light yellowish brown (10YR 2/4) loam, mod. to large crumb, more compact but still easy to work, mod. moist, OM low, no roots, no fauna, occ. stones.

P 105 - Soil Profile Description

Location	8174 1051
Topo-drainage Class	Shedding (I)
"Parent Material"	? unsorted/water-sorted glacial material
Altitude	46 m ± 2 m (150' ± 5')
Slope and Aspect	5°, south-east
Land Use	Pasture

0-18 cms	A_1	Slightly reddish brown (7·5YR 3/4) silty loam, small and medium crumb, mod. tilth, mod. moist, no mottles, OM mod., roots abund., occ. earthworms, stones frequent - up to 5 cms (quartzitic sandstone, quartzitic conglomerate, soft sandstone, red siltstone).
18-40 cms	$?B_w/C_1$	Yellowish brown (10YR 3/4) silty loam, more compact but easily workable, mod. moist, no mottles, OM low, occ. roots, occ. earthworms, freq. stones - varied sandstones.
40-55+ cms	C_2	Brown (10YR 4/4) silty clay loam, more compact but still workable, mod. moist, no mottles, no OM, no roots, no fauna, freq. stones - sandstones (as before).

P 122 - Soil Profile Description

Location	8006 0895
Topo-drainage Class	Shedding (I)
"Parent Material"	Red siltstone (sandstone phase)
Altitude	55 m ± 2 m (180' ± 5')
Slope and Aspect	5°, south
Land Use	Pasture - grass and clover

0-19 cms	A_p	Reddish-brown (5YR 3/3) stony, sandy clay loam, small and medium crumb, good tilth, mod. moist, no mottles, OM low - mod., abund. roots, freq. worms, abund. stones.
19+ cms	C	Large fragments of soft green sst. - rounded, in finer matrix.

PEDOGENETIC MAP
OF
SOUTH-WEST DYFED, WALES

1975 J.K. HORBACZEWSKI