Soil creep: a process study in Killhope basin, upper Weardale, northern Pennines, England

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SOIL CREEP : A PROCESS STUDY IN KILLHOPE BASIN, UPPER WEARDALE, NORTHERN PENNINES, ENGLAND

by

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To those brave people who don't live to die, but die to live;

To all who have fought to enable others to live without fear;

To all who have suffered often innocently and sometimes by their death for sincerely held beliefs.

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ABSTRACT

The object of this research is to investigate the rate of soil creep and its controlling variables at Killhope basin in Upper Weardale (Northern Pennines). The experimental work was designed to trace the movement of soil. Five sites were selected for study (three on peaty soils and two on mineral soils). at each site a set of four different instruments (an Anderson's tube, a Young's pit, wooden pillars and Rashidian's instrument) were used to measure creep rates for 18 months. To investigate which variables control this process, soil samples from sampling sites were used for quantitative analysis.

The results of this study indicate:

1. Annual linear rates of soil creep varied from 0.58 mm to 1.52 mm.
2. A strong relationship between creep rate and soil moisture content and its fluctuations.
3. Higher creep rates for organic soils than for mineral soils.
4. Non-exponential decline of rate of movement with depth.
5. No evidence for the influence of slope angle on creep rate.
6. The small differences in values recorded by different instruments show that the Rashidian technique was sufficiently accurate and useful for monitoring seasonal soil creep.

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CHAPTER ONE

BACKGROUND TO THE STUDY

1.1 Introduction

One of the remarkable aspects of planet Earth is the infinite variety of its surface forms which have provided a source of fascination for many explorers and scientists. The more it has been studied, however, the greater is seen to be the complexity of relationships between the land forms and their formative processes.

Geomorphology, as the scientific study of land forms, is concerned with the explanation of the varied morphology of the land surface, and its basic tenets are that morphological variations are not accidental or haphazard, but that patterns and processes can be identified. It is possible to understand and account for the various landform assemblages which have been described from various parts of the world. Although the necessity for the study of processes has often been stated throughout the history of the science (e.g. Chorley, Dunn and Beckinsale 1964, 1973), the record of achievement of the subject shows that until 1960 there was limited substantive investigation of processes by geomorphologists. Since 1960 there have been a number of approaches to, and trends within geomorphology. Increasing attention has been paid to the measurement of the landforms and the way in which processes may affect them. The major advance came with a series of U.S. Geological Survey Professional Papers, culminating in the publication of '<u>Fluvial Processes in Geomorphology</u>' (Leopold, Wolman and Miller, 1964). Dury (1969) recognized that great scope for applied work exists in the investigation and prediction of geomorphological processes and their effects. The necessity of understanding geomorphological processes has now been amply demonstrated in situations that involve such things as flooding, landsliding, soil erosion by wind or water, and deposition. Now, geomorphologists are increasingly realising the value of their work in the solution of applied problems, especially in the measurement and interpretation of both form and process, and their inter-relationships. However, it remains a fact that fundamental aspects of most processes are still not completely understood (Leopold, Wolman and Miller, 1964). This results from the shortage of data and the fact that varying processes interact in both space and time. Carson (1972), emphasised that understanding the changes and evolution of landforms demands ;

(a) The recognition of the nature of the processes on the land surface.

(b) An appreciation of the operation of the mechanism of the processes that are involved.

(c) An understanding of the way in which the process affects the form.

Monitoring and clarification of these three aspects will result in the advancement of the subject. It should not be forgotten that geomorphological processes never operate in isolation, but are generally part of a whole system of interacting phenomena.

As a result, there will remain many phenomena which should be researched to evaluate the results of process operation.

This thesis is especially concerned with the process of "seasonal soil creep", its rate and controlling variables.

1.2 The forces in hillslope processes

Hillslopes are usually covered with some sort of loose material. This may be derived from weathering or it may be material which has been derived elsewhere and transported to its current position. In order to understand how soil is transported, it is necessary to look at different types of force on hillslopes. All movement requires the application of a force which tends to change the state of motion of a body. The most important forces can be classified as:

a) Gravitational acceleration

Everywhere on the earth's surface, gravity pulls continually downward on all materials. Therefore, transfers of solid material take place within the drainage basin in a number of ways.

b) Water

Water is capable of exerting forces upon and within soils, which are important in transport processes. Water contained in the pore-spaces of a soil behaves in a number of ways. If the pore-spaces are not completely filled with water (i.e. the soil is unsaturated) then a suction force is exerted which tends to draw the soil grains more strongly together. If the pore-spaces are completely water-filled, that is the soil is saturated, the water exerts a pressure within the pore-spaces which tends to push grains apart.

Thermal changes - another source of force on hillslopes is due to expansion and contraction of soil grains, or of water within pore-spaces and cracks in bedrock or regolith. Expansion cycles may be caused by a number of mechanisms, all of which are related to climatic factors. Direct heating by the sun and cooling at night, or during winter, cause expansion and contraction. Also, water contained in pore-spaces in soils expands on freezing and contracts again when it melts. These may cause net shift of material.

c) Other forces

Plants, animals and human activity are able to exert forces on soils and can therefore be locally important.

1.3 Mass movement

The term 'mass movement' indicates the downward movement of material on slopes under the influence of gravity and other agents aided by the presence of rainwater or snowmelt. Mass movement as an important process in geomorphology has received increasing attention since 1950; before 1950 only a few systematic studies were made. Thornbury (1954) summarized the classification proposed by Sharpe (1938) as follows:

1. Slow flowage types:
   Creep - The slow movement downslope of soil and rock debris which is usually not perceptible except through extended observation. Soil creep, or scree creep, rock creep, rock glacier creep and solifluction are in this category.
2. Rapid flowage types: i.e. earth flow, mudflow and debris avalanche.

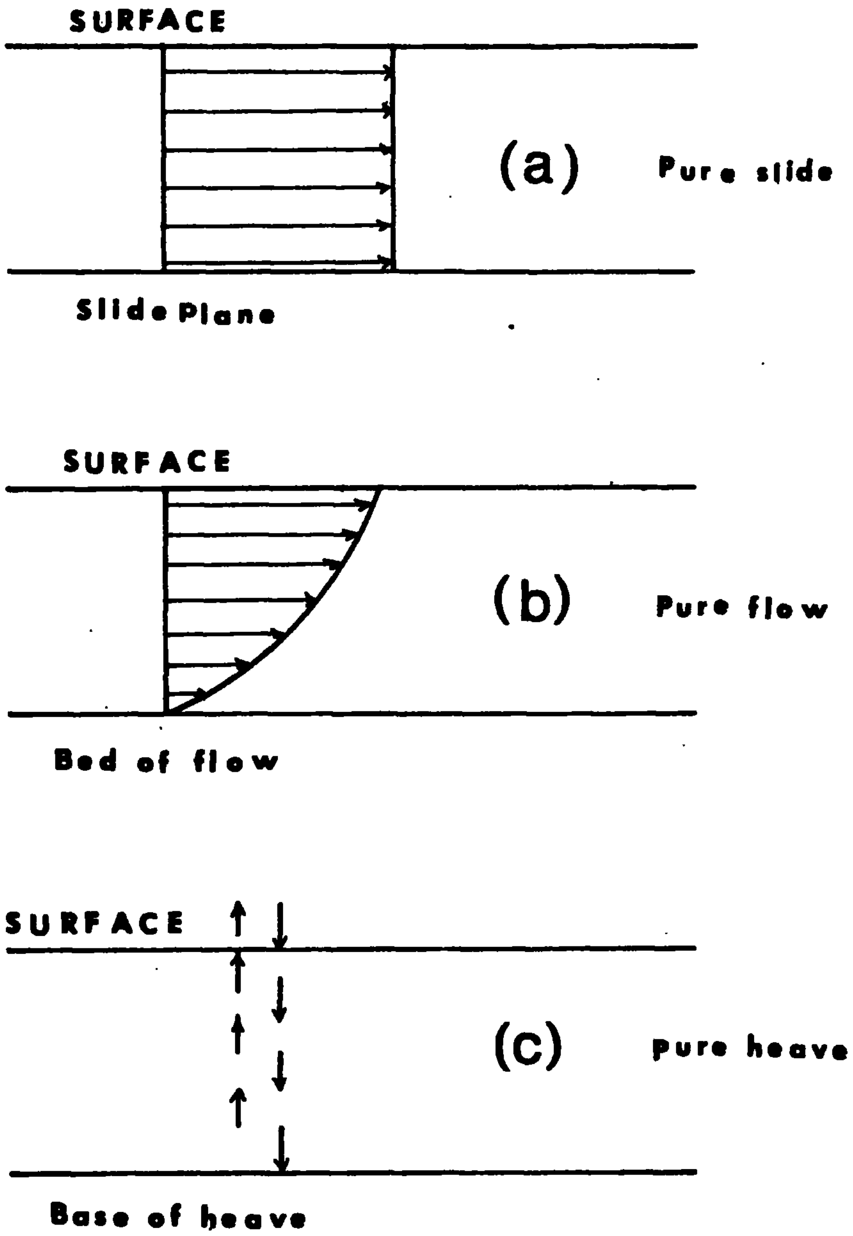

Fig 1—1 Velocity profiles for ideal mass movement

3. Landslides: Those types of movement that are perceptible and involve relatively dry masses of earth debris, i.e. slump, debris slide, debris fall, rock slide and rock fall.

4. Subsidence: Downward displacement of surficial earth material without a free surface or horizontal displacement.

Hutchinson (1968) also distinguished four types of mass movement phenomena, namely creep, frozen-ground phenomena, landslides and subsidence. In this scheme, type of movement depends on the size of particles, their condition, the extent of saturation, the vegetation cover, the gradient of slope, and climate. Carson & Kirkby (1972)(pp.99-101)classified mass-movement mainly in three types: a flow, a slide and a heave (Fig. 1.1). In a pure flow there is no sharply defined failure surface, but instead shear is distributed throughout the moving mass. At the base shear is usually at a maximum, but the velocity is very low and all the movement occurs as differential movement within the body of the flowing mass (Fig.1.1b). In a pure slide, resistance to movement drops sharply once an initial failure has occurred along a well-defined thin surface. The mass above the slide surface moves as a block with no internal shear (Fig.1.1a). Debris moves down the hillside until conditions (e.g. reduced slope angle) change to slow down and stop the moving mass.

The third type of movement is a pure heave, in which the soil expands perpendicular to the surface and subsequently contracts (Fig. 1.1c). This motion is not a lateral transport in itself, but provides the basic mechanism for some processes,

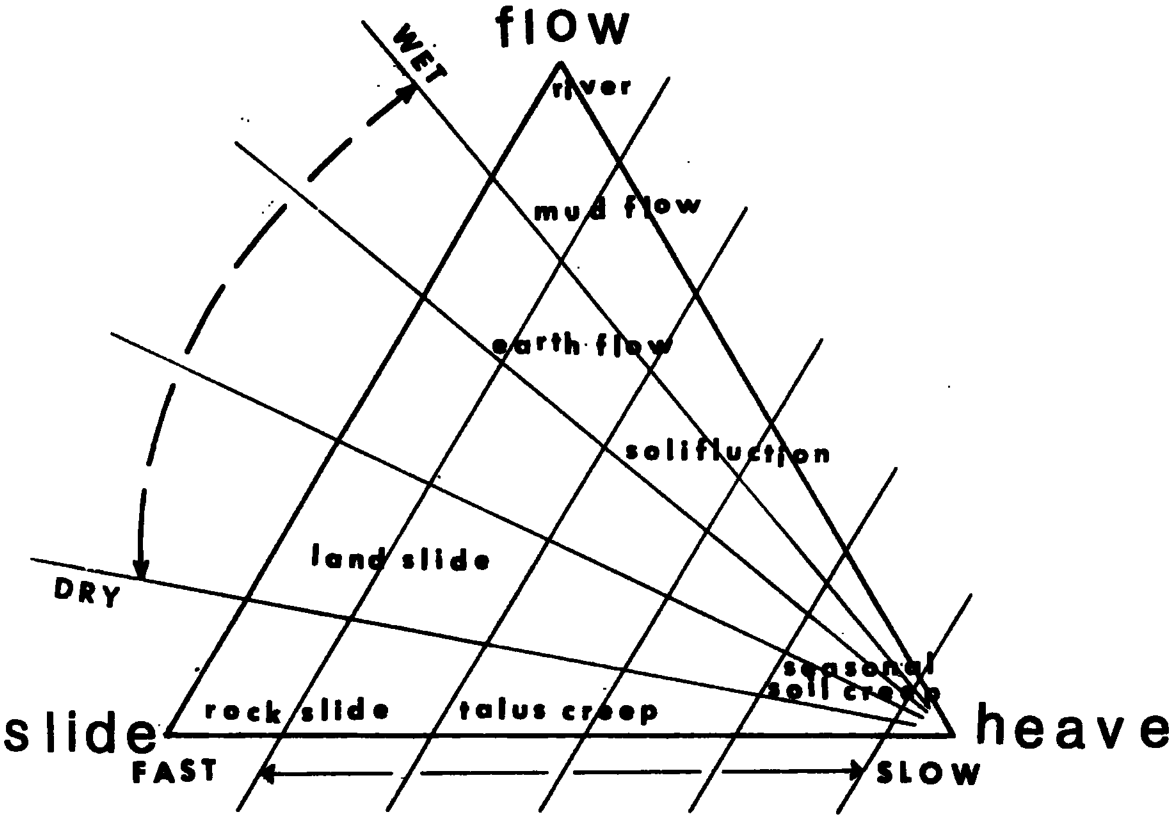

FIG 1-2 Classification of mass movement processes (Carson & Kirkby 1972)

especially seasonal soil creep, and acts as a trigger to more rapid movements, providing the last small contribution which finally overcomes the soil resistance.

However, actual mass movement processes are rarely, if ever, a pure flow, pure slide or pure heave, but are commonly a combination of the three, perhaps with some basal sliding, some internal shear, and some response to the triggering action of heaves. Thus, a triangular diagram (Fig.1.2) can provide a convenient basis for classifying by types of movement. The diagram can also be used to indicate varying rates of movement during transport, and to show the moisture content of the movement. Flows tend to be moist, and slides dry, while heave may be at any moisture content, so that a series of lines radiating from the 'heave' corner show relative moisture contents. Also, movements which are mainly flow tend to be rapid, whereas movements which are mainly heave tend to be slow.

Although many classifications of mass movement processes have been proposed by geomorphologists and engineers, such as that of Sharpe (1938), the most important and difficult problem facing these classification exercises is that essentially there appears to be continuous variation in the types of movement which occur. This limits the value of any division into discrete classes, and implies that the three-fold classification of Carson and Kirkby, which allows continuous variation to be stressed, is one of the most useful schemes in practice. However, there are several objections to the diagram.E.g no mention is included of falls or avalanches.

1.4 The mechanism of mass movement

It has already been stated that a force is an action tending to change the state of motion of a body. Most of the bodies with which we are concerned are soil particles or masses of soil moving as a single unit. An important point to understand about force systems is that they are always in equilibrium. That is, if a force is exerted on a particle there will be an equal and opposite force set up called the reaction (Fig. 1.3a). The force of gravity acting vertically tends to pull a boulder into the ground with a force which is the weight W. It does not do so because gravity is resisted by an equal and opposite reaction (R_w) within the ground. In this static case the reaction is the force maintaining the boulder in a stationary condition. In fact, even if the boulder were moving at a constant velocity, the reaction (R_f) would exactly balance the driving force (F) (Fig. 1.3b). This reaction is due to frictional resistance between the boulder and the surface (Finlayson B. & Statham, I (1980)(pp. 51-60). In the case of hillslopes, we require the analysis of forces acting on particles or masses of soil on sloping surfaces, which are tending to cause movement downslope. The main force, that due to gravity, does not operate directly down the slope but acts vertically. Consequently it is necessary to find how much of the gravitational force acts in the direction of slope. In the example of Fig.1.4a the force of weight acts vertically and is balanced by a reaction force (R_w). The force components acting on the boulder in two directions; parallel to the slope which tends to cause the boulder to move downslope, and normal to the slope which

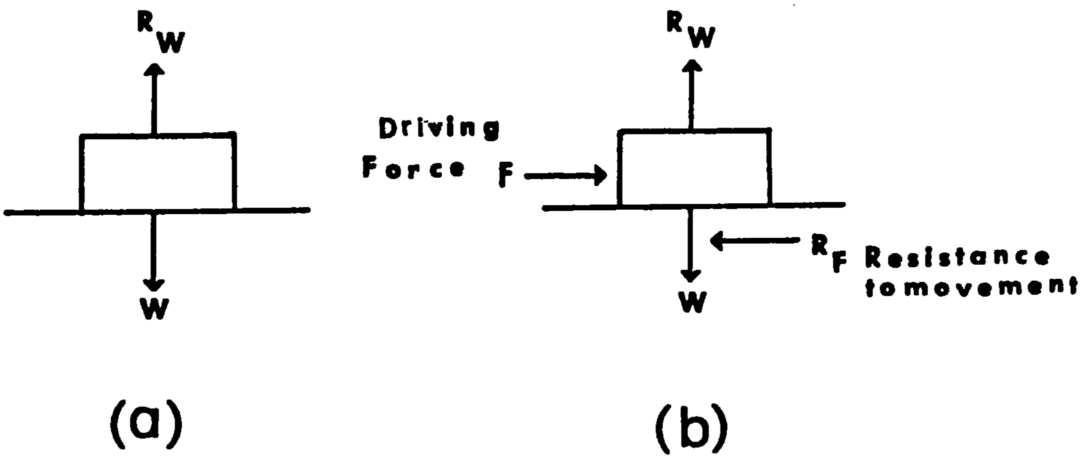

Fig. 1.3: Force systems acting on stationary and moving boulder

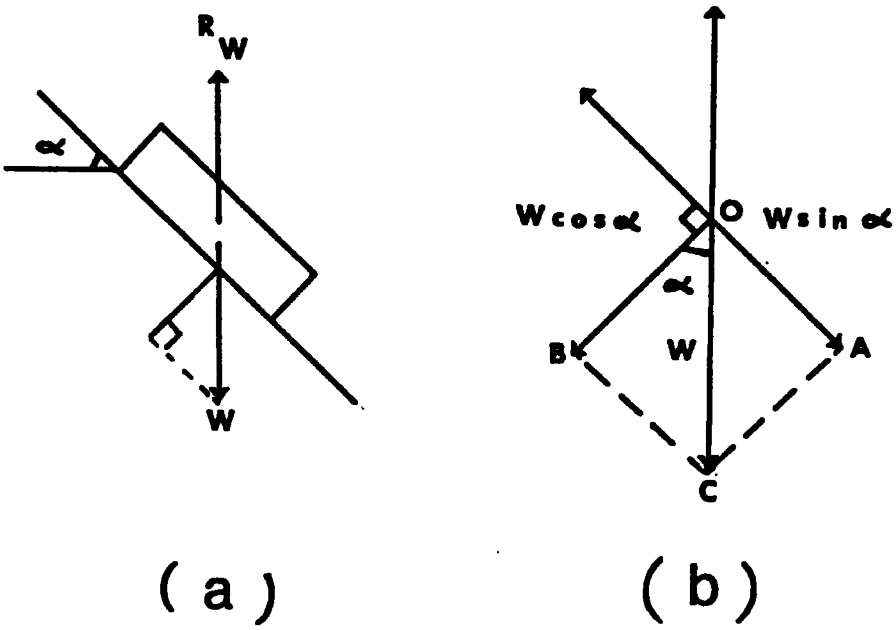

Fig. 1.4: Forces acting on a boulder resting on a slope

tends to keep the boulder static. The magnitude of these force components may be found geometrically by constructing a parallelogram and is drawn with length proportional to the weight of the boulder (Fig. 1.4b). If the diagram is drawn, the lengths of OA and OB are proportional to the magnitude of the force components, which can be found by measuring them. For slope angle α it can be seen that

$$OA = W \sin \alpha$$

$$OB = W \cos \alpha$$

Hence the downslope component of gravitational force is proportional to sine of the slope angle.

1.5 Soil creep

Soil creep has been discussed in the geographical and geological literature for at least 90 years : Davison 1889; Gilbert 1909; Sharpe 1938; Terzaghi 1950; Young 1958; Kirkby 1963; Everett 1963; Selby 1968; Kojan 1967; Owens 1969; Evans 1974; Anderson 1975; Fleming & Johnson 1975; and Finlayson 1976.

Two general types of creep i.e. seasonal or mantle creep and continuous, or mass creep were usefully distinguished by Terzaghi (1950). According to Terzaghi, the term mantle creep refers to the soil movements which occur within the zone of seasonal variations of temperature and moisture. The second main category of creep, mass creep, is due to the action of the force of gravity on the materials underlying slopes. Mass creep is due to the fact that the shearing stresses may produce slowly increasing shear deformations even in the event that their intensity is considerably smaller than the shearing resistance of the materials involved. Kojan (1967) has described the difference between creep and rapid mass failure as follows: "In contrast to the often spectacular final stages of a landslide, natural soil creep is a more or less continuous process in time and space. The terrain features usually called landslides represent the movement of a relatively small body of material with relatively well-defined boundaries, whereas creep may involve the ground beneath all slopes throughout a large region. In the case of creep, no sharp boundary usually exists between stationary and moving material."

Carson and Kirkby (1972, p.272) wrote that: "Soil creep may be caused by systematic reworking of the surface soil layers as soil moisture and temperature vary, by random movements due to organisms or micro-seisms among other causes, and by the steady application of a downhill shear stress." If movement is mainly due to the last of these agents, this can only concern permanent (deep) creep. Furthermore this will only occur if the shear stresses do not exceed the shear strength of the soil, as should it be exceeded, failure would of course result. It is also true that no soil creep will occur in the absence of some downhill shear stresses.

Hutchinson (1968) classified creep in three categories:

1. Shallow, predominantly seasonal creep;
    (a) Soil creep
    (b) Talus creep

This type of creep is largely confined to the weathered surface zone of fluctuating ground temperature and moisture content. Viscous movements contribute little to the net downslope creep.

2. Deep-seated continuous creep; mass creep. This type of creep can be expected to occur in all soils and rocks which are subjected to shear stresses in excess of the critical. It is probably the result of viscous movements and has a much lower order of magnitude than the other forms of creep mentioned.

3. Progressive creep. Creep movements of this type occur in slopes which are approaching failure. They are thus characterised by a stress level near to that at which failure take place and by gradually increasing and relatively high rates of movement.

From drained laboratory tests on clays, continuing, long-term creep (deep creep) is known to take place at stresses that are only a fraction of their peak strength (Bishop 1966). Clear field evidence of mass creep has yet to be obtained.

It can be seen that these definitions do not coincide exactly. However, it is generally accepted that:

1. Soil creep is a process of slow downslope movement and its results can become obvious over a long period of time.

2. Soil creep has been recognized as an important process in slope development, Young (1972).

3. Observations of tilt or displacement of fixed references suggest that the rate of soil creep can be sufficient to damage man-made structures.

4. Soil creep as a process results from the combined

action of several factors such as gravity, expansion and contraction resulting from changing temperature and moisture, and biological stress. Among these factors, gravity is essential and the others are possible aids.

However the knowledge of this process (cause, mechanism and rates) is still limited. Therefore, the study of this topic can be justified.

1.6 The process of soil creep

Soil creep is initiated by expansion and contraction of soil by heating and cooling, freezing and thawing, or wetting and drying. Volumetric expansion by any cause displaces particles toward the free surface of the expanding mass, or normal to the ground surface. On contraction, however, a loose particle is not pulled back into its former position, but settles with a gravitational component. It should be emphasised that expansion or heaving forces are not responsible for moving material downslope; they produce molecular stresses which lift material so that gravity can then exercise an influence. Such expansion forces can occur due to changes in moisture content, expansion of water on freezing, and effects of crystallization of salts in arid areas. Young (1972) classified the main agents of disturbance as follows:

I. Expansion and contraction due to temperature changes.

II. Expansion and contraction due to wetting and drying.

III. Freezing and thawing of soil moisture.

IV. Plant roots : growth, decay, and forces transmitted from swaying of vegetation in the wind.

V. Soil fauna : worms, moles and other burrowing animals, termites and micro-fauna.

VI. Volume changes on weathering, including loss of material in solution.

VII. Temporary increases in load on the soil surface : precipitation, animals.

Agents I to III operate through the heave mechanism; and agents IV to VII produce more irregularly distributed streses. Young (1972) also distinguished the inter-particle stresses which are the forces operating between particles. The inter-particle stresses are ultimately derived from gravitational, molecular, and biological stresses. To this classification we should add: VIII Microseisms. I - III are seasonal; V, intermittent; IV, VI and VIII, continuous creep. Further understanding of the processes of soil creep requires further information from field evidence, improvement and modification of instruments and measurement procedures and increasing the period of sample monitoring to acquire further data. However, cooperation between geomorphologists, soil engineers and geologists will produce the best results.

1.7 Mechanism of soil creep

To understand the mechanism of soil creep it is necessary to appreciate the principles governing mass movement. The need for such an appreciation of physical principles was first demonstrated by Davison (1889), and has been emphasised by Strahler (1952), and many others.

Davison (1889) considered that the expansion of soil during cycles of freeze and thaw would be exactly normal to the surface, but the subsequent contraction would be exactly vertical (Fig. 1.5a). This model of the downhill movement assumes a soil cohesion which is great enough to prevent completely any displacement parallel to the surface during expansion, but which is zero during the subsequent contraction of the soil. Kirkby (1967) modified Davison's theory and wrote that "Davison's practical experiments showed that, in a soil where ice needles were not present, the expansion was almost normal to the surface, but that cohesion caused the contraction movement to take a line intermediate in direction between the normal and the vertical (Fig.1.5b). The result of this zigzag movement will be to produce a net displacement in the soil parallel to its surface. This displacement tends to decrease with increasing depth, so that the net result appears similar to that which would be caused by a laminar shear, although the actual motion is more complex. This resultant relative displacement is referred to below as the "net shear". This theory can be used to predict the velocity profile which is to be expected in the ground, due to soil creep. The rate of net apparent soil shear is assumed to be proportional to the frequency of freezing and thawing multiplied by an expansion coefficient for the soil; consequently the rate is greatest at the surface and declines approximately exponentially with depth (Fig. 1.5c)." Kirkby also mentioned that Davison's analysis leaves out of consideration the forces which are tending to move the soil downhill. The only force present

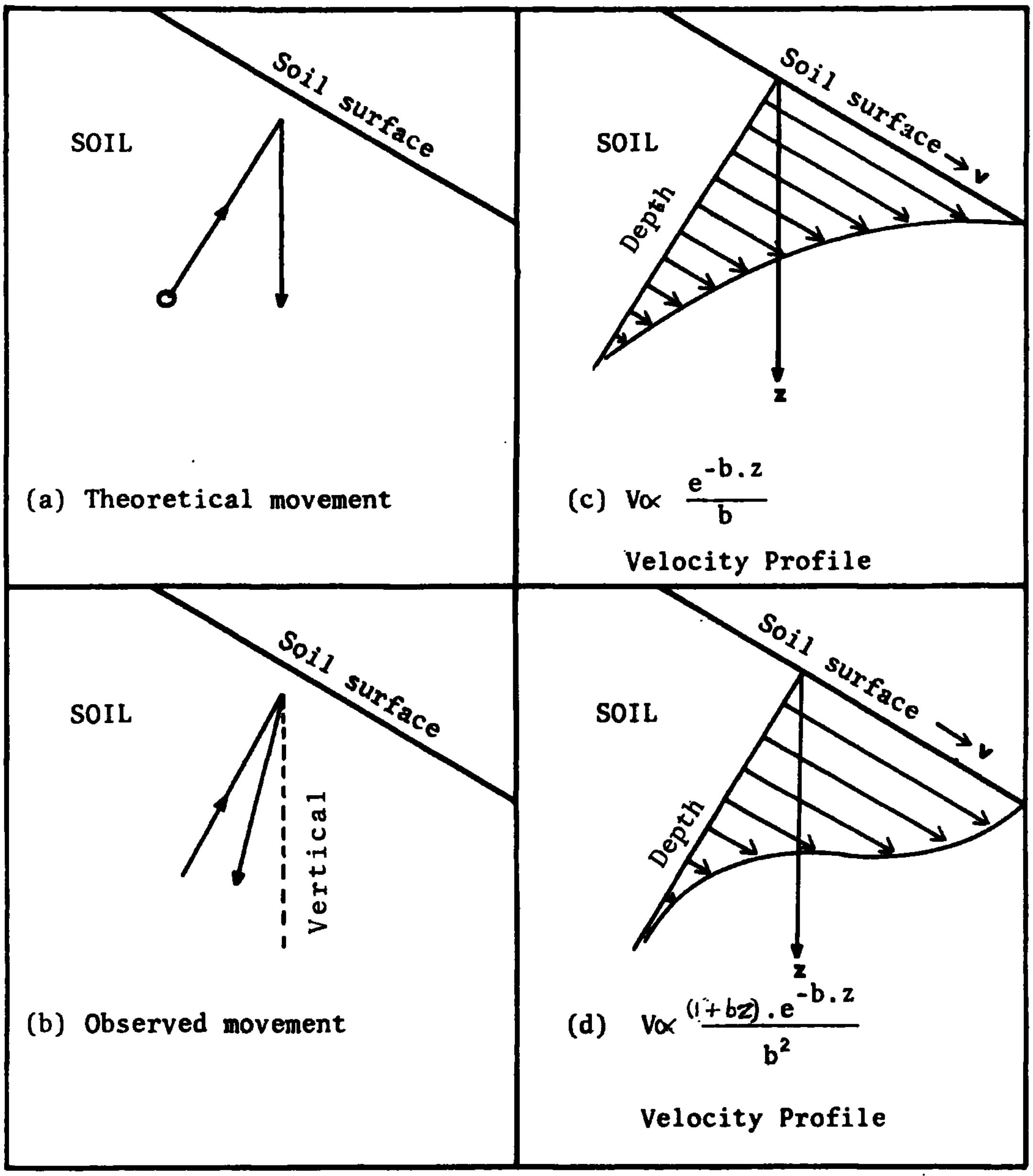

Fig. 1.5 : (a) Theoretical Path of a Soil Particle (after Davison);
(b) Actual Path of a Soil Particle (after Davison);
(c) Predicted Velocity Profile From Davison Theory;
(d) Predicted Velocity Profile From Kirkby Theory.

(Kirkby, 1967)

V = Downslope velocity
b = Constant
z = Depth vertically below the surface
e = 2.718

which is able to do this is the weight of the soil overburden. At the surface, there is no overburden and so the soil cannot suffer a net shear, even though the amount of movement normal to the surface is at a maximum. At great depth, the soil does not expand or contract so that there can be no net shear components, however great the overburden (provided that it is not great enough to initiate the conjectural deep creep). In between, at some finite depth will be a zone of maximum net shear rate, so that the velocity profile is qualitatively as shown in Figure 1.5d. Young (1958) wrote "the particles comprising a soil rest upon each other in a condition of equilibrium. When this condition is disturbed for any particle or group of particles they move into a new equilibrium with each other; the force of gravity gives a constant downward component to these movements, which is translated by the opposition of the sloping rock surface beneath the soil into a down slope tendency. Such inter-particle movements in time affect all parts of the soil, causing the process of creep."

Kirkby (1967) also wrote "according to the field evidence derived from workers' investigations in different areas, it has been proved that all features resulting from soil creep are due to the essentially laminar nature of creep. Each layer of soil is carried downhill by the motion of the layer beneath it, and the effect is cumulative, with the maximum rate at the surface exponentially decreasing to zero with depth. As a result, soil creep does not shear across immobile rock or soil at depth."

1.8 The rate of soil creep

Although creep is too slow to be observed instantaneously, the cumulative results become obvious over a period of years. However, as has been pointed out by several workers, creep operates on surficial material and its rate is thought to vary with such factors as depth, texture, slope angle, soil moisture and temperature. Young (1960) wrote that "the gravitational force is vertically uniform over the earth's surface, therefore, the rate of soil creep may be expected to vary with the sine of slope angle and magnitude and frequency of disturbances to individual particles." On the other hand, Anderson and Cox (1981), and others, have found that sine of the slope angle is a very weak control by comparison with other variables such as soil moisture conditions. It seems that in field studies, both measurement of the rate of creep, and monitoring of a widespread range of influential factors are desirable.

1.9 Methods of measuring soil creep

Measurements are required to demonstrate the type of processes operating to indicate how effective the processes are, and to give the basis for an understanding of how processes operate.

With the exception of creep produced as a diffusion process (Culling, 1963), movements involved in soil creep are thought to be mass movements, that is to say the soil moves together and neighbouring soil particles remain close together throughout the movement.

In an ideal measurement, therefore, a column of soil is identified initially with reference to fixed points; and its position is remeasured periodically. In practice it may be impossible to reach bedrock at the base of a measurement profile. But it is assumed that on average creep movement dies away with depth, so that the lowest part of a measured profile is assumed to be static. However, many investigators tend to use simple techniques with relatively large numbers of replications, and to continue the measurements for relatively long periods to offset any resulting loss of sensitivity. One of the first steps in attempting to measure and understand the rate of soil creep is the accurate measurement of soil deformation as a function of depth. In this connection, the work of Young (1960), Kirkby (1963), Kojan (1967), Evans (1974) and Anderson (1977) is prominent. For this, several techniques have been used to measure soil creep in the field: e.g., tilt bars (T-bars), Young's pit, pillars, Anderson's tubes, Anderson's Inclinometer, and Selby's cones. Each technique and instrument has some advantages and limitations. This will be detailed in Chapter two.

1.10 Programme of study

Understanding the mechanisms of the soil creep process and measuring its rate in relation tothe factors and agents which are involved requires using several methods and instruments, because there is as yet no standard method or technique for this purpose. The approach used here involved selecting five sampling sites in upper Weardale, using four selected techniques suited to short or long time periods, comparing the results from a number of instruments and designing a new technique to acquire a profile of the rate of soil movement in relation to depth. In addition to a programme of field work, laboratory studies are necessary to determine the differences in material properties.

This programme includes the following aims:

a) To separate the factors controlling soil creep and assess their relationships.

b) To explain the process and rates of soil creep in the study area (Killhope basin).

c) To compare results from selected techniques and instruments in the study area.

d) To determine the effect of variables controlling creep rate.

e) To compare results with other workers working at similar environment.

A summary of this research is shown in Figure 1.6.

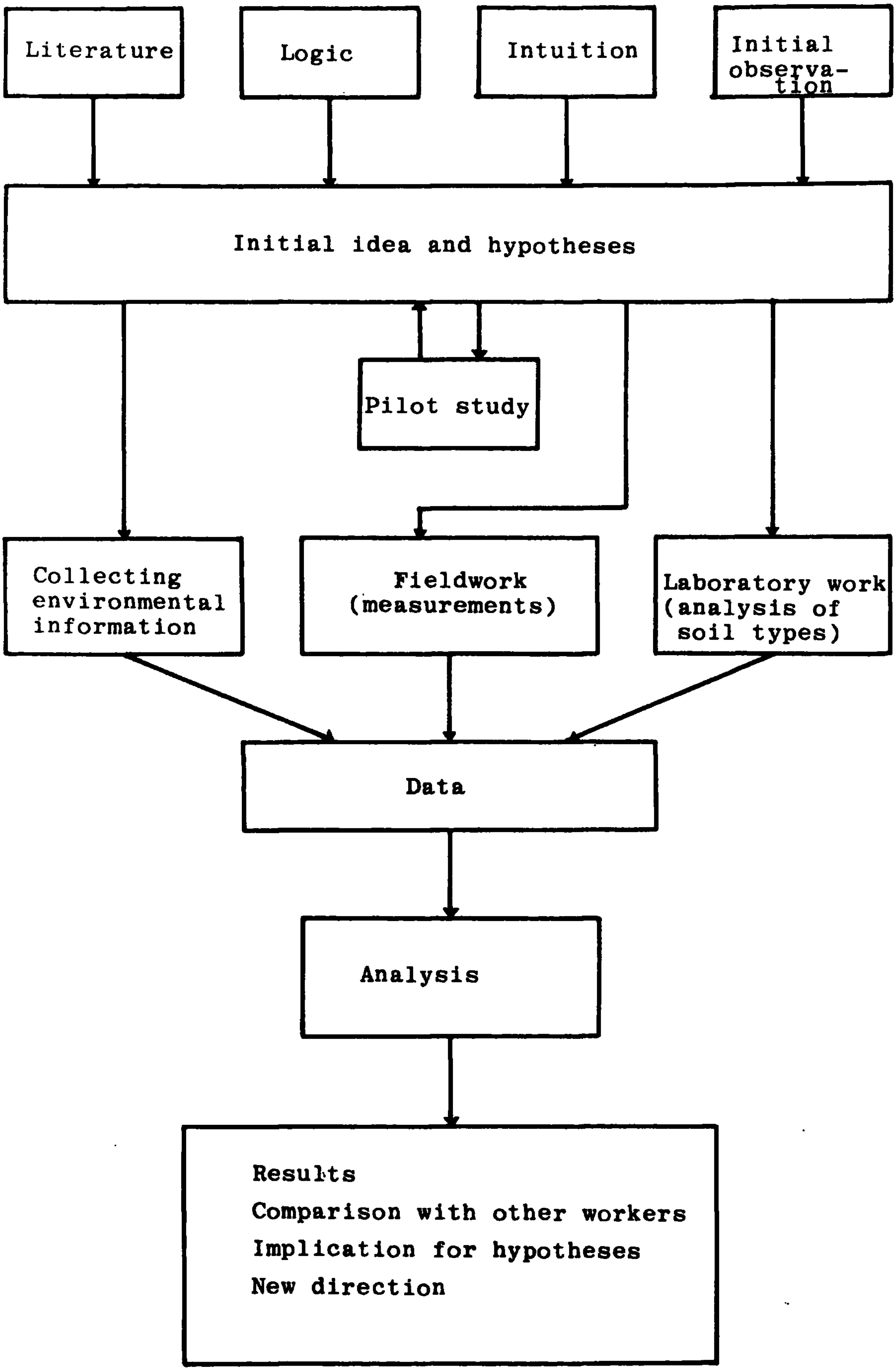

Fig. 1.6: Research design diagram.

CHAPTER TWO

TECHNIQUES AND INSTRUMENTS FOR MEASURING SOIL CREEP

2.1 Introduction

2.2 Instruments which measure extremely accurately

2.3 Instruments which magnify and measure the changes

2.4 Instruments which measure in the long term

2.5 Techniques and instruments selected for this study

- 2.5.1 Aim of selection
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CHAPTER TWO

TECHNIQUES AND INSTRUMENTS FOR MEASURING SOIL CREEP

2.1 Introduction

Soil creep is a hillslope process, operating very slowly; it is therefore difficult to measure. In spite of attempts by many experienced workers to establish the best technique for measuring the rate of soil creep (e.g. Kirkby, 1967; Evans, 1967; Selby, 1968; Young, 1972; Fleming, 1973; Finlayson 1981; Anderson & Finlayson, 1975), there is not yet a standard method of investigation. This uncertainty can be overcome in a number of ways, e.g. by using a set of instruments which can measure creep over both long and short periods of time. Increasing emphasis on the quantitative study of soil creep requires the wides possible use of accurate instruments to measure the rate of movement and the control factors involved.

All the techniques and instruments, however, have their own advantages and limitations. As far as the aims of this study are concerned only some of them can be selected. Classification of techniques and instruments makes this selection easier. Anderson and Finlayson (1975) classified these techniques and instruments according to their specifications and applications, and most of them have been described in detail by Anderson (1977).

The methods and instruments which have been used in this study will be described in detail, and furthermore, some of the advantages and limitations of other techniques and instruments will be summarized as a background for justifying the reasons for the selection.

2.2 Instruments which measure extremely accurately

The most common instruments falling into this category are : Fleming's Tiltmeter System, S.G.I. Rod Inclinometer, Linear motion transducers and strain gauges. The main advantages and limitations of these are:

a. Advantages

- They are sufficiently accurate to be useful for special purposes.
- Using these instruments not only can soil movement be measured as a function of depth (Fleming's tiltmeter system and S.G.I. Rod Inclinometer) but also a continuous record can be made of movement, allowing the results to be interpreted in relation to other continuously recorded variables such as soil moisture and temperature (Fleming's tiltmeter system and linear motion transducers).

b. Limitations

- These instruments are relatively complicated and their construction must be carried out in an instrument work shop.
- They are costly and not available on the open market.
- Measurements are taken using several devices which can be operated only by experienced workers.
- Replacements are not easy, and thus they cannot be used in extensive studies.

- Finally, as the instruments need to be left in the field, there is a great risk that such expensive devices will be stolen, disturbed or destroyed.

For these reasons none of the instruments in this category has been chosen for this study.

2.3 Instruments which magnify and measure tilt

The instruments falling into this category are: Kirkby's "T" Pegs, Evans' "T" Bar, and Anderson's Inclinometer. These instruments are relatively sensitive and accurate. The basic idea of these instruments is to measure the tilting of the pegs inserted in the soil with either a sensitive spirit level placed on the pegs, an inclinometer, an Abney level, or some other suitable equipment. The main advantages and limitations for this category are :

a. Advantages

- They are simple to use, easy to read, replicable and cheap.
- Readings can be repeated for a long term as the peg position remains unaltered.

b. Limitations

- If the rate of soil creep decreases with depth approximately in a negative exponential manner (Young, 1972), readings of tilt from rigid bars or pegs will be inadequate. Thus for research to be satisfactory these instruments should be supplemented by a number of other instruments or techniques which produce a profile of movement with depth.

- To prevent any alteration in the peg's position as the inclinometer is placed over it, great care is required. Otherwise, there will be a tendency for the peg's movement to be affected by the inclinometer when the housing is tightened on the peg and the reading scale is adjusted.
- Finally, the major difficulty arises in locating the point about which the peg pivots.

2.4 Instruments which measure in the long term

The most common instruments and techniques falling into this category are : Boreholes, Pillars, Selby's cones, Young's pits, Cassidy's tubes, Anderson's tubes and painted rocks or markers. The methods and devices in this category have many advantages and some limitations. Although most of these techniques are simple, inexpensive and easy to use, they also have disadvantages which render them unsuitable if they are used in isolation. The Borehole technique provides a velocity profile of soil movement with depth, but it is useful only over long periods of time. Furthermore, disturbance of the soil during excavations is probable.(Fig.2.1b).

Pillars can be employed widely to obtain transects without serious limitations. They reflect bodily movement and are more useful in comparison with the other instruments (Fig. 2.1a).

Selby's Cones provide an absolute movement and velocity profile, but great problems arise during installation and

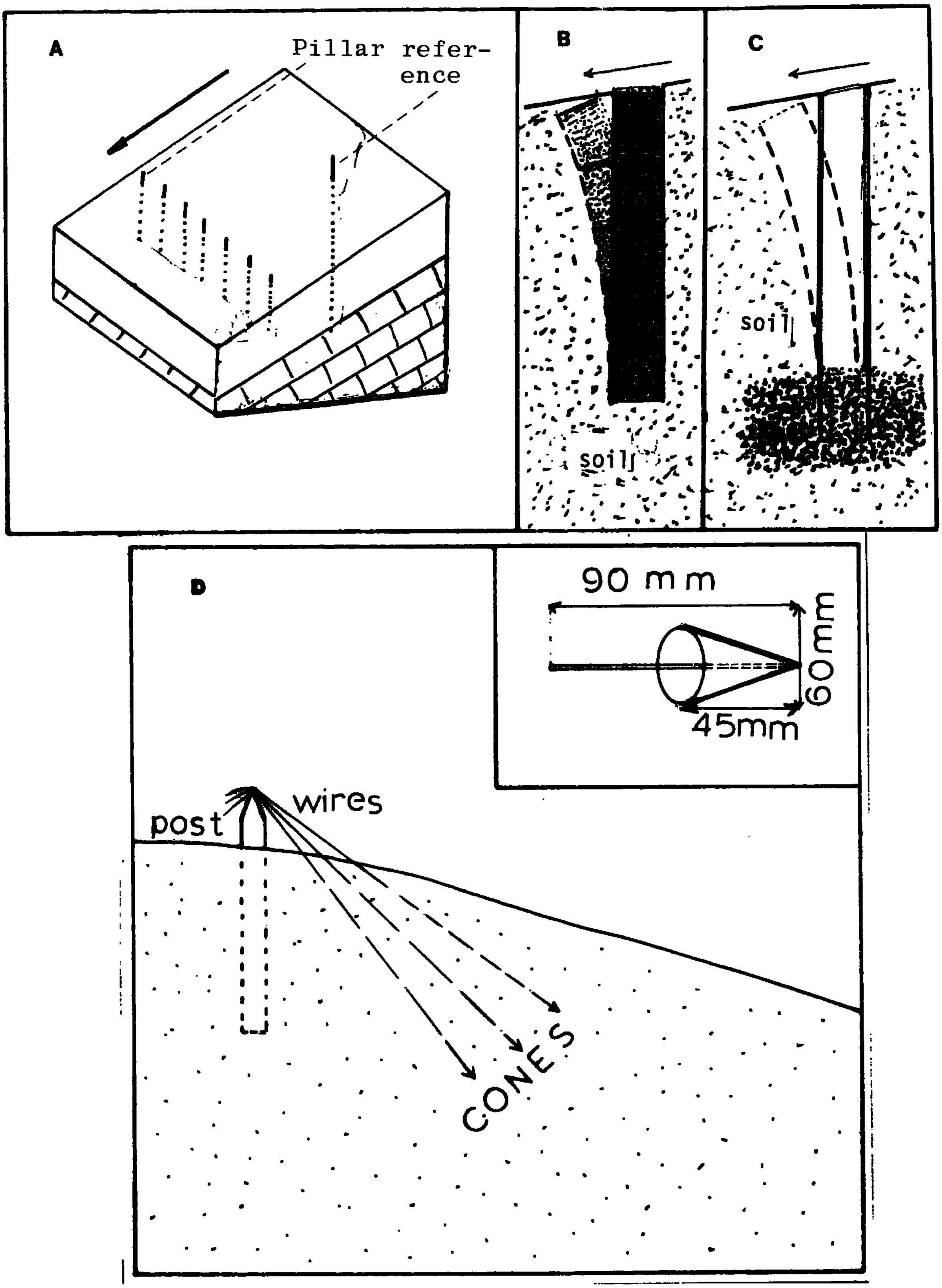

Fig. 2.1 A : Pillars, B : Boreholes, C : Flexible tube, D : Selby's cones.

reading (Fig.2.1d). The painted rock technique is simple and reading is easy and very fast, but inaccurate as an estimate of soil movement. The great advantages of the Young's pit method are that the measurement is direct and both horizontal and vertical movements are observed, but disturbance of the soil during excavation is likely and it should be read over a long time period.

Anderson's tube is very simple, easy in use and both angular and bodily movement can be measured, but it cannot provide a profile of movement with depth.

For the above mentioned reasons, it is therefore logical to use a number of these instruments together in any one plot. They thus provide sufficient data, and each can be regarded as a control for the others.

2.5 Techniques and instruments selected for this study

2.5.1 Aim of selection

It has already been stated that there are several suitable tachniques and instruments for measurement of soil creep with their own particular advantages and limitations.

The main points considered in the selection of techniques and instruments were:

a) To measure the rate of soil creep when it is required for either a short or a long period of time.
b) To produce a velocity profile of movement with depth.
c) To measure both mass and angular movements.
d) To be satisfactorily accurate, easy to use, cheap and replicable.

With such ideas in mind the following techniques and instruments were selected:

i. Young's pit method

This method has been used and modified by several workers including Emmett (1965), Leopold (1962), Kirkby (1967), and Anderson (1977). The basic idea is one of the most common options: the profile of the rate of soil movement with depth over a long period of time.

ii. Wooden pillars technique

This technique was applied using three different lengths of wooden pillars (50mm, 100mm, 150mm) along a contour line. Each pillar was measured from the appropriate fixed point which is an iron rod inserted into the soil. The results obtained from these measurements can produce a profile of movement with depth.

iii. Anderson's tubes

This technique was adopted in widespread sampling plots in each selected sample site.

iv. Rashidian's technique

This technique was designed during the pilot study in 1980, and was modified for this study.

2.5.2 Procedure

The procedure adopted was:

a) Observation of the study areas and selection of five sites with varied characteristics for instrumentation.

b) Establishing a collection of selected techniques at sampling station for each selected characteristics (Plate 2.1).

Plate 2.1 Instrumentation of control station

c) Application of a number of Anderson's tubes (p.41) in various conditions for each characteristic, such as differences of vegetation, soil material, slope angle and altitude.

d) All samples were plotted in five groups.

2.6 Techniques selected

2.6.1 The Young pit technique

The Young pit was first used by A. Young (1960). The following description is of the pits used for this study. A pit was dug as deep as possible into the soil, with a vertical face running along a line of the steepest slope for a horizontal distance of about 0.4m. A number of 1mm diameter steel wires 70mm long were inserted into the wall face, each placed at right angles to the face using a sheet of transparent plastic with a range of holes at 20mm intervals (Fig. 2.2). The sheet of transparent plastic permitted the wires to be placed at the same interval. A plumbline was hung close to the wall face and over a steel rod which was inserted vertically into the bedrock. Then the distance between the tops of the wires and the plumbline was measured and plotted. When the measurements had been completed, the face was covered with a sheet of flexible transparent plastic, and the hole was refilled, taking great care to avoid disturbing the face being measured.

Last, the refilled pit and measurement face site were marked, using some pieces of coloured plastic fixed by means of thin wires along the line of the wall to assist the location of the wall face for eventual re-excavation. Because of

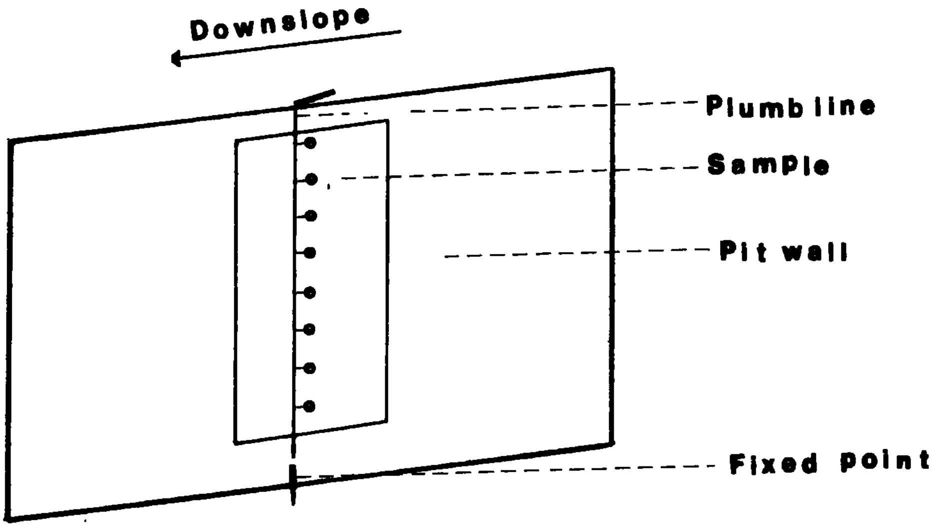

Fig. 2.2 : General view of buried wires. (Young's Pit method).

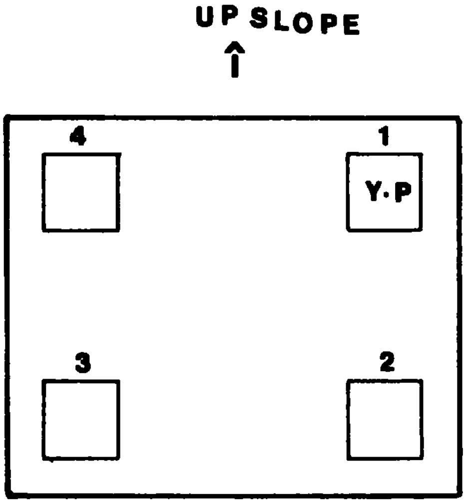

Fig. 2.3 : Layout of circular sampling for Young's Pit method.

disturbances to the soil including changing its density through excavation, it is best to excavate each Young's pit only once.

ii. Reading

To obtain a reading the pit should be carefully re-excavated. Using a protruding stake a plumb line is suspended centred on the controller rod, and the difference between the new and the original figures is a direct measurement of the net differential shear between the wires. Absolute values for downslope translation can only be assured if the bottom wire is secured in bedrock, and this is not normally practicable. For the pits in this study, the depth of the bottom wire varied between 0.3 and 0.4m. The accuracy claimed for this approach varies; Young (1960) 0.8mm, Emmett (1965) and Anderson (1977) 0.25mm.

iii. Advantages and limitations

The advantages of this method are:

a) The measurement is direct and therefore unambiguous.

b) Both horizontal and vertical movements are observed.

c) Since the wires are buried they cannot be disturbed and they can be left for a long period of time.

Limitations

a) Disturbance of the soil during excavation, refilling and re-excavation.

b) Concentration of moisture could occur in the reconstituted soils, and as moisture is postulated as a major cause of creep, this could lead to serious errors (Anderson 1977).

c) If the excavation is done with sufficient care, the measurement site is subject to no more outside disturbance than the surrounding ground. However, this proviso can never be guaranteed; there is always some risk of disturbance (Kirkby 1967).

d) The method cannot give results of much meaning in very open soil close to the surface, where the wires are not securely held by the soil and almost all methods break down.

iv. Conclusion

In spite of some great advantages, the use of this technique involves some problems including the disturbance of natural soil or regolith conditions caused by the apparatus and the relocating of markers or pits; also it is limited to studies of either long term movement, or unusually fast movement. The problem of reading limits could be overcome if circular sampling in a plot is adopted.

The procedure can be as follows:

a) Using a 0.1 x 0.1m grid, 4 sample points in 4 corner sites are determined.

b) The determined sample points are marked and numbered in clockwise direction (Fig. 2.3).

c) The samples are established in each point in such a way that while one point is being established no other point is disturbed.

d) After a pre-determined period of time has elapsed (1-2 years), one of the samples is chosen at random and re-excavated carefully. To avoid disturbance the lower samples should be re-excavated first.

e) The results of the readings are recorded on a relevant plot.

In this way one of the main limitations of Young's pits could be overcome.

2.6.2 Modified pillar technique

i. The basic ideas in this technique are similar to those of ones adopted by Kirkby (1967), Emmett (1965) and Anderson (1977). The technique is very simple and comprises:

a. A 0.5m long sectional aluminium sampling gauge with three holes of10mm diameter in the middle for the fixed rods and three semi circular holes of 10mm diameter in the leading edge to define the starting places of the movable rods.
Two sets of spirit levels are fixed on the gauge to ensure that the gauge is horizontal when it is required.

b. A series of steel rods 0.6m long and 10mm in diameter which are used as fixed points. The distance between these rods is 0.2m.

c. A series of 60mm, 110mm and 160mm long hard wooden rods 10mm in diameter which are used as movable rods (Fig. 2.4).

ii. Field procedure

1. The aluminium sampling gauge is placed in the ground along the contour. Then three steel rods are inserted through the holes, into the soil, so that each rod acts as a fixed point.

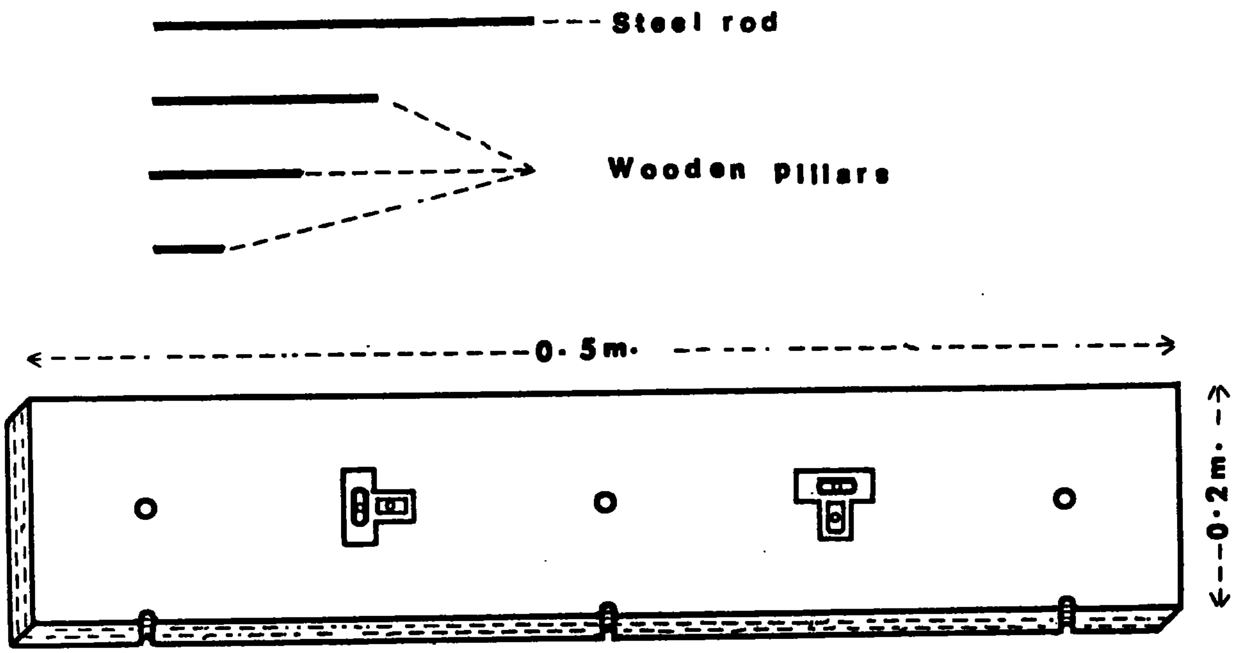

Fig.2-4 Modified instrument for pillar technique

2. Three hard wooden rods are inserted through the semi-circular hole into the soil as movable points.

3. The initial distances between each steel rod and the corresponding wooden rod are accurately recorded.

4. This action is repeated as a transect along the contour as far as is required.
Any changing in the position of wooden rods can be measured from the fixed points (steel rods).

iii. Advantages

a. This technique is simple, and the equipment is cheap and replicable.

b. Using the aluminium sampling gauge as a controller helps to establish all the fixed points along a straight line.

c. Readings can be taken at any interval of time or when they are required.

iv. Limitations

a. Soil is disturbed during the installation of the rods.

b. The parts of the rods protruding above the ground make them vulnerable to disturbance.

c. Measurements require more precision to avoid error, especially when a Vernier calliper is used.

d. This technique cannot represent the rate of movement with depth.

v. Conclusion

This technique is very simple and can be used easily, but because of its limitations defined above it can be used only as one of a set of instruments. An accuracy of 0.25mm has been claimed for this method by Miller and Leopold (1963). Using this modified method and using a Vernier calliper for measurement an accuracy of 0.1mm can be attained.

2.6.3 The Anderson tubes

This technique was designed by Anderson to record both the bodily and angular movement produced by soil creep, thus overcoming one of the limitations of Kirkby's pegs and Evans' "T" Bars.

Because of the author's close acquaintance with Anderson's tube and the advantages of this technique it was adopted, with a slight modification, as one of the instruments for sampling.

The following descriptions are taken mainly from Anderson (1977) :

The principle is that the steel rod inserted into the rock acts as a fixed point about which the tube moves.

i. Equipment

a) The tube

An 0.2 - 0.3m length of 59mm internal diameter plastic tube with two small holes 25 mm apart, 25mm from the top end. The thickness of the tube wall is 2mm.

b) The rod

A 10mm diameter steel rod 0.6m long, with one end sharpened, acts as a fixed point.

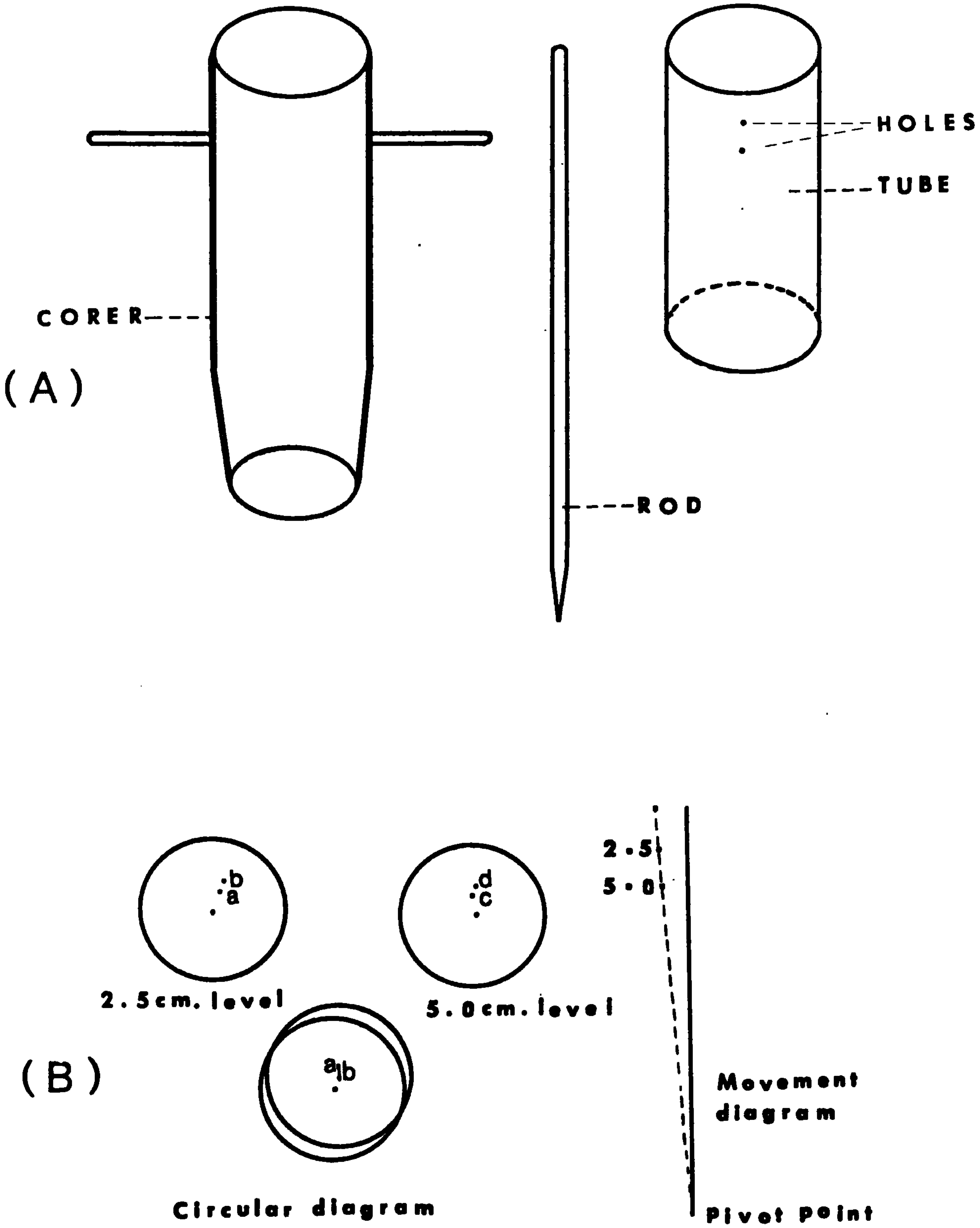

Fig.2-5 Anderson's tube

ii. Procedure

a) A bore hole is dug by means of a sharpened steel pipe* (Fig.2.5A). The depth of the bore hole varies with soil thickness.

b) A plastic tube of suitable length is slid gently into the bore hole so that the small holes in the tube identify the upslope side. About 5.0cm of the tube protrudes above the ground.

c) The steel rod is placed in the centre of the tube and driven into the rock below until its top is level with the upper edge of the plastic tube.

d) Prior readings are taken by measuring the distance of the rod from the top edge and the small holes on the tube (Fig. 2.5A).

iii. Measurements

In taking readings, one arm of a pair of inside Vernier callipers is held against the top edge of the plastic tube and the callipers are extended until the other arm just touches the rod. The width of the calliper arm is read to 0.1mm using the Vernier scale. This procedure is then repeated for the other points (two small holes made in the tube, 25mm and 50mm from the top edge of the tube as marked points.

iv. Analysis

The reading for each level is plotted on a separate circular diagram (Fig.2.5B) a circle of 5.9cm diameter with the centre and the reference points marked (0.0, 25, 50mm). Also required are a pair of compasses and a transparent

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* A sharpened steel pipe is used with the same diameter as the plastic tube for digging the bore hole.

overlay on which is drawn a circle of radius 5mm with its centre marked.

a) From each reference point an arc is drawn inside the circle, the radius being equal to the measurement from that point.

b) The overlay is placed on the diagram so that its circle is tangential to the arcs and its centre spot is marked on the diagram. This is the position of the centre of the rod.

c) The readings for the other level taken on the same date as the above are plotted on a diagram and the position of the centre of the rod is found.

d) The apparent distance the rod centre has moved is measured for each level and the two readings are plotted at the appropriate level on the movement diagram.

Subsequent readings can be plotted in the same way, the apparent movement being measured from any previous rod position. However, it is assumed that the movement is in the downslope direction so that the tubes are centred on the same movement diagram as the readings which have already been plotted.

v. <u>Advantages and limitations</u>

The advantages of Anderson's tube are that :

a) It is cheap to make and simple to use.

b) It is accurate to 0.1mm.

c) The pivot point can be found.

d) Both angular and bodily movement can be measured.

e) An overall picture of movement can be obtained.

f) Readings can be repeated if necessary.

The main limitations are :

a) Disturbance to the soil caused by insertion.

b) Protrusion of a part of the tube above the ground makes it liable to be disturbed by animals or other agents.

c) It cannot provide a profile of movement with depth.

However, this technique is useful particularly when combined with other techniques which provide the variation of soil movement with depth.

2.6.4 The Rashidian technique

a. Introduction

It has been recognized that soil creep is essentially laminar and each layer of soil is carried downhill by the motion of the layer beneath it (Young 1958; Kirkby 1967; Bloom 1978; Derbyshire et al. 1979). Also it is emphasized that the rate of movement varies with depth. However, the main points of significance in studies of soil creep would seem to be a facility for producing both an absolute movement and a profile of velocity with depth.

Approaching this subject several techniques have been designed such as Young's pits, dowelling pillars, and bore holes. All of these possess some advantages but also some limitations and a great number of problems remain to be solved.

However, few techniques are able to record the absolute rate of movement and velocity profiles with depth. In this category, the Young pits technique has been widely utilized (Young, 1958; Kirkby, 1967; Owens, 1969; Anderson, 1977). However, it should be remembered that this technique can only be used for long period readings and only one reading can be provided. Also, disturbance of the natural soil during re-excavation is great. Therefore, it was decided to design a new technique for overcoming some of these problems. The technique ought to satisfy the following criteria:

i. To measure over long and short time scales.

ii. To produce an accurate reading of movement and a velocity profile with depth.

iii. To be inexpensive and replicable.

iv. To be easy to operate and take readings.

v. To provide readings without any disturbance to the natural soil, or the equipment.

This technique was designed after a pilot study in an attempt to work towards studies of soil creep, and it has been developed during instrumentation of the main study area at Killhope in Upper Weardale.

It was initially tested at the University Observatory in Durham City for six months with generally satisfactory results.

In order to test the validity and accuracy of the Rashidian Technique a pilot study was undertaken. The results showed movement due to soil creep in a range from 0.2 - 0.5 mm which agrees well with the measurements from the

Anderson Inclinometer and Anderson's tube techniques similarly tested over the same period.

The close agreement of the Rashidian technique with established techniques such as Anderson's Inclinometer and Anderson's tube in this controlled pilot study shows that some confidence can be placed in this technique and it is worthy of further investigation.

b. <u>Equipment</u>

The equipment consists of six parts (Fig.2.6, Plate 2.2):

i. An aluminium sampling gauge divided into three sections.

ii. A steel corer for various depths.

iii. Steel rods.

iv. Wooden blocks.

v. Metal wires.

vi. Plastic tubes.

1. The length of the sectional sampling gauge is 1.59m and it is 13mm thick. It can be separated into three sections. Each section has three sample holes 25 x 25mm to allow the vertical insertion of the sampling devices. The distance between the holes is 175mm.

The sections can be fixed together by locating pins and side fasteners secured by wing nuts. When placed on the ground, the gauge is held in place by three vertical steel rods which pass through three 1.0cm diameter locating holes, one on each end and one in the centre.

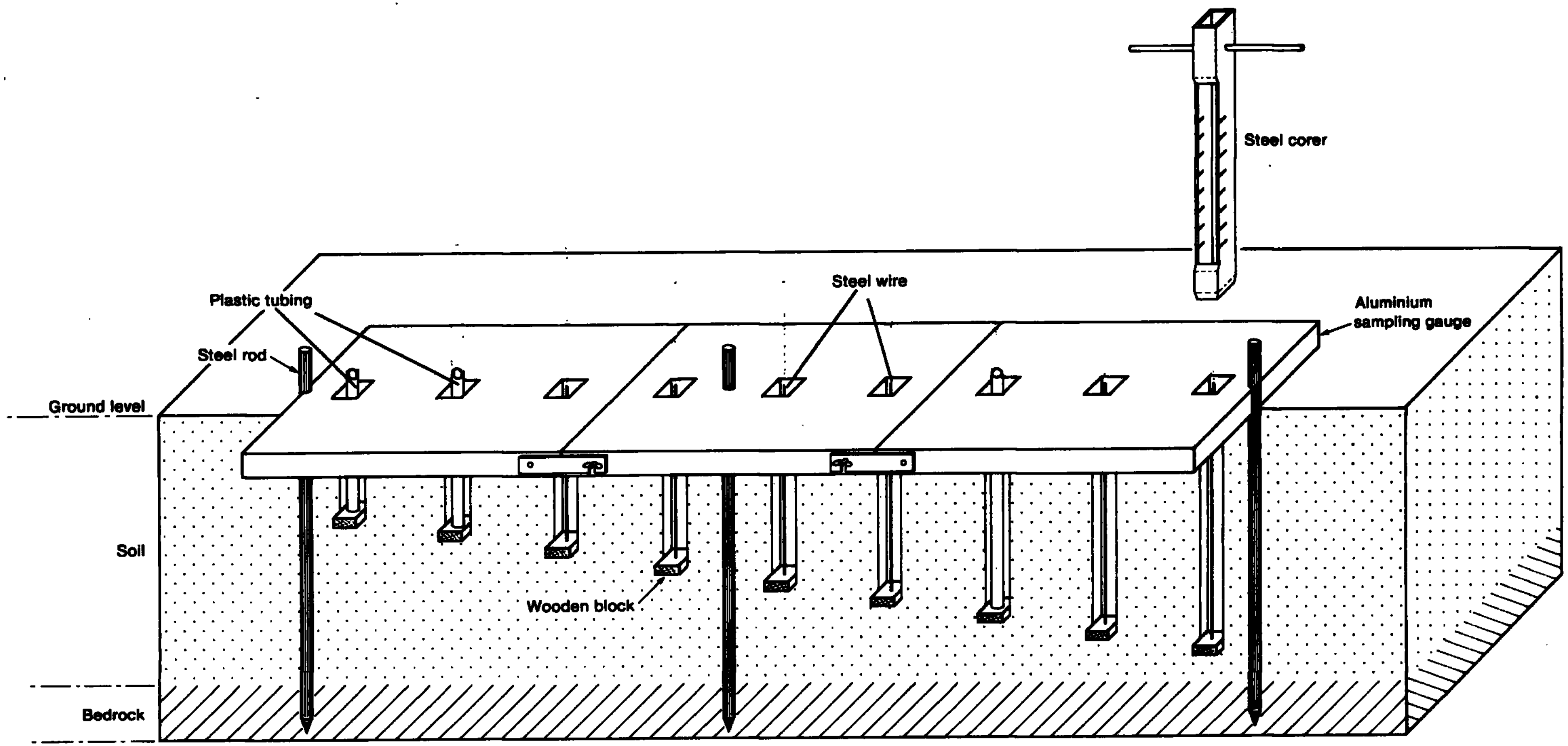


Fig. 2 - 6 RASHIDIAN'S SOIL CREEP MEASURING APPARATUS

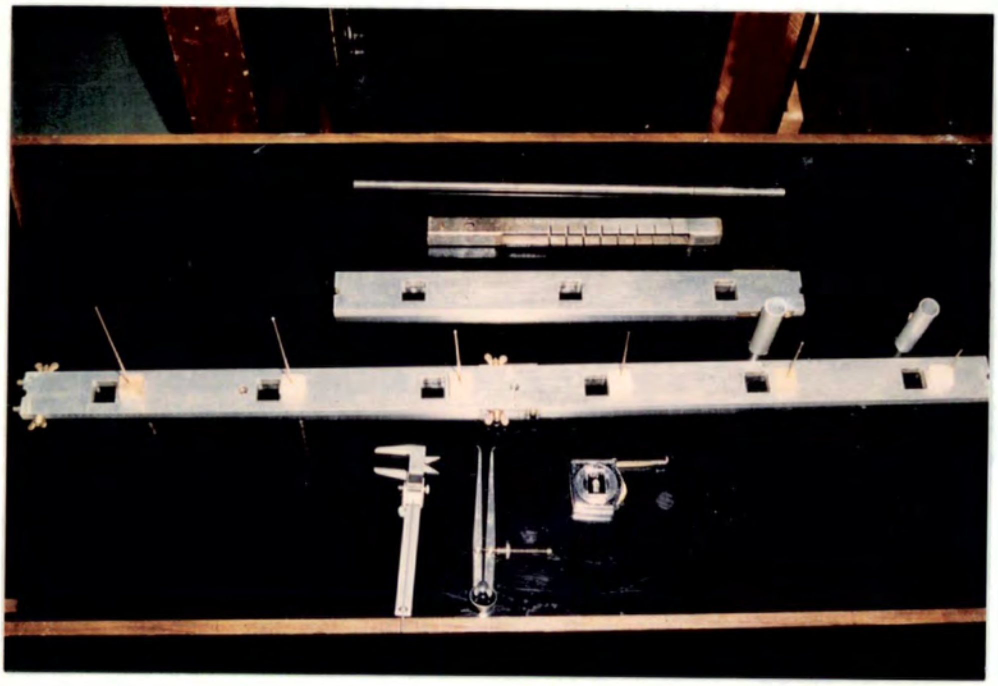


Plate 2.2 : Rashidian's technique apparatus and measuring devices

ii. A square hollow steel tube 35 cm long, with calibrations, was used to remove soil so that the samples could be located at different depths. Part of the face is exposed to aid extraction of a sample. The maximum depth for a sample is 275mm, but it could be increased if required. However, the sample can be split into sections each of 20 mm or more deep.

iii. A series of square wooden blocks 2.5 x 2.5 x 1.0cm, with a small hole drilled 0.5cm deep in the centre, are used. Each is placed at the bottom of a sample hole. Wooden blocks are sufficiently durable, but other suitable materials (preferably hard plastic) could be used.

iv. A 1.0mm diameter steel wire is fitted tightly into the central hole of each wooden block. The wire responds to any changes in the position of the blocks due to soil movement at each depth.

v. Three steel rods 60.0cm long and 1.0cm in diameter are used, both to keep the sections of aluminium gauge stable on the ground surface during sampling, and to retain their initial position for readings to be taken.

vi. 2.5cm diameter plastic tubes of different lengths are inserted in the holes to prevent collapse and other disturbances.

c. Field operations

The sequence of operations is as follows:

i. - A sample location is determined and the sectional aluminium gauge is fixed across the slope, parallel to the contours.

ii.- Three steel rods are placed into the three sample holes on the gauge and inserted in the bedrock with a heavy hammer to hold the aluminium gauge stable on the ground.

iii.- Sample holes are made using the square corer at locations determined by the square holes on the sampling gauge.

The corer is pressed into the soil to obtain sample holes to the required depth. The first sample hole on the left is taken as the initial hole in the set and its depth is 3.0cm.

Each subsequent sample hole is 3.0cm deeper than the previous one in the series.

Alternatively, the depth of subsequent sample holes could be varied randomly (e.g. determined by random numbers).

iv.- Wooden blocks, with wires of differing lengths fixed to the centre, are placed at the bottom of the sample holes, so that the wires protrude 1.0cm above the ground and coincide with the top edge of the square sample hole.

v.- The initial positions of the wires are determined by measuring the distance of the wires from each edge of the square sample hole on the aluminium gauge, using a Vernier calliper. The squares act as a control for measuring changes in the wires.

vi.- The sections of aluminium are carefully removed, leaving a set of wires and steel rods along the line of instrumentation.

vii.- To prevent the holes from collapsing or the wires from being disturbed by vegetation roots or worms, each is protected with a plastic tube which is inserted in the hole, so that the tube end is above the wooden block and the top is approximately level with the edge of the hole or above it.

d. Measurement

i. - The sections of aluminium gauge are replaced precisely over the sample. Steel rods guide the aluminium gauge to the exact position previously used.

ii.- Readings are taken by measuring the distances between the top of the wires and the edge of upper sides of the square sample holes in the gauge.

iii.- The resultant change in position of each wire is recorded on the appropriate table.

iv. - Initial readings are used as a base point and subsequent readings are compared with the initial values. The changes in the wires are used to determine a displacement profile.

e. Analysis of the equipment

1 - Sectional aluminium gauge.

The sectional aluminium gauge with square sample hole on it is used as a guide for :

i.- Making sample holes as near vertical as possible.

ii.- Taking a series of sample holes at optional depth.

iii.- Acting as a control for measuring the changes in position of the wires.

2 - Steel section tube (corer)

This equipment has been designed to the following specifications:

i. - The sample holes required can be taken at optional depths.

ii. - A soil profile can be taken from a sample of soil if required.

iii. - 5.0cm from the top end of the tube, a 1.0cm diameter hole has been drilled for fitting a handle to remove the corer,

iv. - To minimise soil disturbance and damage, the cutting edge has been sharpened and the case hardened.

3 - Cubic wooden blocks

i. - To avoid decay, durable wooden blocks were chosen and they can easily creep with the soil, so that a change in orientation of the blocks and therefore the wires will give an accurate measurement of soil movement.

ii. - The blocks exactly fit the sample holes. Any movement can be reflected by the block and the wire.

4 - Wires

i. - Metal wires 4.5cm to 28,5cm long were each placed in the appropriate sample holes.

f. <u>Advantages and limitations</u>

The main advantages of this technique are that :

i. The problem of obtaining short-term readings in Young's pits, bore holes and dowelling pillars has been overcome.

ii. Using this technique, it is possible to obtain direct measurements in the soil profile.

iii. Disturbances to the soil system while setting up the apparatus are comparatively small.

iv. It is possible to take frequent measurements without disturbing the soil and instruments.

v. Simultaneous measurements of soil variables, such as temperature and moisture, can be made if required as well as measurements of changes in the wires.

vi. No more than 1.0cm of wire protrudes above the soil surface; therefore the risk of disturbance and vandalism is small.

vii. This technique is sufficiently precise (0.1mm resolution if a Vernier calliper is used for measuring).

viii. This technique is simple to use, cheap to make and replicable, and it may be adopted for different values of soil-thickness and slope angle and curvature.

Limitations

i. The major limitations and difficulties arise from variations in the size of the wooden block during wet and dry periods which may affect the positions of the wires. Using hard plastic instead of wood overcomes this problem.

ii. No measurements are produced of movement at just below the surface of the soil, as the first measurement is at 3.0cm depth.

iii. Occasional disturbance of the samples may be caused by animals.

iv. The main problem is that of differentiating between linear movements and vertical changes. In practice this could be done by monitoring the position of the wire top from the top edge of the square sample in the aluminium gauge.

v. It would be ideal if the steel rods could be inserted into bedrock. This can be done when the bedrock is easily accessible, otherwise any attempts to secure the steel rods perfectly may cause significant soil disturbance.

2.6.5 Conclusion

The application of four different instruments has many advantages:

a. The results from all instruments can be compared.

b. Each instrument can be regarded as a control for the others.

c. By comparing the results of measurements, any disturbance of an instrument can be identified.

d. Both angular movements (linear) and mass movements (volumetric) can be inspected.

e. Short term and long term period of creeping soil can be measured.

Two important points should also be noted.

i. The reference points for all techniques used in this study are assumed to be fixed, if some are not absolutely stable, their movements in comparison with movable instruments (wires in Young's Pit, Wooden block in Rashidian's Technique, Plastic tube in Anderson's tubes and wooden pillars) are very small. If they move downslope, values measured for creep will underestimate the absolute rate.

ii. In cases where the soil is so deep that the reference points cannot be driven into the rock, excavation of soil would cause massive disturbance. It was decided therefore not to cement the reference points into the soil.

CHAPTER THREE

SELECTION OF THE MAIN EXPERIMENTAL AREAS

CHAPTER THREE

SELECTION OF THE MAIN EXPERIMENTAL AREAS

3.1 Introduction

In Chapter One, the process of soil creep and factors affecting it were discussed. Criteria for selecting a study area have been mentioned by several workers, for example Leopold (1962), Slaymaker and Chorley (1964), and Anderson (1977). For studies such as this, choices are made on at least four scales involving :

1. The general region for study
2. Basins within that region
3. One particular basin
4. Sites or units within that basin

With due attention to the above and using Ordnance Survey maps at scales of 1:63360 and 1:10000, a Geological map at 1:63360, aerial photographs, and the advice of Dr. Anderson, who has considerable relevant experience (having worked on a similar subject in Rookhope during 1972-1977), the Killhope basin within Weardale, located in the western uplands of County Durham, was selected (Figs. 3.1, 3.2).

3.2 Criteria for selection

The main criteria for this selection can be summarised in three stages:

a. General region

The western uplands of County Durham (North Pennines) were chosen because :

- A combination of low temperatures and locally high effective precipitation has produced an environment in which the soil creep process is particularly effective.
- Meteorological data and detailed information about the geology, soil and vegetation were available.
- It was accessible by road.

b. Basin within the North Pennine region

The Killhope Moor basin was selected because :

- Although it has not been investigated from the point of view of soil creep, other workers have researched in comparable areas including Young (1963), Kirkby (1967), Evans (1974) and Anderson (1977). Therefore the results can be compared.
- It is sufficiently remote that vandalism is relatively rare, so that it seems quite safe for this study.
- Slope facets, at a variety of angles, were clearly distinguishable.
- Local meteorological data were available.
- The facilities offered by the Field Centre located nearby in Lanehead were very helpful.

c. Particular basin within Killhope Moor :

A unit on both sides of the road between Lanehead and the Killhope pass was selected. The length of this unit is about 4 kilometres. The main reasons for selecting this particular area were :

- It is entirely within the drainage basin of Killhope Moor.
- It allows a profile of the study area rising to the watershed on both sides of the valley to be studied.
- Variations in environmental conditions in the region and of course in the basin can be distinguished and sampled.
- The distribution of the sites is such that they can be measured during one visit.
- Access from a road facilitating the installation and use of apparatus, was another reason for this selection.

3.3 Location of the study area

The area chosen for field measurements is located in the west of County Durham. It is a part of the drainage basin of the River Wear in Upper Weardale and it is centred on Killhope Moor. The highest point in the basin is the summit of Killhope Law, 673m above sea level, and the outlet of the basin is at an elevation of 371m, giving a relief of 302m. The area of the basin is 23 square kilometres, and it is surrounded by high ground which is represented by the hill tops of Killhope Law (673m), Stangent Rigg (618m), Knoutberry Hill (668m), Lamb's Head (647m), Highwatch Currick (639m) and Cow Horse Hill (625m) (Plate 3.1). The high western part of County Durham and the watershed is represented in this area by Killhope pass which, at the point where the A689 road passes into Cumbria, has an elevation of 618m. This road runs through the study area and allows easy access.

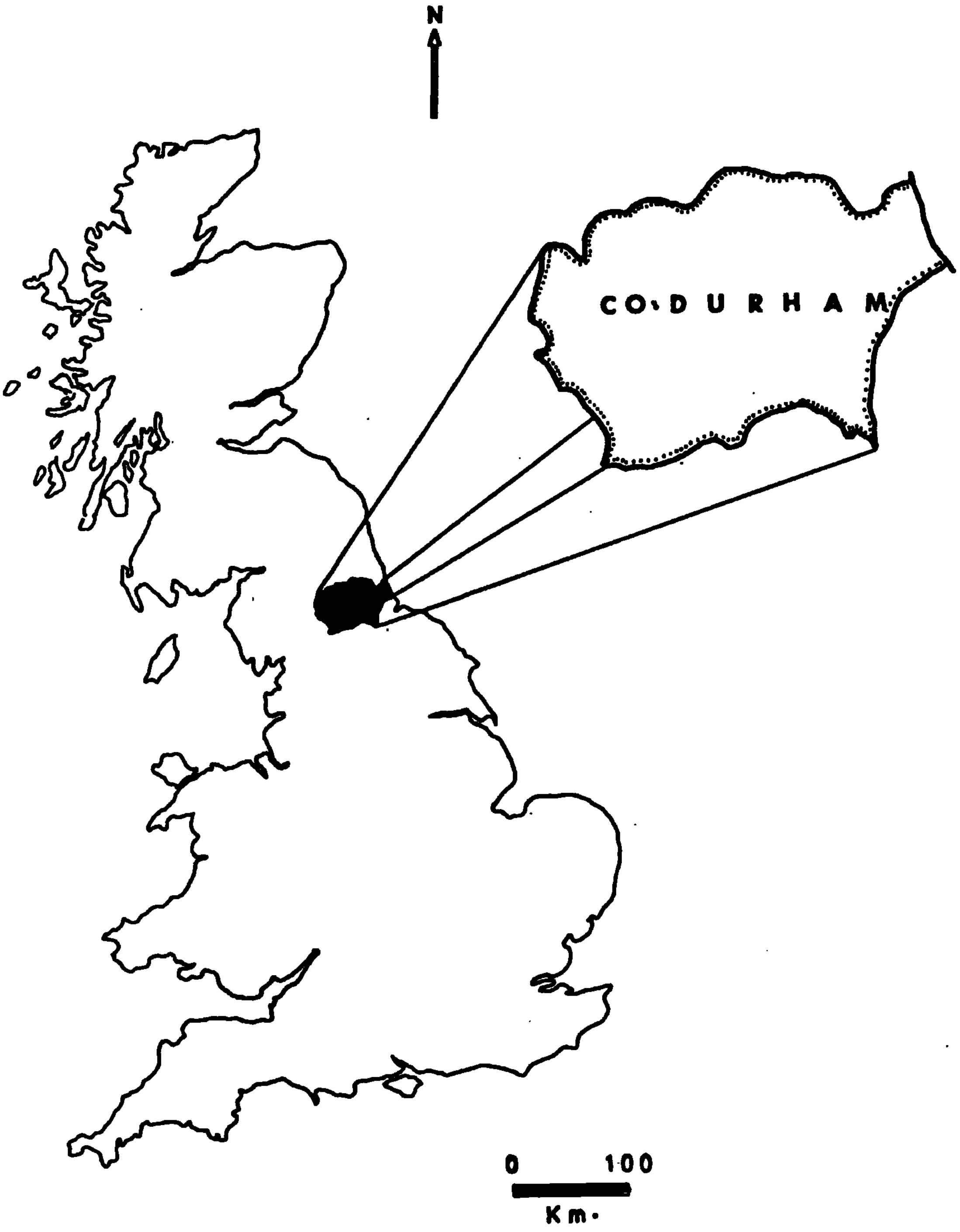


Fig. 3-1 Location of County Durham

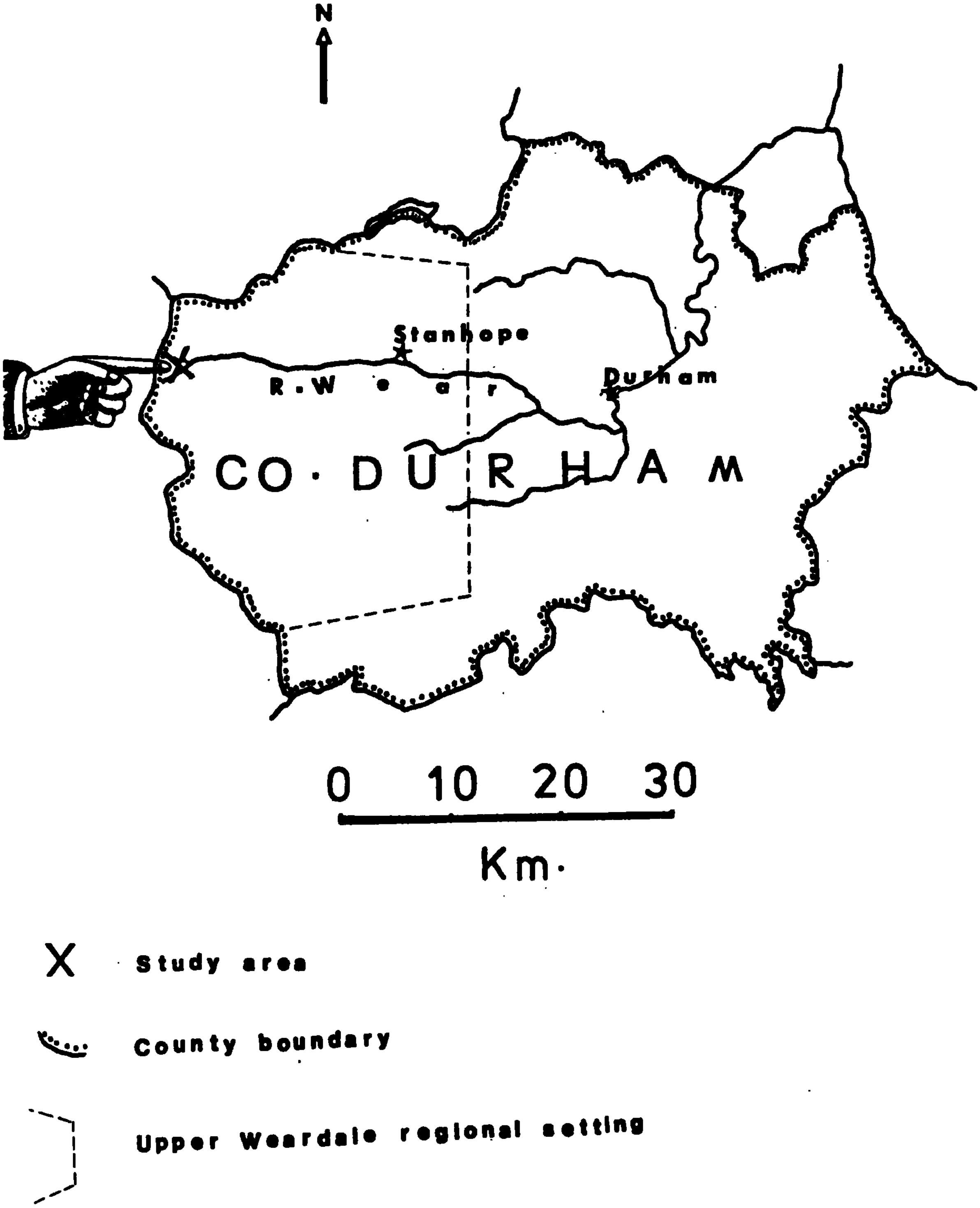


Fig. 3-2 Study area in Upper Weardale

Plate 3.1 : Ordnance survey map of study area

Scale 1:30000

The basin is drained by numerous permanent streams which flow mainly from north to south and west to east (Plate 3.1).

This particular catchment was selected because of its accessibility for data collection.

3.4 Background to Upper Weardale and the study area

Since the last century, Weardale has attracted the attention of many scientists, particularly with regard to land use, water use, geology, mineralogy and pedology. The most important geomorphological documents on the area are those by Dwerryhouse (1902), Trotter (1929), Raistrick (1931), Maling (1955), Atkinson (1968), Beaumont (1968), Vincent (1969), Falconer (1970) and Anderson (1977).

In Weardale the dominant feature is the gently warped mass of Carboniferous sediments of the Alston Block. The River Wear drains eastwards through a basin opening eastward from the centre of this Block, the highest and northernmost section of the Pennine Upland (Plate 3.2).

3.4.1 Geology

The geology of this region has been investigated in detail by Westgarth Forster (1809), Winch (1817), Wallace (1861), Dunham (1948), Maling (1955), Bott (1960), Johnson (1967), Burgess and Wadge (1974), King (1976) and Robson (1980).

It is, however, considered necessary to include a short review of this information in the present work, placing Upper Weardale in the context of the whole Alston Block.

The underlying rigid block of the region is a granitic mass, as was first suggested by Dunham (1948), supported

Plate 3.2 : The River Wear drains eastwards through study area (Killhope basin)

by Bott and Masson-Smith (1953, 1957), and proved in 1961 at the Rookhope boring at a depth of 390.4m; the hole was continued to 806m. It was found that the granite was pre-Carboniferous in age and that mineralization continued down into the granite itself. The tectonic effect of the buried granite was to stabilize the region into a morphological unit called the Alston Block which has been structurally positive with a tendency to steady uplift throughout its history. Uplift during the Devonian created a land of mountains and intermontane basins in Northern England. The region underwent continuous erosion during the Devonian and early Carboniferous; much of the Palaeozoic cover was eroded away and the Weardale granite was finally exposed at the surface. Until late in the Lower Carboniferous the upland was an island in an archipelago, but finally it was submerged by the Carboniferous sea and subsequently covered by sediments. The main Carboniferous rock types are limestone, mudstone, sandstone, seatearth and coal, which are arranged in various cyclic or rhythmic sequences.

Carboniferous basin formation:

The earliest Carboniferous deposits are coarse conglomerates derived from local parent materials which filled the hollows in the old land surface and vary in thickness and composition. Gravity surveys have shown that the Lower Carboniferous involved relatively thin deposition on the Alston Block (Fig.3.3). The Weardale granite has controlled this pattern of subsidence. The Lower Limestone Group succeeds the basement and is dominated by the light coloured Melmerby Scar Limestone, which is well exposed on the margins

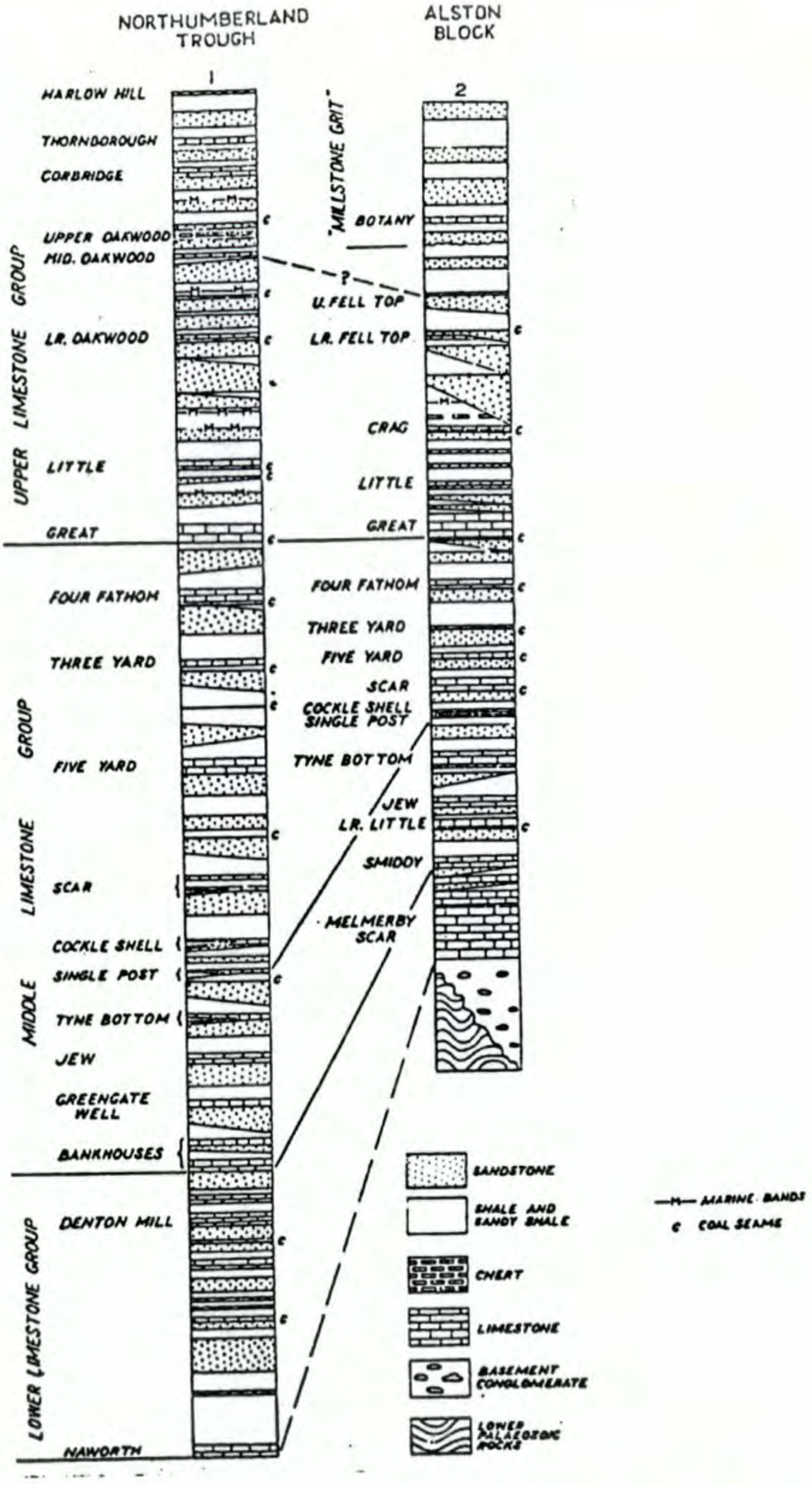


Fig. 3.3 : The Carboniferous succession of the Northumberland trough and Alston Block

(From Johnson 1963)

of the Teesdale inlier. Above the Melmerby Scar Limestone, darker limestone bands separated by shales and sandstones enter the succession. These cyclic beds are characteristic of the Middle Limestone Group, the top division of the Lower Carboniferous. The Middle Limestone Group has a wide outcrop in the region. The base of the Upper Carboniferous is taken at the base of the Great Limestone. The Great Limestone lies at the base of the Millstone Grit Series which consists of two facies, a lower limestone - shale - sandstone cyclic group, and an upper grit - shale sequence. The Great Limestone is one of the most persistent lithological marker horizons in the Pennines; its outcrop in Weardale is quarried extensively (Plates 3.3, 3.4).

The Upper division of the Millstone Grit consists of coarse grits with interbedded sandstones, shales and ganisters together with marine bands and thin coal seams. Earth movement, which had caused gentle folding during the latter part of the Carboniferous period, reached a climax around the Carboniferous-Permian boundary in the Hercynian Orogeny. Uplift with doming, folding, faulting and thrusting took place and the Great Whin sill was intruded. Subsequently, both the granitic mass and the Carboniferous strata have been metamorphosed along the lines of mineral veins, which are extensive in the Alston Block.

In the Killhope study area there is a series of horizontally bedded sandstones, limestones and mudstones which form the lower strata of the Carboniferous. These are affected by a complex of mineral veins and their associated micro-metamorphism imposed on the highest of the series.

Plate 3.3 : Great Limestone outcrop in Upper Weardale (Killhope)

Plate 3.4 : Old quarry in Upper Weardale (Killhope)

The highest in present day altitude is the 'Millstone grit' series which forms the watershed area and below this level the bands of sandstone of this series form valley side 'steps' (Fig. 3.4). This series overlies the Upper Limestone Group and the succession to the Scar Limestone of the Middle Limestone Group is fully represented. The southern part of the catchment is formed of the Yoredale series, a sequence of limestones, shales and sandstones.

The topography reflects the geology of the catchment; The more resistant Four Fathom and Great Limestone bands together with the Grit Sill stand out as benches around the catchment. These bands cause small waterfalls where they are crossed by the stream channels. Investigation of the superficial deposits has yielded interesting results. In the lower parts, terrace deposits and till are found mainly around the main streams. Variations in altitude, slope, parent material, precipitation and vegetation even in such a small area have a great influence on the development of the soils. There are several faults mainly trending north-south and north-west-south-east as well as mineral veins in different directions (Fig. 3.4).

3.4.2 Geomorphological development

The last stage of deposition of the Carboniferous rocks of the Northern Pennines took place about 290 million years ago. At the beginning of Tertiary time a land-mass came into being and the present topography began to form. During this period the solid rocks were eroded. Throughout the region,the main relief features have been created largely

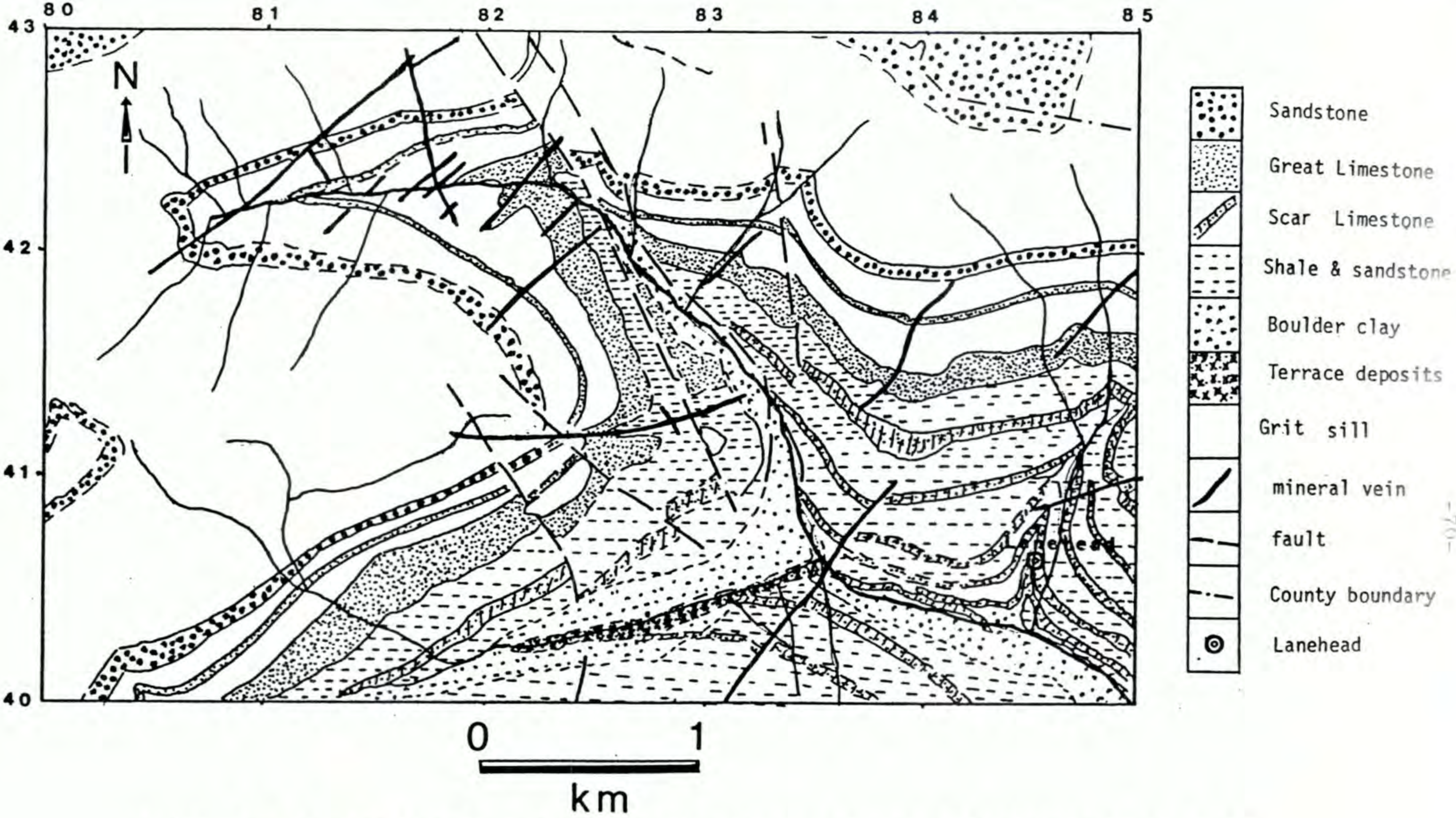


Fig.3-4 Full Geological Structure Of Study Area

Enlargement of Geological Survey of Great Britain (England and Wales) sheet 25 'ALSTON'.

as the result of erosion during the Tertiary. From the end of the Tertiary, nearly two million years ago, general climatic cooling during the Quaternary led to the gradual development of glaciers. During this period the region was covered by ice-sheets which eroded and moulded the topography. Post-glacial time began about ten thousand years ago, and erosion of bedrock and glacial deposits has continued during this period and the alluvium, peat and soil which now cover the ground surface have gradually accumulated. The glacial sequence of the Pennines, including the study area (Upper Weardale) has been studied by several workers (Dwerryhouse, 1902 ; Trotter, 1929 ; Raistrick, 1931 ; Dunham, 1948 ; Tufnell,1969 ; Johnson & Dunham, 1963; Beaumont, 1968; Vincent, 1969; Burgess, 1974; Lunn, 1980). These studies can be summarised as follows:

Trotter found evidence of two major glaciations in the region. He correlated the major glaciations with the Older and Newer Drift of eastern England. In the Older Drift, or early Scottish Boulder Clay glaciation, ice from southern Scotland and the Lake District deposited a lower till. This ice sheet was followed after a period of time by Newer Drift or Main Glaciation. During the Main Glaciation ice sheets from the Lake District and Scotland formed a great glacier over the Vale of Eden which escaped north-eastwards into the Tyne valley and south eastwards over Stainmore (Fig.3.5). Trotter also demonstrated that ice from the Vale of Eden crossed every col in the Pennine escarpment north of Cross Fell, into the south Tyne valley. Raistrick (1943) suggested that only the higher parts of Cross Fell, and the hills around Upper Weardale, remained uncovered by ice during the glacial maximum. Vincent (1969), in a detailed study of the north-western part of the Alston Block, has shown that at the maximum phase of glaciation the region was covered by ice from Eden side, while, at a later stage, Cross Fell became an important area of ice dispersal.

The glacial history indicates that Weardale fell within the limits of Wolstonian and Devensian glaciation of the British Isles (West, 1968). Much work has been carried out concerning the direction of erratics in Weardale. Dwerryhouse, in his work on the distribution of ice, described the glacial deposits of Weardale as a stiff blue boulder clay and Atkinson (1968) stated "It [the till] is a bluish grey in colour with reddish blotching around included stones and root channels." Moore (in Francis 1972, p.141, Geology of Durham County) notes the presence of a lower till which rests on rockhead, and this is locally overlaid in the Eastgate-Swinhope area by another till, which has been reworked by solifluction. Moore also notes the presence of extensive sands, gravels, silts and clays which at Eastgate station extend to 25m below the present flood plain. The first features of deglaciation are thought by Moore to be high level melt water drainage channels at about 550m in the Ireshopeburn and Allenheads areas. A feature interpreted as a Kame-terrace was formed in the later stages of deglaciation, most extensively along the northern side of Weardale. After the disappearance of the ice, some resorting of the deposits by fluvial means took place, but this was also a period of intermittent solifluction, and deposits of

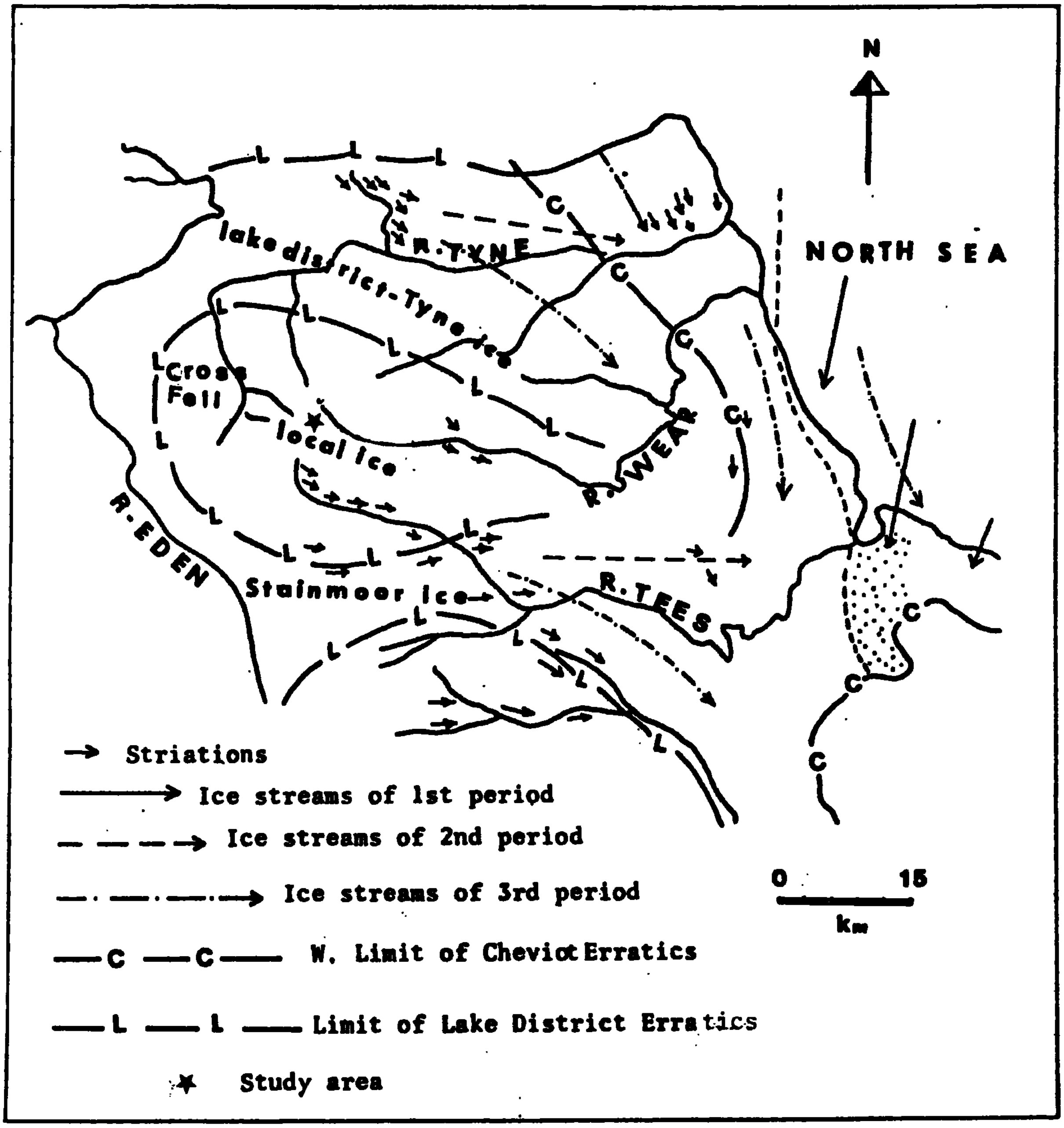


Fig. 3.5 : Glaciation of a part of Northumberland and Durham, The pattern of Late Devensian ice movement (After Raistrick 1931)

head are found interbedded with fluvial sand and gravel. On the higher ground, solifluction was marked and fossil patterned ground and block streams have also been recorded by Moore. Such observations on the existence of periglacial phenomena in this area are in accord with other observations made in adjacent areas, for example by Tufnell (1969), and by Johnson and Dunham (1963) in the Cross Fell area. Most of these phenomena originated following the disappearance of the ice sheets, and they may generally be referred to as the end of the Devensian, perhaps with some extension into the early Flandrian. Johnson (1963) also stated that in Upper Weardale the retreat of the ice left deposit composed of coarse gravels and sands into which the post-glacial stream eroded to form a sequence of terrace features above the present flood plain.

The late-glacial and post-glacial action in Upper Weardale has been studied in detail by Atkinson (1968) and Falconer (1970). Falconer stated that "the characteristics of the surface layers of material in many parts of Weardale attest the action of frost in their development" (Ph.D. Thesis, p.36). However, according to Falconer's investigations, the Late- and Post-Glacial era in Weardale must have been one of intense periglacial climate with permafrost having a considerable effect on the character of the clay-rich rock strata. Mass wasting and hill wash must at this stage have been active in the production of the typically stratified hillslope material with a layer of large stones found about one foot below the surface.

3.4.3 Soil

Recent investigations of the superficial deposits in Upper Weardale (Maling, 1955; Atkinson, 1968; Falconer, 1970) have yielded interesting results that can be summarized as follows:

a. The lack of erratics or other evidence for glacial contributions from outside the confines of the Dale, particularly in the study area, emphasises the local origin of all soil parent materials;

b. Soil parent materials are derived either directly from the underlying strata, or indirectly by glacial transport or mass movement from fairly similar strata.

c. Over much of the area solid rock is near the surface but the drift varies considerably in depth over very short distances (Falconer, 1970).

d. Atkinson (1968) recognised five major categories of parent material in Upper Weardale including : weathered rock (limestone, shales, sandstones, Whin Sill), solifluction deposits, till, alluvia, and spoil (Table 3.1) (Fig. 3.6, 3.7). Also he identified three main classes of superficial deposits in Upper Weardale namely:

i. The upland regolith on ridges and interfluves.

Table 3.1 : A classification of soil parent materials

Parent material		Genetic process
Increasing degrees of mixing and contamination	1. Weathered Rock (Limestone, shales, sandstone, Whin Sill)	Weathering; some hillwash contamination.
	2. Solifluction deposits	Mass movement: Late-glacial; some contemporary.
	3. Till	Transport and deposition by local ice.
	4. Alluvia	Fluvial processes.
	5. Spoil	Disturbance by man (miners)

ii. Solifluction deposits on slope flanks and valley sides.

iii. Till, and river alluvia, in valley bottoms.

According to Atkinson (1968), on interfluves where solid rock occurs near the surface, a superficial regolith is often present in Weardale and correlates well with what Ragg and Bibby (1966) described as a frost weathering product.

The Upland regolith of Weardale shows a pronounced stratified morphology, and an upper layer which consists of stony, subangular rubble.

Although the major forms of the slope deposits are thought to derive from a previous permafrost period and are hence relict rather than contemporary features, present freeze-thaw cycles are of importance locally. In addition to important pedologic influences such as peat erosion and increased spring-melt, the formation of ice leads to the heaving of surface horizons, both organic and mineral, and produces patterned microrelief features (Atkinson, 1968). In the case of till and alluvial material Atkinson states that deposits laid down by a Quaternary glacier in Upper Weardale are restricted to the main valley floor and lower side slopes, particularly along the southern side of the valley. The till of the lower slopes varies in texture and composition but generally it is a stiff clay or clay loam, containing boulders of local rock which are characteristically smooth and striated. Within the slope deposits the included stones consist predominantly of sandstones which are generally subangular and seldom smoothed and striated. By contrast, till contains large numbers of sandstone and limestone erratics.

There are not any fluvio-glacial sands and gravels in Upper Weardale; upstream from the Kame terrace at Eastgate all coarse material along the valley floor is fluvial in origin.

The most significant feature of Upper Weardale is that much of the basin is covered by blanket-peat up to 1m thick. The peat largely consists of Calluna, Eriophorum and Sphagnum. Spoil, mine tailing, disused shafts and hushing are common features in Upper Weardale because of the long history of mining and quarrying. During the last two decades drainage activity and afforestation have occurred in Upper Weardale especially on gentle slopes covered by blanket peat. The results of these activities may be of importance in renewed pedogenesis.

However, the following sequence which supports and completes Falconer's work was identified along a profile (1,2) which passes through the instrumented area (Fig. 4.2 and 3.8). The co-operation of Mr. M.J.Alexander of the Department of Geography in identification of soil patterns in the field is gratefully acknowledged.

a. Blanket peat

Like the other parts of the study area, the high ground over 550m supports an extensive cover of blanket peat. It varies in thickness from 0.2m on the grit stone to 2.0m on the gentle shale slopes, covers all the highest points and extends over a wide range of land surfaces in the study area.

b. Peaty gley

The upland peat gives way on lower ground to peaty gley soils. The gleyed horizon shows a variety of mottling

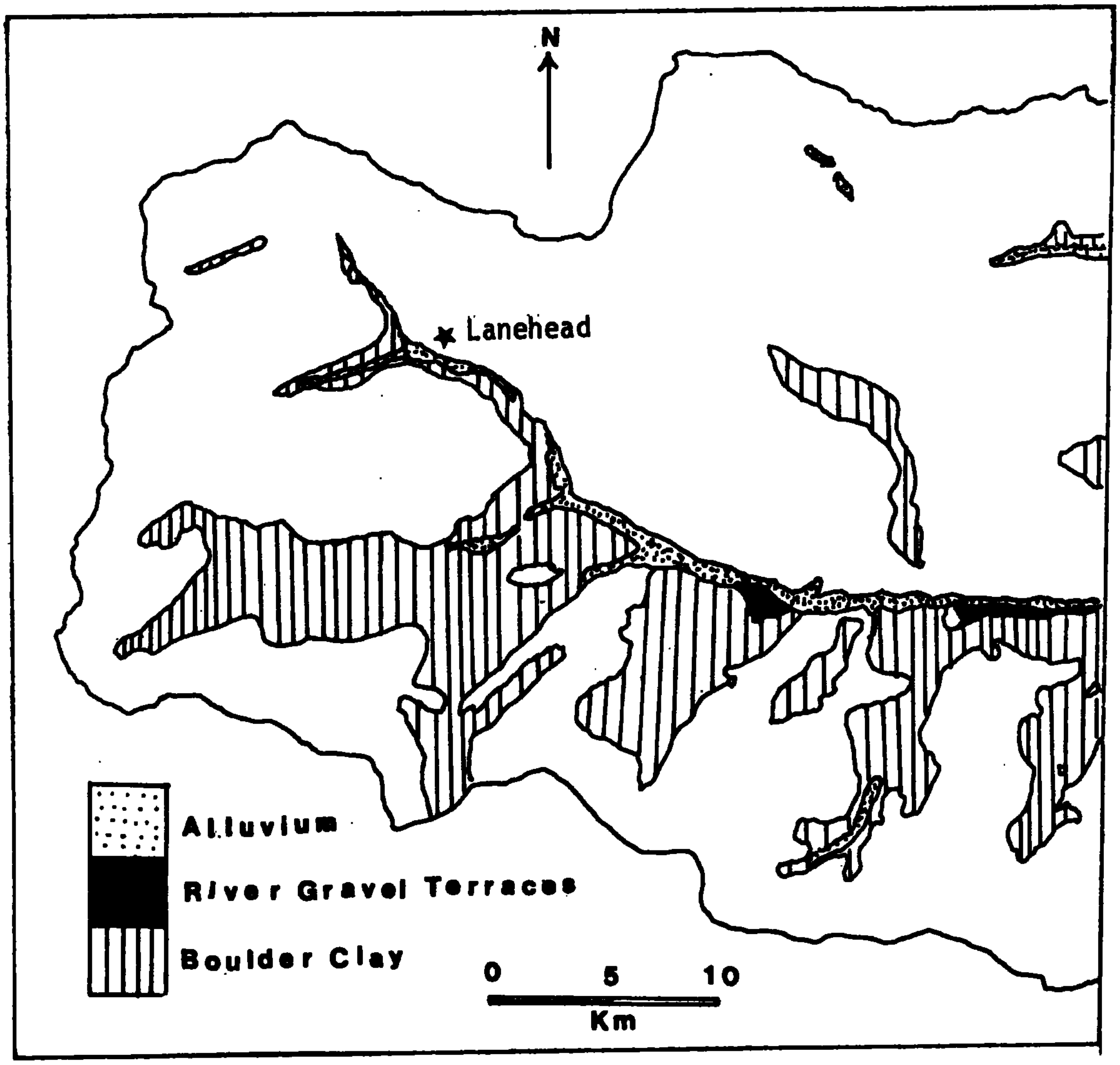


Fig.3-6 Superficial Deposits in Upper Weardale

(After Atkinson)

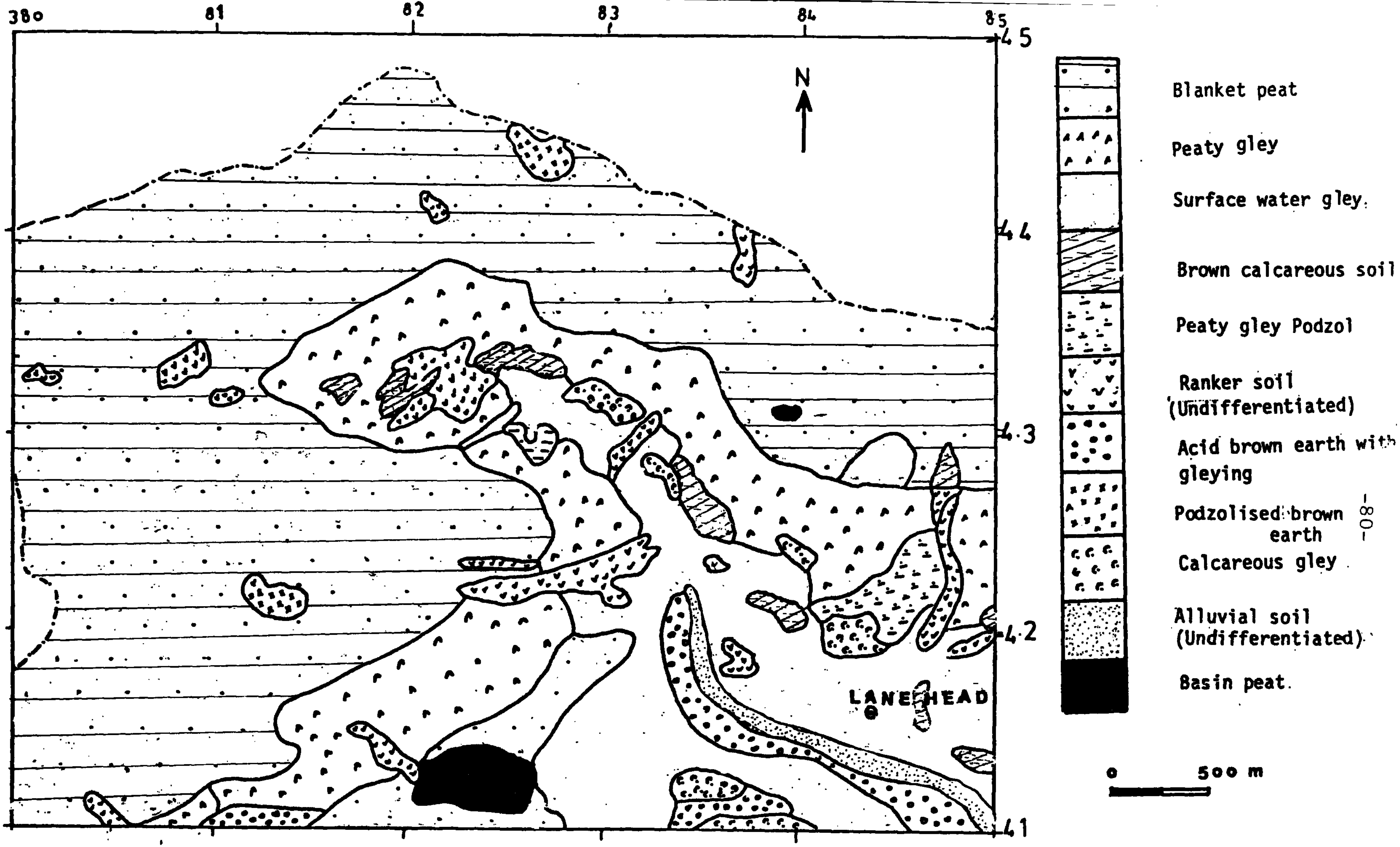


Fig. 3-7 Distribution of soil, sub groups, (After Atkinson)

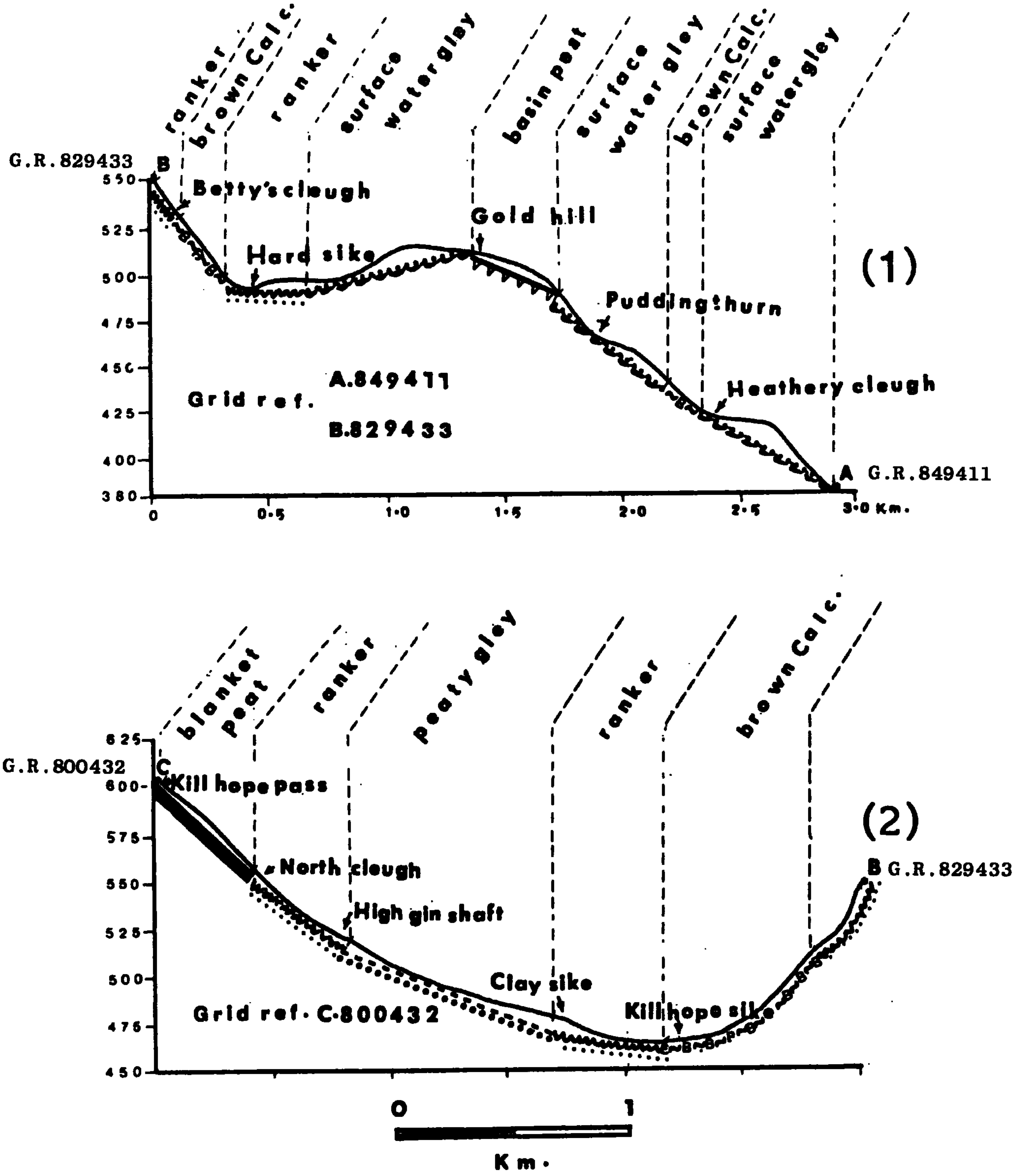


Fig. 3—8 Soil Pattern profile of study area

patterns with the presence of red and brown segregations around rotted sandstone fragments. In the profile, the area between Claysike and High Gin Shaft is covered by this soil.

c. Ranker soil

This pattern, in which humus-rich soil with mineral content is less than 0.3m thick, can be found below peaty gley, mainly in the Great Limestone area. The profile shows four patches of this soil between Snodbery Cleugh and North Cleugh.

d. Surface water gley

In this pattern, the surface organic matter horizon is very thin and it overlies about 0.25m of saturated and gleyed mineral material. This gives way with depth (more than 0.3m) to a drained subsoil with mottling. The area between Lanehead and Hardsike is mainly covered by this pattern of soil.

e. Brown calcareous soil

This pattern of soil occurs mainly on limestone outcrops and is distributed on both sides of the main road, between Lanehead and Killhope head bridge.

3.4.4 Climate

The climate of the Pennine uplands has been a subject of special interest to climatologists and meteorologists on account of the great contrasts to be found over relatively short distances (Atkinson, 1968). This is definitely the case in Upper Weardale. The most important variations are caused by such contrasts as altitude, aspect, exposure and land configuration. The distribution of precipitation, temperature range and speed and direction of wind are direct functions of these variables. However, the prime climatic contrasts within the drainage basin of Upper Weardale are conditioned by altitude and exposure. Atkinson (1968) pointed out that the extremes and severity of the climate over 550m is moderated on valley slopes, and further moderation is in evidence in relatively sheltered tracts of the valley floor. The climatic character of the area is thus a reflection of the topographic character. He also quoted records obtained at Lanehead School during the 1960-1961 season - that on the higher parts of Upper Weardale precipitation approaches 1850mm, falling to approximately 875mm at Stanhope (Fig.3.9). Distributions tend to be even throughout the year and rain can be expected on more than seventeen days in August and on more than fourteen days in both July and September. Also, the number of raindays per year varies from about 220 in the west to 180 in the east of the Dale section. Snowfall records taken by Manley (1939-43) and records from Alston and Nenthead, just to the west of the study area, indicate that snow-cover follows the dominant altitudinal gradient, averaging 80 days over 510m in the west and decreasing steadily to 30 days at Stanhope (182m) in the east.

The study area is in the highest section of the Dale, in which the heaviest snowfall occurs. Variation in the duration of snow cover is great from year to year (e.g. the extended period of snow-lie from October 1965 to May 1966 at Lanehead School (442m). Snowfall has been recorded in all months except July and August, with maximum falls occurring

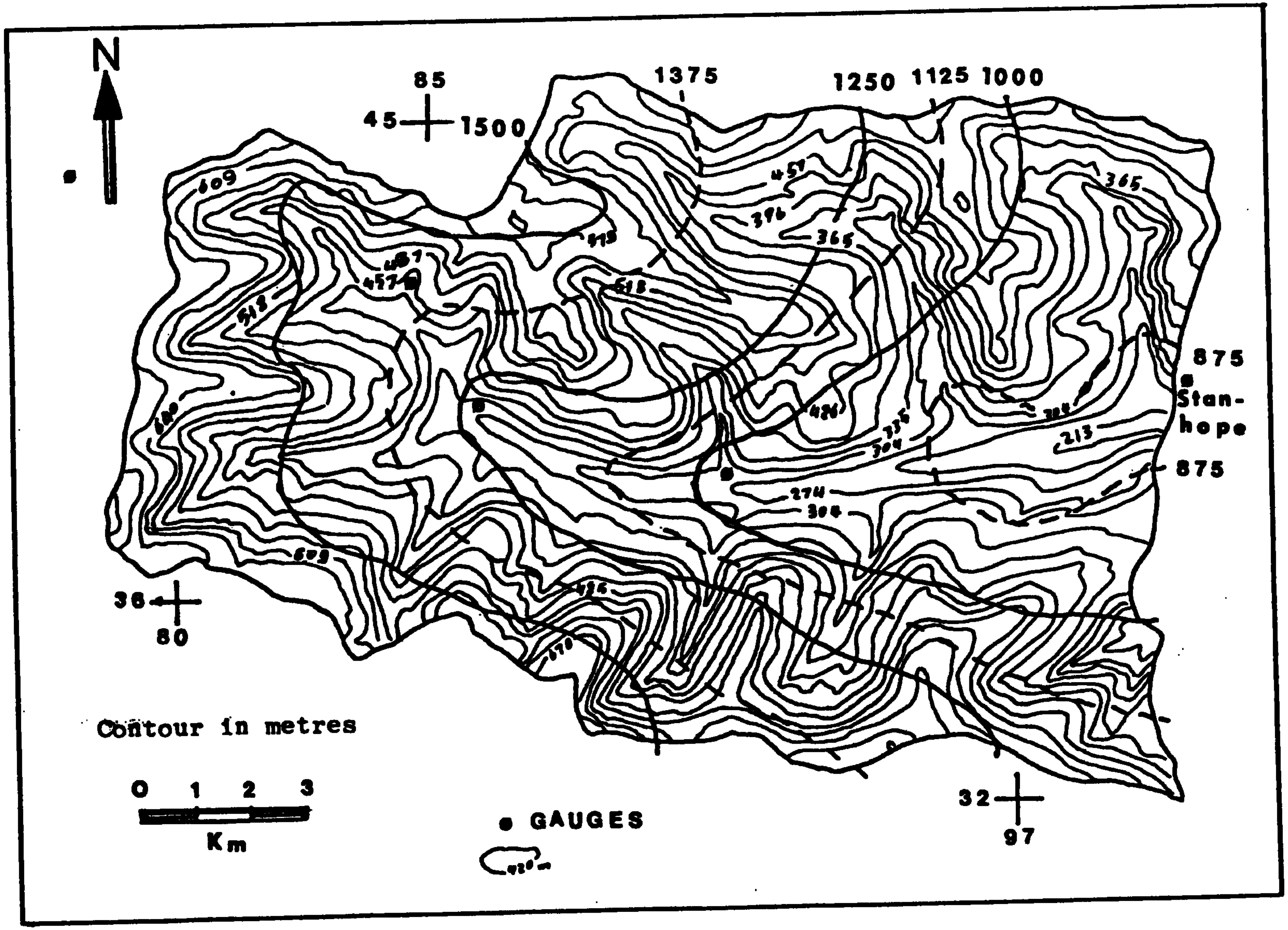


Fig. 3.9 : Mean annual precipitation in Upper Weardale (After Atkinson 1968)

in January, February and March (Atkinson, 1968). Within the study area, data are more scarce for temperature than for rainfall. Temperature records collected by Catchpole (1960-61) for Lanehead School (442m) are quite useful to help understand the annual temperature changes in the study area (Fig.3.10). These records show a difference of 20.6°C between the lowest monthly mean of 0.5°C (January), and the highest monthly mean of 21.1°C (August). This compares with longer standing records at Nenthead (457m) with mean January and July temperature of 0.5°C and 12.2°C respectively. Statistics for both stations indicate a pattern of cool summers and cold winters. Atkinson related the length of growing season to altitude, quoting a decrease at a rate of ten days per 76m.

Mean wind speeds also reflect altitude, velocities being recorded in Upper Weardale which can be twice those of the lowlands to the east. Anderson (1977) illustrated the monthly readings for Moor House and Durham (Table 3.2 and Fig.3.11).

Table 3.2 : Mean Monthly Wind speed Knots:

Moor House and Durham

Station	J	F	M	A	M	J	J	A	S	O	N	D	Year
Moor House 555m	16.2	15.9	16.0	13.5	13.2	11.9	11.1	11.6	12.3	13.5	13.7	15.7	13.7
Durham 101m	8.8	8.8	9.4	8.3	7.1	6.1	5.8	5.9	6.0	6.6	7.2	8.8	7.4

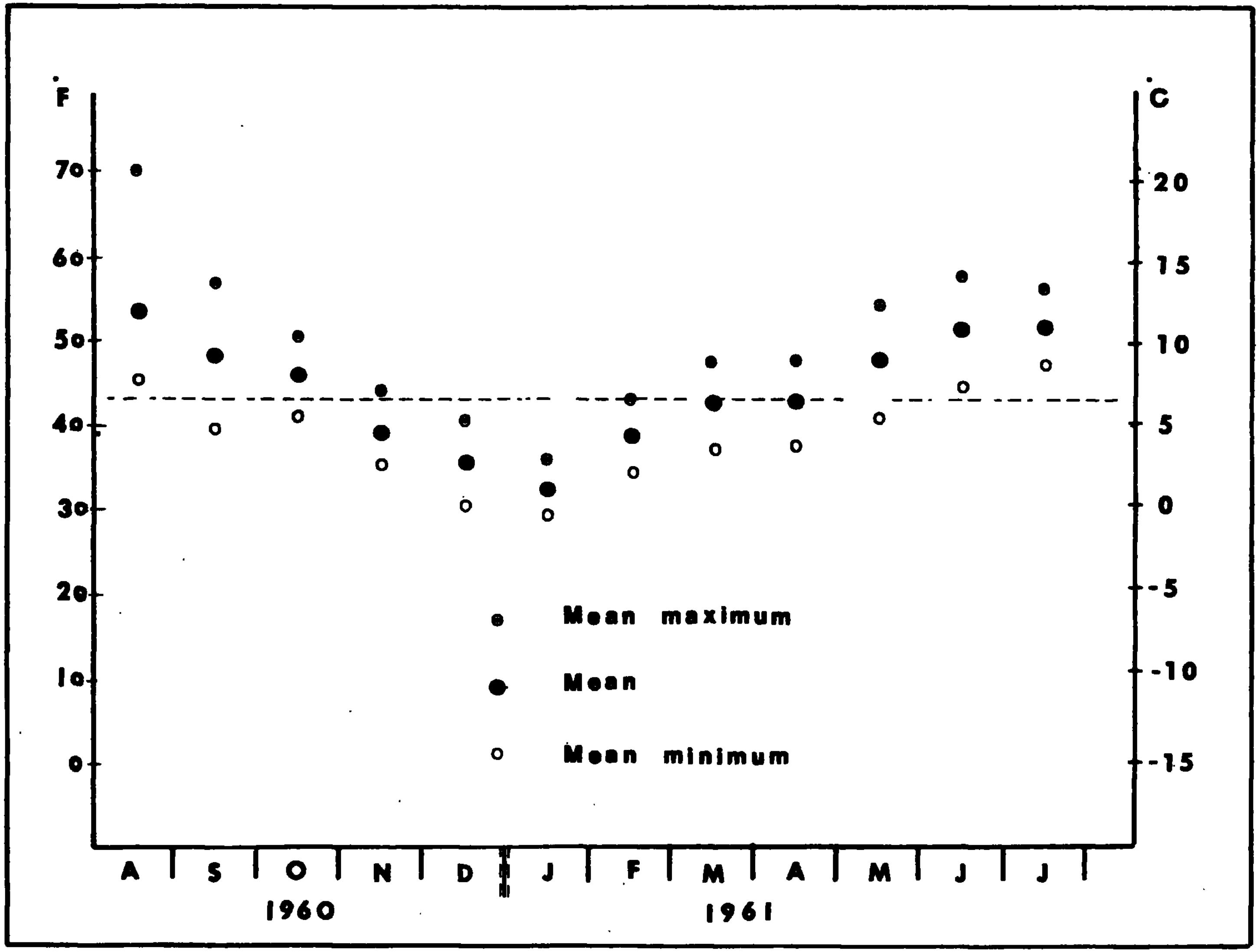


Fig. 3.10 : Mean air temperatures in Lanehead school (442 m)

From Catchpole

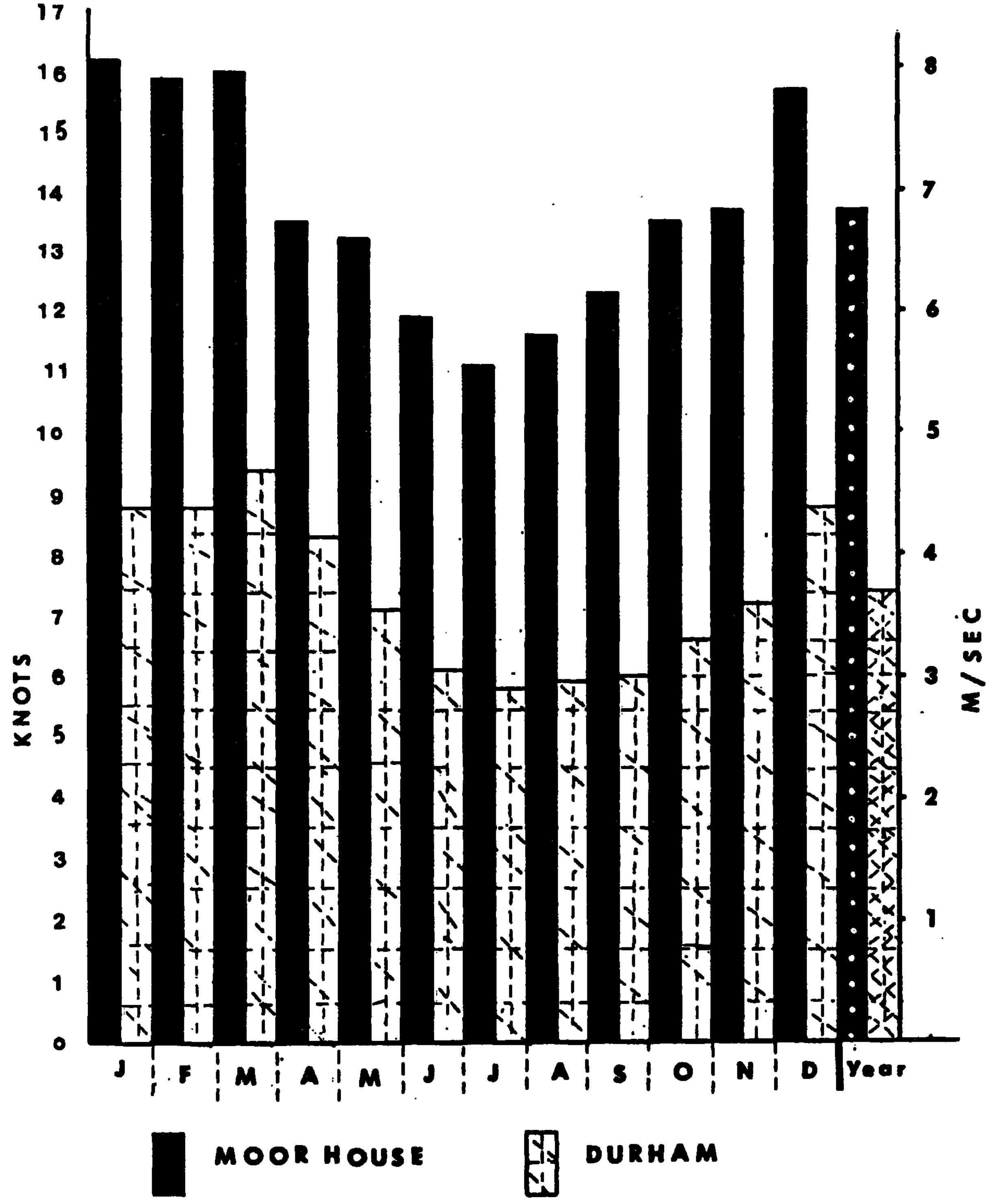


Fig. 3.11 : Mean monthly windspeed for Moor House and Durham

However, because of the lack of a permanent Meteorological Station in the catchment, it is difficult to obtain accurate data for the study area. To enlarge on the previous information it seems to be useful to present the meteorological data for Moor House for a relatively long period of time (1970-1980) (Tables 3.3, 3.4) together with meteorological data available for a restricted period (1960-1961) for both Moor House and Lanehead (Tables 3.5, 3.6 and Figs. 3.12, 3.13). This is justifiable because the environmental conditions of the study area are very similar to those of Moor House. Another source of information was meteorological data obtained directly from Lanehead for 1960-61 by Catchpole (1966) and 1968-70 by Lavis (1973) Fig. 3.13.

According to the available data, the monthly precipitation in the study area varies between 47.5mm and 235mm and the total precipitation in Lanehead (442m) is 1362.5mm. This is expected to be less than annual precipitation in Killhope (600m) because of the difference in altitude. Since precipitation occurs during all months of the year, much of the surface of the sites tends to remain permanently damp. This condition is helped by the generally low temperatures which do not rise above 14.0 °C. Also, not only is the warm season short but the winters are long and severe. Although snow is an obvious element of interest for this study, because of the lack of permanent observations, information on frequency of snowfall and snow cover are limited. An interview with some of the local people indicated that snowfall usually begins early in November and the whole area is covered by snow for more than 50 days during November, December, January, February and March. This period extends to 70 days at Killhope (above 600m). However precise assessment for snow cover is not easy in this catchment. It is interesting to plot monthly precipitation, with mean temperature, against time (Fig.3.14). The variation is quite wide; some cold months may also be dry (February and March). It seems reasonable to suggest that the persistence of a general snow cover in the area is probably more closely related to the mean temperature than to the frequency of occurrence of days with snow falling.

In general, the period of snow cover is increased by both low mean temperature and high altitude.

Table 3.3: Annual rainfall totals (mm) 1970-1981 Moor House

C 573 metres O.D. Lat 54°41' N. Long. 2°23'W.

Nat Grid. Ref NY/758328

Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
1970	154.5	275.5	151.5	199.7	60.2	94.2	167.7	182.2	152.2	262.5	236.7	170.0	2107.5
1971	138.8	154.1	127.2	53.6	76.4	129.1	63.7	186.6	41.1	140.2	172.7	61.6	1345.1
1972	198.6	91.8	150.3	157.9	222.9	159.0	103.6	97.3	30.4	41.8	328.2	206.3	1788.1
1973	123	129	74	121	131	65	112	179	83	119	116	233	1485
1974	365.1	214.8	151.8	16.4	75.2	118.0	154.2	91.6	189.3	133.1	272.0	442.4	2230.9
1975	341.0	31.6	96.6	141.2	43.0	68.9	179.4	119.9	235.8	64.7	150.4	111.6	1584.1
1976	258.1	123.2	130.3	104.0	182.2	50.5	63.2	29.0	228.7	239.2	165.4	302.4	1876.2
1977	520.9	198.5	179.4	185.7	80.5	144.6	86.2	103.8	181.6	159.4	251.8	194.1	2288
1978	500.0	334.9	297.8	51.9	45.4	54.1	93.9	116.5	264.0	103.0	222.0	263.8	2347.3
1979	379.4	465.7	508.7	168.7	172.2	78.9	102.2	174.6	159.5	155.8	241.3	358.8	2965.8
1980	189.0	170.7	166.0	10.2	23.6	219.9	112.4	203.9	168.1	249.2	227.4	265.4	2005.8
Mean	288.0	199.0	184.8	110.0	101.1	107.4	112.5	134.9	157.6	151.6	216.7	237.8	2002.1

Table 3.4 Meteorological summary for Moor House 1970-1980

	J	F	M	A	M	J	J	A	S	O	N	D	Total	Mean 1970–80
Mean max temp°C	2.2	2.0	3.5	6.5	10.6	13.7	13.9	13.6	11.9	9.1	4.9	3.6	95.50	8.6
Mean min temp°C	-2.3	-2.5	-1.5	-0.5	2.1	5.2	7.2	7.7	5.9	3.6	0.0	-1.0	23.93	2.1
½(max+ min)°C	-0.1	-0.2	0.9	3.0	6.4	9.5	11.2	11.2	8.9	7.3	2.4	1.3	61.8	5.6
Earth temp 30cm 09.00hr	2.0	1.6	2.0	3.6	6.5	9.5	11.4	11.8	10.1	7.7	4.9	3.3	74.4	6.7
Ground frost (days)	25.6	24.3	26	21.5	15.2	8.0	5.5	5.5	7.0	12	21	24	174.7	15.8

Table 3.5 Meteorological summary for Moor House (1960-61)

	A	S	O	N	D	J	F	M	A	M	J	J	Total	Mean	Rain day
Rainfall mm	107.2	81.7	210.7	307.2	188.0	253.0	167.5	123.7	115.0	88.7	82.5	191.2	1916.9	159.7	245
Maximum Temp°C	14.0	12.26	8.58	4.95	2.58	1.32	4.84	6.98	8.58	10.17	12.92	13.14	*8.33		
Minimum Temp°C	6.98	5.28	4.18	0.55	-2.58	-3.68	0.22	1.59	1.98	2.75	5.28	7.15	*2.47		
Mean Temp°C	10.5	8.8	6.4	2.5	0.0	-1.2	2.5	4.3	5.3	6.5	9.1	10.1	*5.4		

Table 3.6 Meteorological summary for Lanehead School (1960-61)

	A	S	O	N	D	J	F	M	A	M	J	J	Total	Mean
Rainfall mm	112.5	62.5	235.0	182.5	102.5	167.5	110.0	77.5	62.5	52.5	47.5	150.0	1362.5	113.5
Maximum Temp°C	20.9	13.47	9.84	6.32	4.56	2.53	5.94	8.36	8.58	12.1	14.08	13.2	*9.99	
Minimum Temp°C	7.2	4.07	4.83	1.32	-0.93	-1.1	1.1	2.86	3.02	4.73	6.93	8.25	*3.52	
Mean Temp°C	14.0	8.8	7.4	3.8	1.8	0.7	3.5	5.6	5.8	8.4	10.5	10.7	*6.75	

* Average

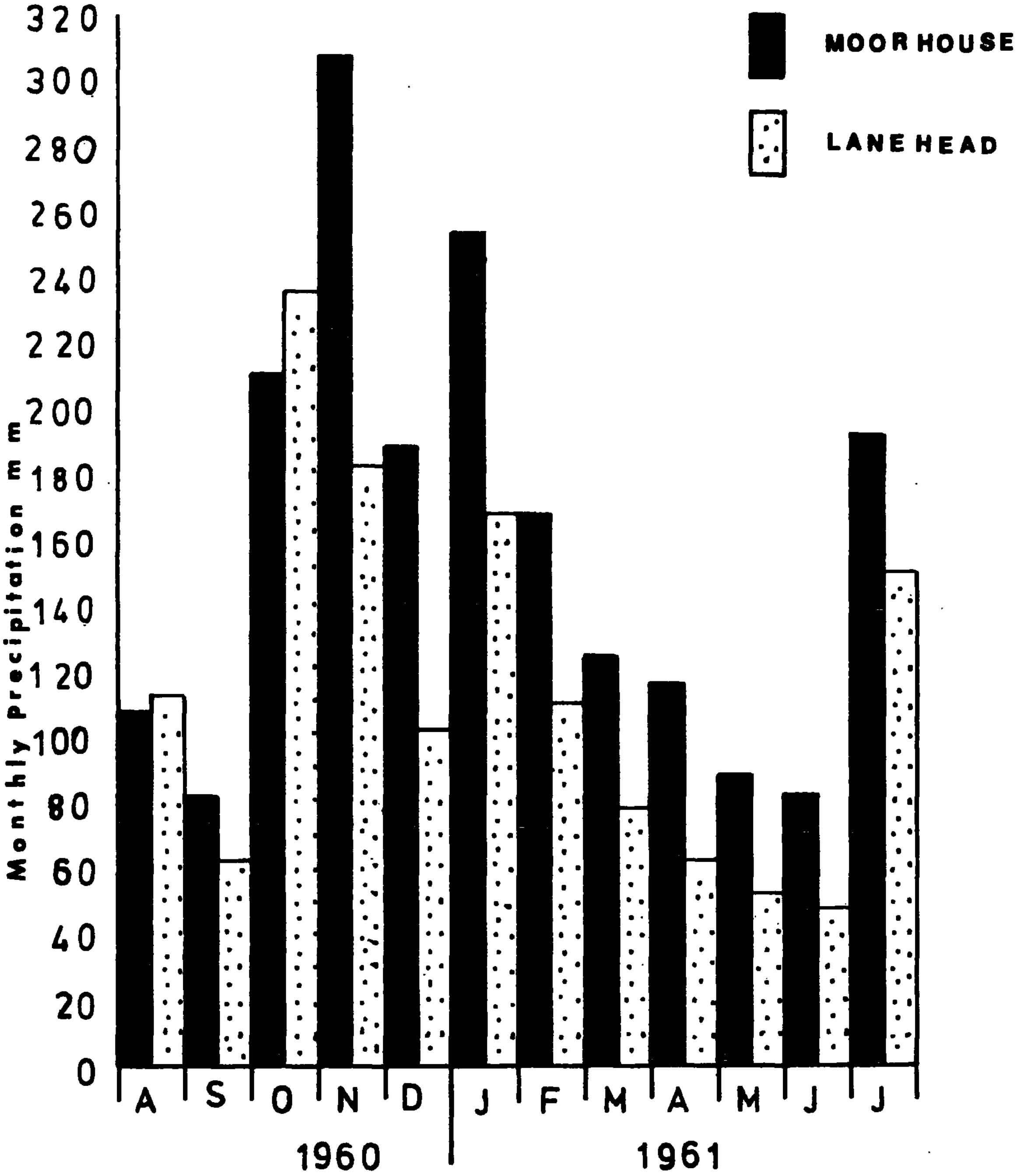


Fig. 3-12 Precipitation Regime in Moor house And Lane head.

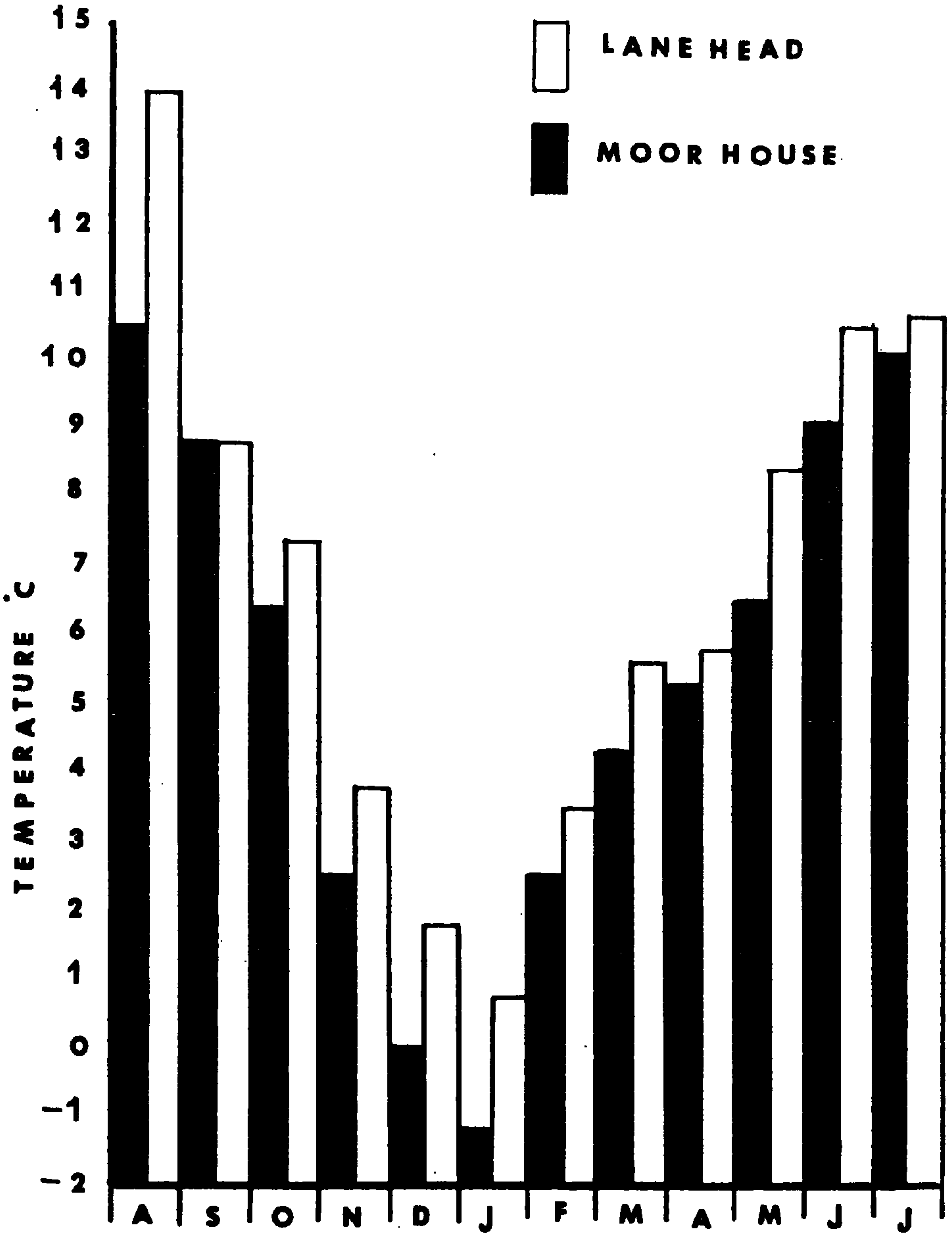


Fig.3-13 Mean Temperature In Lane head And Moor House 1960–61

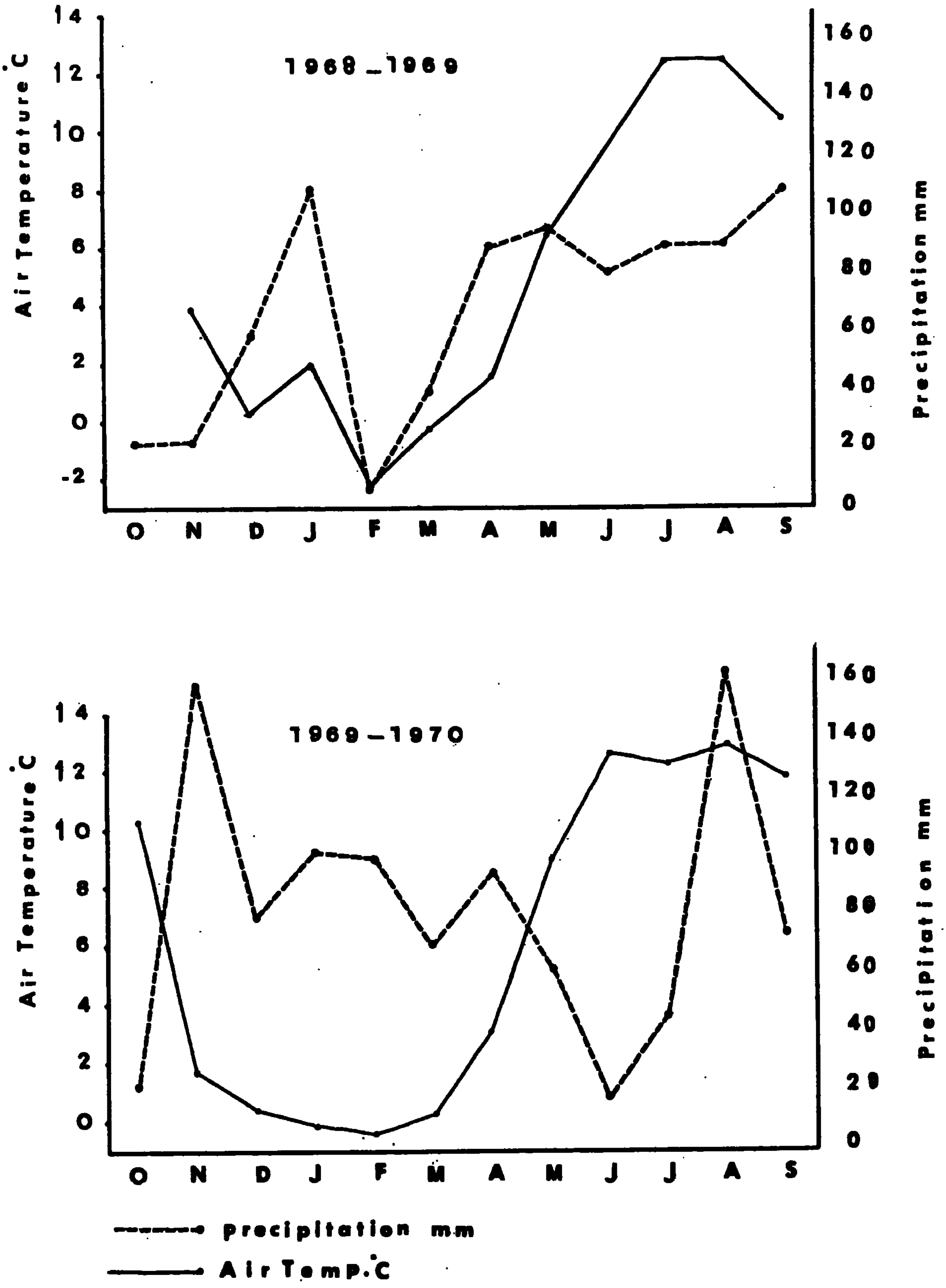


Fig.3-14 Mean Monthly Air Temperature And Monthly Precipitation in Lane head .

3.4.5 Vegetation

Climate and vegetation both exercise an influence on soil formation and movement, so it is necessary to consider both in the study of soil creep. However, full understanding of the present pattern of vegetation distribution requires detailed information on past changes and distributions. Valuable information on the vegetation history of Weardale can be obtained from the works of Raistrick (1931),Pearsall (1950), Johnson (1963), Atkinson (1968), Pennington (1969) and Bellamy (1970). The present complicated mosaic of vegetation is the result of several interacting factors (Atkinson, 1968). In Upper Weardale this complication is more striking than in the middle or lower parts of the Dale. The most important reason for this striking contrast is the greater effect of relief in the Upper Dale. Variations in the slope and altitude produce differences in micro-climate. Variations in parent material, aspect and drainage are also considerable. Lewis (1904) presented a generalised vegetation map of the Alston Block which includes the study area (Fig. 3.15a). Atkinson's 1964-68 investigations showed some changes since Lewis's original map (Fig.3.15b). A comparison of Atkinson's map with that of Lewis (1904) reveals that many of the "mixed" associations are changing from one vegetation type to another, or missing some type as a result of sheep grazing or human interference. A classification of present vegetation in Upper Weardale as given by Atkinson (1968) is listed in Table 3.7.

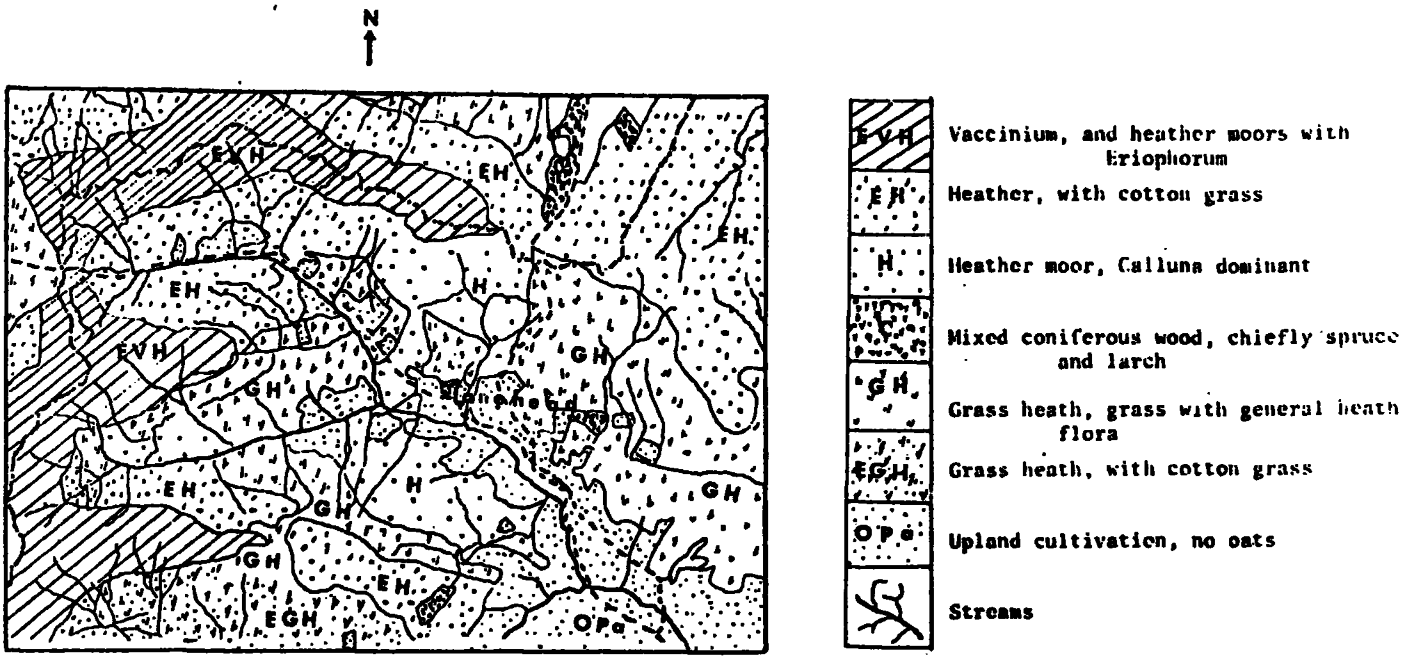


Fig. 3.15a : Distribution of vegetation in the basin of the Killhope burn. After Lewis (1904)

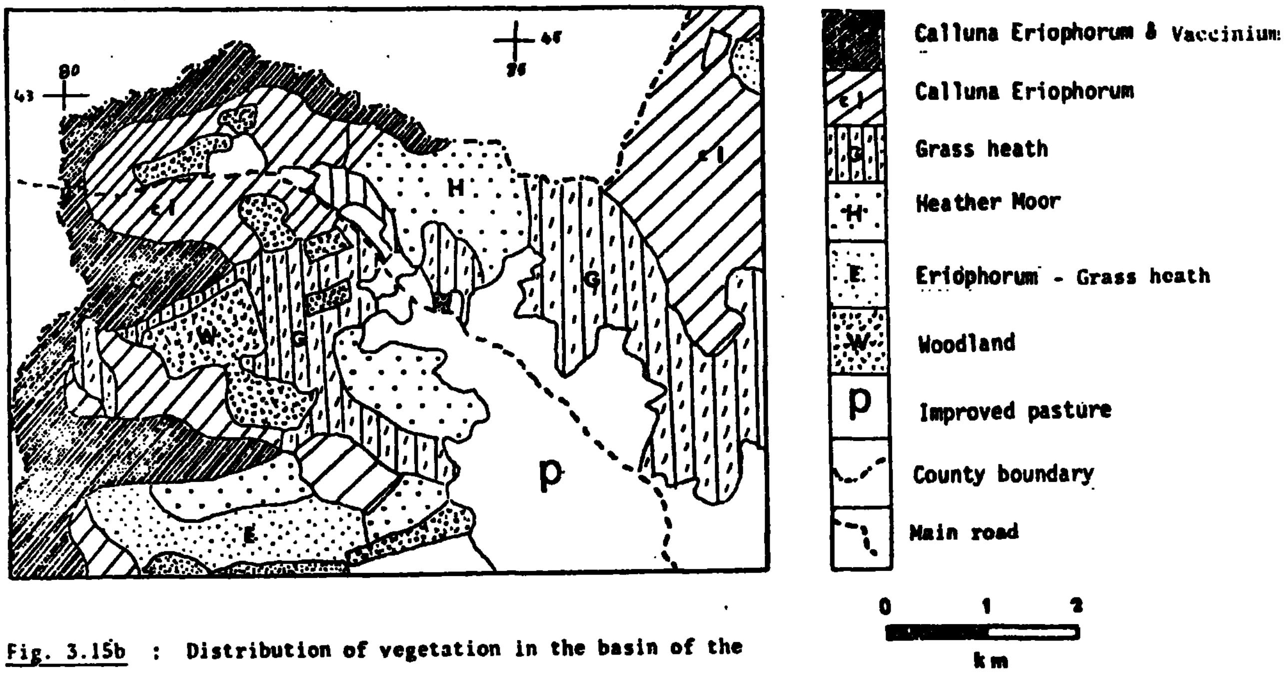


Fig. 3.15b : Distribution of vegetation in the basin of the Killhope burn. After Atkinson (1968).

Table 3.7 Weardale vegetation : Major communities

A Grasslands	1	Meadow Pastures
	2	*Agrostis* - *Festuca*
	3	*Nardus*
B Woodlands	1	Mixed Deciduous
	2	*Betula*
	3	*Pinus*
	4	Spruce
C Heaths	1	*Calluna* - *Eriophorum* - *Vaccinium*
	2	*Calluna* - *Eriophorum*
	3	*Calluna* - Grass heath
	4	*Calluna* - *Juncus squarrosus*
	5	*Calluna* - *Nardus*
	6	*Pteridium*
D Moorland	1	*Sphagnum* Bog
	2	*Juncus squarrosus* Bog
	3	*Juncus effusus* Bog
	4	*Eriophorum* Bog
	5	*Molinia* Bog
	6	Mixed Wet Bog
	7	*Molinia* - *Eriophorum*
	8	*Eriophorum* - *Vaccinium*
	9	Erosion complex

After Atkinson (1968)

3.5 Man's effect upon the landscape

The present landscape of the study area bears the marks of old lead mining activity (Plate 3.5). The importance of this is emphasised by the presence of large mine dumps, spoil-heaps of lead-mines, hushes and disturbed ground (Plate 3.6). A little further down the valley large gashes are to be found in the valley sides. These are 'hushes',[where the lead ore which occurred in vertical veins was extracted]. The workings were open-cast and the remaining scars are similar to very small quarry workings. The spoil heaps of the lead mines and the large areas of disturbed ground are typical of the Dale (Dunham, 1948).

The major agricultural activity today is pastoral farming which is carried on around these relict features. Between Lanehead and Killhope Burn, several farms exist. Wellhope Burn also has many small farms scattered along its valley sides. A large area has been planted by the Forestry Commission mainly below 580 metres. Above this altitude the peat moorland is used mainly for sheep grazing. Part of the moorland has been drained by cutting shallow trenches in order to modify the vegetation to give better pasture (plate 3.7).

3.6 Conclusion

1. The study area (Killhope basin) is a catchment on the watershed drained by a headwater tributary of the River Wear in County Durham.

2. In the study area there is a series of horizontally bedded Sandstone, Limestone and Mudstones which form the lower strata of the Carboniferous affected by a

Plate 3.5 : Evidence of former lead-mining activity in Upper Weardale

Plate 3,6 : Cowhorse Hush, a part-natural but largely artificial erosional feature.

Plate 3.7 : A draining trench on the peat moorland (above 600 m)

complex of mineral veins.

3. The glacial history indicates that the study area fell within the limits of Wolstonian and Devensian glaciation of the British Isles, but the ice was of local (Pennine) origin.

4. The most common feature of the study area is that much is covered by blanket peat (particularly on the high ground over 550 metres). Brown calcareous soil occurs mainly on limestone outcrops but various types of gleyed soil are more frequent.

5. The study area can be considered as one of the coldest and wettest part of the Pennine Uplands in which the heaviest snow fall occurs. In this catchment the most important variations are caused by such contrasts as altitude, aspect, exposure and land configuration (Plate 3.8).

6. Variations in altitude, aspect, slope, parent material and drainage produce differences in microclimate and vegetation. The most common vegetation types are Heather moor (*Calluna* and *Eriophorum*), Grass heath, (*Vaccinium*), and mixed coniferous wood, chiefly spruce (*Picea*) and larch (*Larix*).

7. The presence of large mine dumps, spoil heaps from lead mining and quarrying, are a common indication of the effect of man on the landscape in this study area.

Plate 3.8 : Photograph shows heavy snow lying on the high ground in the study area.

CHAPTER FOUR

INSTRUMENTATION OF STUDY AREA

CHAPTER FOUR

INSTRUMENTATION OF STUDY AREA

4.1 Introduction

During the preliminary reconnaissance of the area, it was observed that there are five different site types in the catchment area. Therefore it was decided that each type be instrumented as a particular sample site. Criteria for sampling were as follows:

- Each selected place presented a particular dominant characteristic.
- The existence of minor differences in aspect, slope angle, vegetation, depth of soil and altitude.
- Easy accessibility.

The method for selecting and mapping the sites was as follows:

a, In each site one main sample station was selected and it was instrumented using an association of different techniques,

b. Environmental variations e.g. vegetation, soil, aspect in each site were instrumented using Anderson's tubes.

c, The main sample positions were assumed to be controls for the Anderson's tube results.

Using this method 44 sample points (Plots) were instrumented and all of them were mapped on five detailed maps which show the location of each sample site.

d, The primary measurement of each sample site was recorded on a detailed table. However, an attempt was made to select the main sample station at each site so that it represented the characteristics of the sites.

4.2 Measurement programme and site selection

The experimental catchment in the Killhope area was established in order to study the nature of the soil creep process and its relationship to certain other factors of the environment within the study area. The emphasis of the study was upon relatively long term measurement, over a period of 18 months of soil creep at five sampling sites within the catchment, using four different methods and instruments.

Understanding the differences in results obtained from each site required the determination of the main variables involved in soil creep. The execution of the experimental design required four stages:

1. Selecting the sampling sites in the study area.
2. Making sketch maps of the sampling sites and surveying relevant profiles using a Suunto clinometer (surveying points at 5m. intervals).
3. Selecting applicable techniques and instruments, bearing in mind their capabilities and limitations.
4. Instrumentation of the sampling sites in the study area.
5. Taking readings and recording the results. For selecting sampling sites, the determination of variations in the study area was carried out in the following stages;

a. Collecting all available documents and data on structural features, soil, vegetation, human activities and other factors involved.

b. Observing the whole study area during three visits and consulting Dr. Anderson and Dr. Cox during initial visits to the study area.

c. Interviewing the local people.

d. Using Ordnance Survey maps (scale 1:63,360, 1:25,000, and 1:10,000), a geological map (scale 1:63,360), soil distribution map (scale 1:23,750), vegetation maps produced by Lewis (1904) and Atkinson (1968) and aerial photographs (scale 1:10,000).

As has been described in Chapter Two, all techniques and instruments designed for measuring the rate of soil creep have advantages and limitations. It seems reasonable to use a range of techniques and instruments. The problem was that using all selected techniques and instruments in each sampling point (plot) was practically difficult and required a long period of time for instrumentation, reading and laboratory test of soil. Therefore, it was decided to select a main sampling control station using a collection of Young's pit, Wooden Pillars, Anderson's tubes and Rashidian's instrument (Fig.4.1). Furthermore, a range of plots varying from the point of view of aspect, slope angle, soil and vegetation was selected and instrumented using Anderson's tubes.
The advantages of this procedure were:

a. The multivariate nature of the controls could be evaluated at each sample site.

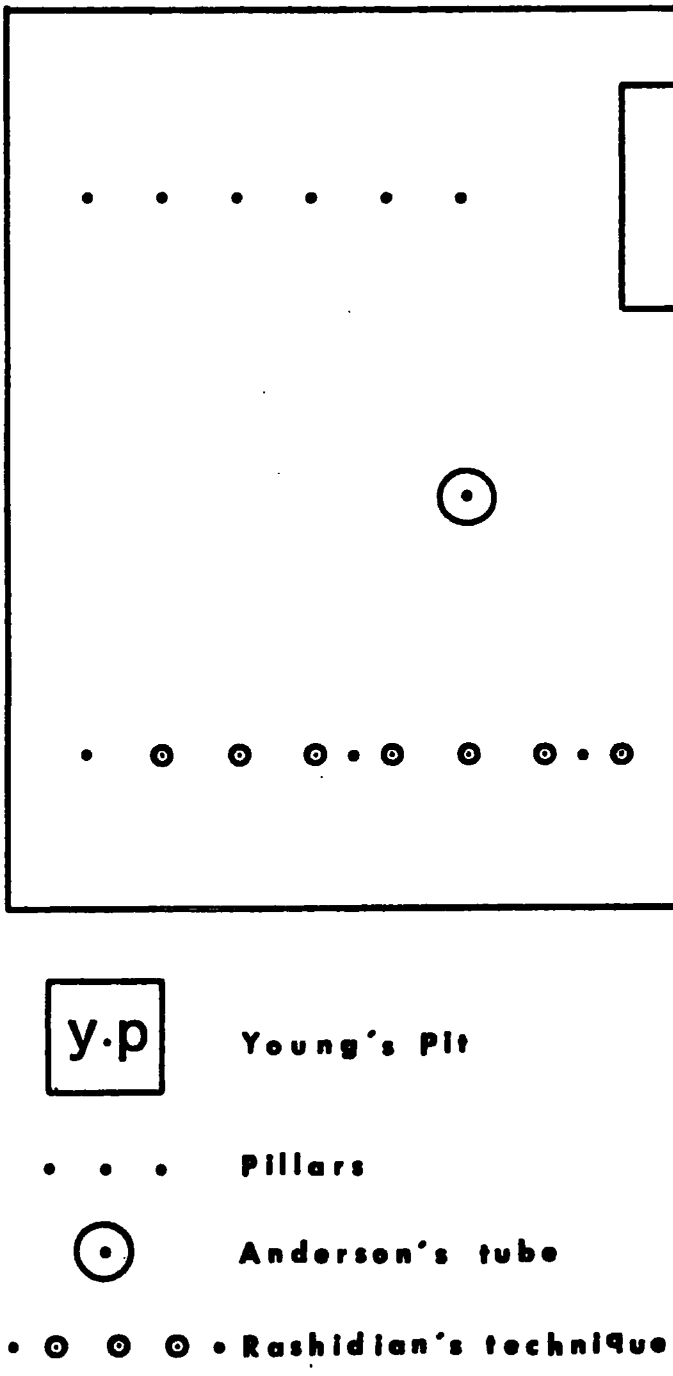


Fig. 4-1 Layout of control station

b. The results obtained from Anderson's tubes could be compared with the results of instruments in the control stations.

c. Using a set of different techniques and instruments at the control station permitted comparison of the results obtained using each technique.

d. The rate of soil creep related to variations in the factors involved in the whole study area could be compared with those obtained in other research.

It should be noted that each site selected in this study is distinctive, differing from the others with respect to altitude, vegetation cover, soil, aspect and slope angle.

Soil depth was measured using an auger to reach the bed rock. In some sites in which it was difficult to reach the bedrock, the depth was assumed to be more than 0.5m. However, according to the differences and variabilities five sampling sites were selected (Fig. 4.2):

Two sampling sites on the top of the North Cleugh tributary's watershed. (sites 1,2).

One site in the planted area near the bottom of the North Cleugh valley. (site 3).

One site in the Great Limestone area on both sides of Killhope Sike, (site 4).

The last site was selected between Puddingthorn pasture and Lanehead, (site 5).

It was thought that such a selection would represent the range of soil creep in the study area.

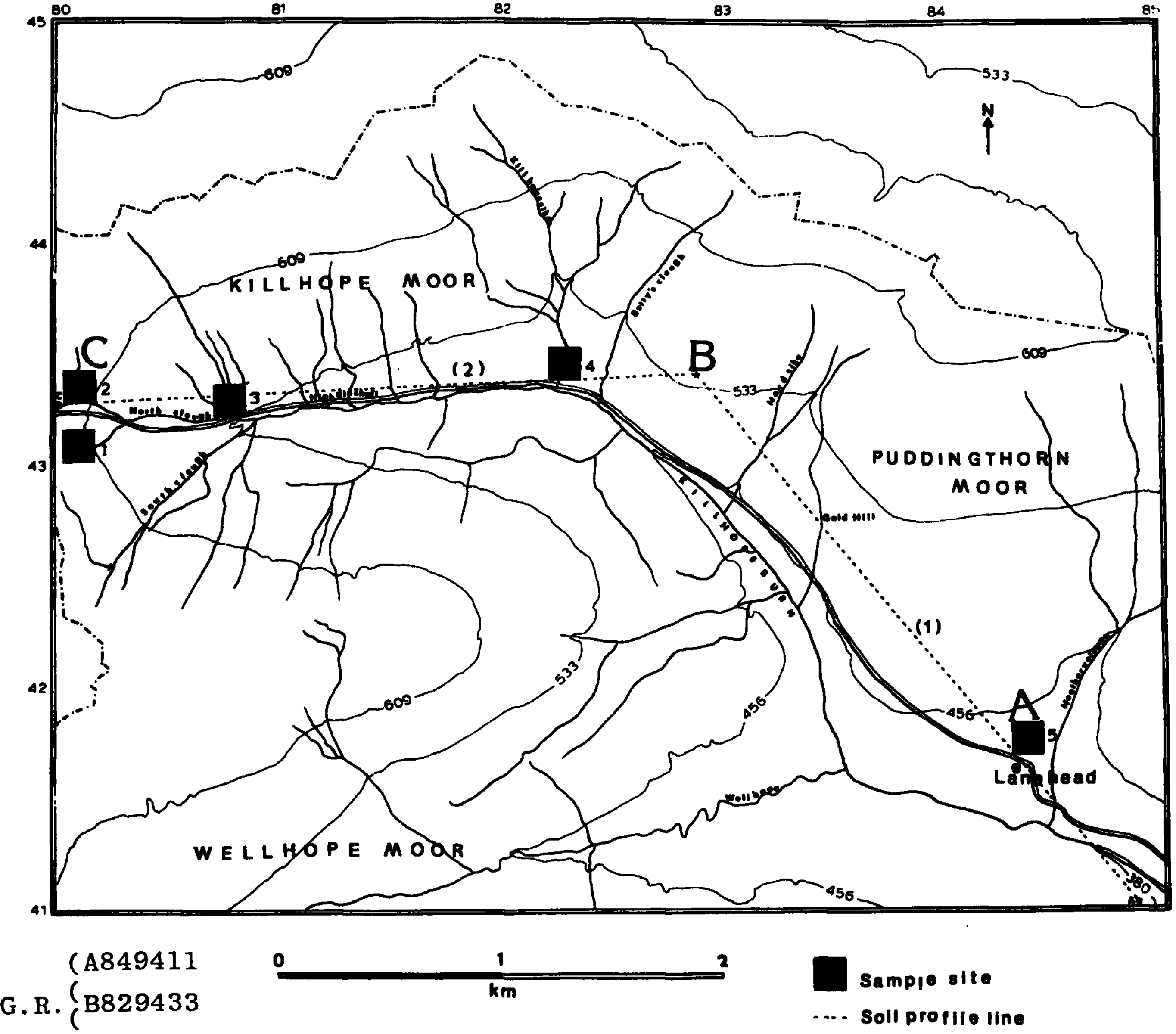


Fig.4-2 Location of sampling sites at Killhope basin

4.3 Location and characteristics of sampling sites

4.3.1 Sampling site No. 1

This basin trends east-west near the watershed of North Cleugh. It is characteristically peat covered. The basin is drained by a small stream and a number of artificial ditches. Disturbed and eroded land caused by old lead mining activities is widespread. A portion of the basin, particularly the stream bank and disturbed soil in weathered shale area is bare. This allows a comparison to be made between the vegetated and bare portions. The vegetated portion consists of Calluna vulgaris, Nardus stricta and Sphagnum spp.

The main control station was established on the vegetated portion and 9 sampling points (plots) distributed in both vegetated and bare portions as a result of differences in vegetation cover, slope angle, soil, and aspect and the Anderson's tube in the control station was used as a standard instrument.

The location and characteristics of control station and plots in this site are shown in Table 4.1 and Figures 4.2 4.3, 4.3a & Plate 4.1.

Soil profile descriptions for plots measured at this site are as follows:

Plot No.1 - Top 3 cm F,H partly decomposed. 3-7 cm Of (Fibrous peat) consisting mainly of well preserved plant remains, 7-10 cm A horizon, 10-25 cm B & C horizon with herbaceous roots and some woody roots. 25-40 cm shale.

Plot No.2 - 0-5 cm F,H accumulated partly decomposed litter. 6-11 cm Of (fibrous peat), 11-25 cm. A horizon with herbaceous roots. Below 25 cm, weathered shale.

Plot No.5 - 0-30 cm C horizon,weathered shale with sparse roots.

Plot No.6 - 0-2 cm L, 2-4 cm F partly decomposed, 4-7 cm Of, 7-15 cm Oh (humified peat) with herbaceous roots. 15-28 cm O and A horizon.

Plot No.7 - 0-1 cm L. 1-4 cm F,H. 4-10 cm Oh with herbaceous roots. 10-18 cm A. Below 18 cm B horizon.

Plot No.9 - 0-1 cm L. 1-4cm F,H. 4-11 cm Oh horizon, strongly decomposed organic material with woody roots 11-30 cm A horizon with fine silty clay (1-3 cm) thick at 15-16 and 21-25 cm.

Plot No.10 - 0-30 cm C horizon, weathered shale with sparse woody roots and mottling.Profile 4.1.

No description has been given for missing plots shown on sketch map. Fig. 4.3.

Note: Describing and sampling soil profile for this study has been carried out using the 'Soil Survey Field Handbook'. Technical monograph No.5, compiled and edited by J.M. Hodgson 1974, and 'Soil classification for England and Wales', Technical Monograph No.14, B.W. Avery 1980.

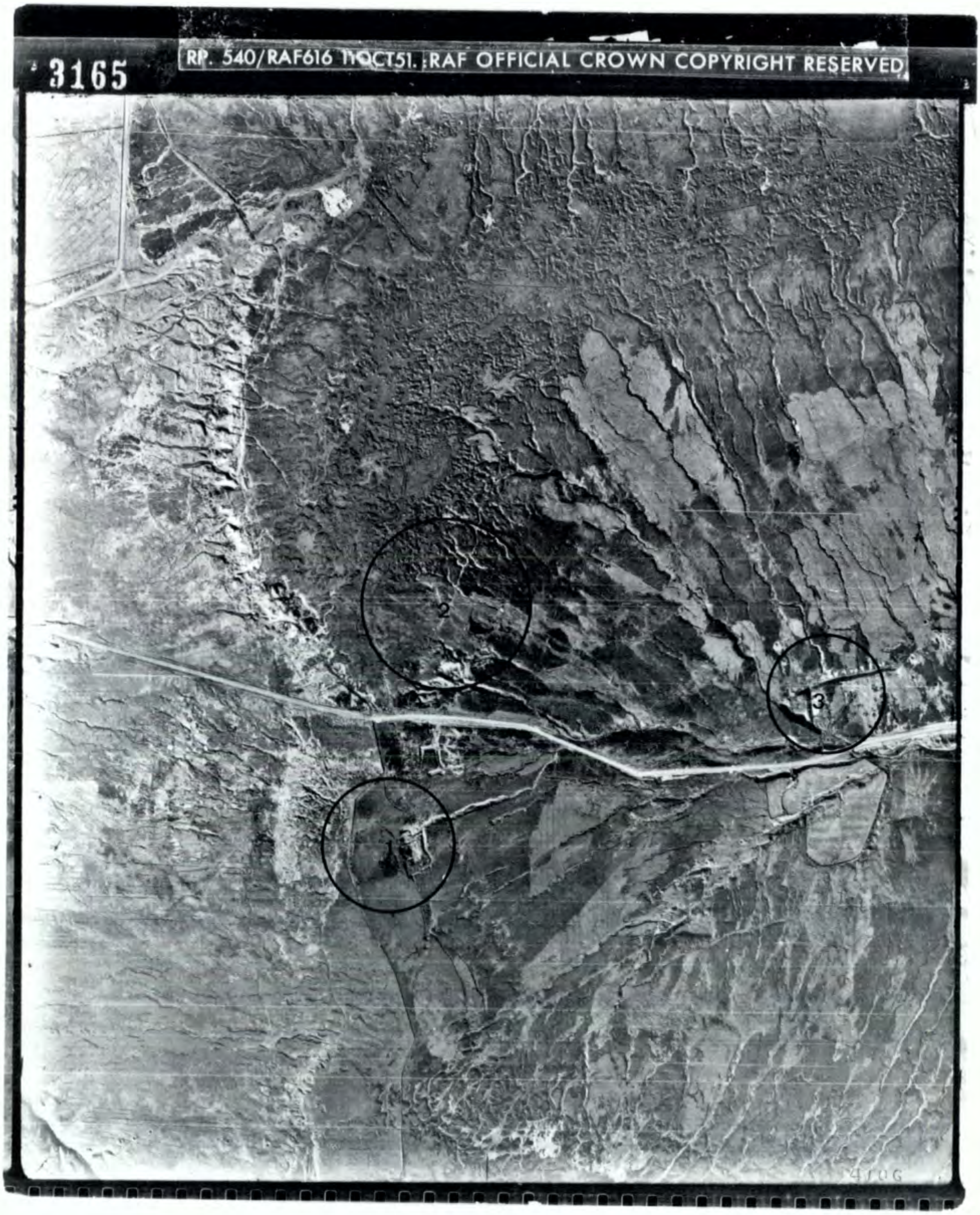


Plate 4.1 : Location of sampling sites Nos. 1,2, and 3 in study area, Killhope basin. (Air Photo, 1951).

Scale 1:11000

Profile 4.1 Soil horizons description at sampling site No.1

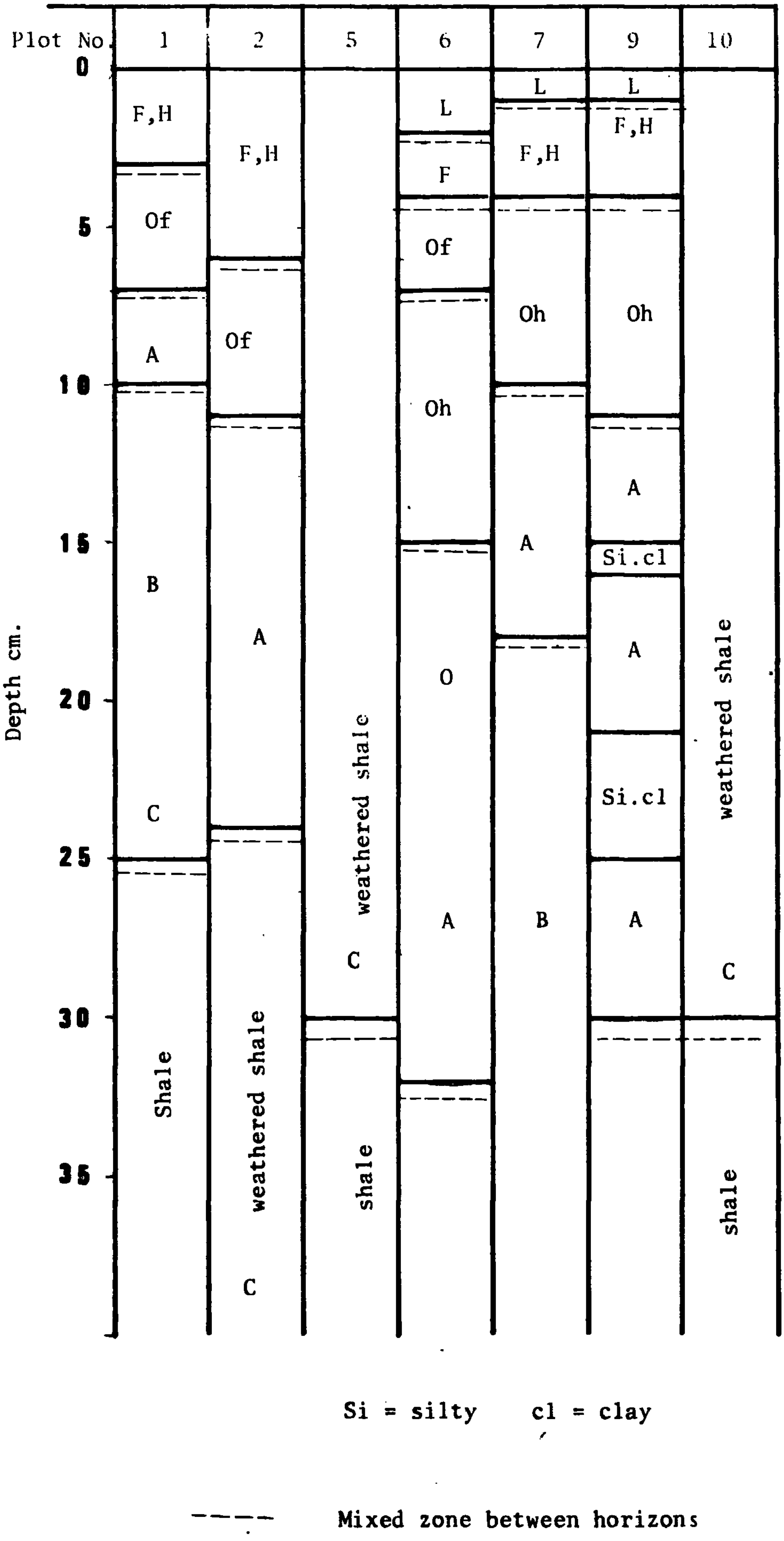


Table 4.1 Characteristics of control station and plots in sampling site No.1

Sample No.	Slope	Depth of soil	Soil	Vegetation dominant
1	10°	>0.5m	Silty clay loam	*Calluna vulgaris* & *Nardus stricta*
2	3°	>0.5m	Loamy sand	*Calluna vulgaris* & *Nardus stricta*
5	15°	0.4m	Clay loam	Bare
6	12°	0. 5 m	Loamy sand	*Nardus stricta*
7	5°	0.45	Loamy sand	*Nardus stricta*
9	3°	0.5m	Loamy sand	*Sphagnum* spp.
10	20°	o.4m	Loam	Bare

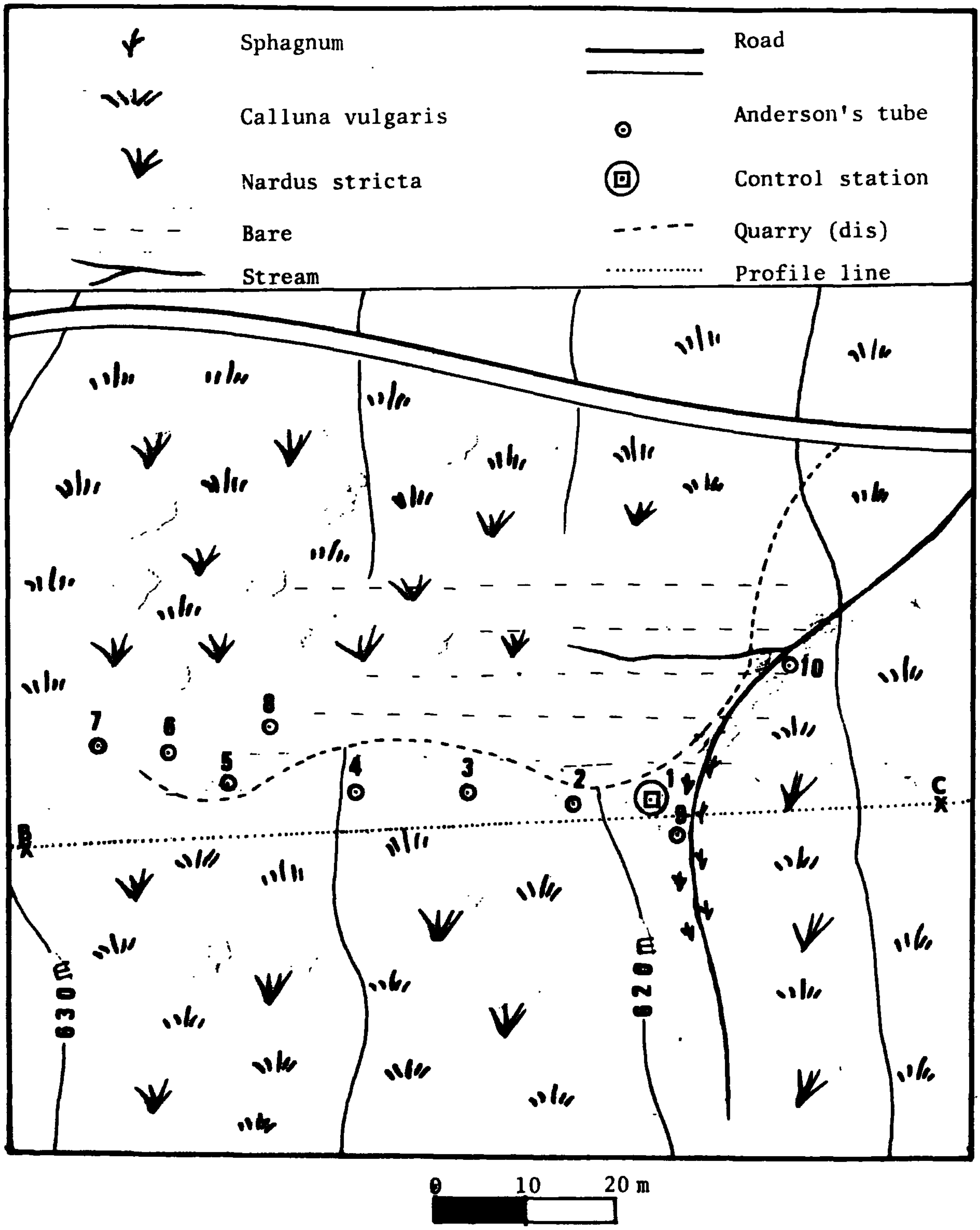


Fig. 4.3 : Sketch map showing sampling site No.1

Control station Grid ref: 801431

Numbered contours are enlarged from O.S : 1 0000 sheet NY 84 SW, others are interpolated by the author.

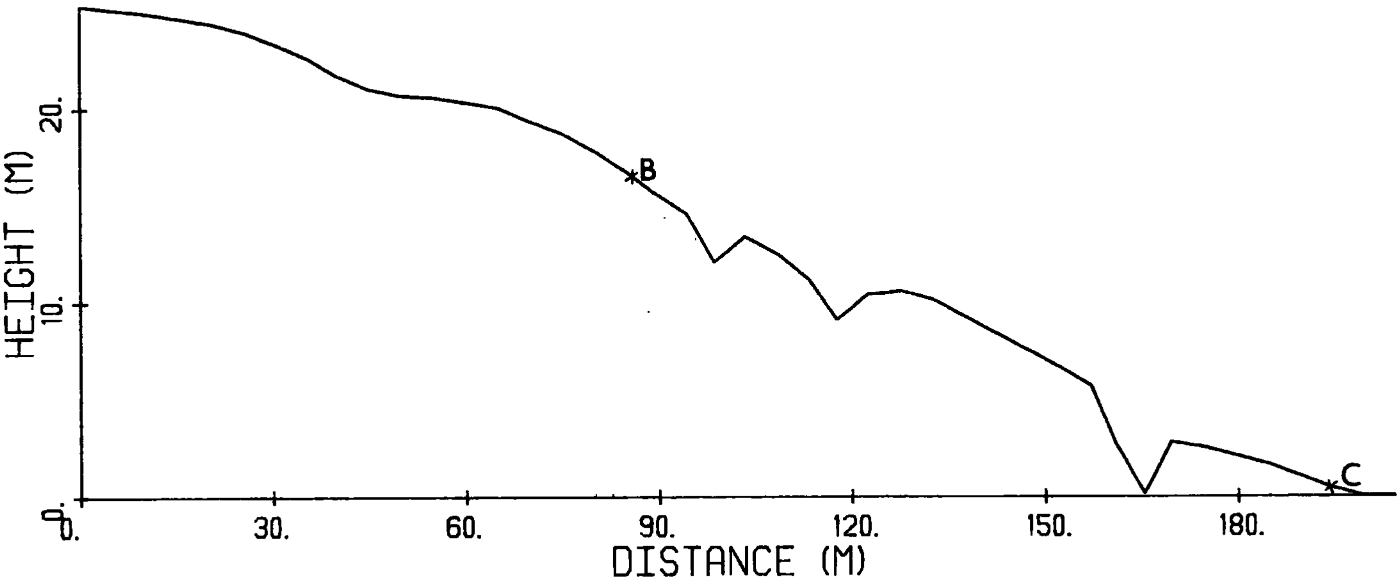


Fig. 4.3a : Slope profile of the instrumented area at sampling site No.1.

4.3.2 Sampling site No.2

The second sampling site was selected at the source of North Cleugh, about 100m north of Killhope Cross. This basin is also covered by peat. The peat covering the gentle slopes of the watershed is characteristically dissected by small channels. The most striking features of this sample site are the presence of relics of old mining activities. Variations in the vegetation are also considerable. The vegetation consists of Calluna vulgaris, Nardus stricta, Juncus squarrosus and Sphagnum spp. Because of the differences of soil, slope and vegetation cover, three transects were selected. Each transect was instrumented using Anderson's tubes (Fig. 4.4). The control station was established in the middle of transects using a Young's pit, Anderson's tube, Wooden pillars and Rashidian's technique. Table 4.2 shows more details of location and specification of this sample site.

Soil profile description for plots at this site are as follows:

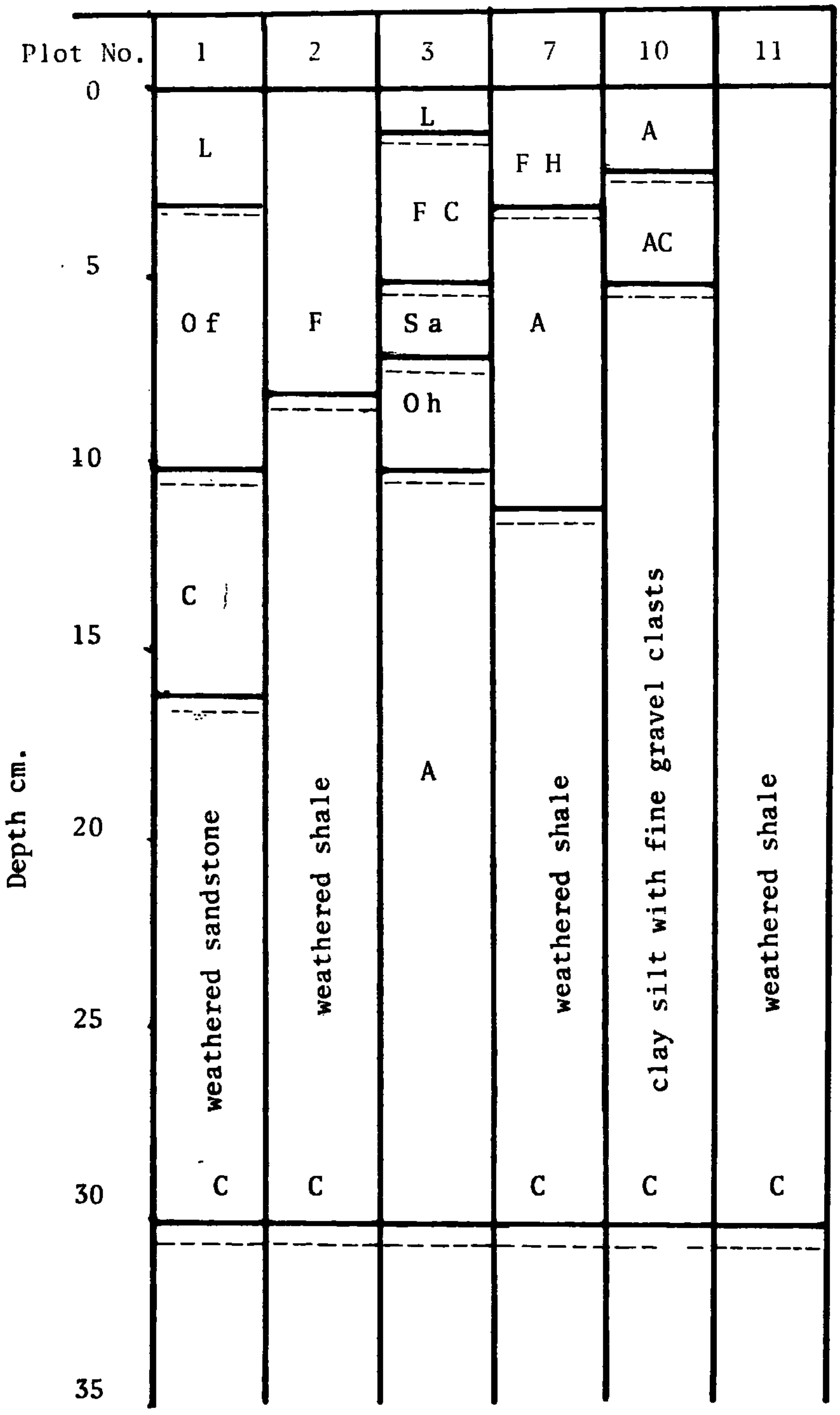
Plot No.1 - 0-3 cm L. 3-10 cm Of (fibrous peat). 10-16 cm C mainly silty clay with weathered sandstone clasts throughout. 16-30 cm weathered sandstone.

Plot No.2 - 0-8 cm A horizon with mottling predominantly along root chanels. 8-30 cm weathered shale.

Plot No.3 - 0-1 cm L. 1-5 cm F, H. 5-10 cm Oh, abundant herbaceous and woody roots. 10-30 cm A horizon. (5-7 cm layer of sand (fluvial).

Plot No.7 - 0-3 cm F, H. 4-11 cm A horizon mainly silty clay. 11-30 cm C horizon, weathered shale. Mottled with sparse herbaceous and woody roots.

Profile 4- 2 Soil horizon description at sampling site No.2



----- Mixed zones between horizons

Plot No. 10 - 0.2 cm A horizon mainly clay silt with fine gravel clasts. 2-5 cm AC - coarse shale clasts. 5-30 cm C horizon clay silt with fine gravel clasts, abundant herbaceous roots.

Plot No.11 - 0-30 am C horizon, weathered shale mottling very prominent, 11-30 cm isolated mottling.

Table 4.2 Characteristics of control station and plots in sampling site No.2

Sample No.	Slope	Depth of soil	Soil	Vegetation dominant
1	8°	>0.5m	Silty loam	*Calluna vulgaris* & *Nardus stricta*
2	8°	0.4m	Clay loam	Bare
3	4°	>0.5m	Sand	*Juncus squarrosus*
7	15°	0.4m	Clay loam	*Calluna vulgaris*
10	20°	0.5m	Loamy sand	*Calluna vulgaris*
11	3°	0.4m	Clay loam	Bare

No description has been given for missing plots shown on sketch map Fig.4.4.

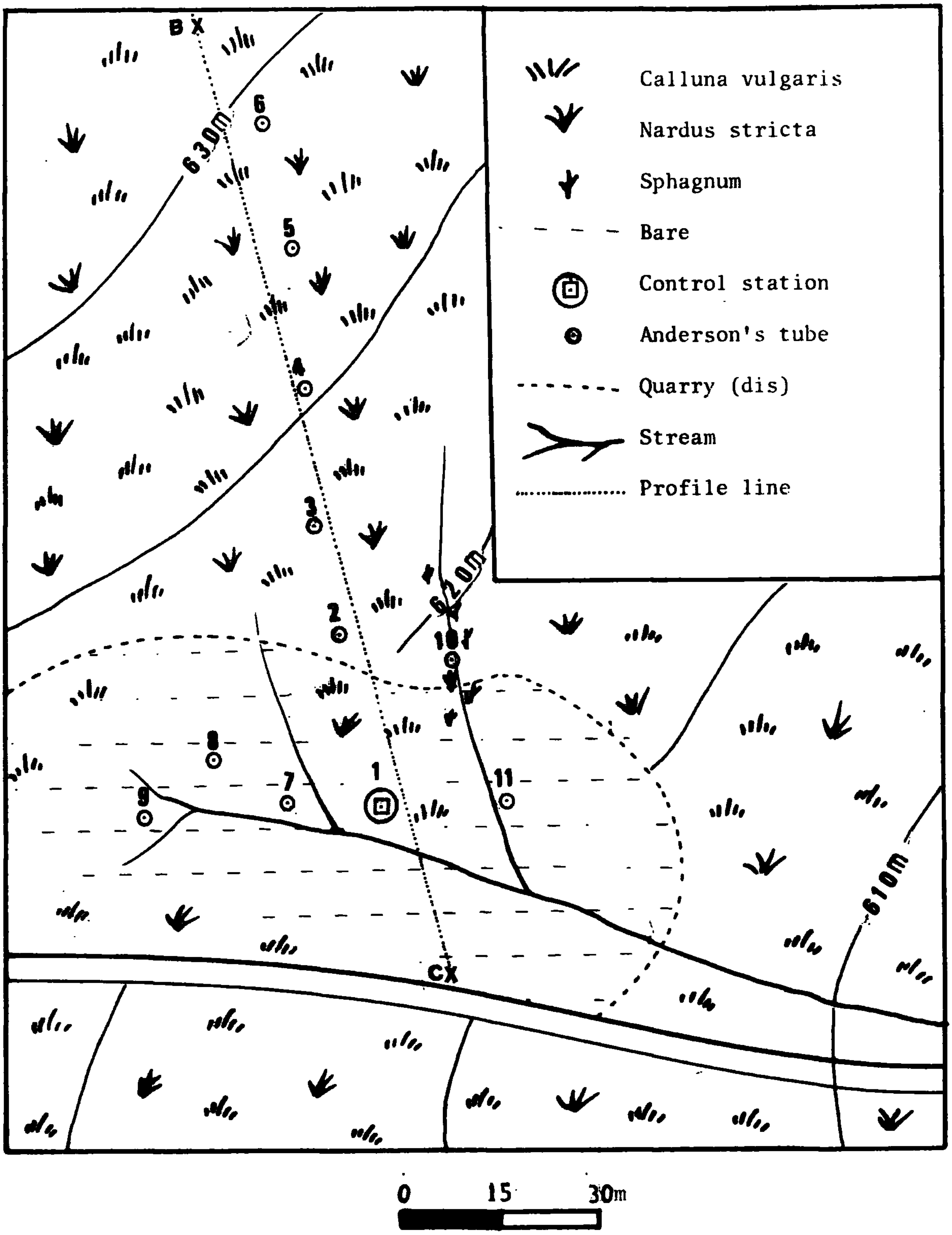


Fig. 4.4 : Sketch map showing sampling site No.2

Control station Grid ref : 802433

Numbered contours are enlarged from O.S. 1:10000 sheet NY 84 SW, others are interpolated by the author.

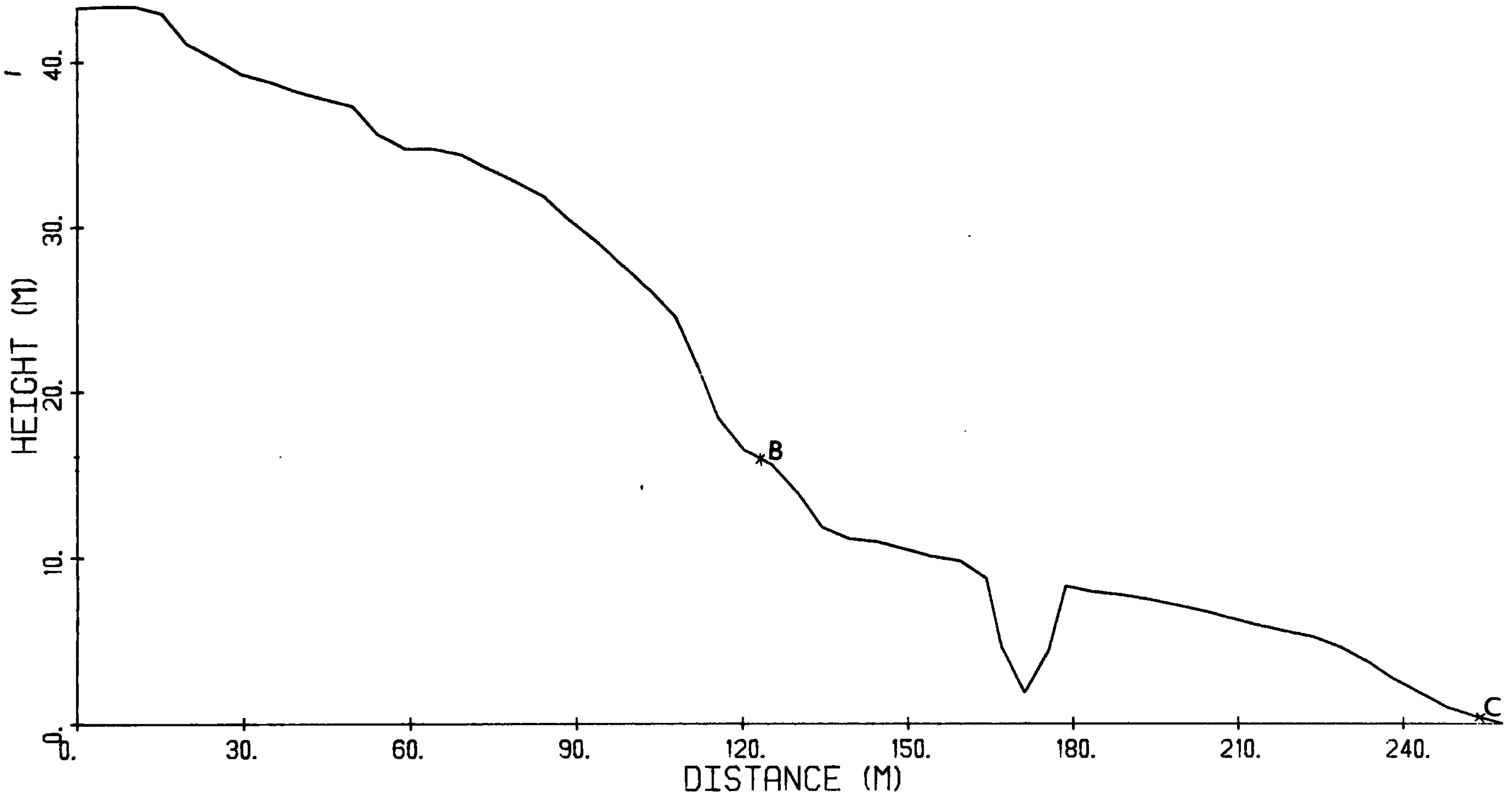


Fig. 4.4a : Slope profile of the instrumented area at sampling site No.2.

4.3.3 Sampling site No.3

Sampling site No.3 was selected in basins of northern tributaries of North Cleugh, north of Killhope head bridge. The soils sampled are mostly humic ranker soil and peat. A portion of this basin has been planted with coniferous trees. The vegetation consists of a generally uniform covering of coniferous forest, *Poa pratensis* and *Festuca ovina*. The main control station was established on the edge of the forest north of Killhope bridge (beyond the fence). Also, two transects were selected, one into the fenced forest and the other one in the unplanted area. In each transect sampling points (plots) were selected and in each plot an Anderson's tube has been established.

The criteria for selecting two transects with different aspects were variations in soil (disturbed and natural soil), and vegetation (vegetated and bare). The first transect in the planted area was placed to the north of the control station. The second transect was placed to the south west of the control station.

The location and specification of this sampling site are shown in Table 4.3 and Figures 4.2, 4.5 and Plate 4.1.

Soil profile descriptions for plots measured at this site are as follows:

Plot No.1 - 0-1 cm L, 1-4 cm Of (fibrous peat) 4-6 cm Om consists mainly of partially decomposed plants. 6-11 cm Oh (humified peat) existing herbaceous roots, 11-30 cm A horizon loamy sand.

Plot No.3 - Top 5 cm Of, 5-14 cm Oh (humified peat) consisting of strongly decomposed organic material. 14-18 cm Ah horizon. 18-30 cm B horizon, silty clay with sandstone.

Plot No.6 - Top cm F, partly decomposed litter. 6-13 cm Oh horizon, 13-30 cm Ah horizon, silty loam with herbaceous and woody roots.

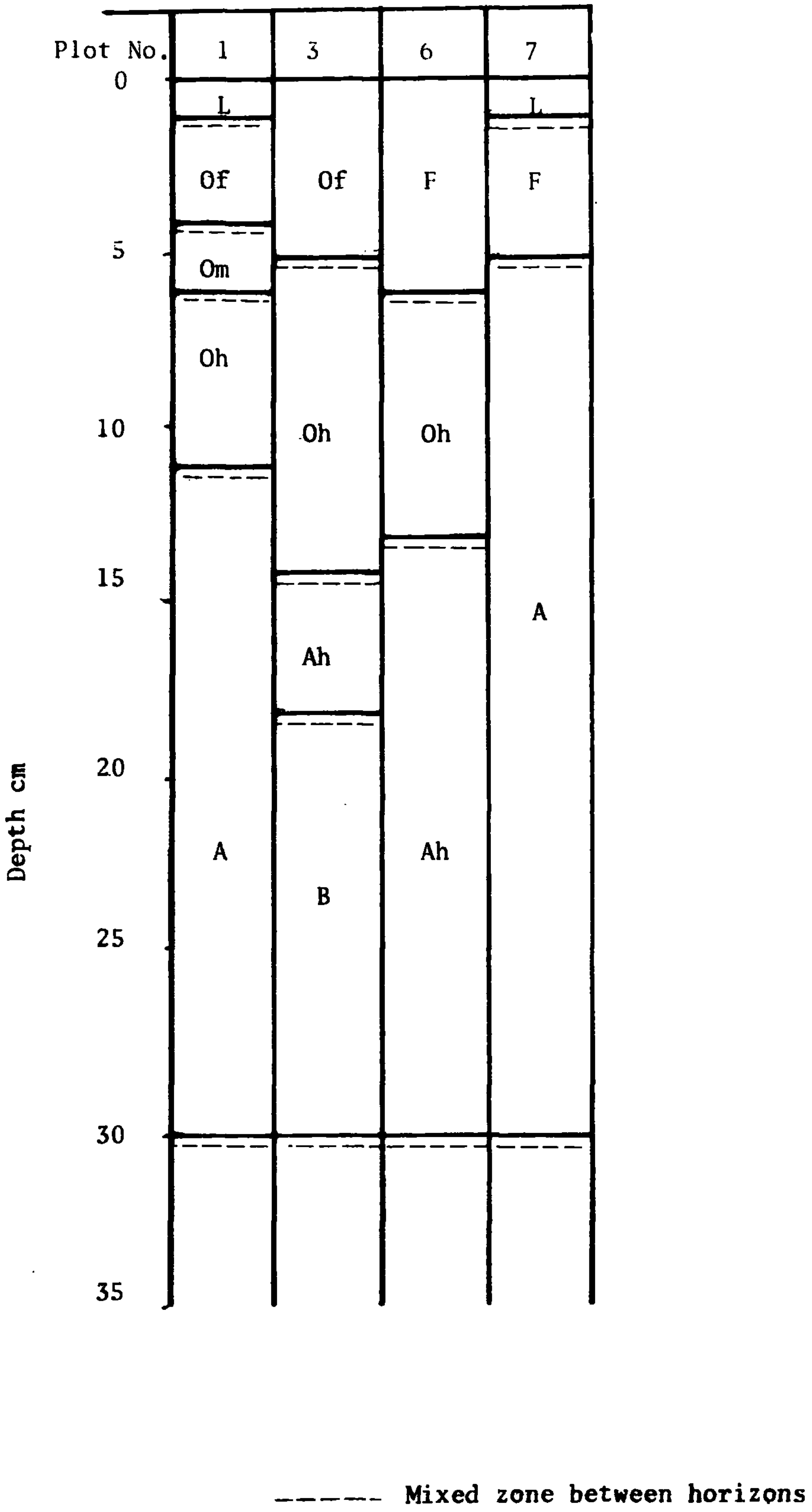
Plot No.7 - 0-1 cm L. 1-5 cm F. 5-30 cm A horizon, sandy loam with medium gravel clasts, Profile 4.3.

Table 4.3 Sample plots characteristics in sampling site No.3.

Sample No.	Slope	Depth of soil	Soil	Vegetation dominant
1	7°	0.5 m	Sand	Coniferous trees *Festuca ovina* & *Poa pratensis*
3	2°	0.4 m	Peat	"
6	10°	0.4 m	Peat	"
7	15°	0.3 m	Silty loam	"

No description has been given for missing plots shown on sketch map Fig. 4.5.

Profile 4-3 Soil horizon description at sampling site No.3.



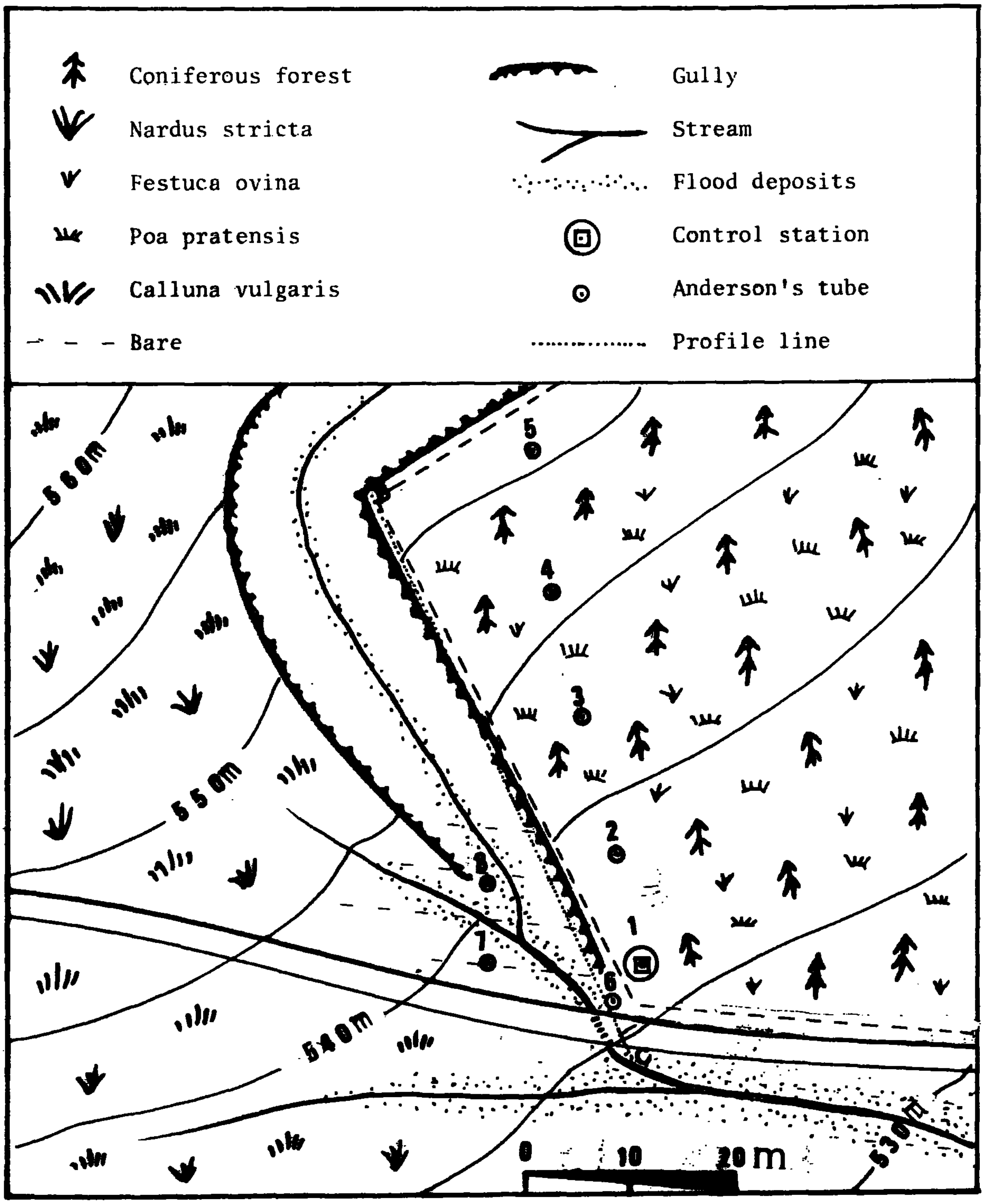


Fig. 4.5: Sketch map showing sampling site No. 3

Control station Grid ref : 802433

Numbered contours are enlarged from O.S. 1:10000 sheet NY 84 SW, others are interpolated by the author.

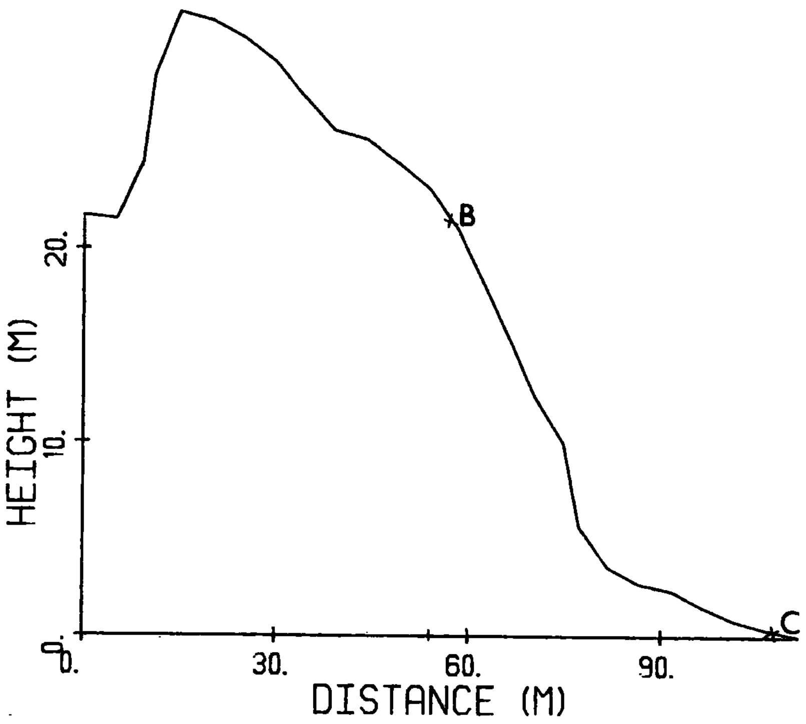


Fig. 4.5a : Slope profile of the instrumented area at sampling site No.3.

4.3.4 Sampling site No.4

Sampling site No.4 was selected in a basin in the Great Limestone area, near the junction of Killhope Sike and Killhope Burn. A large portion of this basin has also been planted by the Forestry Commission using coniferous trees.

The area includes slopes with angles of between 5° and 35°, a soil depth of between 0.1m and 0.5m, and a variety of drainage conditions. Vegetation-covered slopes are dominated by Poa pratensis and Poa angustifolia in the woodland, and Juncus effusus and Sphagnum spp in the unwooded area. Also within the selected basin are old mining remains and quarries so that it is seriously disturbed.

The control station was established at the boundary of the forest and two transects were selected on both sides of the stream. In each transect Anderson's tubes were installed randomly. It was intended that these would provide an interesting comparison between creep rates on natural and disturbed soils on both sides of the stream. The location and characteristics of the control station and sampling points (plots) are shown in Tables 4.4 and 4.6 and Figure 4.6, and Plate 4.2.

Soil profile descriptions for sampling plots measured at this site are as follows:

Plot No.1 - Top 2 cm F partly decomposed litter. 2-15 cm A horizon. Sandy clay loam with herbaceous roots. Below 15 cm C horizon, weathered sandstone.

Plot No.2 - Top 2 cm F. 2-20 cm A horizon sandy loam with roots. 20-30 cm B horizon, illuvial concentration combining humus and minerals, mainly silty clay.

Plate 4.2 : Location of sampling site No.1 in study area, Killhope basin. (Air Photo 1951)

Scale 1:11000

Plot No.3 - 0-15 cm A horizon, dark brown sandy loam with roots and fine to coarse gravel.

Plot No.4 - 0-1 cm L. 1-12 cm Of with fibrous herbaceous roots. 12-18 cm A horizon, silty clay with roots, decreasing with depth. 18-27 cm mottled silty loam with coarse clasts and roots.

Plot No.5 - 0-25 cm A horizon, sandy clay loam with oxidized sandstone clasts; herbaceous roots extend to 25 cm. Below 25 cm C horizon.

Plot No.7 - 0-1 cm L. 1-4 cm F. 4-25 cm A horizon. Dark brown sandy silt with coarse sandy gravel and roots. 25-30 cm brown sandy gravel with herbaceous roots.

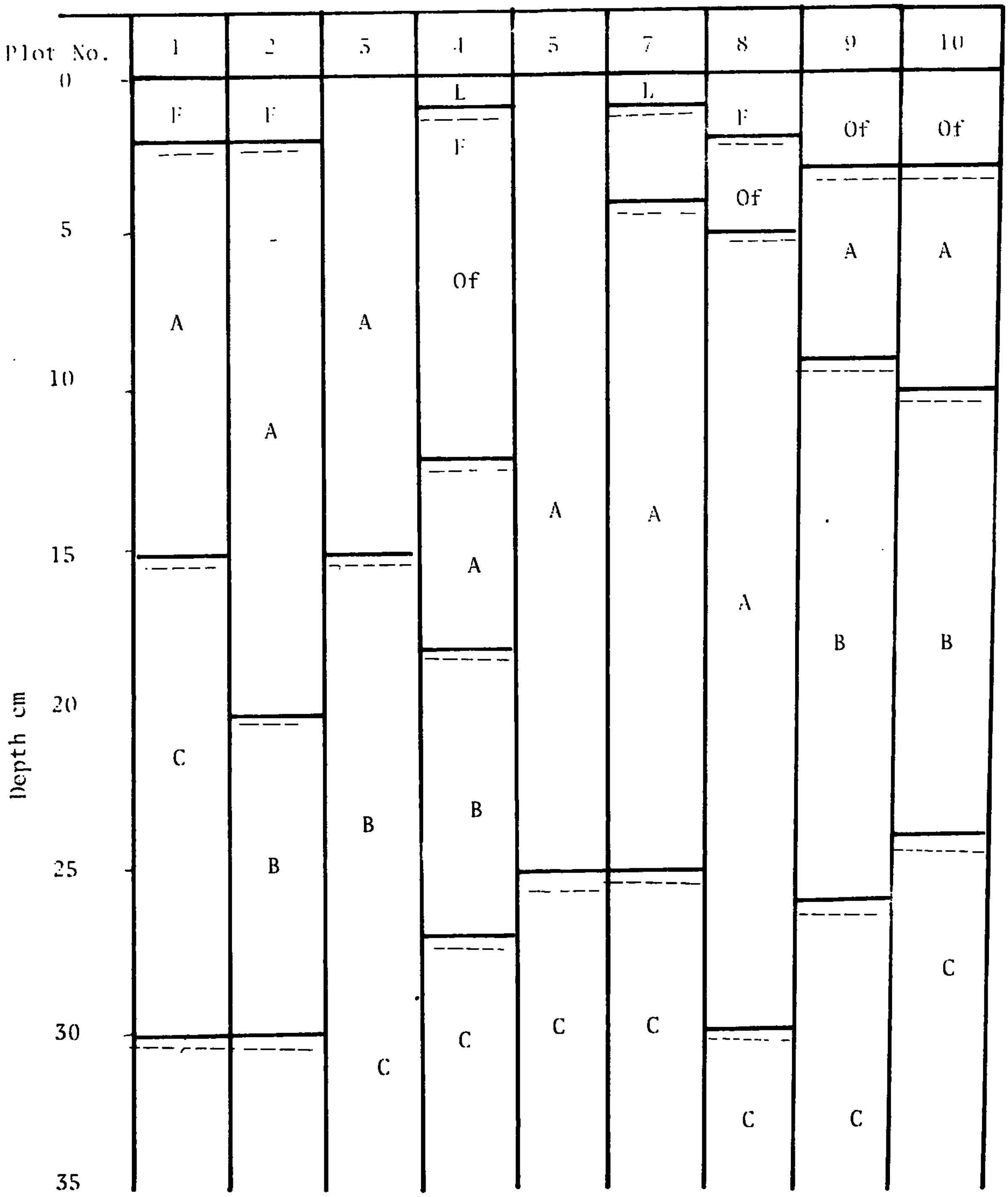
Plot No.8 - 0-2 cm F. 2-5 cm Of. 5-30 cm A horizon, fine sand and silty clay with herbaceous roots, coarse sandy gravel and oxidized sandstone.

Plot No.9 - 0-3 cm Of. 3-9 cm A horizon organic sandy silt. Colour black. 9-26 cm B horizon. Colour brown highly mottled, fine sand and silty clay, sandstone clasts with herbaceous roots.

Plot No.10 - 0-3 cm Of. 3-10 cm A horizon organic sandy silt (colour dark brown) with abundant herbaceous roots. 10-24 cm B horizon. Below 24 cm C horizon.

No description has been given for missing plots shown on sketch map Fig.4.6.

Profile 4-4 Soil horizon description at sampling site No. 4



------ Mixed zone between horizons

Table 4.4 Sample plots characteristics in sampling site No.4

Plot No.	Slope	Depth of soil	Soil	Vegetation dominant
1	15°	0.3m	Loam	Poa pratensis & Poa angustifolia
2	15°	0.3m	Loamy sand	"
3	20°	0.3m	Loamy sand	"
4	12°	0.3m	Silty clay	"
5	4°	0.3m	Clay loam	"
7	2°	0.35m	Loamy sand	Poa pratensis & Calluna vulgaris
8	30°	0.4m	Loamy sand	"
9	3°	0.5m	Loamy sand	"
10	10°	0.5m	Loamy sand	Juncus effusus

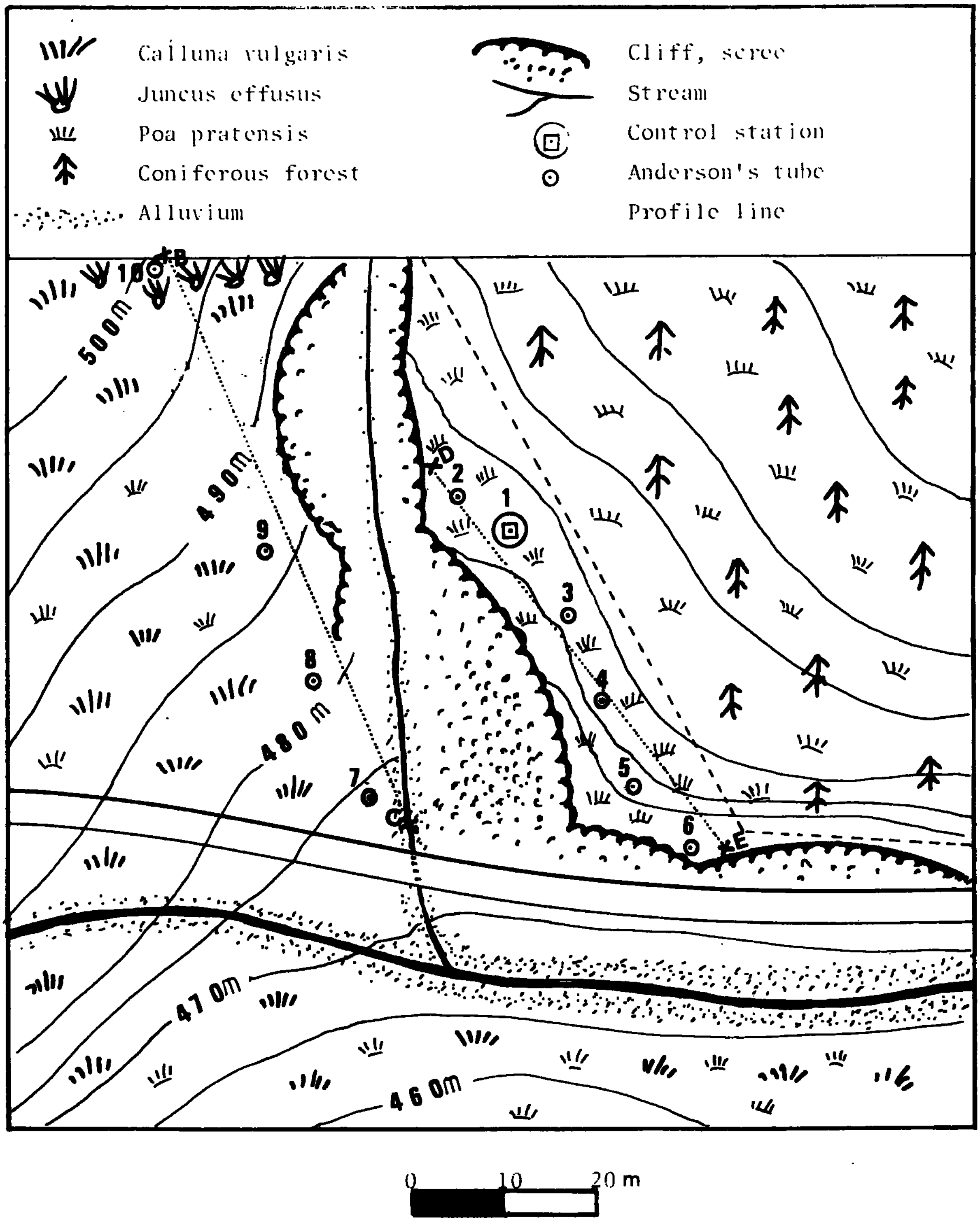


Fig. 4.6 : Sketch map showing sampling site No. 4.

Control station Grid ref : 802433

Numbered contours are enlarged from O.S. 1:10000 sheet NY 84 SW, others are interpolated by the author.

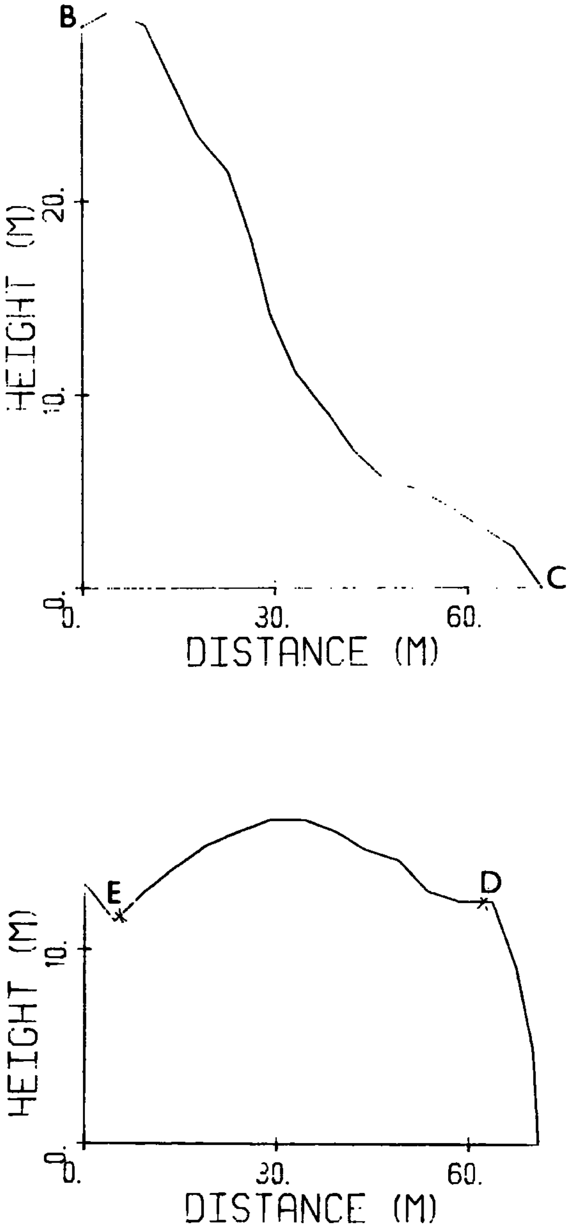


Fig.4.6a : Slope profiles of the instrumented area at sampling site No.4.

4.3.5 Sampling site No.5

Sampling site No.5 was selected in the Lanehead area and includes Lanehead school grounds, the Lanehead plantation area, and Pudding Thorn pastures area. The sampling site includes slopes with angles of between 1° and 15°. The depth of soil at the sampling points (plots) varies between 0.2 m and 0.5 m. Vegetation covering the sampling points varies due to soil differences and elevation. The northern part of the school area is coniferous woodland, and the rest of the study area is covered by Calluna vulgaris, Nardus stricta, Juncus squarrosus and Sphagnum spp. It can be said that each portion is dominated by one of the major types of vegetation.

The control station was established about 20m east of the school building, and from this a transect was selected towards the north passing through the walled pastures of the farms. Along this transect sample points (plots) were selected. In each plot an Anderson's tube was installed. It was intended that all differently vegetated areas should be instrumented. This should allow a direct indication of the variations of movement with vegetation and soil to be obtained. Tables 4.5 & 4.6 and Figure 4.7 & Plate 4.3 show the location and specification of the control station and sample plots.

Soil profile descriptions for plots measured at this site are as follows:

Plot No.1 - 0-10 cm A horizon, sandy clay silt with herbaceous roots. 10-30 cm C horizon weathered sandstone with herbaceous roots (colour brown).

Plot No.3 - 0-1 cm L, 1-20 cm A horizon, fine sandy clay Loam. 20-30 cm sand.

Plot No.4 - 0-2 cm F partly decomposed litter. 2-5 cm H horizon. 5-12 cm A horizon organic sandy clay, well developed roots throughout. 12-25 cm sand and silty clay. 25-30 cm sand and silt.

Plot No.5 - 0-4 cm A horizon 4 to 14 cm O horizon 14-30 cm fine sand with some coarse gravel, and roots to below 30 cm.

Plot No.6 - 0-10 cm ÔFhorizon, fibrous peat. 10-20 cm A horizon, organic silty clay (colour dark brown).

Plot No.7 - 0-16 cm Oh humified peat 16-30 Om horizon, partly humified peat with herbaceous and woody roots (colour brown to dark brown).

Plot No.8 - 0-2 cm F. 2-4 cm H. 4-30 cm Oh strongly decomposed organic material.

Plot No.9 - 0-7 cm F, partly humified peat. 7-20 cm Oh strongly humified peat. Below 20 cm Om organic silty clay, existing roots.

Plot No.10 - 0-2 cm L. 2-5 cm H, well decomposed litter mixed with mineral matter. 5-14 cm Of. 14-30 cm Bh horizon containing translocated organic matter with medium to coarse sand with fine gravel. Profile 4.5.

Plate 4.3 : Location of sampling site No.5 in study area, Lanehead School. (Air Photo 1951)

Scale 1:11000

Profile 4-5 Soil horizon description at sampling site No. 5

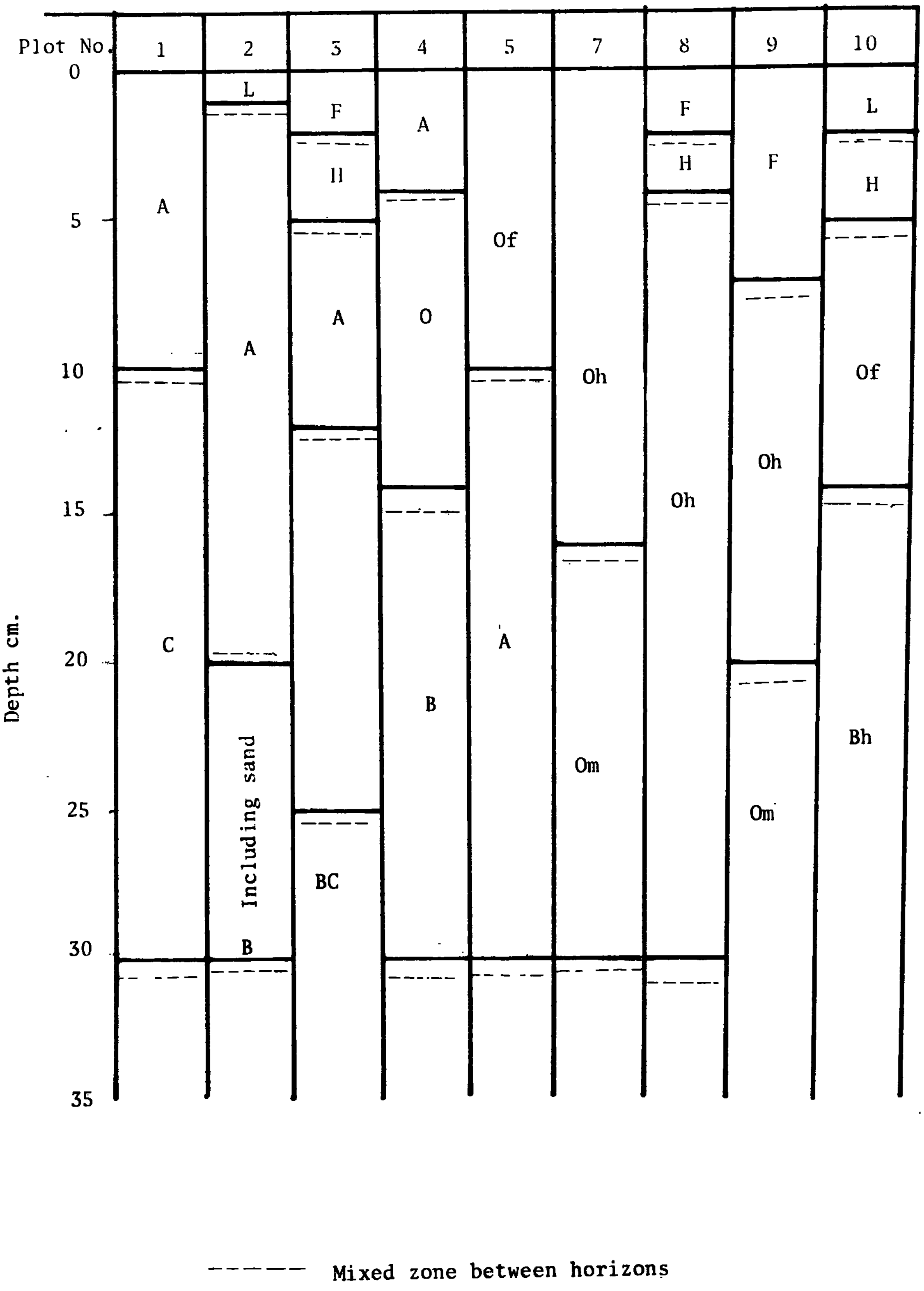


Table 4.5 Sample plots characteristics in sampling site No.5

Sample No.	Slope	Depth of soil	Soil	Vegetation dominant
1	3	0.3 m	Loam	*Poa pratensis*
2	3	0.4 m	Loam	"
3	5	0.4 m	Loamy sand	*Nardus stricta* & *Poa pratensis*
5	5	0.5 m	Peaty gley	"
6	7	0.5 m	Peaty gley	*Sphagnum* spp. *Juncus squarrosus* & *Nardus stricta*
7	3	0.5 m	Peaty gley	"
8	2	0.5 m	Peaty gleyed podzol	*Calluna vulgaris* & *Nardus stricta*
9	1	0.5 m	"	"
10	15	0.5 m	"	*Calluna vulgaris*

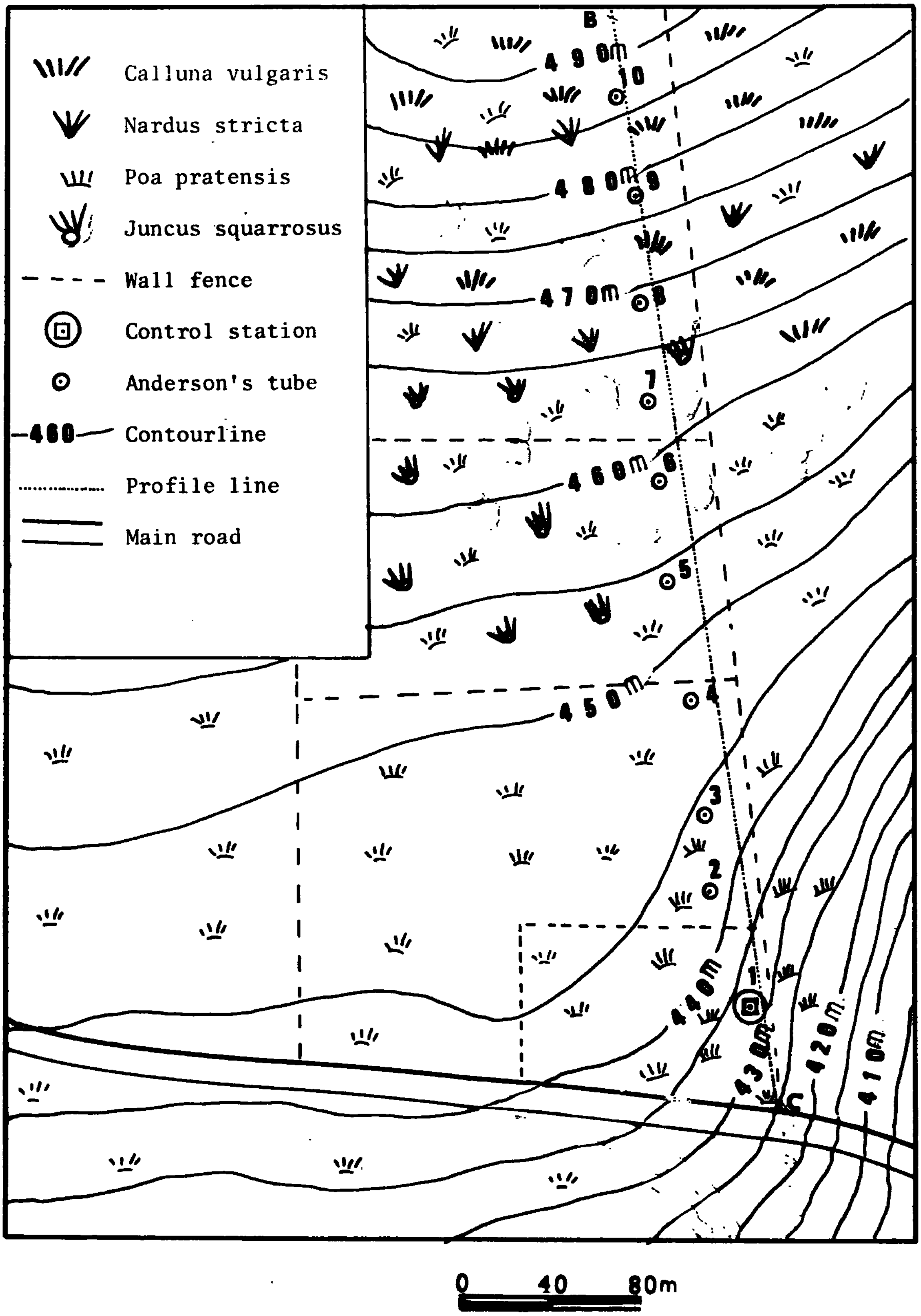


Fig. 4.7 : Sketch map showing sampling site No.5

Control station grid ref : 844417

Numbered contours are enlarged from O.S 1:10000 sheet N.Y 84 SW, others are interpolated by the author.

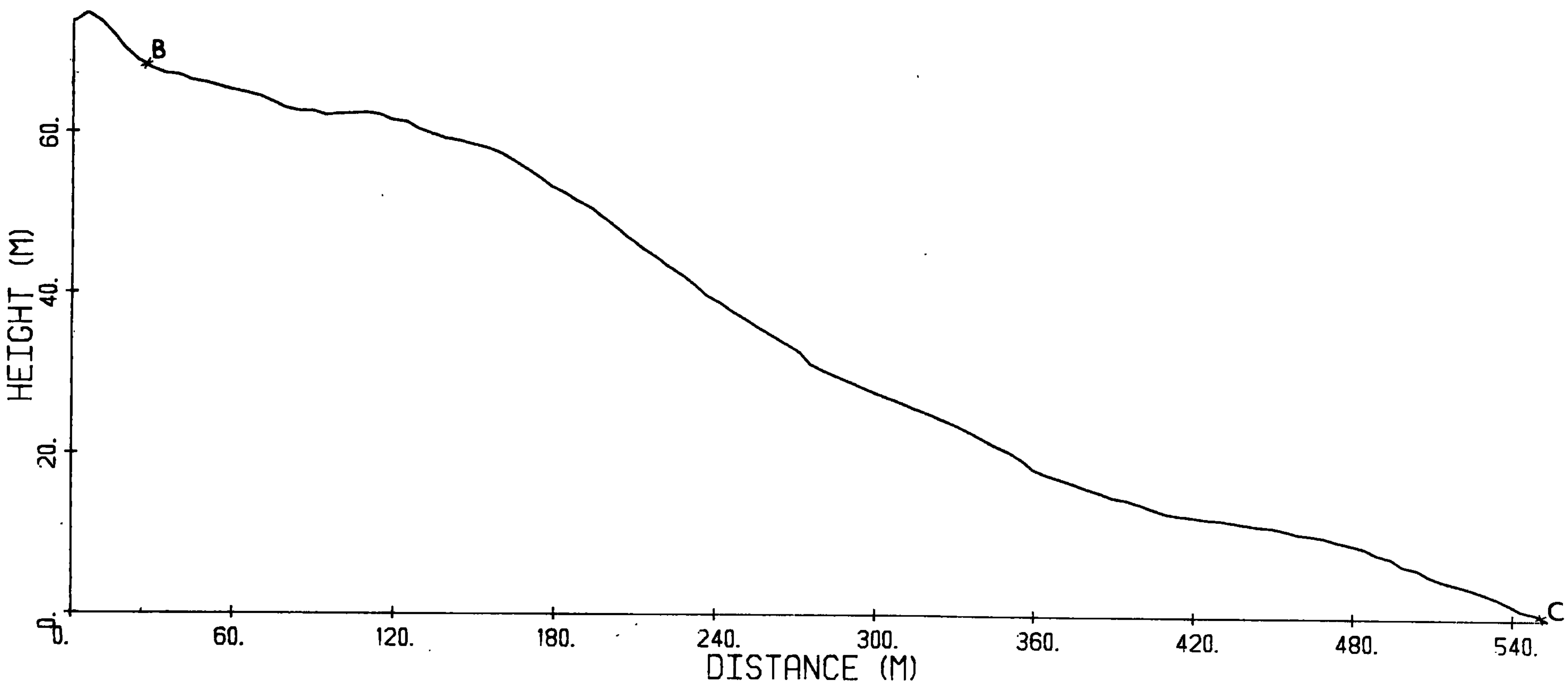


Fig. 4.7a : Slope profile of the instrumented area at sampling site No.5.

Table 4.6 Location and specification of control stations in five sampling sites

Control Station No.	Map Sheet	Grid reference	Height m.	Aspect	Slope Angle	Soil	Depth of soil m.	Vegetation dominant	Land Use
1	NY84SW	801431	620	S.W.	10°	Silty clay loam	0.55	Calluna vulgaris, Nardus stricta	Unenclosed sheep grazing, open ditch drainage by 0.45 m. deep ditches at interval of 80 m.
2	NY84SW	802433	610	East	8°	Silty loam	0.6	Calluna vulgaris, Nardus stricta, and Rhytidia delphus squarrous	Unenclosed sheep grazing and gullied and waste land around old mining
3	NY84SW	80 43	530	South	7°	Sand	0.5	Coniferous trees, Festuca ovina and Poa pratensis	Forestry enclosure
4	NY84SW	823435	490	West	15°	Loam	0.3	Poa pratensis and Poa angustifolia	Forestry enclosure
5	NY84SW	844417	442	South	3°	Loam	0.3	Poa pratensis	Walled, not in use for sheep grazing or farming activity

4.4 Conclusion

- The sampling sites were selected, as was the pattern of experimental basins in the study area, with regard to the variables affecting the rate of soil creep.
- The sampling points (plots) were each defined as a subdivision of a complex sampling site which has a dominant vegetation cover, soil type or definite slope degree.
- Using the procedure employed in the instrumentation of the sampling sites, it was thought that the effects of variations in the control of soil creep could be measured. For this, an attempt was made to instrument each characteristic aspect on each sampling site.
- The techniques and instruments used at the control station were capable of reflecting bodily movement and providing a profile of the rate of creep with depth in both the short term and the long term.
- The results obtained from the Anderson's tubes at the sampling points (plots) could be controlled by comparison with results from instruments including Anderson's tube in the control station.
- It was desirable that all the sampling points (plots) could be read during one visit. This was possible due to the short distance of the sampling sites from the main road which passes through the study area.
- The greatest difficulty arising in this experimental design was in selecting the control station. Every attempt was made to ensure that the control station location reflected the major characteristics of each sampling site.

CHAPTER FIVE

EXPERIMENTAL STUDY

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EXPERIMENTAL STUDY

5.1 Introduction

A full study of the process of soil creep requires an understanding of the influence of all the factors involved. Following Carson (1969) the factors effective in controlling the rate of soil creep may be divided into two general groups : (a) bioclimatic setting, and (b) characteristics of the rockmass. Anderson (1977) classified the effective factors in the process of soil creep into three categories:

a) External factors
b) Surface factors
c) Internal factors

The main external factors suggested as possible controls of the rate of soil creep are meteorological cycles (wetting and drying, cooling and heating, freezing and thawing) which have been regarded as triggers for net downslope movement. Among the surface factors, slope angle, vegetation cover, human and animal influences are considered. The determination of the influence of human and animal activities is not easy and there is some doubt about the importance of slope angle in comparison with some other variables such as soil moisture content (Anderson and Cox, 1981).

Internal factors consist of soil characteristics and burrowing animals (soil fauna). In this study, some of the soil properties which have been regarded as important controls were of interest; these included soil moisture in wet and in dry conditions, organic content, soil texture, liquid limit, plastic limit, plasticity index, shear strength, bulk density, specific gravity, dry bulk density, porosity and void ratio. An attempt was made to provide a clear indication of soil properties at each sampling plot, using facilities of the soil laboratories in the Geography Department and in the Engineering Geology section in Durham University. The method for each test will be described briefly, together with the instruments used. The effect of the growth and the decay of plant roots was difficult to assess in quantitative terms but should be regarded as a cause of soil movement.

5.2 Slope angle

Since microfacets are considered important for this study and the plots selected are so small, more accuracy is needed. Micro-features on the soil surface and vegetation cover may affect the results. Slope angle in each plot was measured using a Suunto clinometer over a 1 m length, 50 mm wide, and 10 mm thick wooden board laid at right angles to the contour. This allowed a resolution of 10 minutes of arc. The results which are based on an average of three measurements for each plot (One reading at each end of the board and one reading at the middle) were obtained and then the sine of the slope angle was calculated for each plot. (Table 5.1); they are plotted in Fig.5.1.

Table 5.1 Sine of slope angle for all sampling plots measured in study area

Plot No. Site No.	1	2	3	4	5	6	7	8	9	10	11
1	0.17	0.05	-	-	0.25	0.2	0.09	-	0.05	0.34	-
2	0.14	0.14	0.07	-	-	-	0.25	-	-	0.17	0.05
3	0.12	-	0.03	-	-	0.17	0.25	-		-	-
4	0.25	0.25	0.34	0.20	0.07	-	0.03	0.5	0.05	0.17	-
5	0.05	-	0.09	0.17	0.09	0.12	0.05	0.03	0.02	0.25	-

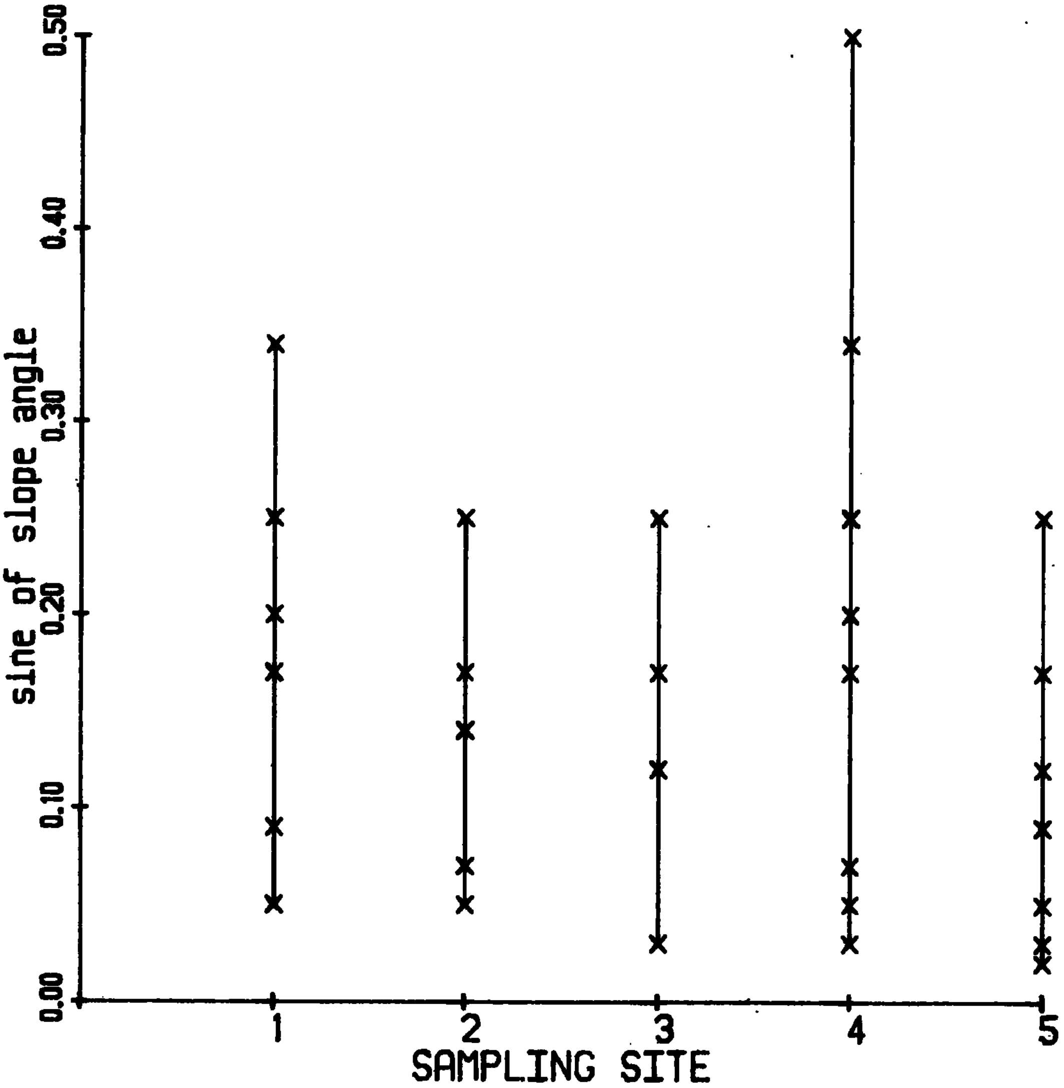

Fig. 5.1 Univariate scatterplots for the sine of the slope angle at five sites (study area).

5.3 Soil depth susceptible to movement

The depth of soil in the study area varied from plot to plot. This variation does not necessarily determine the zone in which the creep process operates, because soil texture, soil moisture content and vegetation cover may affect the soil depth susceptible to creep. Therefore it was decided to calculate the soil depth susceptible to movement using Anderson's tubes which give the pivot point about which the tube's position changes (Chapter two, pp. 40 -44). The strong correlation between soil depth measured or estimated (for more than 50 cm depth) in the field and soil depth susceptible to movement calculated accurately, can justify the adoption of second values (susceptible depth) for data analysis. The results of this calculation for all sampling plots measured in the study area are shown in Table 5.2 and Figure 5.2.

5.4 Laboratory programme

It was decided to undertake a laboratory programme where initially the soil sample of each sampling plot would be subjected to a variety of soil property tests. For this purpose two samples of soil were taken, one from each sampling station and one from each plot. The samples were dug out fresh in the field (one metre away from each control station) and taken to the laboratory in an air-sealed container or a plastic tube. The plastic tube samples were used for those tests for which the sample should necessarily be undisturbed. Depending on the soil thickness the depth of sampling was varied between 0.25m and 0.4m.

Table 5.2 Soil depth cm susceptible to creep for sampling plots measured in the study area

Plot No. Site No.	1	2	3	4	5	6	7	8	9	10	11
1	30 50*	31 50*	-	-	36 20*	32 45*	30 45*	-	33 40*	34 40*	-
2	30 50*	24 40*	33 50*	-	-	-	25 40*	-	-	30 50*	24 40*
3	31 50*	-	28 40*	-	-	29 40*	25 30*	-	-	-	-
4	28 30*	27 30*	25 30*	26 30*	25 30*	-	27 35*	27 40*	32 40*	33 50*	-
5	25 30*	-	26 40*	26 40*	30 50*	30 50*	31 50*	33 50*	32 50*	30 50*	-

Values marked with * represent depth of soil measured in the field for each plot.

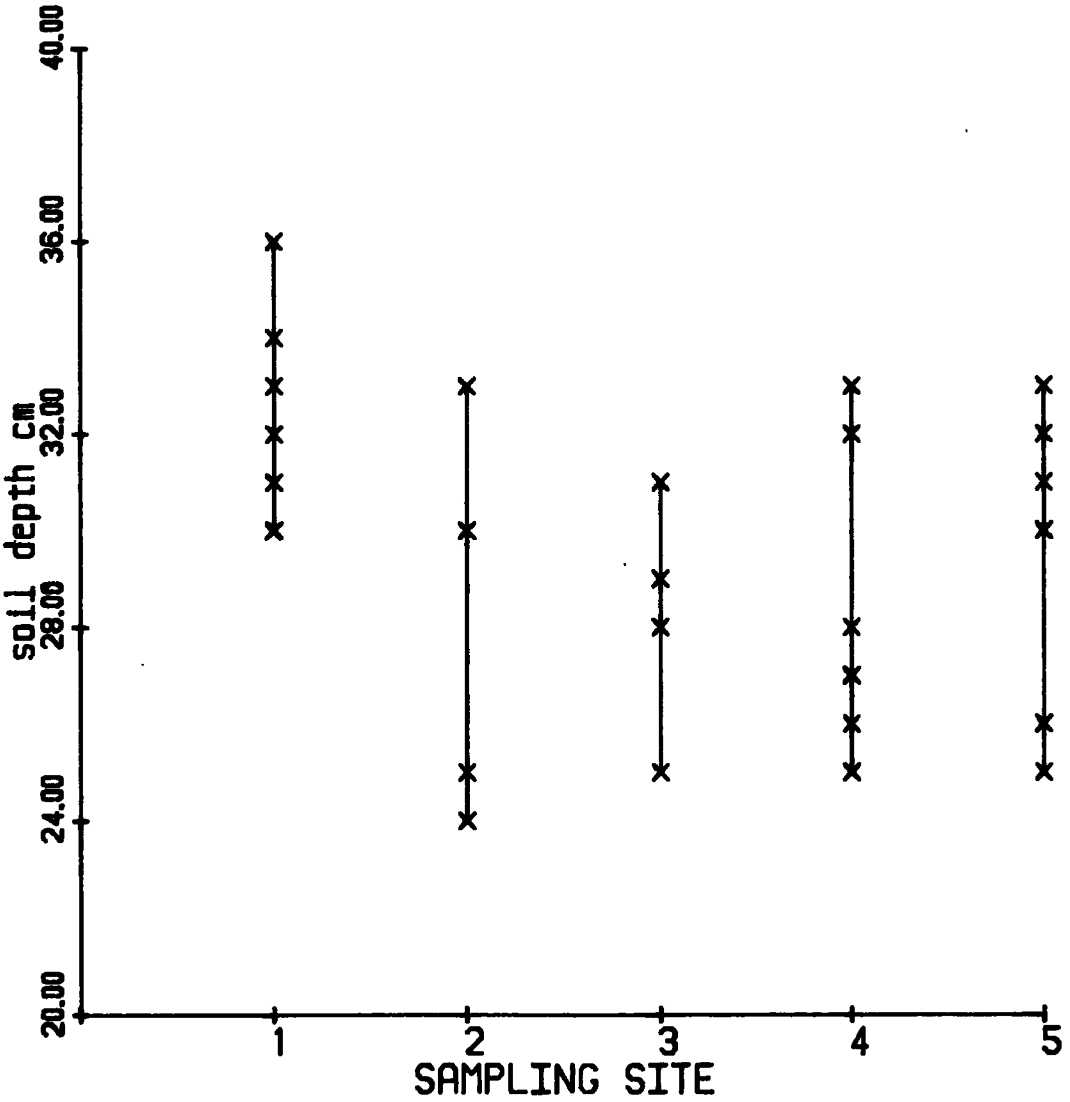

Fig. 5.2 Univariate scatter plots for the soil depth susceptible to movement at five sites (study area).

To avoid confusion arising in the analysis, all samples were taken on the same depth (between 0.05m to 0.15m) from the surface when the soil was at or near maximum water content at a certain depth (0.3m from the surface). From this a section (between 0.05 - 0.15m) was obtained for testing soil properties for each plot.

5.4.1 Soil moisture content

(i) Scope. The moisture content of a soil is a property which is determined probably more frequently than any other(Akroyd 1964). For each plot samples were taken when the soil was near maximum water content (wet sample) and minimum water content (dry sample). The test was carried out by drying the samples in an oven. To overcome the difficulty of definition of moisture content it is usual to express the moisture content as a percentage of the weight of the soil after it has been dried to constant weight at 105 to 110°C for 24 hours. After being dried to constant weight at this temperature any water still held in the soil is considered as part of the soil solids.

(ii) Apparatus. A drying oven at a controlled temperature of 105 to 110°C for 24 hours.

(iii) Procedure. A clean container was dried when weighed for each sample. An amount of soil was then put in each container. The containers and contents were weighed, placed in the oven and dried to constant weight, at a temperature of 105°C for a period of 24 hours. After drying, the samples were removed from the oven and allowed to cool; then the samples were weighed together with their containers.

(iv) Calculations. The moisture content of the soil (MC) as a percentage of dry weight is given by

$$\text{MC} = \frac{\text{Loss of weight}}{\text{dry weight}} \times 100 \text{ per cent}$$

where Loss of weight = container and wet soil - container & dry soil

and Dry weight = container and dry soil - container empty

(v) Results. The results obtained from sampling plots are shown in Table 5.3 and Figure 5.3.

Table 5.3 Moisture content %(wet) for sampling plots in study area

Plot No Site No.	1	2	3	4	5	6	7	8	9	10	11
1	48	107	-	-	19	227	92	-	270	18	-
2	104	37	317	-	-	-	30	-	-	40	24
3	191	-	389	-	-	309	31	-	-	-	-
4	43	102	34	34	45	-	37	30	170	209	-
5	49	-	48	45	338	320	557	1150	617	151	-

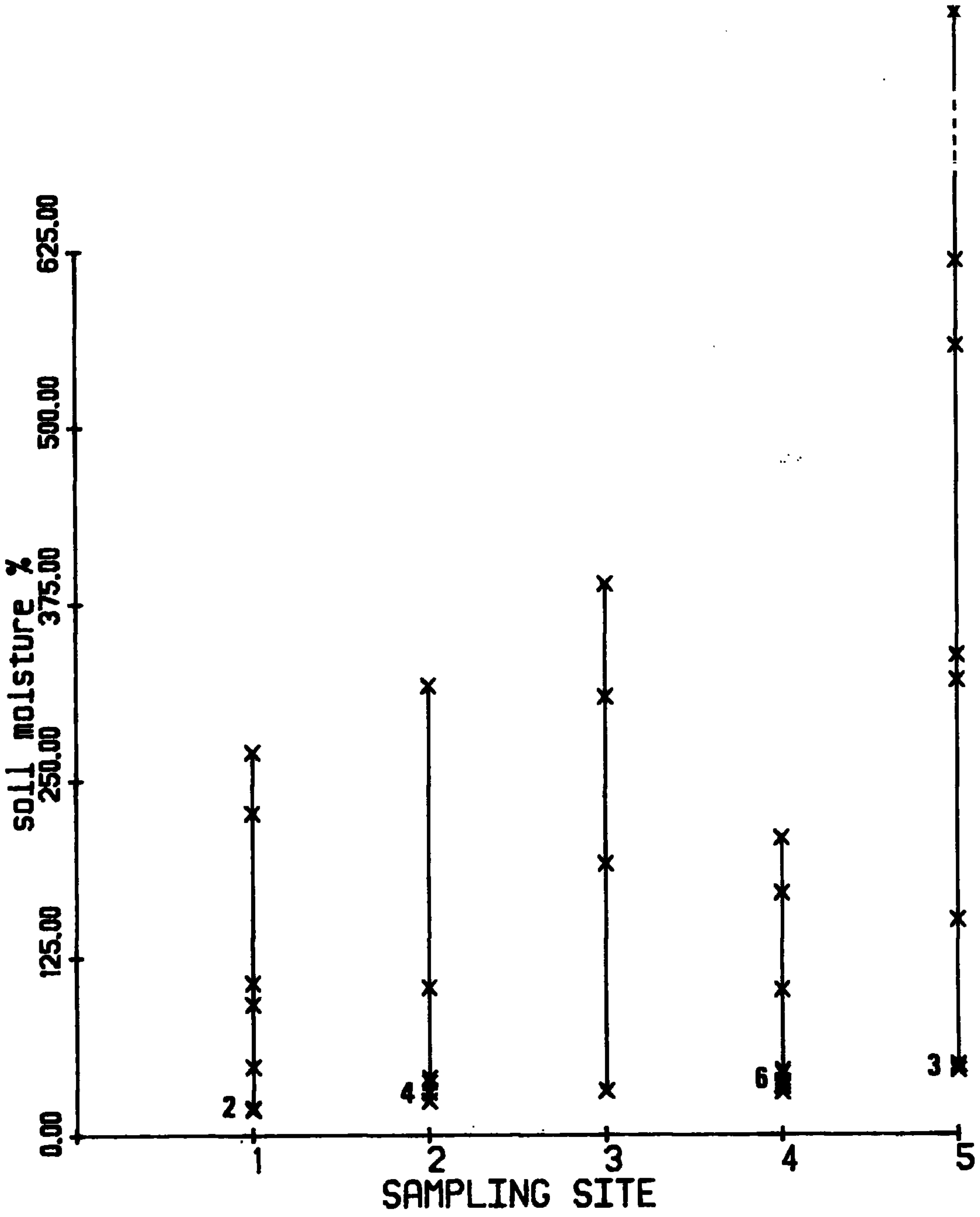

Fig. 5.3 Univariate scatter plots for the moisture content (wet season) at five sites (study area) (Moisture content for one outlier plot in sampling site No. 5 is 1150%).

5.4.2 Soil moisture (dry season)

This measure was used because it was realised that tha changing soil moisture affects certain other soil properties e.g shear strength. The value of this measurement is shown in Table 5.4 and Figure 5.4

Table 5.4 Soil moisture % (dry) for 35 sampling plots measured for this study

Plot No. Site No.	1	2	3	4	5	6	7	8	9	10	11
1	25.0	45.0	-	-	18.0	135.0	75.0	-	138.0	11.0	-
2	88.0	31.0	142.0	-	-	-	16.0	-	-	22.0	17.0
3	169.0	-	212.0	-	-	174.0	22.0	-	-	-	-
4	34.0	66.0	28.0	30.0	37.0	-	32.0	23.0	95.0	182.0	-
5	42.0	-	39.0	36.0	127.0	110.0	277.0	816	285	120	-

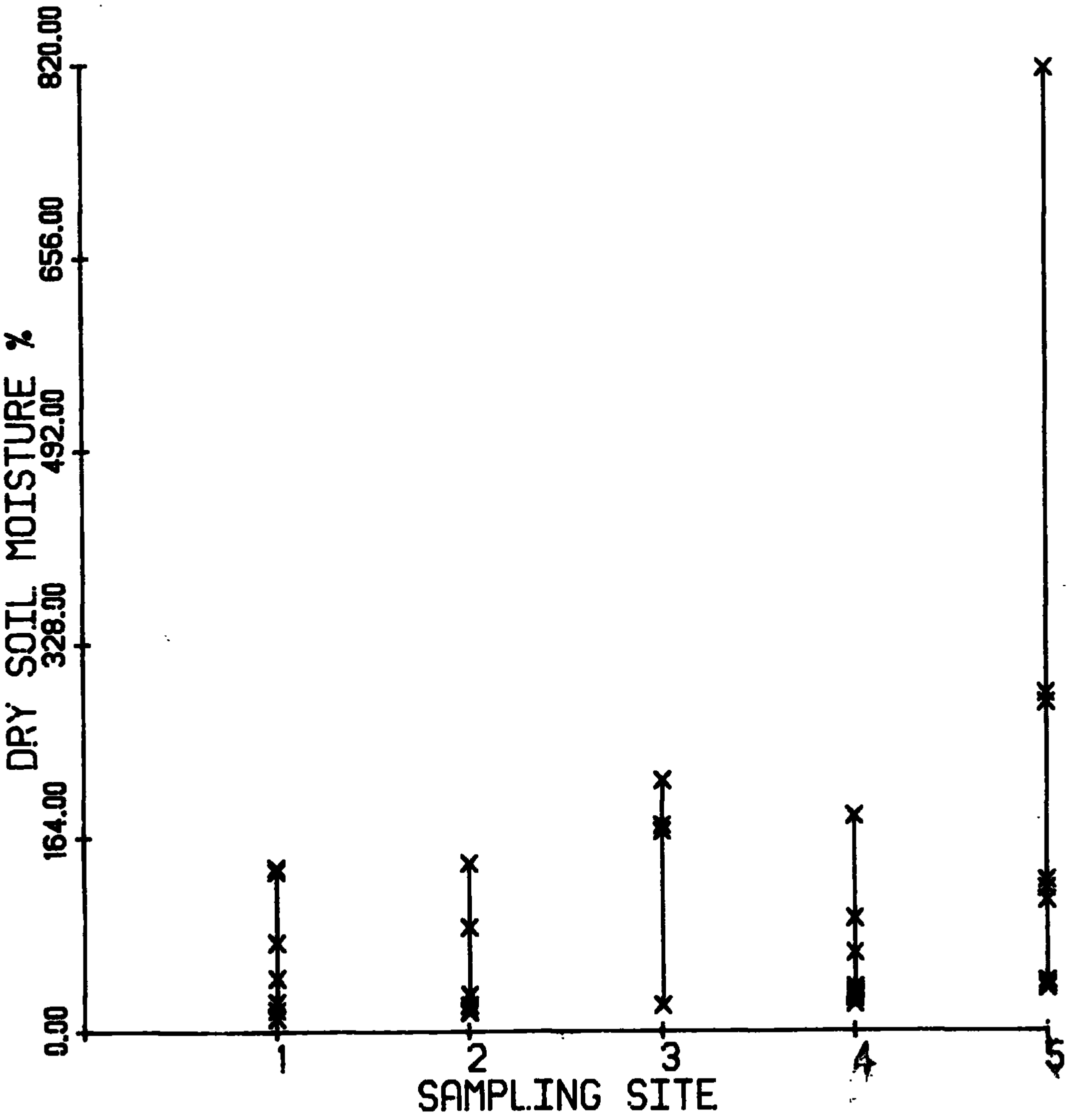

Fig 5.4 Univariate scatter plots for the soil moisture content (dry season) at five sites (study area).

5.4.3 Organic matter content

i. Scope

The method adopted for this test was loss on ignition, to give the percentage approximating to weight of organic matter. It is realised that the organic matter content and the weight loss on ignition are not quite the same measure.

ii. Apparatus

(1) A drying oven at a controlled temperature of 60°C and 105°C.

(2) A muffle furnace at a controlled temperature of 275°C.

iii. Procedure

a) An accurately weighed amount (about 10g) of soil (oven-dried at a temperature of 105°C for 24 hours to constant weight) was obtained and placed in a weighed nickel crucible.

b) The samples were put in a muffle furnace at a temperature of 275°C for 16 hours.

c) After this time the samples were removed from the furnace, allowed to cool and reweighed. Loss on ignition is indicated as a percentage of the weight of oven-dried soil.

iv. Calculation

The percentage of organic matter, which is percentage of loss on ignition, is calculated by:

$$\%\ \text{loss on ignition} = \frac{F - G}{F - E} \times 100$$

in which

weight of crucible = E

weight of crucible + oven dry soil = F

weight of crucible + ignited soil = G

weight of oven dry soil = F - E

v. Results

The results of loss of ignition for the sample sites are shown in Table 5. 5 and Figure 5. 5.

Table 5. 5 % loss of ignition (organic matter) for sampling plots in study area

Plot No. / Site No.	1	2	3	4	5	6	7	8	9	10	11
1	9.13	20.18	-	-	2.26	50.41	34.31	-	60.01	3.36	-
2	41.14	6.45	60.89	-	-	-	5.12	-	-	9.45	3.27
3	46.97	-	93.12	-	-	73.23	6.40	-	-	-	-
4	7.66	20.13	7.36	40.79	7.44	-	7.22	7.65	39.81	14.31	-
5	10.97	-	12.07	11.05	88.15	67.90	93.44	96.50	91.15	64.49	-

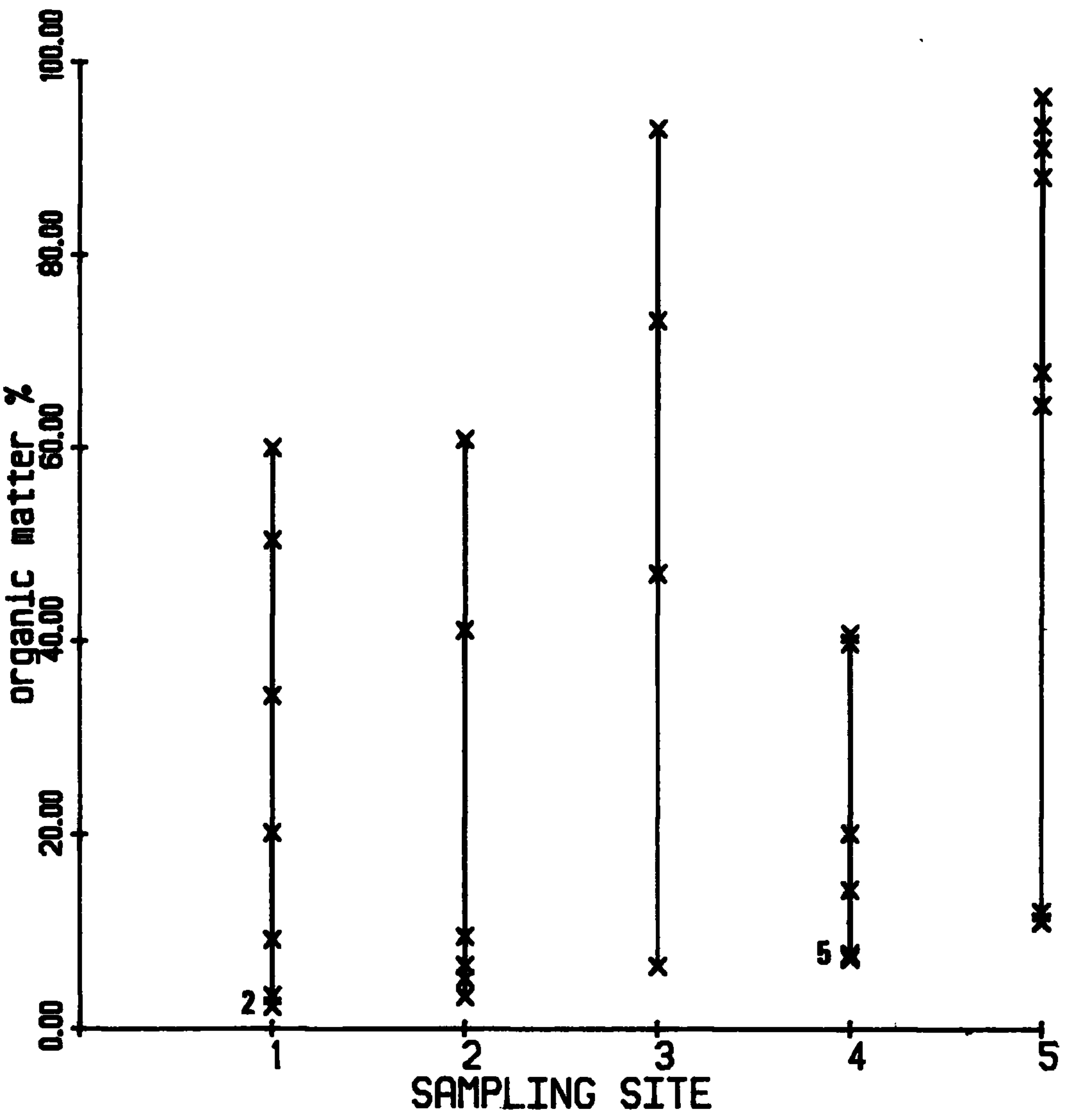

Fig. 5.5 Univariate scatter plots for the organic matter at five sites (study area).

5.5 Particle size analysis

1. Scope

There are several methods for the determination of particle size distribution in a soil, including wet sieving, dry sieving, the pipette method and the hydrometer method. The pipette method is the most accurate and has been recommended for engineering geology (Akroyd 1964), but the method adopted for this study is a modification by the Soil Survey of Scotland of the technique devised by Bouyoucos in 1934, which is simple and easy to use.

ii. Apparatus

(1) A milk bottle

(2) A shaker machine

(3) A litre measuring cylinder

(4) A Bouyoucos hydrometer

(5) A rubber bung fitted to the top end of cylinder

(6) A stop watch

(7) A thermometer

iii. Procedure

a) All samples, each weighing 20-50 g, of less than 2 mm (diam.) air dried soil were obtained from the bulk samples and each was placed in a milk bottle. 400 ml of distilled water and 10 ml sodium hydroxide (NaOH) were added and the bottles were shaken end over end for 16 hours. Sodium hydroxide was added to aid the dispersion of the soil particles.

b) The bottles were removed from the shaker and they were shaken vigorously before transferring the contents to a litre measuring cylinder. Using a little distilled water, all the mineral matter was washed from the bottle.

c) The Bouyoucos hydrometers were inserted into the suspension which was made up to volume (1000 ml) with distilled water.

d) The hydrometer was removed from each cylinder, and a rubber bung was placed in the end of the cylinder. Then it was shaken end over end for one minute.

e) Each cylinder was placed on the bench, the bung was removed and the hydrometer was inserted again. After 40 seconds the first hydrometer reading was taken at the top of the meniscus. The second reading was taken 4 minutes 48 seconds after sedimentation started.

f) The hydrometer was carefully removed and the temperature of the suspension was taken. The samples were left undisturbed for 2 hours and then the third reading was taken for each sample.

iv. Calculations

(a) Before reading the hydrometer the following corrections were made for temperature, as recommended (Durham University, Department of Geography).

1. For each degree C above 19.5°C, 0.4 was added to the hydrometer reading.
2. For each degree C below 19.5°C, 0.4 was subtracted from the hydrometer reading, as recommended.

(b) The international texture method was adopted for this test as follows:

% sand (2000 µm - 20 µm)

$$= 100 - \frac{\text{2nd corrected reading}}{50 - (0.5 \times mc)} \times 100$$

% clay (<2 µm)

$$= \frac{\text{3rd corrected reading}}{50 - (0.5 \times mc)} \times 100$$

% silt (20 µm - 2 µm) = 100 - (%sand + %clay)

mc = moisture content

v. Results

The results, and the analysis of this test are shown in Tables 5.6, 5.7, 5.8, 5.9 and Figures 5.6, 5.7 and 5.8.

Table 5.6 Particle size analysis (clay %) for sampling plots measured in study area

Plot No. / Site No.	1	2	3	4	5	6	7	8	9	10	11
1	30.73	4.03	-	-	25.73	0.55	3.04	-	9.76	14.75	-
2	8.24	27.88	0.60	-	-	-	27.44	-	-	7.60	26.05
3	1.60	-	P	-	-	P	10.47	-	-	-	-
4	21.82	1.39	3.50	58.62	28.63	-	8.12	8.00	2.00	1.30	-
5	18.20	-	16.00	5.10	P	P	P	P	P	P	-

P = peat

Table 5. 7 Particle size analysis (sand %) for sampling plots measured in study area

Plot No. / Site No.	1	2	3	4	5	6	7	8	9	10	11
1	42.92	85.70	-	-	65.32	86.70	84.50	-	75.84	67.86	-
2	62.43	57.29	95.60	-	-	-	55.34	-	-	67.60	56.05
3	93.80	-	P	-	-	P	64.18	-	-	-	-
4	62.69	88.85	80.75	7.36	54.36	-	77.26	81.20	89.20	89.59	-
5	62.40	-	64.80	86.37	P	P	P	P	P	P	_

P = peat

Table 5. 8 Particle size analysis (silt %) for sampling plots measured in study area

Plot No. / Site No.	1	2	3	4	5	6	7	8	9	10	11
1	26.4	10.3	-	-	9.0	12.8	12.4	-	14.3	17.3	-
2	29.3	19.8	3.2	-	-	-	17.2	-	-	24.8	41.9
3	4.6	-	P	-	-	P	25.3	-	-	-	-
4	15.4	9.8	15.8	34.0	17.0	-	14.6	10.8	9.4	9.1	-
5	19.4	-	19.2	83.8	P	P	P	P	P	P	_

P = peat

Table 5. 9 Soil texture of sampling plots in study area

Plot No. / Site No.	1	2	3	4	5	6	7	8	9	10	11
1	silty loam	loamy sand	-	-	clay loam	loamy sand	loamy sand	-	loamy sand	loam	-
2	silty loam	clay loam	sand	-	-	-	clay loam	-	-	silty loam	clay loam
3	sand	-	P	-	-	P	silty loam	-	-	-	-
4	loam	loamy sand	loamy sand	silty clay	clay loam	-	loamy sand	loamy sand	loamy sand	loamy sand	-
5	loam	-	loam	loamy sand	P	P	P	P	P	P	P

P = peat

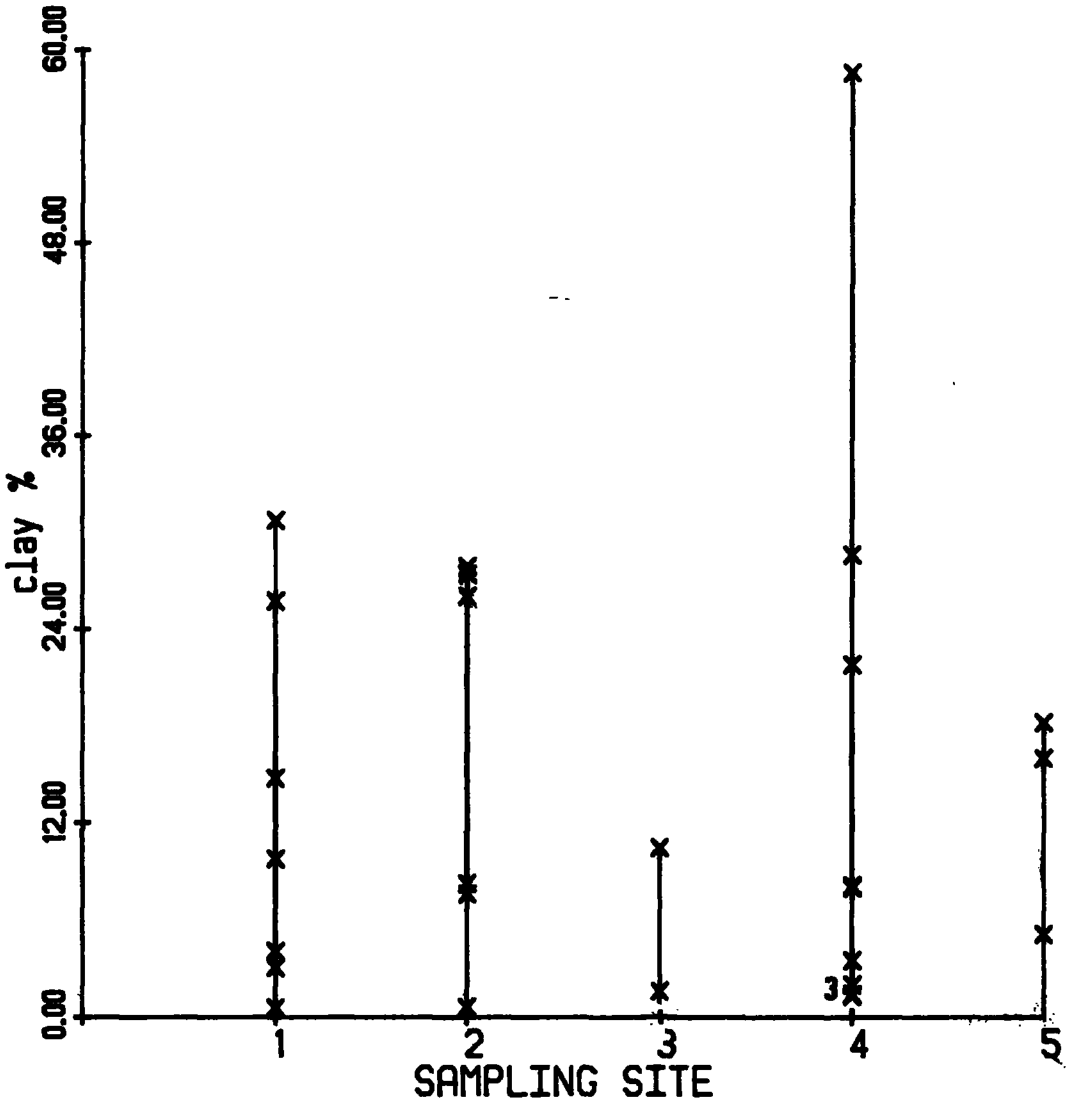

Fig. 5.6 Univariate scatterplots for the clay% at five sites (study area).

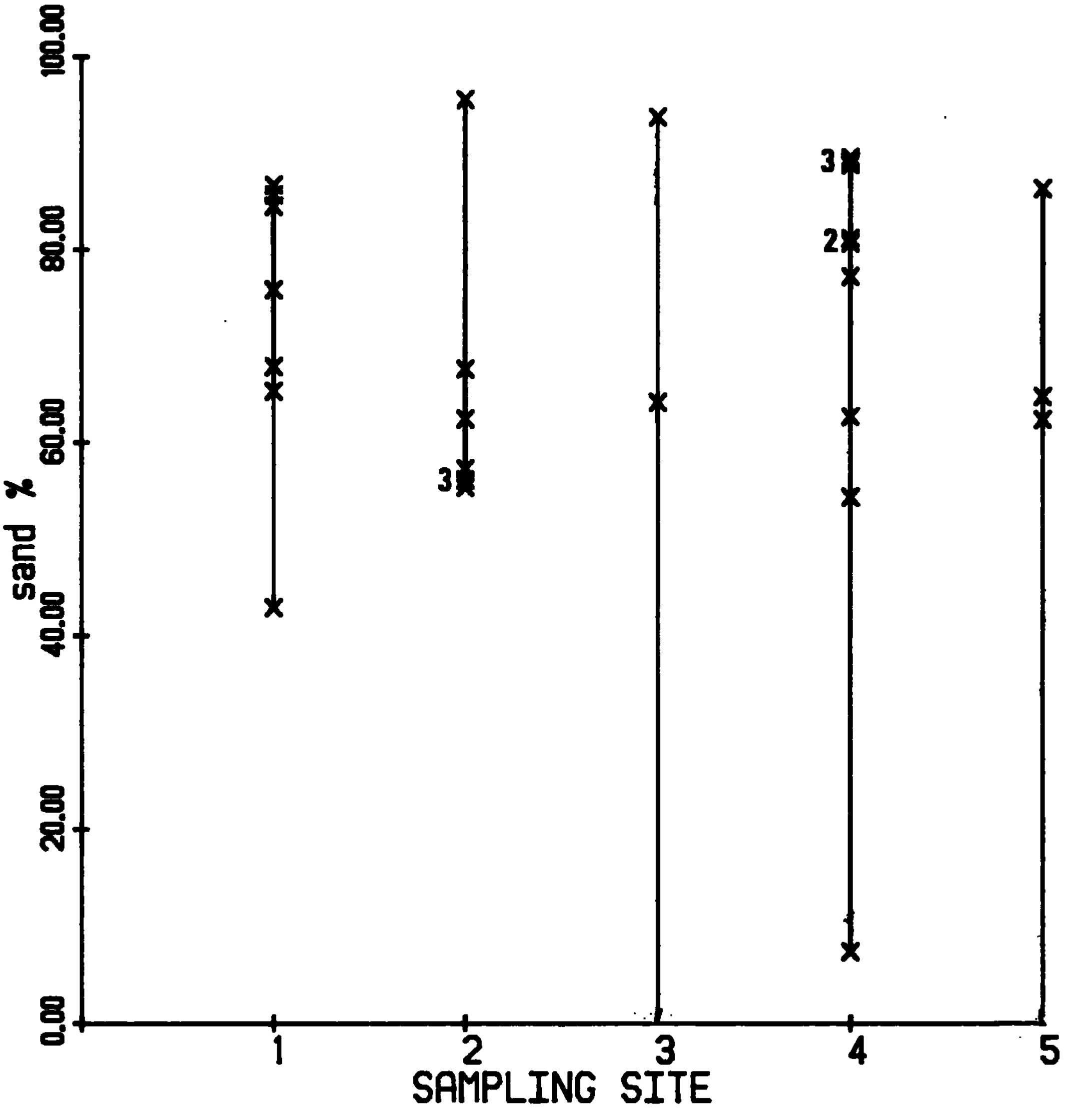

Fig. 5.7 Univariate scatter plots for the sand% at five sites (study area).

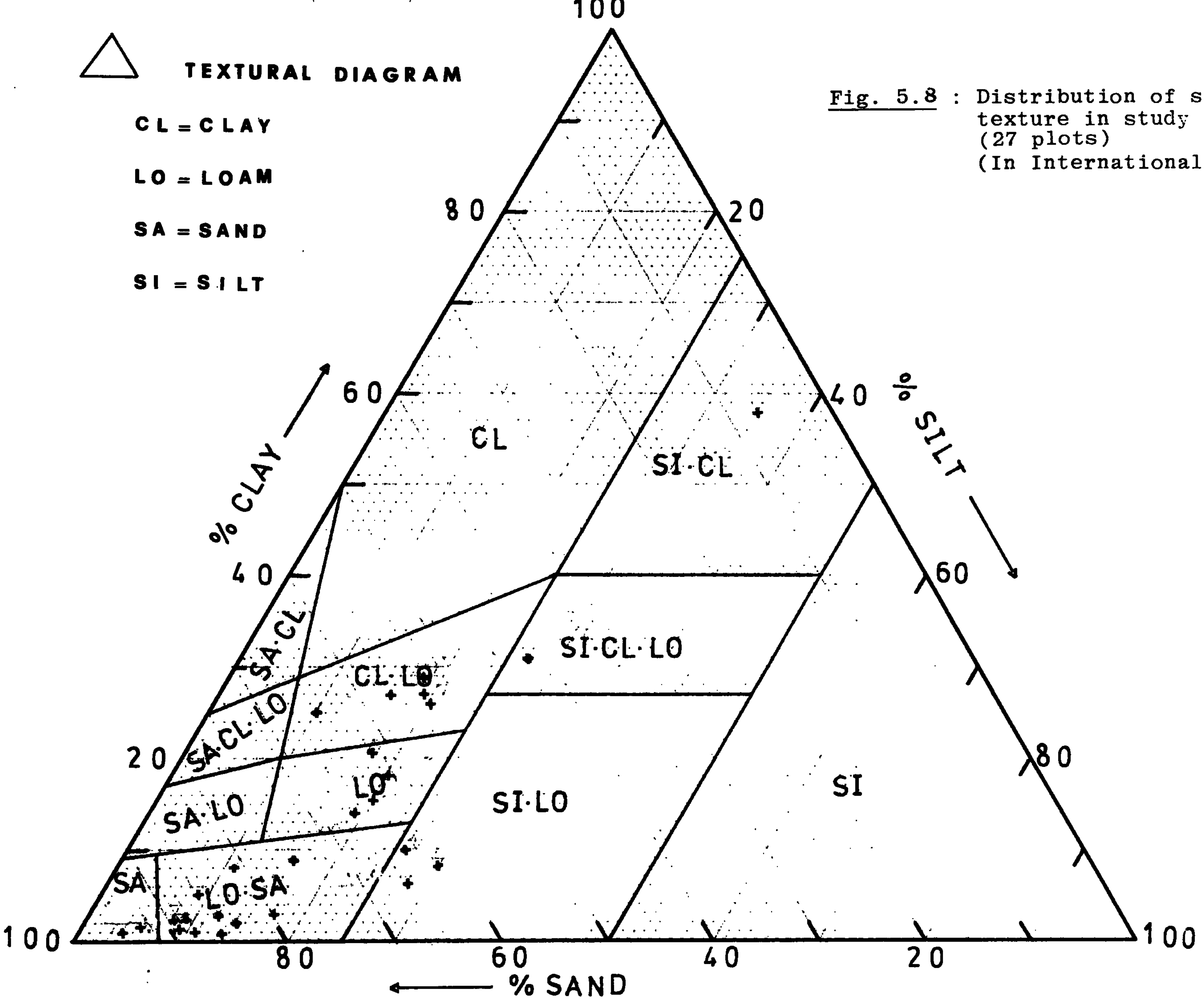

Fig. 5.8 : Distribution of soil texture in study area (27 plots) (In International scale)

5.6 Definition of the Atterberg Limits

The consistency of a soil is the manifestation of the forces of cohesion and adhesion acting within it at various moisture contents (Pitty 1979). On drying, a soil may pass through several stages of consistency, which can be described as the liquid, plastic, semi-solid and solid stages. Changes in consistency do not take place sharply at precise moisture content levels, and therefore arbitrary moisture content limits proposed by Atterberg (1911) have been adopted. The lower limit of plastic consistency is known as the plastic limit (PL) and the upper limit as the liquid limit (LL). Plasticity itself is measured by the plasticity index (PL), which is simply the difference between the liquid and plastic limits. These limits are important in determining the ground conditions of stability and firmness.

5.6.1 Liquid limit

i. Scope

The liquid limit (LL) is the point at which a soil becomes semifluid. It is the moisture content, expressed as a percentage of the dry weight, when the flow of a sample of soil in a special brass cup, after twenty-five jarring blows of the cup dropped through 1.0 cm, just closes a groove 11 ± 0.25 mm previously made in the soil.

ii. Apparatus

a) BS sieve No.36 (mesh 0.422mm).

b) A glass plate about 1.0cm thick and 50.0cm square.

c) Two palette knives.

Plate 5.1 : Liquid Limit apparatus

d) A liquid limit apparatus (Plate 5.1).

e) A standard grooving tool (Casagrande type) with gauge handle.

f) Moisture content test apparatus.

iii. Procedure

a) Each sample weighing about 120g was taken from the air dried soil passing the B.S. sieve No.36 and each sample was carefully mixed with required distilled water on the flat glass plate.

b) For each sample a required quantity of soil paste was put in the brass cup and levelled off parallel to the base; the maximum depth of soil in the cup was 1cm. Using the grooving tool, the paste in the cup was divided along the cup diameter. This leaves a V-shaped gap, 2mm wide at the bottom, 10mm at the top, and about 8mm deep. The liquid limit apparatus is checked to make sure the cup drops exactly 1cm when the handle is turned.

c) By turning the handle the cup was lifted and dropped. This was continued until the two parts of the soil came into contact at the bottom of the groove along a distance of about 15mm. The number of blows at which this occurred was recorded. If the total of blows was over fifty or less than 25, the experiments were repeated adding more water or soil.

d) The experiment was performed twice more taking a different sample from the paste without adding water or soil, and the average was calculated from the three recordings.

e) A quantity of soil from the portions of the paste that just flowed together was removed with a spatula and put in a container for determination of moisture content. This process was repeated at least four times for each sample.

iv. Calculation

The moisture content corresponding to each of the average number of blows was calculated. For each sample the average number of blows was plotted on a logarithmic scale against its corresponding moisture content. A straight line was drawn through the resulting points giving the flow-curve, from which the liquid limit of the soil can be found.

v. Results

The results obtained from plots measured in the study area are shown in Table 5.10 and Figure 5.9.

Table 5.10 Liquid limit obtained from calculation for sampling plots measured in study area

Plot No. / Site No.	1	2	3	4	5	6	7	8	9	10	11
1	51.11	58.14	-	-	40.23	* 89.90	96.60	-	* 54.87	30.50	-
2	* 70.00	47.40	* 99.18	-	-	-	84.80	-	-	50.35	41.67
3	* 33.50	-	P	-	-	P	37.40	-	-	-	-
4	49.00	* 39.75	40.00	* 57.40	66.40	-	56.40	37.40	* 48.60	* 49.60	-
5	54.80	-	54.80	51.69	P	P	P	P	P	P	-

P = Peat

* The plots values marked with * contain either high proportion of sand, slightly humified organic matter or both. Such soils usually stand out since it is difficult to obtain a reliable value for the liquid limit. Therefore, these measurements are less reliable.

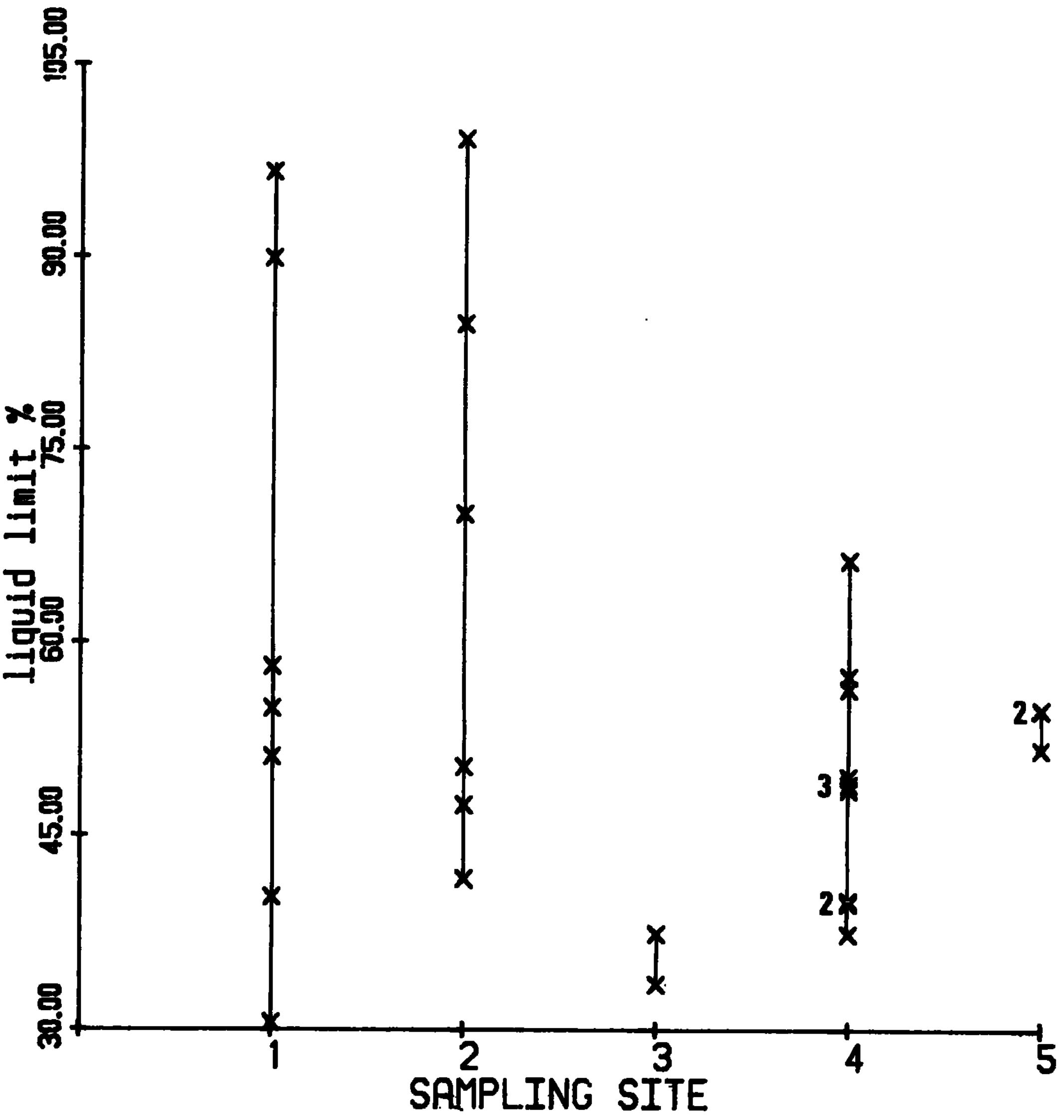

Fig. 5.9 Univariate scatter plots for the liquid limit at five sites (study area).

5.6.2 Plastic limit

i. Scope

The plastic limit (PL) of a soil is the moisture content, expressed as a percentage of the dry weight when the soil, rolled into threads about 3mm in diameter, just crumbles (Akroyd 1964).

ii. Apparatus

The apparatus used for the test was the same as for the liquid limit test except that there is no need for the Casagrande apparatus and the grooving tool (Plate 5.1).

iii. Procedure

a) A sample of about 15g of soil sieved through B.S. No.36 sieve was obtained for each test.

b) It was thoroughly mixed on the glass plate with sufficient distilled water to make it plastic enough to be shaped into a ball.

c) The ball was then rolled between the palm of the hand and the glass plate with just enough pressure to form it into a thread. This process was continued until the thread became about 3mm in diameter.

d) The portions of crumbled soil were collected and placed in a weighing container and the moisture content determined. This test was repeated for each sample.

iv. Calculation

The average of the moisture content was taken in the same way as for the liquid limit test,

Table 5.11 Plastic limit obtained from calculation for sampling plots measured in study area

Plot No. / Site No.	1	2	3	4	5	6	7	8	9	10	11
1	34.68	46.77	-	-	30.39	* 87.26	92.10	-	* 45.37	23.93	-
2	* 64.10	35.27	* 93.28	-	-	-	32.97	-	-	39.75	29.47
3	* 32.60	-	P	-	-	P	28.31	-	-	-	-
4	39.56	* 20.53	31.81	* 51.56	* 41.86	-	48.08	33.33	* 43.39	* 46.07	-
5	16.58	-	48.53	49.19	P	P	P	P	P	P	P

P = Peat

* The plastic limit cannot be determined for poorly to mid humified organic soil. For other samples having a high degree of humification, the plastic limit was measured but the results are not satisfactory despite the averaging of two or three determinations.

$$\text{i.e.} \quad MC = \frac{\text{Loss}}{\text{Dry soil}} \times 100\%$$

$$\text{or} \quad MC = \frac{\text{weight of moisture}}{\text{weight of dry soil}} \times 100\%$$

v. Results

The results from sampling plots measured in the study area are shown in Table 5.11 and Figure 5.10.

5.6.3 Plasticity Index

1. Scope

Plasticity index is a range in moisture content over which the soil is plastic.

ii. Procedure

The Liquid Limit (LL) and Plastic Limit (PL) determined in the Liquid Limit and Plastic Limit tests have been used.

iii. Calculation

The Plasticity Index for each sample was calculated from the formula :

Plasticity Index = Liquid Limit - Plastic Limit for each sample

iv. Results

The results taken from sampling plots measured in study area are shown in Table 5.12 and Figure 5.11.

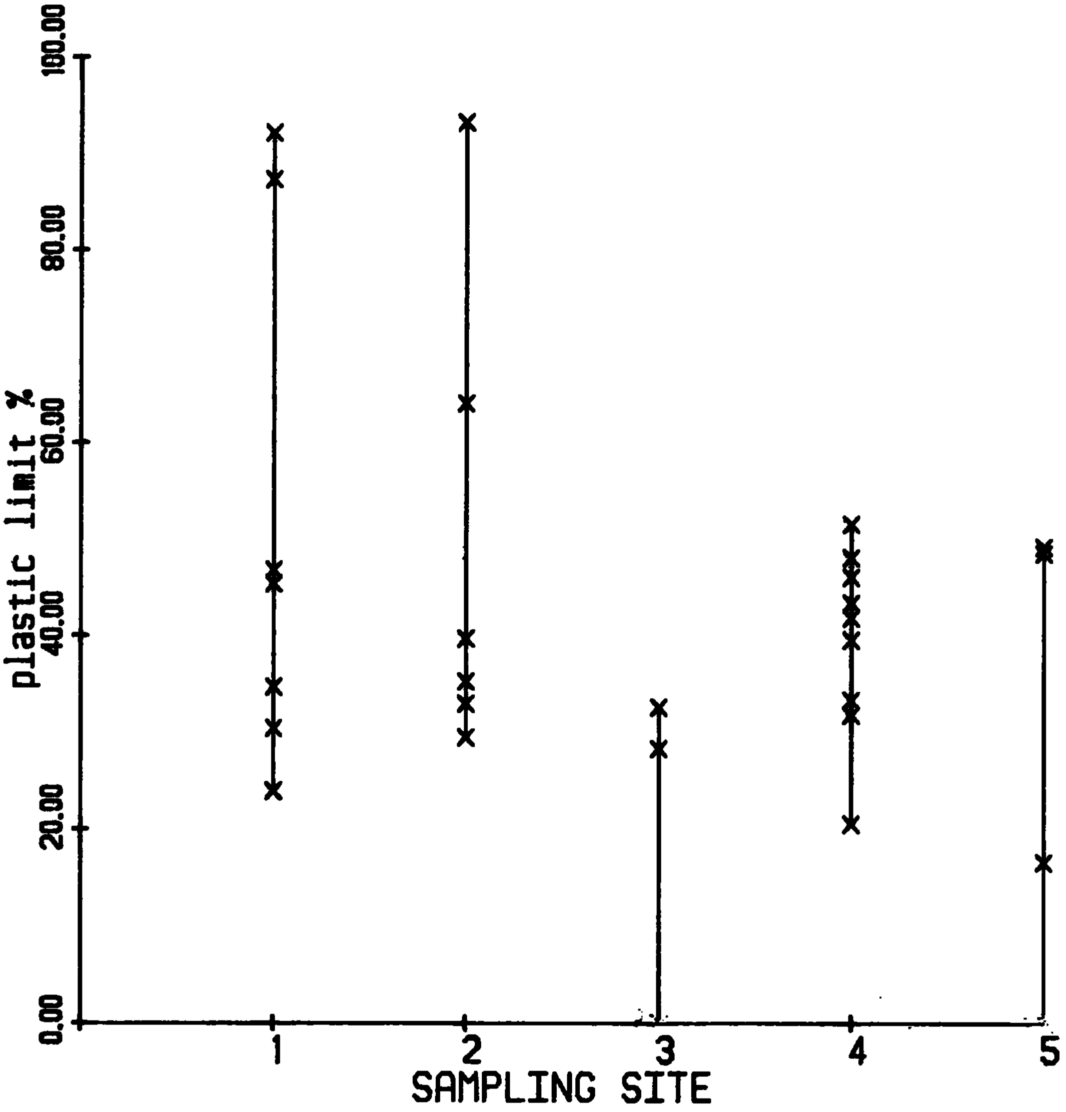

Fig. 5.10 Univariate scatterplots for the plastic limit at five sites (study area).

Table 5.12 Plasticity index obtained from calculation for sampling plots measured in study area

Plot No. Site No.	1	2	3	4	5	6	7	8	9	10	11
1	16.43	11.37	-	-	9.84	*2.64	4.50	-	*9.50	6.57	-
2	*5.90	12.13	*5.90	-	-	-	51.83	-	-	10.60	12.20
3	*0.90	-	P	-	-	P	9.09	-	-	-	-
4	9.44	*19.22	8.19	*5.84	*24.54	-	8.32	4.07	*5.21	*3.53	-
5	38.22	-	6.27	2.50	P	P	P	P	P	P	-

P = Peat

* = Values marked with * are unreliable results for these plots. Such soils are regarded as non plastic.

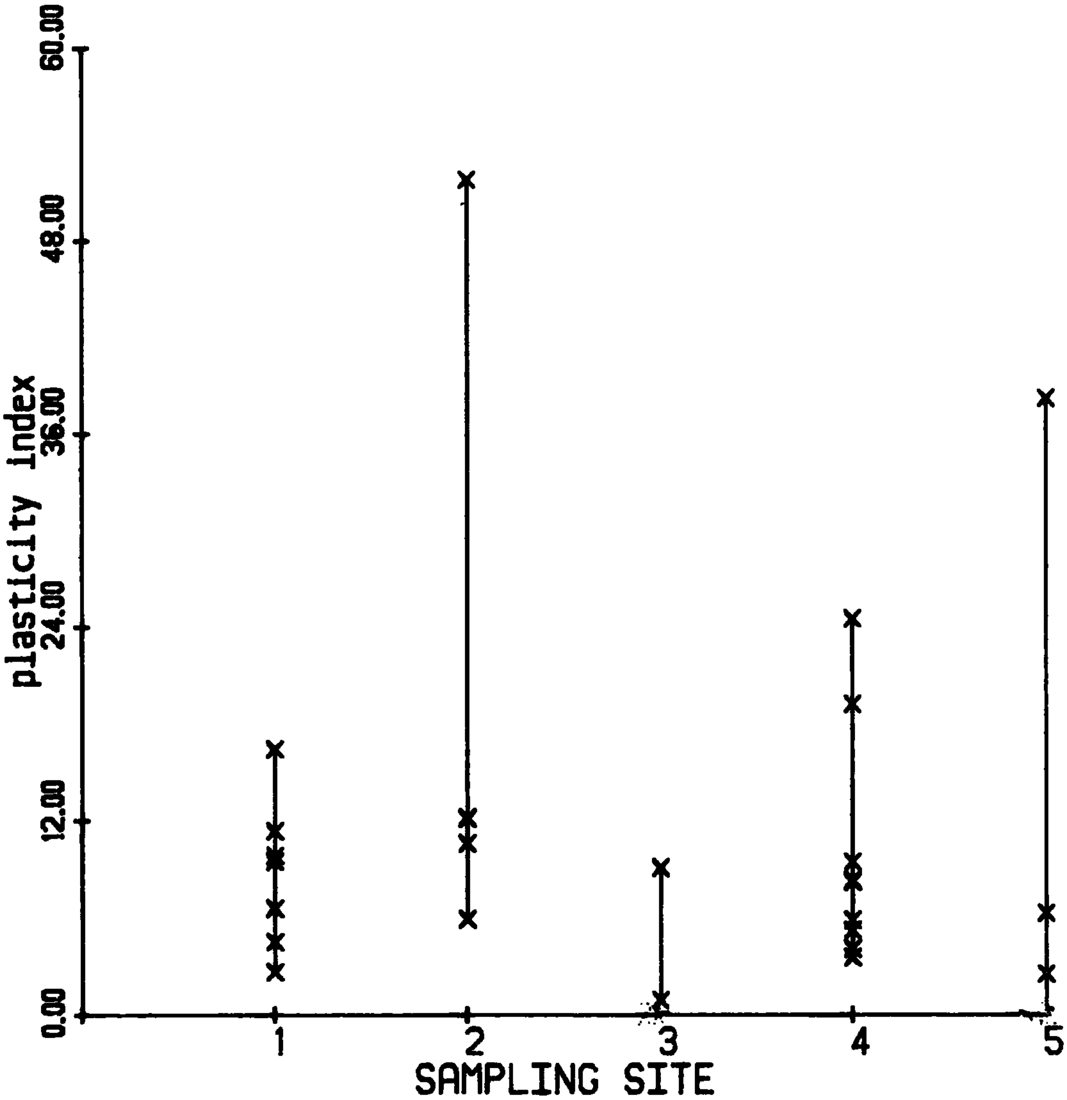

Fig. 5.11 Univariate scatterplots for the plasticity index at five sites (study area).

5.7 Bulk density

i. Scope

Since the processes of creep mainly result from expansion and contraction caused by changing moisture, it was decided to determine the bulk volume, from which the bulk density and dry density could be calculated. For this the Ruska Universal Porometer has been used, Plate 5.2. The density of soils varies considerably and is influenced by several factors : the mineral content, the particle shape and void ratio. Soil density can affect the rate of soil movement and soil stability.

ii. Apparatus(1)

The porometer consists of a 100 cm³ volumetric mercury pump, to which a pycnometer is attached. The pump has a precision ground and honed, handchrome plated, stainless steel plunger and an alloy steel measuring screw.

The chamber of the stainless steel pycnometer has a volume of approximately 50 cm³ and admits cores up to 1¼" (32 mm) long and 1½" (38 mm) in diameter.

The pycnometer lid has a rapid acting breach-lock closure with an "O" ring seal. A needle value in the lid opens the chamber to the atmosphere. The movement of the pump metering plunger is indicated on two scales. The right and left hand scales provide, respectively, decreasing and increasing readings with the forward stroke of the plunger. Both scales are graduated to read the plunger displacement in cubic centimetres. The handwheel dial is graduated in

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(1) Ruska Porometer, Model No. 1051-801 serial No. 24495 Ruska Instrument Corporation, Houston, Texas.

0.01 cm^3 subdivisions and permits estimation of plunger displacement to 0.001 cm^3.

The right hand scale is used to provide bulk-volume readings. The right hand and left hand scales are respectively referred to as the volume scale and pore space scale (Plate 5.2). The numbers on the volume scale slant right and those on the pore space scale slant left, facilitating selection of the corresponding numbers on the hand wheel dial. Those slanting right supplement volume scale readings and those slanting left supplement pore-space scale readings.

iii. Procedure

There are several methods of determining the Bulk Density. In this study the Bulk Density of samples was determined using the Ruska Universal porometer for which the mass of wet samples and their volumes were accurately determined.

(a) An appropriate clean tray was dried and weighed for each sample.

(b) An appropriate amount of soil (about 50g) from a solid block sample was selected for each sampling plot test, and trimmed into a more or less regular shape.

(c) The sample was placed in the tray and accurately weighed.

(d) The sample was removed from the tray and put into the pyconometer for determining the volume.

(e) After determination of volume, the specimen was oven dried at the temperature of 105°C for a period of 24 hours until the samples were of constant weight, after which the final volume and weight of each sample was measured.

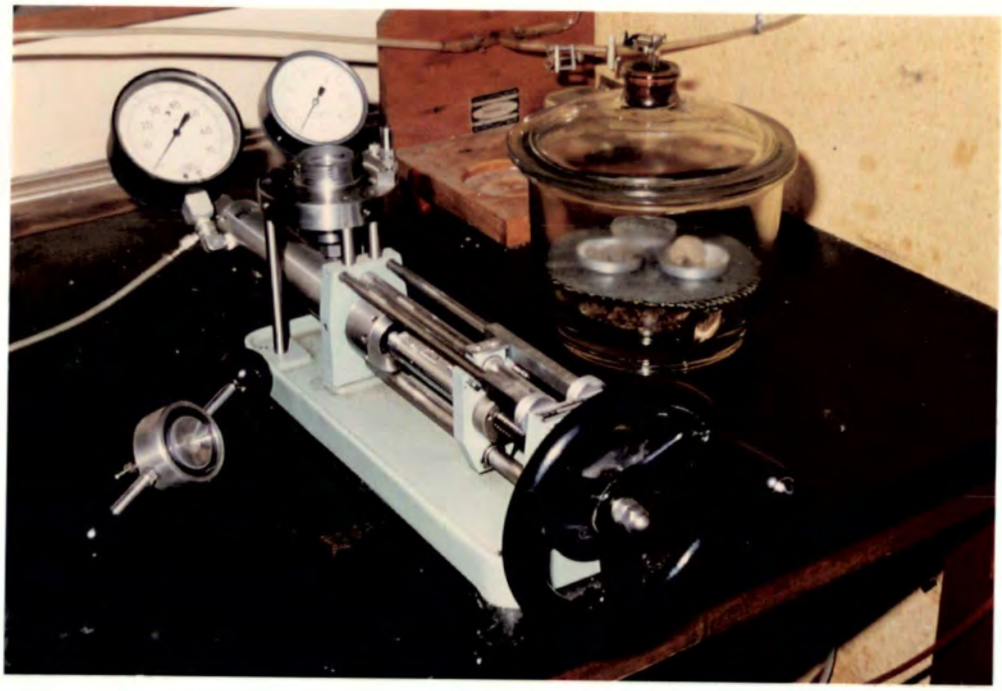

Plate 5.2 : Ruska Universal Porometer.

iv. Calculation

The Bulk Density of soil for each sampling plot was calculated using the formula:

$$Pd = \frac{ms}{Vt}$$

where Pd = Bulk Density of soil

ms = mass of sample

and Vt = Volume of sample

v. Results

The results of Bulk Density of soil for samples from each of the 35 sampling plots in the study area can be seen in Table 5.13 and Figure 5.12.

5. 8 Dry bulk density

Because of changing soil moisture through the time, it was also decided to calculate dry bulk density which is constant. The formula used for this calculation was:

$$Pd = \frac{\text{Bulk Density}}{1 + \frac{m/c}{100}}$$

The results are shown in Table 5.14 and Figure 5.13.

Table 5.13 Bulk density Mg/m^3 obtained from calculation for sampling plots measured in study area

Plot No. Site No.	1	2	3	4	5	6	7	8	9	10	11
1	1.68	1.38	-	-	2.05	1.25	1.17	-	1.35	2.11	-
2	1.04	1.84	1.18	-	-	-	1.93	-	-	1.68	2.03
3	1.27	1.20	-	-	-	1.09	1.86	-	-	-	-
4	1.64	1.47	1.80	1.03	1.73	-	1.67	1.80	1.36	1.30	-
5	1.53	-	1.27	1.59	1.03	1.20	1.10	0.99	1.00	0.98	-

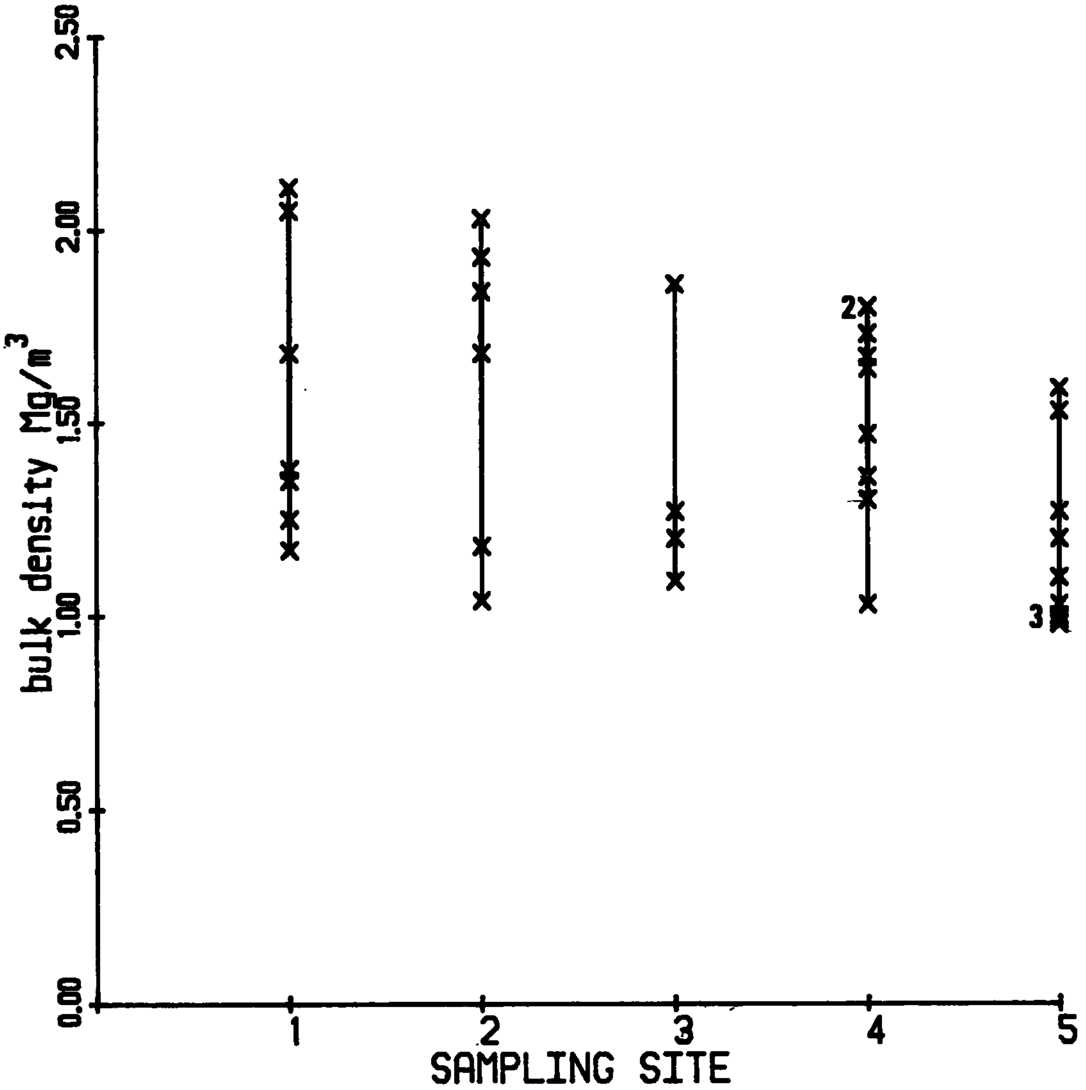

Fig. 5.12 Univariate scatterplots for the bulk density at five sites (study area).

Table 5.14 Dry bulk density Mg/m^3 obtained from calculation for sampling plots measured in study area

Plot No. / Site No.	1	2	3	4	5	6	7	8	9	10	11
1	1.34	0.96	-	-	1.70	0.77	0.71	-	0.77	1.79	-
2	0.60	1.45	0.63	-	-	-	1.56	-	-	1.27	1.68
3	0.74	-	0.71	-	-	0.51	1.5	-	-	-	-
4	1.24	1.01	1.38	0.56	1.45	-	1.27	1.41	0.85	0.69	-
5	1.16	-	0.90	1.25	0.47	0.60	0.44	0.40	0.43	0.33	-

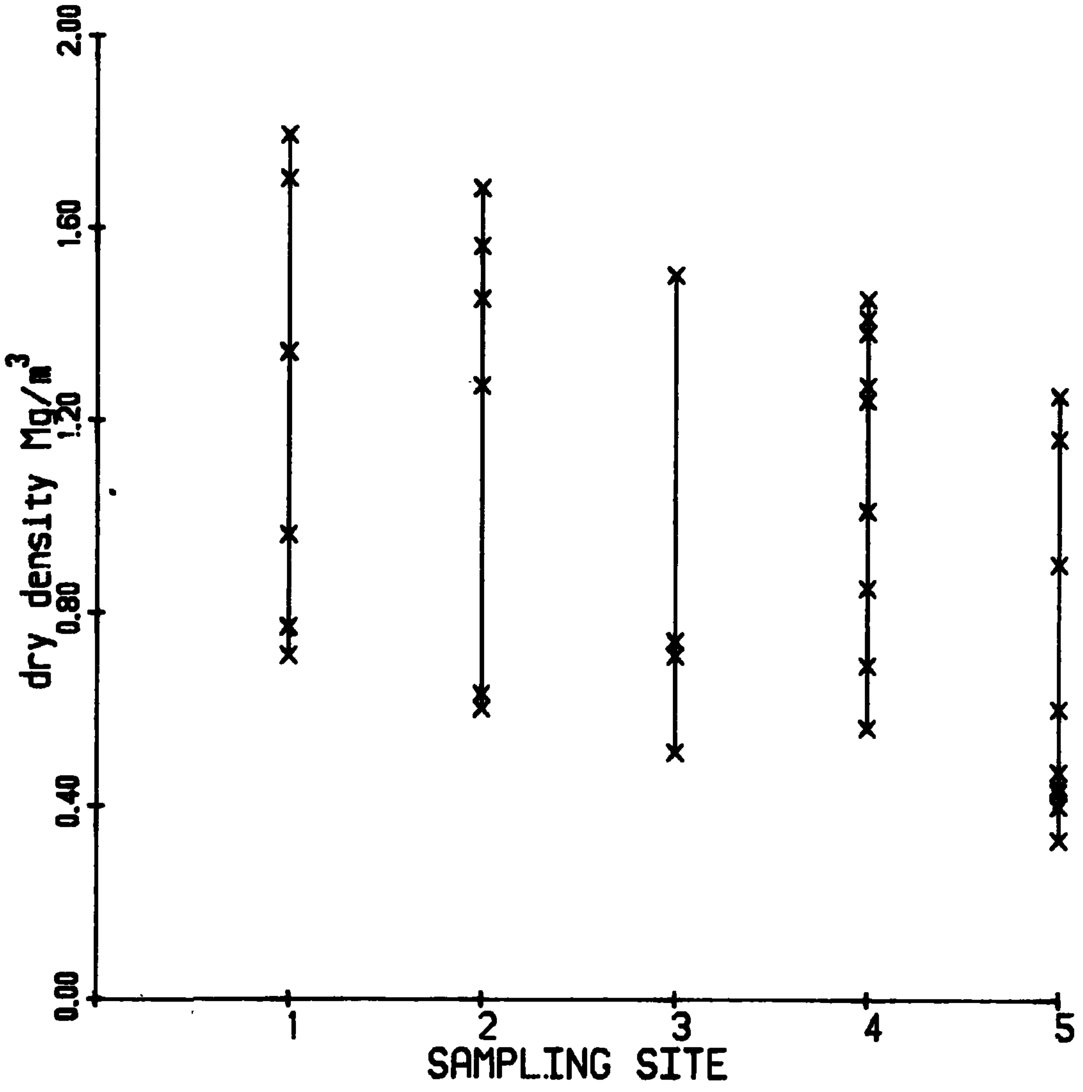

Fig. 5.13 Univariate scatter plots for the dry bulk density at five sites (study area)

5.9 Specific gravity

i. Scope

This was measured using the density bottle method for only five soil samples obtained from the five main sampling stations. This limitation was imposed because a general impression of specific gravity variation was required. It was considered a less important variable than bulk density.

ii. Apparatus

(a) Two density bottles (Pyc-nometers) of approximately 50 ml capacity.

(b) A water bath maintained at a controlled temperature of 25°C.

(c) A vacuum desiccator.

(d) A drying oven at a controlled temperature of 105°C.

(e) A vacuum pump Plate 5. .

iii. Procedure

(a) The density bottles were completely dried and weighed to 0.001 g.

(b) Approximately 10 g of oven dried soil passing sieve No. 36 B.S. and cooled in a desiccator were put into each density bottle.

(c) The bottles were weighed with contents to the nearest 0.001 g and then sufficient air-free distilled water was added, so that the soil in the bottle was covered. (In the case of peat samples alcohol* was used instead

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* The sp. gra. of alcohol at 25°C is 0.78522.

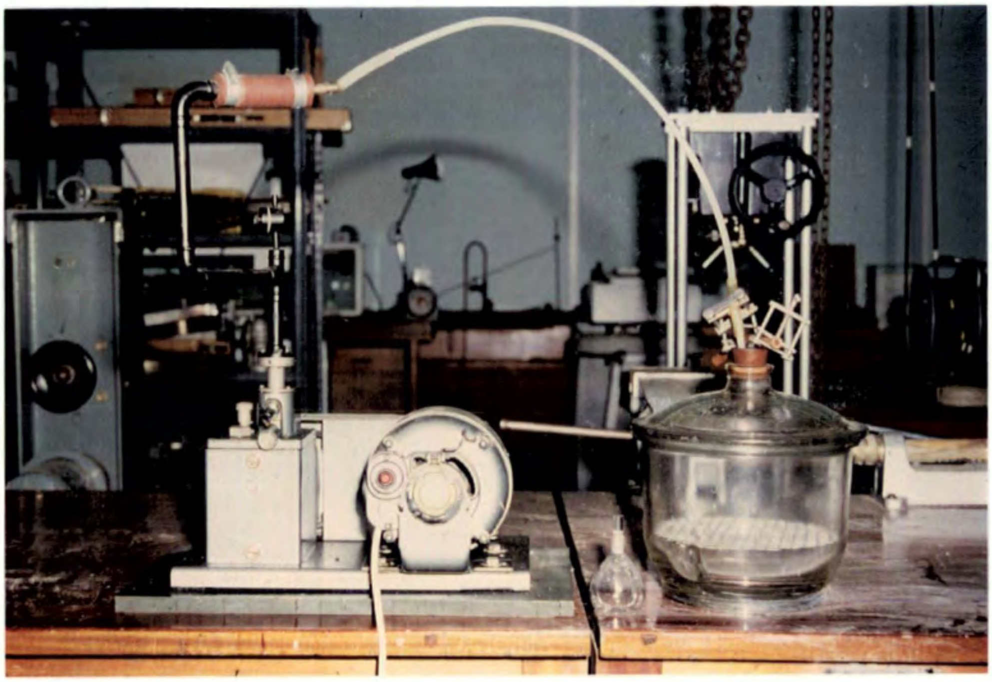

Plate 5.3 : Apparatus for determining the specific gravity

of water, because a part of the specimen was floating when water was used).

(d) The bottle with stopper removed was placed in a vacuum desiccator, and a vacuum gradually applied until there was no more air to be released from the soil. This took approximately 20 hours.

(e) The bottles were then removed from the desiccator and filled up with air-free distilled water. The stoppers were inserted, and the bottles were immersed in the constant temperature bath until it had maintained a temperature of 25°C for an hour, and then the bottles were taken out of the bath and weighed to 0.001 g.

(f) The bottles were cleaned out and completely filled with air-free distilled water, the stoppers were inserted and the bottles were immersed in the constant temperature bath until they attained the constant temperature of the bath.

(g) The bottles were taken out of the bath. wiped dry and weighed to 0.001 g.

iv. Calculation

The specific gravity of the soil particles was calculated from :

$$SG = \frac{\text{weight of dry soil}}{\text{weight of liquid displaced}} \times \text{SP.Gr of liquid}$$

where : weight of liquid in full bottle

= SP.Gr of liquid x bottle volume.

Bottle volume can be determined from the formula:

$$\text{Bottle volume} = \frac{\text{weight of water in full bottle}}{\text{SP.Gr. of water*}}$$

* SP.Gr of water is 0.99704 at 25 C.

v. Results

The results for specific gravity of the soil in five sampling stations are shown in Table 5.15 and Figure 5.14.

Table 5.15 Specific gravity of soil particles for five sampling sites in study area

Sampling Station No.	Location	Specific Gravity
1	Killhope Cross	2.36
2	Killhope Cross	2.20
3	North Cleugh bridge	1.01
4	Killhope Low Sike	2.47
5	Lanehead School	2.50

Table 5.15a

Form K.5

SPECIFIC GRAVITY OF SOIL PARTICLES

Loc. Killhope Cross

Date 10.2.82

SAMPLE No. 1

BATH TEMP. 25 °C

SIEVE 36 B.S

DISPLACING LIQUID:- WATER

$$\text{SPECIFIC GRAVITY OF SOIL} = \frac{\text{Wt of Dry Soil}}{\text{Wt of Liquid displaced}} \times \text{Sp. Gr. of Liquid}$$

BOTTLE No.		Wt. of bottle		Bottle volume
Wt. of BOTTLE + DRY SOIL	44.993			
Wt. of BOTTLE EMPTY	32.955			
therefore Wt. of DRY SOIL	12.038			
Wt. of BOTTLE + SOIL + LIQUID	142.541			
therefore Wt.of LIQUID	97.548			
Wt. of LIQUID IN FULL BOTTLE*	102.618	135.573	102.618	102.260
therefore Wt of LIQUID DISPLACED	5.070			
Sp. Gr. of SOIL	2.367			

*CALCULATE THIS FROM: Wt. of liquid in full Bottle = Sp. Gr. of Liquid x Bottle Volume.

N.B. - THIS VARIES WITH THE SP. GR. OF LIQUID USED.

S.G. of water is 0.99704 at 25°C

BATH TEMP. ....°C

N.B. Water must be distilled and air free

BOTTLE No.				
Wt. of BOTTLE EMPTY				
Wt. of BOTTLE + WATER				
therefore Wt. of WATER				

$$\text{BOTTLE VOLUME} = \frac{\text{Wt. of Water in Full Bottle}}{\text{Sp. Gr. of Water}}$$

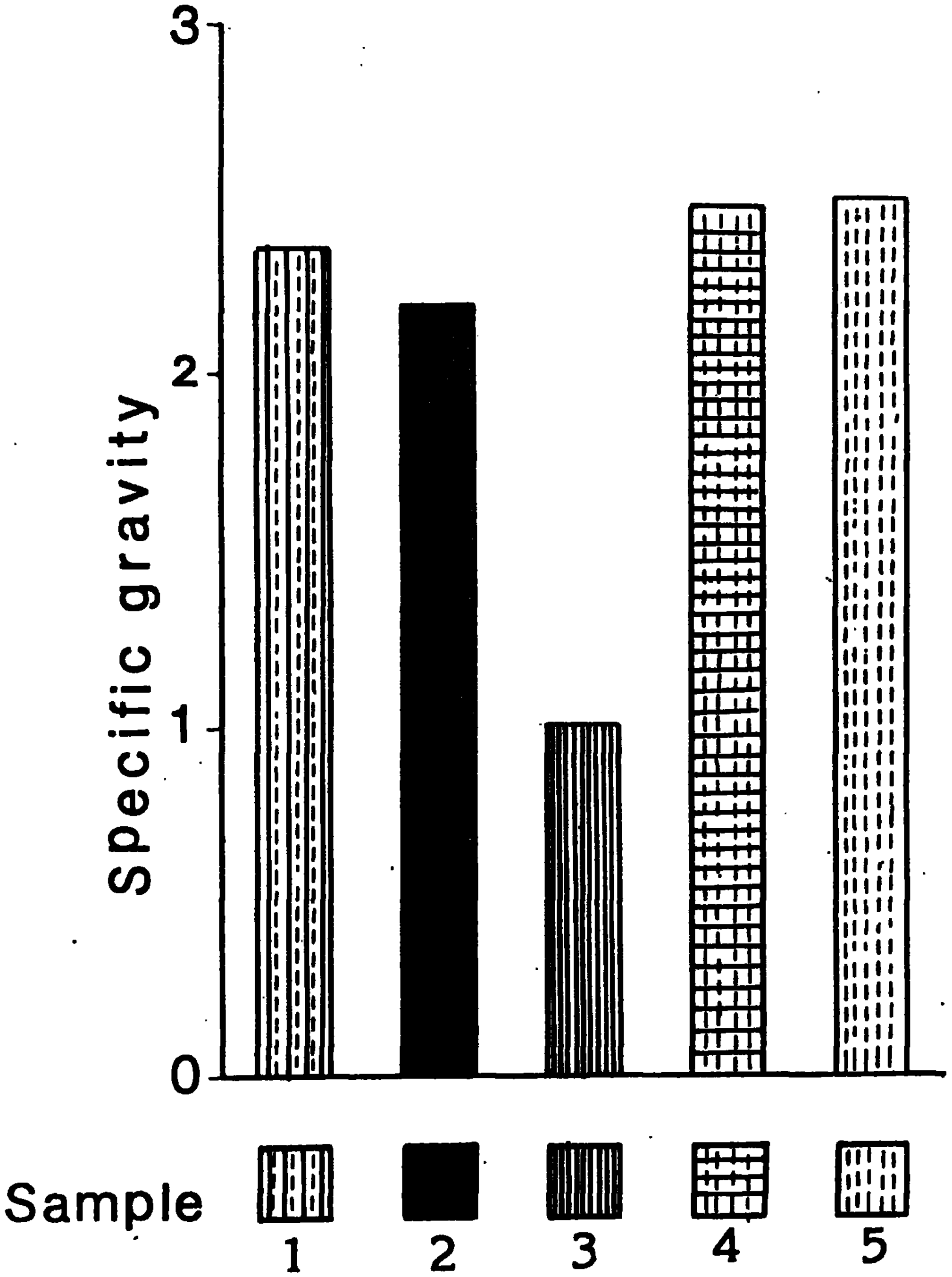

Fig. 5.14 : Specific gravity for five sampling stations in study area.

5.10 Porosity and void ratio

5.10.1 Porosity

i. Scope

The way soil behaves depends not only on the type and size of individual particles, but also on how they are arranged and bonded together. This is also an important aspect of soil for any analysis of the soil creep process. In the porosity index the volume of pore space is expressed as a fraction of the soil volume.

ii. Apparatus

For this the apparatus applied in the Shrinkage Limit test or specific gravity test can be used.

iii. Procedure and calculation

Several methods are available for determining porosity, and two different formulae were used for this:

(a) Porosity $$\varepsilon = \frac{(V_1 + V_g)}{V_t} = \frac{\text{loss}}{\text{volum}} \qquad (1)$$

in which V_1, V_g and V_t represent respectively the volumes of liquid, of gas, and the total or bulk volume.

(b) Porosity $$n = 1 - (Wd/G_{\gamma w}V) \qquad (2)$$

in which W_d = dry weight of sample

G = specific gravity

V = volume of sample

and γw - unit weight of water

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(1) Marshall, T.J. and Holmes, J.W. 1979. Soil Physics, Cambridge University Press, p.9.

(2) McGreal, W.S. 1981 in Geomorphological Techniques, p.94.

The results obtained from both formulae were very similar.

In the second formula, the final dry weight and volume of the sample were respectively used for W_d and V_1. Specific gravity, S.g, was determined for all samples in the specific gravity test.

iv. Results

The results obtained for all sampling plots measured in the study area are shown in Table 5.16 and Figure 5.15.

Table 5.16 Soil porosity obtained from calculation for all sampling plots measured in study area

Plot No. / Site No.	1	2	3	4	5	6	7	8	9	10	11
1	0.34	0.42	-	-	0.35	0.47	0.45	-	0.58	0.32	-
2	0.44	0.39	0.55	-	-	-	0.37	-	-	0.44	0.35
3	0.53	-	0.50	-	-	0.57	0.36	-	-	-	-
4	0.40	0.45	0.42	0.46	0.27	-	0.40	0.39	0.50	0.60	-
5	0.36	-	0.36	0.33	0.56	0.60	0.65	0.58	0.57	0.61	-

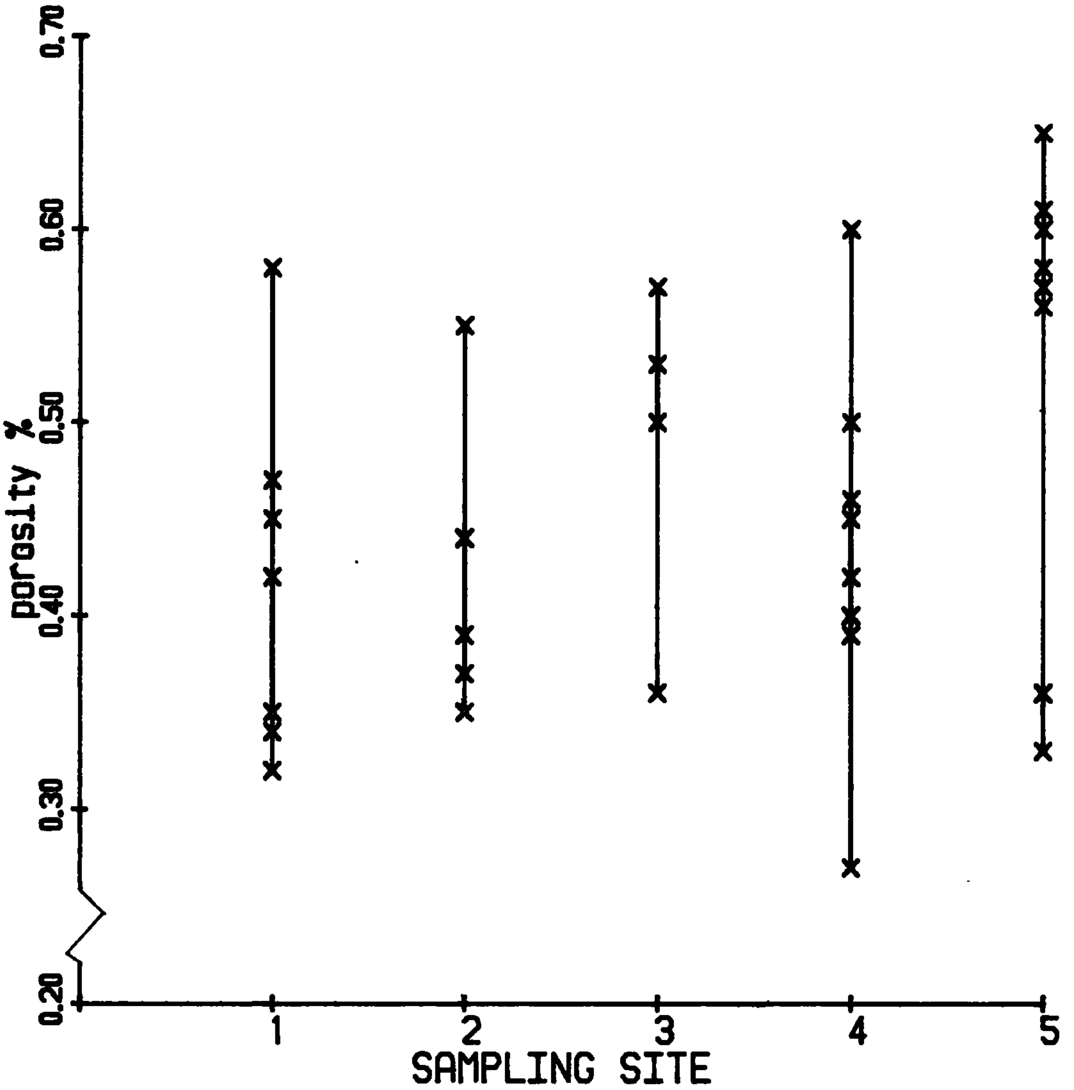

Fig. 5.15 Univariate scatter plots for porosity at five sites (study area).

5.10.2 Void ratio

i. Scope

Void ratio is the ratio of intergranular voids to volume of solid material in a sediment or sedimentary rock. Like porosity it is important in the behaviour of soil particles. Given its relationship to soil moisture properties and permeability it may be considered as an important controlling variable in the rate of the soil creep process.

ii. Procedure and calculation

The method adopted for this study was as follows: The relationship between porosity (ε) and void ratio (e) from the equation $\varepsilon = (V_l + V_g)/V_t$ becomes, by dividing the numerator and denominator by volume of solid (V_s);

$$\varepsilon = \frac{e}{(1 + e)} \qquad (1)$$

$$\text{or} \quad e = \frac{\varepsilon}{(1 - \varepsilon)}$$

iv. Results

The results of the void ratio calculations for all sampling plots are tabulated in Table 5.17 and can be seen in Figure 5.16.

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(1) Marshall, T.J. and Holmes, J.W. 1979, Soil Physics, p.9.

Table 5.17 Void ratio obtained from calculation for all sampling plots measured in study area

Plot No. / Site No.	1	2	3	4	5	6	7	8	9	10	11
1	0.51	0.72	-	-	0.53	0.88	0.81	-	1.38	0.47	-
2	0.78	0.63	1.22	-	-	-	0.58	-	-	0.66	0.53
3	1.12	-	1.00	-	-	1.32	0.56	-	-	-	-
4	0.66	0.81	0.72	0.85	0.36	-	0.66	0.63	1.00	1.50	-
5	0.56	-	0.56	0.49	1.27	1.50	1.85	1.38	1.32	1.56	-

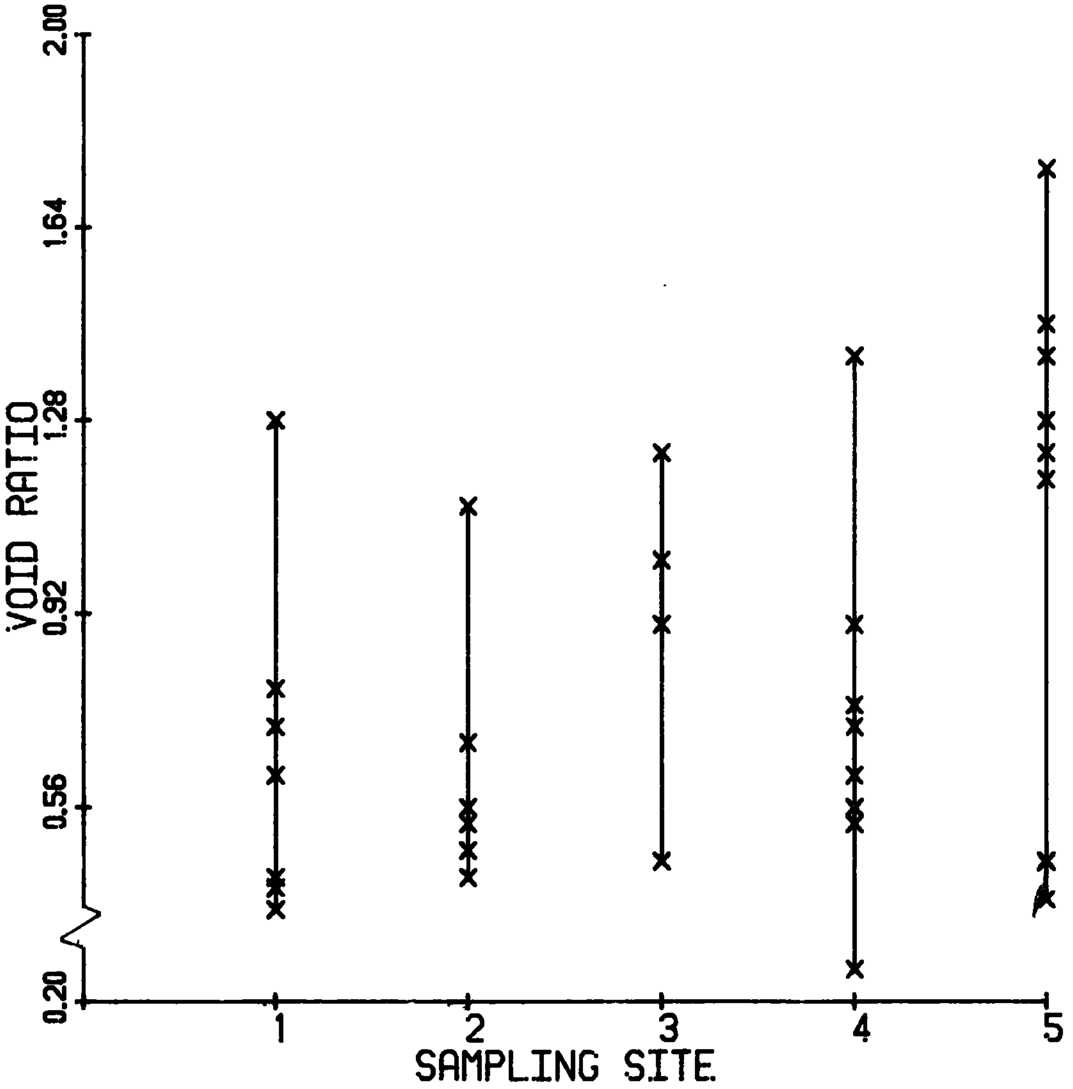

Fig. 5.16 Univariate scatter plots for the void ratio at five sites (study area).

5.11 Shear strength

1. Scope

In the measurement of the shear strength many problems arise in attempting to produce accurate results. Accurate soil mechanics techniques are available and commonly used on restricted sites. However for a large site like a drainage basin which is of geomorphological concern, a portable instrument capable of measuring several plots rapidly can be very useful.

The accuracy of such instruments cannot be compared with the standard laboratory shear box or similar equipment. Yet the advantages of portable and flexible equipment like the Vane Borer in allowing measurements to be carried out in the field compensates for its lesser accuracy. Bearing in mind that geomorphologists are usually dealing with soils in situ in a large area, full coverage is more important than high accuracy.

2. Determination of shear strength in the field using inspection Vane Borer

i. General

This method covers the measurement of the shear strength of soils in the field using a vane of cruciform section, which is subjected to a torque of sufficient magnitude to shear the soil.

ii. Apparatus

The measuring part of the instrument as described in Geonor A/S (1966) is as follows: (Fig.5.17).

A spiral spring (2), (max torque transmitted 30 kg cm). When the handle (1) is turned, the spring deforms and the upper part(3) and the lower part (5) of the instrument receive a mutual angular displacement. The size of this displacement depends on the torque which is necessary to turn the vane (7). By means of a graduated scale (4) the shear strength of the soil is obtained.

The lower and upper halves of the instrument are connected by means of a screw thread. The scale (4) is also supplied with threads and follows the upper part of the instrument by means of two lugs. The zero point is indicated by a line on the upper part (3). When torque is applied, the scale-ring follows the upper part of this instrument, and when failure in the soil is obtained, the scale ring (4) will remain in its position due to the friction in the threads.

Three sizes of four-bladed vane (7) are used: 16 x 32 mm (extra) - multiply readings by 2, 20 x 40 mm (standard) - direct readings, and 1" x 2" (extra) multiply readings by 0.5. This makes it possible to measure shear strength of 0 to 20, 0 to 10 and 0 to 5 t/m^2 respectively. The "area ratios" of the vanes are 14%, 16.5% and 24% respectively (ratio of cross sectional area of the vane to the area to be sheared). The size which was used for this investigation was the smallest one (16 x 32 mm).

The vane blades are soldered to a vane shaft (6) which can be extended by one or more 0.5 m long rods. The connection between the shaft rods and the instrument is made by threads. To make the connections as straight as possible, the rods

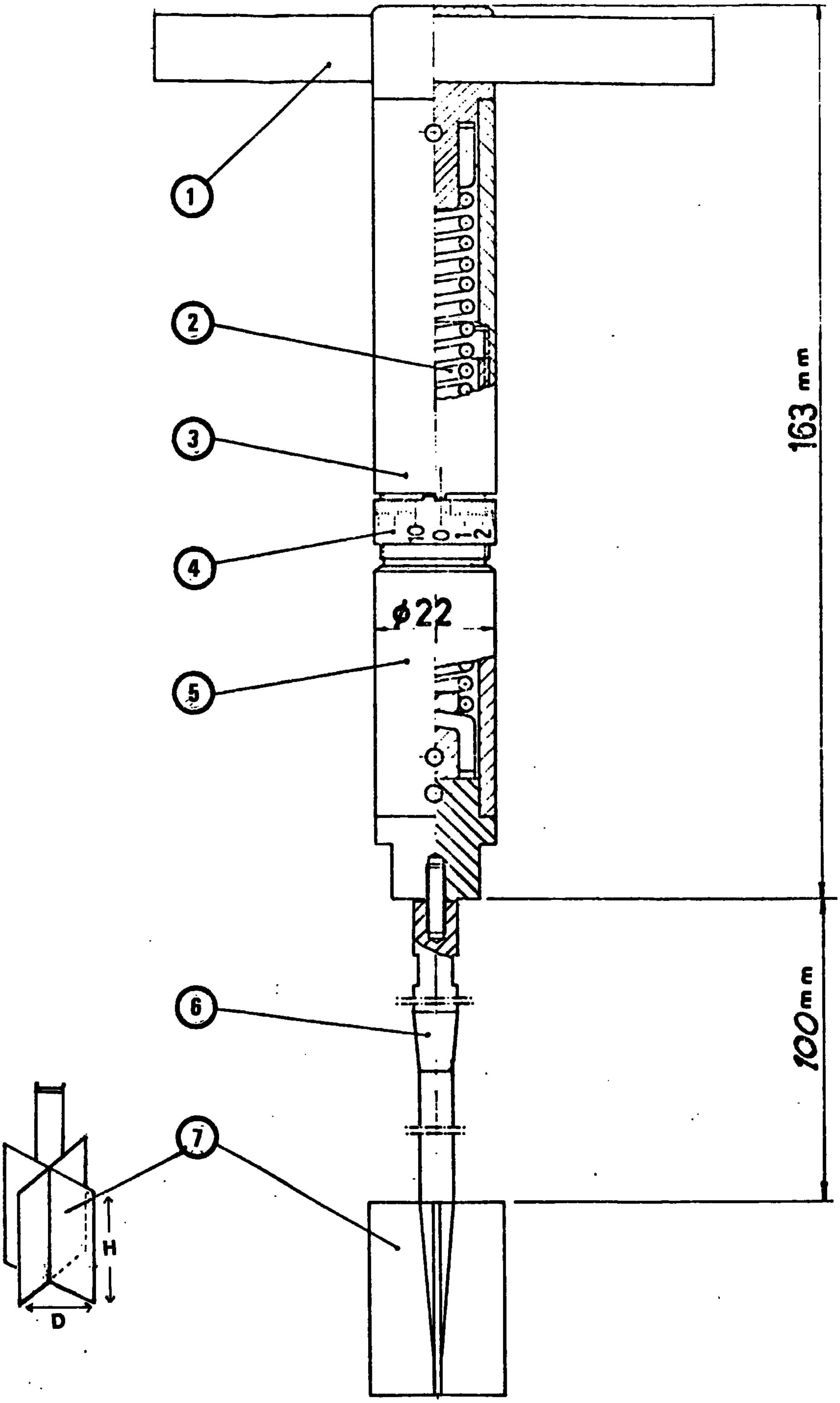

Fig. 5.17 : Inspection vane borer

have to be screwed tight together and the threads cleaned.

3. Measurement procedure

For measuring soil shear strength using the shear vane (inspection vane borer) the following procedure is used:

i. Connect required vane (7) and extension rods to the inspection vane instrument.

ii. Push the vane into the ground to the required position (The inspection vane should not be twisted during penetration).

iii. Make sure that the graduated scale (4) is set to the zero-reading.

iv. Turn the handle (1) clockwise as slowly as possible at constant speed.

v. When the lower part (5) follows the upper part (3) around, or even falls back, failure and maximum shear strength is obtained in the soil at the vane.

vi. Holding handle firmly, allow it to return to zero position. The handle should not be allowed to spring back.

vii. Note the reading on the graduated scale. The position of the graduated ring should not be touched or disturbed until the reading is taken.

viii. Write down the reading together with plot number and depth.

ix. Turn the graduated scale anti-clockwise back to zero position.

x . To determine the remoulded shear strength, the following procedure is used:

Turn the vane quickly at least 25 revolutions. Zero the scale and take at least two measurements by turning the instrument as slowly as possible. The minimum value is considered the correct one.

xi. Push the vane down to next position.

xii. Repeat the above measurement procedure (3 - 10).

The instrument is very simply designed, easy to use and allows multiple readings to be taken quickly.

4 Calculation

The vane shear strength of the soil, S in KN/m^2, is calculated from the following equation: (B.S.1377 : 1975)

$$S = \frac{M}{K}$$

where

M is the torque to shear the soil (Nm);

K is the constant depending on dimension of the vane. Assuming the distribution of the shear strength is uniform around the vane then:

$$K = \pi \frac{D^2 H}{2} \left(1 + \frac{D}{3H}\right) \times 10^{-6}$$

D is the measured width of the cross vane (mm);

H is the measured height of the cross vane (mm).

As the ratio of length to width of the vane is 2 to 1 the value of K may be simplified in terms of the diameter so that it becomes:

$$K = 3.66D^3 \times 10^{-6}$$

The result reported for each plot is an average of 10 readings at depths of 50 to 150 mm from the soil surface. The results of the readings for 35 plots in the study area are shown in Table 5.18 and Figure 5.18.

Table 5.18 Shear strength K N/m^2 for all sampling plots measured in the study area

Plot No. / Site No.	1	2	3	4	5	6	7	8	9	10	11
1	60.99	37.07	-	-	32.16	17.06	19.42	-	19.81	39.03	-
2	25.89	51.58	11.37	-	-	-	68.45	-	-	26.28	58.64
3	31.18	-	12.16	-	-	10.08	21.96	-	-	-	-
4	24.12	26.28	39.03	13.73	72.57	-	57.86	37.46	55.90	0.59	-
5	36.48	-	21.37	20.87	23.73	7.64	11.96	9.41	16.47	23.34	-

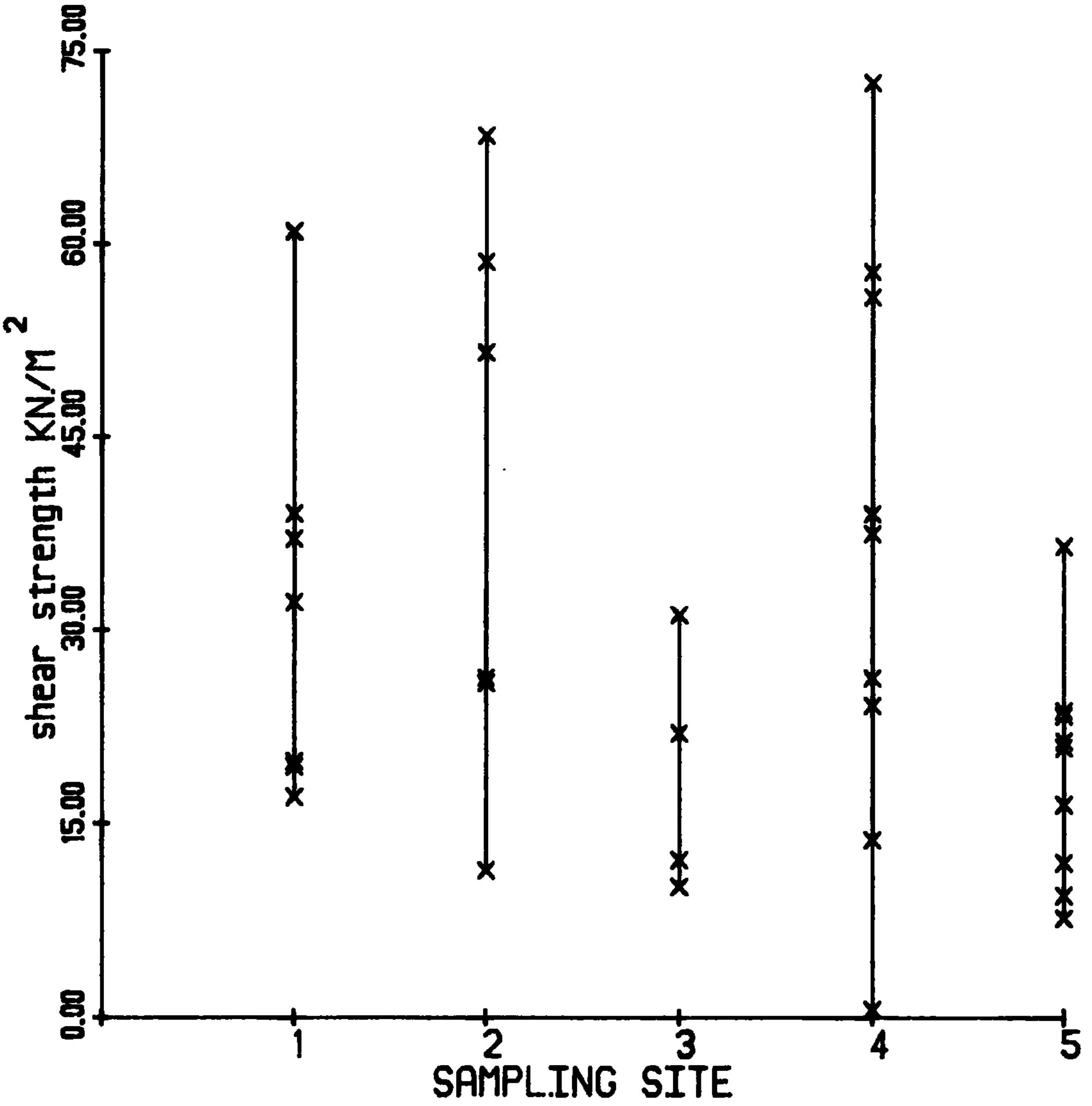

Fig.5.18 Univariate scatter plots for the shear strength at five sites (study area).

Table 5.19 Variables measured for this study

Variable		No.of Plot	Mean	Std.Dev.	Skew
1	Sine of slope	35	0.15	0.11	1.07
2	Soil depth	35	29	3.23	0.06
3	Wet soil moisture	35	178	229	2.54
4	Organic matter	35	34	32	0.70
5	Clay	27	13.7	13.6	1.44
6	Sand	27	70.6	19.0	-1.29
7	Bulk density	35	1.44	0.35	0.32
8	Porosity	35	0.46	0.10	0.22
9	Void ratio	35	0.90	0.39	0.71
10	Liquid limit	27	55.24	18.50	1.09
11	Plastic limit	27	44.0	20.0	1.33
12	Plasticity index	27	9.9	7.7	2.18
13	Shear strength	35	29.8	18.6	0.76
14	Dry density	35	0.99	0.43	
15	Dry moisture	35	106.00	142	

5.12 Climatic factors

Climatic factors are considered to be very important, as has already been mentioned (p. 82). There is no permanent Meteorological station in the study area, but Moor House Meteorological station, about 10 km from the study area, provides accurate meteorological records for the period of this study. From these, only mean monthly maximum temperature, mean monthly minimum temperature, median monthly temperature (i.e. (max + min)/2), mean monthly earth temperature at 0.3 m depth at 9 a.m., monthly rainfall, days of snow lying and of ground frost were assumed to be of importance for this purpose (Table 5.20). Because of the small scale of the study area and the short distance between the sites, the data were taken to apply to the whole experimental area at Killhope basin. Therefore readings were not taken for individual plots or sites. It must also be remembered in this context that the altitudinal range of the sites is about 180 m which may cause major climatic changes between the sites. Therefore the altitude of the main stations was measured using Thommens Altimeter. (Table 4.6).

5.13 Soil temperature

The occurrence of creep due to changing soil temperature and frost action in a temperate climate has been reported by several workers.

Systematic observations on the depths to which the ground was frozen have been made in the Upper Derwent basin by Young (1958). These depths varied little with height,

Table 5.20

Meteorological data from November 1980 to April 1982

(Moor House)

	1980		1981												1982				monthly mean	S.d
	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A		
Mean max temp. C	5.1	4.4	3.2	1.5	5.5	7.7	12.1	12.2	14.4	15.7	13.4	6.8	6.2	-0.9	2.2	3.4	5.0	9.4	7.07	4.66
Mean min temp. C	0.9	-1.0	-2.4	-2.4	-0.4	-0.3	3.3	5.4	7.5	7.5	6.9	0.5	1.1	-6.6	-4.0	-1.3	-1.3	0.1	0.69	3.91
½(max + min C)	3.0	1.7	0.4	-1.0	2.6	3.7	7.7	8.8	11.0	11.6	10.2	3.7	3.7	-3.8	-0.9	1.1	1.9	4.8	3.9	4.25
Earth temp 30 cm 0900	4.8	3.6	2.4	2.2	3.4	5.0	7.2	9.8	11.4	12.4	10.8	6.9	5.1	2.1	1.0	2.4	2.3	4.8	5.42	3.45
Rainfall mm	227	265	186	82	253	94	135	114	125	58	262	269	280	77	231	131	221	48	170	79
Days snow lying	4	10	15	11	9	4	0	0	0	0	0	0	3	25	17	1	9	0	6	7.13
Ground Frost (days)	20	21	30	17	23	24	13	5	2	8	5	23	17	30	22	21	31	21	19.0	8.72

but were related mainly to vegetation as follows:

Bare ground	100 - 200 mm
Short heather	25 - 76 mm
Long heather	25 - 50 mm
Short grass	38 mm
Long grass	0 - 50 mm

According to the Moor House Meteorological records the depth of frozen soil has never reached 0.3 m below the soil surface, i.e. frozen depth ranged from 0 to 0.3 m. (maximum depth of plot measured by the Rashidian Technique was 275 mm).

5.14 Conclusion

The following points emerged:

1. Soil tests were carried out only for the 35 undisturbed plots in the study area.
2. Soil texture (particle size analysis), Liquid Limit, Plastic Limit and Plasticity Index have not been calculated for 8 plots which consist of more than 61% organic matter (peat).
3. Organic soils were significantly wetter than mineral soils.
4. There were substantial differences between soil moisture content obtained in wet and dry seasons. Most significant differences were observed for more organic soils.
5. Mineral soils were denser than organic soils.
6. Porosity and void ratio, which affect soil permability, were higher in organic soils than in mineral soils.

7. In inorganic soils, high shear strengths were found for soil samples with higher proportions of clay.
8. Finally, due to the variation in soil properties such as soil texture, permeability, moisture content etc., the vegetation cover differs between sampling sites and plots.

CHAPTER SIX

RATES OF SOIL CREEP IN STUDY AREA

6.1 Introduction

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  6.2.1 Results

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6.5 Young's pit

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6.7 Volumetric rates of creep

  6.7.1 Introduction

  6.7.2 The Rashidian technique

  6.7.3 The Young's pit

  6.7.4 The Anderson's tubes

  6.7.5 Wooden pillars

6.8 Volumetric rate comparison

6.9 Comparison with other results

CHAPTER SIX

RATES OF SOIL CREEP IN THE STUDY AREA

6.1 Introduction

Measurements of the rate of soil creep were made in the Killhope basin (study area) for a period of one year and six months from 5 November 1980 until 7 May 1982, using Anderson's tubes on 35 plots and three further methods at five sampling stations. Instrumentation by all selected methods was completed in early October 1980 but, to exclude the effect of soil disturbances during the instrumentation, it was decided to record the initial reading one month later. The time interval for reading all instruments was not the same. At least one reading of the Rashidian technique was taken every month, but measurements of other instruments were not regular. The date of the seven readings of Anderson's tubes and nine readings of wooden pillars was coincident with the Rashidian technique. Therefore, a comparison of the rate of creep for the same period of monitoring may be of interest. The final readings of all instruments were taken on the same date (7th May 1982). Thus each category of instrument monitored creep rates over the same period (18 months). To avoid confusion in data analysis, it was decided to calculate the annual creep rates over the twelve months. Two categories of method, i.e. the Rashidian technique and the Young's pit, were capable of producing both linear movements and profiles of velocity against depth. The other two, i.e. Anderson's tubes and wooden pillars, measured linear movements only. There is no record from 6th

January to 4th April 1981 and from 3rd December 1981 to 1st April 1982. This is because during these periods the instruments were covered by snow (Plate 6.1). During the monitoring of creep rates, some disturbances or damage occurred mainly caused by sheep grazing. In that case a new instrument was installed and the monitoring for the period between the last reading before disturbance and the observation was omitted. The annual rates of soil creep produced by the different methods are tabulated and discussed for five control stations in sampling sites. The monitoring programme for each instrument is discussed so that the total and annual rates of creep recorded can be judged in context. Finally, in interpreting the results of creep rate the following errors must be noted:

a. To avoid major soil disturbances, the references for all methods were installed into the soil at depths of between 0.35 and 0.5m. Since some of the references may have moved slightly, results for all methods are regarded as measurements of marker movement relative to the references, and not of absolute movement.

b. Errors due to expansion and contraction of references and marks caused by changing temperature or to slight rusting were inevitable. Such errors were too small to affect measurements of relative movement.

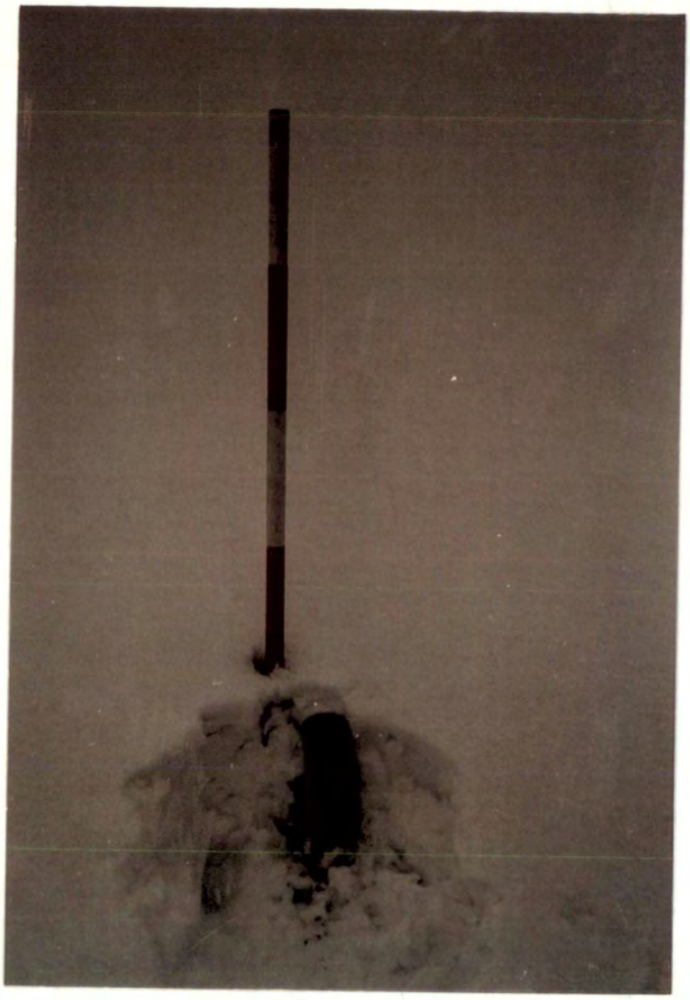


Plate 6.1 : Instrument covered by show during February March and April

6.2 The Rashidian technique

The positions of the set of wires centred in movable wooden blocks located in soil at depths from 30 mm to 270 mm were measured from the top edge of the square holed on the gauge toward the up-slope direction and recorded on a total of twenty two occasions, in which only readings closest to the beginning of each month were taken into account. The only problem in taking measurements was when the instruments were covered by snow. In each reading great care was taken to ensure that the aluminium gauge was precisely located in its previous position. The shallow plot, i.e.30 mm depth was conventionally at the left end of the sample and the deepest was at the right end. Depending on the soil thickness, maximum depth of samples varied between 180 and 270 mm. Maximum depth of samples 1, 2, 3, 4, 5 was respectively 270, 270, 270, 180 and 210 mm.

6.2.1 Results

Since the Rashidian technique was the only one for which measurements were made regularly, and a profile with depth was produced, it provides the standard data set with which other results can be compared. Variations in the rate of creep seem to be dominated by differences in soil properties between sites.

At sampling sites Nos. 1, 2, and 3 the mean annual movements are respectively 1.39 mm, 1.52 mm, and 1.33 mm. On the other hand, in sampling sites Nos. 4 and 5, lower rates were observed. The mean annual movement for sample 4 was 0.69 mm and for sample No. 5, 0.58 mm Table 6.1 . Maximum movement occurred at 120 mm below the soil surface for samples 1, and 2; 90 mm for samples 3 and 4; and 60-90 mm for sample No.5 (Fig. 6.1). The time of slowest movement for sampling sites also varied. Minimum movement for sample No.1 happened in September; for sample No.2, in June; for sample No. 3, in June, August and September; for sample No.4, in August and for sample No.5 in August and September (Fig. 6.1). Overall, August and September are the two months of greatest soil stability.

Consistency: The fact that in Figure 6.1 lines do not cross, shows that rates are all near the average for the sites. Tables 6.1a, 6.1b, 6.1c, 6.1d, 6.1e show monthly changing of plots positions for five control stations and Table 6.1f represent minimum, maximum and annual creep rates of soil with depth at five control stations.

Table 6.1 Annual linear movement in sampling stations (Rashidian Technique)

Sample Site No. / Depth mm	1	2	3	4	5	mean	sd
	Move-ment mm	Move-ment mm	Move-ment mm	Move-ment mm	Move-ment mm	mm	mm
30	1.66	1.86	1.46	0.8	0.66	1.28	0.47
60	1.73	1.93	1.8	1.0	0.86	1.46	0.44
90	2.2	2.2	2.33	1.2	0.86	1.71	0.58
120	2.26	2.4	2.26	0.73	0.53	1.63	0.82
150	1.53	1.73	1.86	0.26	0.46	1.16	0.67
180	1.2	1.46	1.13	0.2	0.46	0.89	0.47
210	0.86	1.0	0.73	—	0.26	0.71	0.27
240	0.66	0.66	0.4	—	—	0.57	0.12
270	0.46	0.46	0.0	—	—	0.46	0.0
Mean	1.39	1.52	1.33	0.69	0.58	1.1	0.43
sd	0.6	0.64	0.77	0.36	0.20		

Depth: below soil surface in mm

sd = standard deviation

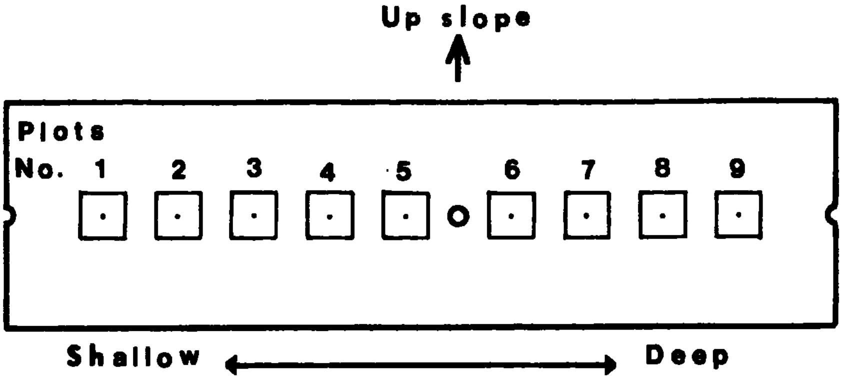
Table 6.1a

Page

The Rashidian Technique Record Form

Sample site No. 1

Date of initial reading 5.11.1980



Plots	1	2	3	4	5	6	7	8	9	Mean
Depth mm	30	60	90	120	150	180	210	240	270	
* Initial reading mm	14.5	13.8	13.9	13.2	14.7	13.5	14.6	12.3	13.5	
Change in mm										
2.12.80	0.2	0.2	0.3	0.3	0.2	0.1	0.1	0.0	0.0	
6. 1.81	0.1	0.1	0.2	0.2	0.1	0.0	0.0	0.0	0.0	
3. 2.81	Instrument covered by snow									
1. 3.81	Instrument covered by snow									
4. 4.81	0.4	0.4	0.4	0.5	0.4	0.3	0.3	0.3	0.2	
8. 5.81	0.3	0.4	0.4	0.4	0.3	0.3	0.2	0.1	0.1	
4. 6.81	0.1	0.1	0.2	0.2	0.1	0.1	0.0	0.0	0.0	
2. 7.81	0.2	0.2	0.1	0.1	0.0	0.0	0.1	0.1	0.0	
7. 8.81	0.2	0.2	0.2	0.2	0.1	0.1	0.0	0.0	0.0	
3. 9.81	0.1	0.1	0.2	0.1	0.2	0.1	0.0	0.0	0.1	
4.10.81	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.0	
1.11.81	0.2	0.2	0.3	0.2	0.1	0.1	0.0	0.0	0.0	
3.12.81	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	
14.1.82 to 1. 4.82	Instrument covered by snow									
7. 5.82	0.5	0.5	0.8	0.9	0.6	0.5	0.4	0.3	0.3	
Total movement	2.5	2.6	3.3	3.4	2.3	1.8	1.3	1.0	0.8	
Annual linear movement	1.66	1.73	2.2	2.26	1.53	1.2	0.86	0.66	0.46	1.39

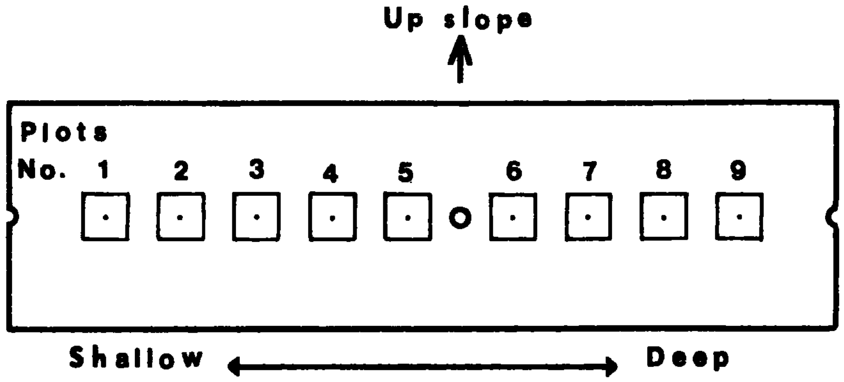
* Wire distance from top edge of plot square

Table 6.1b

The Rashidian Technique Record Form

Sample site No.2

Date of initial reading 5.11.1980



Plots	1	2	3	4	5	6	7	8	9	Mean
Depth mm	30	60	90	120	150	180	210	240	270	
* Initial reading mm	13.2	14.4	13.2	15.7	14.1	13.6	12.2	14.5	14.4	
Change in mm										
2.12.80	0.2	0.3	0.4	0.3	0.2	0.2	0.1	0.1	0.1	
6. 1.81	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.0	
3. 2.81	Instrument covered by snow									
1. 3.81	Instrument covered by snow									
4. 4.81	0.3	0.3	0.5	0.6	0.3	0.3	0.2	0.1	0.1	
8. 5.81	0.3	0.3	0.4	0.5	0.4	0.4	0.3	0.2	0.1	
4. 6.81	0.1	0.1	0.1	0.2	0.2	0.1	0.0	0.0	0.0	
2. 7.81	0.2	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	
7. 8.81	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	
3. 9.81	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
4.10.81	0.2	0.1	0.2	0.2	0.2	0.1	0.1	0.0	0.0	
1.11.81	0.2	0.2	0.3	0.3	0.2	0.2	0.1	0.1	0.0	
3.12.81	0.2	0.3	0.2	0.3	0.2	0.2	0.2	0.1	0.1	
14.1.82 to 1. 4.82	Instrument covered by snow									
7. 5.82	0.8	0.9	0.9	0.8	0.6	0.5	0.4	0.3	0.2	
Total movement	2.8	2.9	3.3	3.6	2.6	2.2	1.5	1.0	0.6	
Annual linear movement	1.86	1.93	2.2	2.4	1.73	1.46	1.0	0.66	0.46	1.52

* Wire distance from top edge of plot square

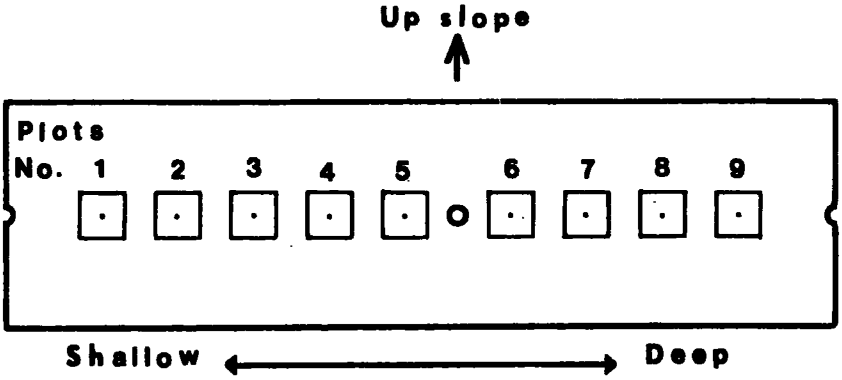
Table 6.1c

Page

The Rashidian Technique Record Form

Sample site No. 3

Date of initial reading 5.11.1980



Plots	1	2	3	4	5	6	7	8	9	Mean
Depth mm	30	60	90	120	150	180	210	240	270	
* Initial reading mm	13.6	16.5	14.5	15.8	16.2	14.8	14.2	15.3	15.2	
Change in mm										
2.12.80	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.0	0.0	
6. 1.81	0.3	0.3	0.3	0.4	0.4	0.2	0.1	0.1	0.0	
3. 2.81	Instrument covered by snow									
1. 3.81	Instrument covered by snow									
4. 4.81	0.5	0.6	0.7	0.6	0.6	0.4	0.2	0.2	0.0	
8. 5.81	0.2	0.2	0.4	0.4	0.3	0.2	0.1	0.0	0.0	
4. 6.81	0.0	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.0	
2. 7.81	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	
7. 8.81	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.0	0.0	
3. 9.81	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.0	
4.10.81	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0	
1.11.81	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.0	0.0	
3.12.81	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.0	0.0	
14.1.82 to 1. 4.82	Instrument covered by snow									
7.5 .82	0.6	0.7	0.8	0.9	0.6	0.3	0.2	0.1	0.0	
Total movement	2.2	2.7	3.5	3.4	2.8	1.7	1.1	0.6	0.0	
Annual linear movement	1.46	1.8	2.33	2.26	1.86	1.13	0.73	0.4	0.0	1.33

* Wire distance from top edge of plot square

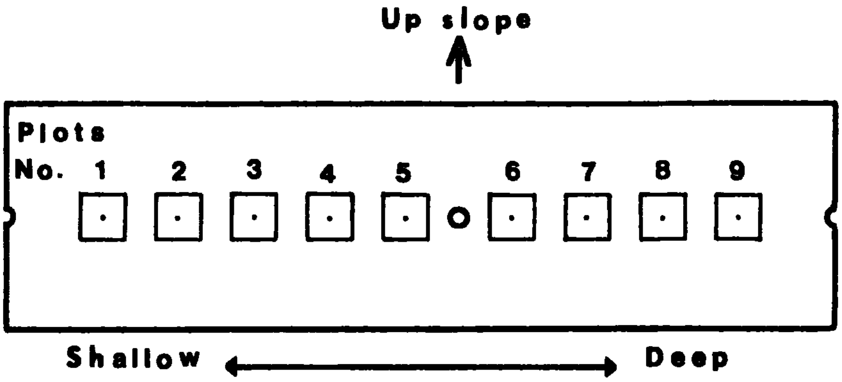
Table 6.1d

Page

The Rashidian Technique Record Form

Sample site No. 4

Date of initial reading 5.11.1980



Plots	1	2	3	4	5	6	7	8	9	Mean
Depth mm	30	60	90	120	150	180	210	240	270	
							No block inserted			
* Initial reading mm	13.3	14.8	15.7	13.4	13.6	15.8	-	-	-	
Change in mm										
2.12.80	0.1	0.1	0.2	0.1	0.0	0.0	-	-	-	
6. 1.81	0.0	0.1	0.1	0.1	0.0	0.0	-	-	-	
3. 2.81	Instrument	covered	by	snow						
1. 3.81	Instrument	covered	by	snow						
4. 4.81	0.1	0.2	0.2	0.2	0.1	0.1	-	-	-	
8. 5.81	0.2	0.2	0.2	0.1	0.1	0.0	-	-	-	
4. 6.81	0.1	0.1	0.2	0.1	0.0	0.0	-	-	-	
2. 7.81	0.0	0.1	0.1	0.1	0.0	0.0	-	-	-	
7. 8.81	0.1	0.1	0.1	0.0	0.0	0.0	-	-	-	
3. 9.81	0.0	0.0	0.1	0.0	0.0	0.0	-	-	-	
4.10.81	0.1	0.1	0.0	0.1	0.0	0.0	-	-	-	
1.11.81	0.1	0.1	0.1	0.1	0.1	0.1	-	-	-	
3.12.81	0.0	0.1	0.1	0.0	0.0	0.0	-	-	-	
14.1.82 to 1. 4.82	Instrument	covered	by	snow						
7. 5.82	0.4	0.4	0.4	0.2	0.1	0.1	-	-	-	
Total movement	1.2	1.6	1.8	1.1	0.4	0.3	-	-	-	
Annual linear movement	0.8	1.0	1.2	0.73	0.26	0.2	-	-	-	0.69

* Wire distance from top edge of plot square

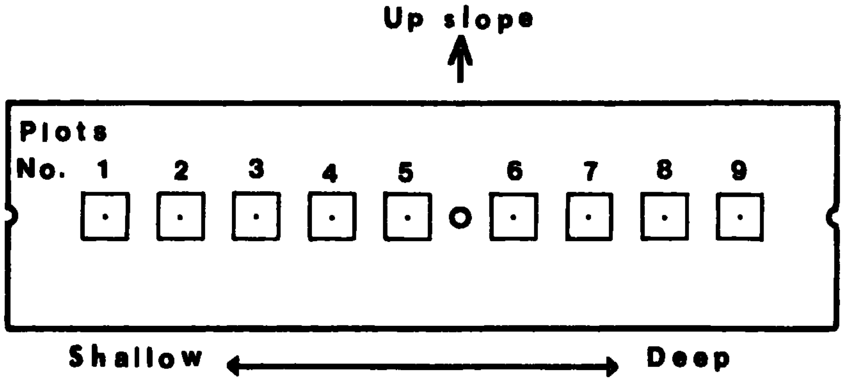
Table 6.1e

Page

The Rashidian Technique Record Form

Sample site No. 5

Date of initial
reading 5.11.1980



Plots	1	2	3	4	5	6	7	8	9	Mean
Depth mm	30	60	90	120	150	180	210	240	270	
* Initial reading mm	13.7	14.5	12.3	15.1	13.5	14.4	12.8	No block inserted -	-	
Change in mm										
2.12.80	0.0	0.1	0.1	0.1	0.0	0.0	0.0	-	-	
6. 1.81	0.1	0.1	0.2	0.1	0.1	0.1	0.0	-	-	
3. 2.81	Instrument covered by snow									
1. 3.81	Instrument covered by snow									
4. 4.81	0.2	0.2	0.2	0.1	0.1	0.1	0.1	-	-	
8. 5.81	0.1	0.1	0.1	0.1	0.0	0.0	0.0	-	-	
4. 6.81	0.1	0.1	0.1	0.0	0.0	0.0	0.0	-	-	
2. 7.81	0.1	0.1	0.1	0.1	0.0	0.0	0.0	-	-	
7. 8.81	0.0	0.0	0.0	0.0	0.1	0.0	0.0	-	-	
3. 8.81	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-	
4.10.81	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-	
1.11.81	0.0	0.0	0.1	0.0	0.1	0.0	0.0	-	-	
3.12.81	0.1	0.1	0.0	0.0	0.0	0.0	0.0	-	-	
14.1.82 to 1. 4.82	Instrument covered by snow									
7. 5.82	0.3	0.5	0.1	0.3	0.3	0.2	0.2	-	-	
Total movement	1.0	1.3	1.0	0.8	0.7	0.7	0.3	-	-	
Annual linear movement	0.66	0.86	0.86	0.53	0.46	0.46	0.26			0.58

* Wire distance from top edge of plot square

Table 6.1f A profile of soil movement with depth obtained by Rashidian's technique

Site	Depth of sample mm	N	Min	Max	Mean	St. dev.	creep mma^{-1}
1	30	12	0.0	.50	.21	.14	1.66
2	30	12	0.1	.80	.23	.19	1.86
3	30	12	0.0	.60	.18	.19	1.46
4	30	12	0.0	.40	.10	.11	0.80
5	30	12	0.0	.30	.08	.09	0.63
1	60	12	0.0	.50	.22	.15	1.73
2	60	12	0.1	.90	.24	.23	1.93
3	60	12	0.0	.70	.22	.22	1.80
4	60	12	0.0	.40	.13	.09	1.06
5	60	12	0.0	.50	.11	.14	0.86
1	90	12	0.0	.80	.27	.20	2.20
2	90	12	0.0	.90	.27	.25	2.20
3	90	12	0.1	.80	.29	.23	2.33
4	90	12	0.0	.40	.15	.10	1.20
5	90	12	0.0	.40	.11	.12	0.86
1	120	12	0.1	.90	.28	.23	2.26
2	120	12	0.0	.80	.30	.23	2.40
3	120	12	0.0	.90	.28	.25	2.26
4	120	12	0.0	.20	.09	.06	0.73
5	120	12	0.0	.30	.07	.09	0.53
1	150	12	0.0	.60	.19	.17	1.53
2	150	12	0.0	.60	.22	.16	1.73
3	150	12	0.0	.60	.23	.20	1.86
4	150	12	0.0	.10	.03	.05	0.26
5	150	12	0.0	.30	.06	.10	0.46
1	180	12	0.0	.50	.15	.14	1.20
2	180	12	0.0	.50	.18	.15	1.46
3	180	12	0.0	.40	.14	.12	1.13
4	180	12	0.0	.10	.03	.05	0.20
5	180	12	0.0	.30	.06	.10	0.46
1	210	12	0.0	.40	.11	.13	0.86
2	210	12	0.0	.40	.12	.13	1.00
3	210	12	0.0	.20	.10	.70	0.73
4	210	12	0.0	.20	.03	.06	0.26
5	210	12	0.0	.30	.09	.11	0.66
1	240	12	0.0	.30	.09	.01	0.66
2	240	12	0.0	.20	.05	.07	0.40
3	240	12	0.0	.30	.07	.01	0.53
4	240	12	0.0	.20	.05	.07	.40
5	240	12	0.0	0.	0.	–	–

N = Number of readings Min = minimum Max = maximum

St.dev = standard deviation.

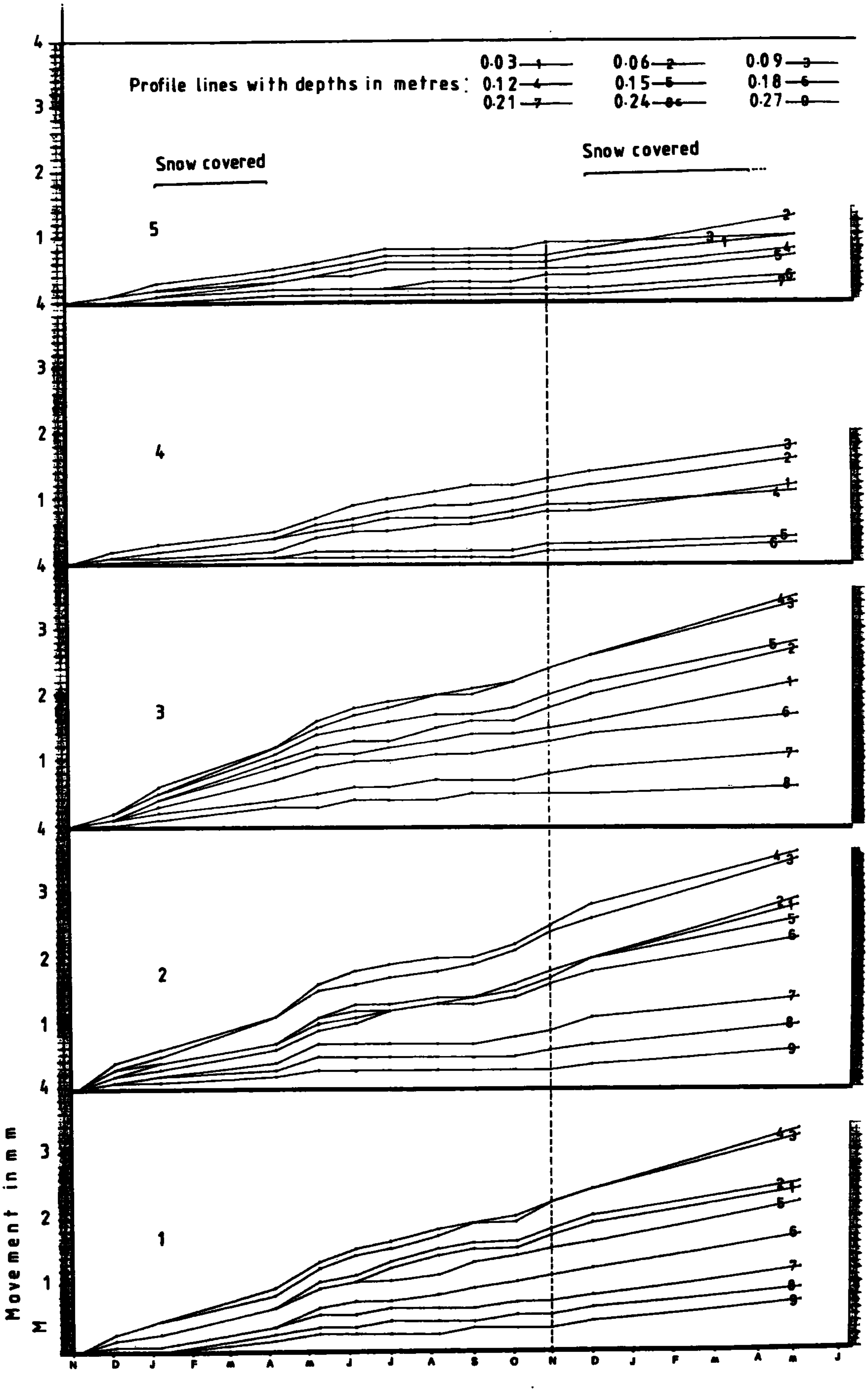


Fig 6.1 Movement profile with depth obtained by the Rashidian technique in five sampling station at Killhope basin from 5th November 1980 to 7th May 1982

6.3 The Anderson's tubes

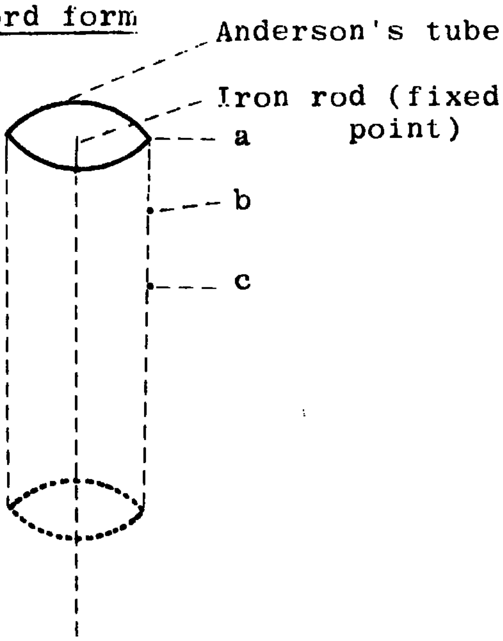
Anderson's tubes were used to determine bodily movement at each plot. After the establishment of each plot the initial distance of the upslope marked points in the tubes was measured from the stationary rod and recorded. On further visits, new positions of the tubes were measured and recorded. Decreasing distance of the tubes from the rod indicated movement caused by soil creep. A comparison of the annual linear creep rates at each control station, calculated from tilt measurement of the tubes used, is given in Table 6.2, with the mean annual linear creep rate of all the tubes used at each sampling site, calculated to show differences of the creep rate between the plots. The highest observed rates occurred with the Anderson's tubes on the station at sampling sites Nos. 1 and 2 (Fig. 6.2) and lower rates of movement are found for sampling sites 4 and 5 (Fig. 6.3). Full results of annual linear creep rate obtained by Anderson's tubes for 35 plots including sampling station are tabulated in Table 6.2f (44 plots were established but owing to disturbance, vandalism, etc. readings could only be obtained from 35.)

Table 6.2 Annual movement at sampling stations (Anderson's tubes)

Sample site No.	Annual linear movement at control stations mma^{-1}	Mean annual linear movement for the plots mma^{-1}
1	1.66	2.06
2	1.86	1.39
3	1.55	1.51
4	0.8	1.10
5	0.66	1.47
Mean	1.30	1.50
Standard Deviation	0.52	0.31

Table 6.2a

The Anderson's tube record form



Sample site No.	1
Plot No.	1
Aspect	S.W
Slope angle	10°
Vegetation	Calluna vulgaris
Soil texture	Silty loam
Depth of tube insertion	0.30 m
Date of initial reading	5.11.1980

Point	a. movement mm		b. movement mm		c. movement mm	
Initial * reading	25.0		25.1		25.2	
3.2.81		0.3		0.3		0.3
8.5.81		0.5		0.4		0.3
2.7.81		0.3		0.3		0.3
21.9.81		0.1		0.1		0.1
4.10.81		0.1		0.1		0.1
1.11.81		0.2		0.2		0.2
3.12.81		0.2		0.2		0.2
7.5.82		0.8		0.7		0.6

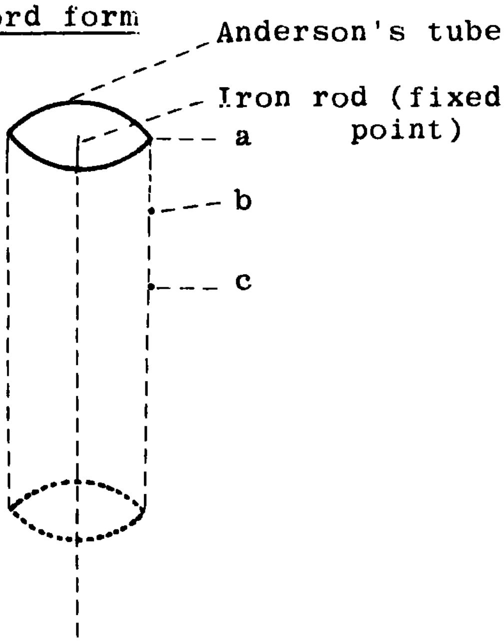
Total movement	2.5	2.3	2.1
Annual movement	1.66	1.53	1.4
Mean annual movement	2.06		

* Fixed point distance from point a, b, c in mm.

Table 6.2b

The Anderson's tube record form

Sample site No.	2
Plot No.	1
Aspect	East
Slope angle	8°
Vegetation	Calluna vulgaris
Soil texture	Silty loam
Depth of tube insertion	0.30 m
Date of initial reading	5.11.1980



Point	a. movement mm		b. movement mm		c. movement mm	
* Initial reading	23.0	-	23.0	-	23.0	-
3. 2.81		0.4		0.4		0.2
8. 5.81		0.6		0.6		0.6
2. 7.81		0.3		0.3		0.3
21.9.81		0.1		0.1		0.1
4.10.81		0.1		0.1		0.1
1.11.81		0.2		0.2		0.2
3.12.81		0.2		0.2		0.2
7. 5.82.		0.9		0.8		0.7

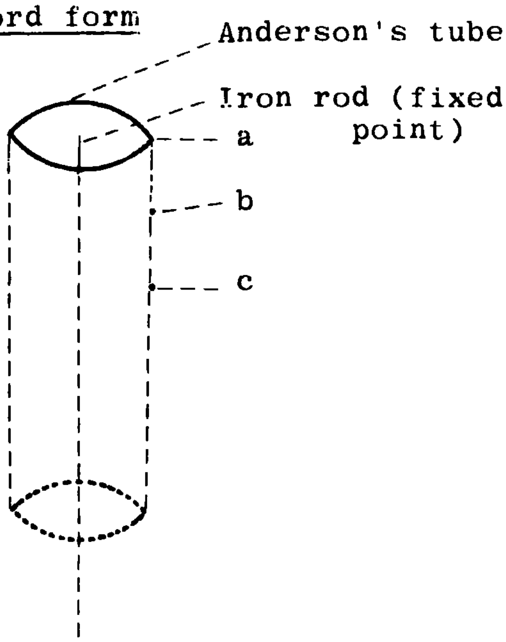
Total movement	2.8	2.6	2.4
Annual movement	1.86	1.73	1.6
Mean annual movement	1.39		

* Fixed point distance from point a, b, c in mm.

Table 6.2c

The Anderson's tube record form

Sample site No. 3
Plot No. 1
Aspect South
Slope angle 7°
Vegetation Coniferous trees, *Festuca ovina*
Soil texture Sand
Depth of tube insertion 0.30 m
Date of initial reading 5.11.1980



Point	a. movement mm		b. movement mm		c. movement mm	
* Initial reading	18.3		18.2		18.1	
3. 2.81		0.2		0.2		0.2
8. 5.81		0.5		0.5		0.4
2. 7.81		0.2		0.2		0.2
21.9.81		0.2		0.2		0.2
1.11.81		0.2		0.2		0.2
3.12.81		0.4		0.3		0.3
7. 5.82		0.6		0.5		0.4

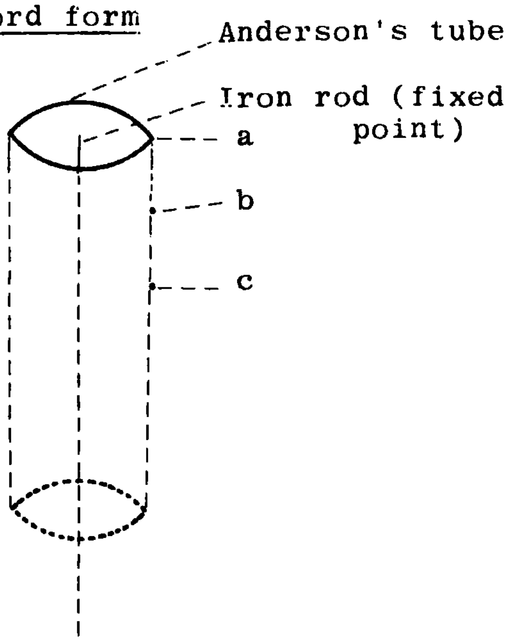
Total movement	2.3	2.1	1.9
Annual movement	1.55	1.40	1.26
Mean annual movement	1.51		

* Fixed point distance from point a, b, c in mm.

Table 6.2d

The Anderson's tube record form

Sample site No.	4
Plot No.	1
Aspect	West
Slope angle	15°
Vegetation	Poa pratensis
Soil texture	Loam
Depth of tube insertion	0.25
Date of initial reading	5.11.1980



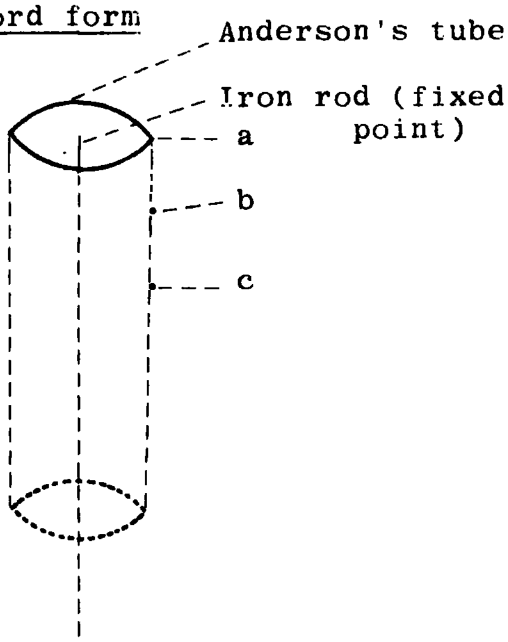
Point	a. movement mm		b. movement mm		c. movement mm	
Initial * reading	13.5		13.3		13.1	
3.2. 81		0.1		0.1		0.1
8.5. 81		0.3		0.2		0.1
2.7. 81		0.1		0.1		0.1
21.9.81		0.0		0.0		0.0
1.11.81		0.1		0.1		0.1
3.12.81		0.2		0.2		0.2
7.5. 82		0.4		0.4		0.4

Total movement	1.2	1.1	1.0
Annual movement	0.8	0.73	0.66
Mean annual movement	1.10		

* Fixed point distance from point a, b, c in mm.

Table 6.2e

The Anderson's tube record form



Sample site No.	5
Plot No.	1
Aspect	South
Slope angle	3°
Vegetation	Poa pratensis
Soil texture	Loam
Depth of tube insertion	0.25 m
Date of initial reading	5.11.1980

Point	a. movement mm		b. movement mm		c. movement mm	
Initial * reading	26.6		26.7		26.8	
3.2. 81		0.1		0.1		0.0
8.5. 81		0.2		0.2		0.2
2.7. 81		0.1		0.0		0.0
21.9.81		0.0		0.0		0.0
1.11.81		0.0		0.0		0.1
3.12.81		0.2		0.2		0.2
7.5. 82		0.4		0.4		0.3

Total movement	1.0	0.9	0.8
Annual movement	0.66	0.60	0.53
Mean annual movement	1,47		

* Fixed point distance from point a, b, c in mm.

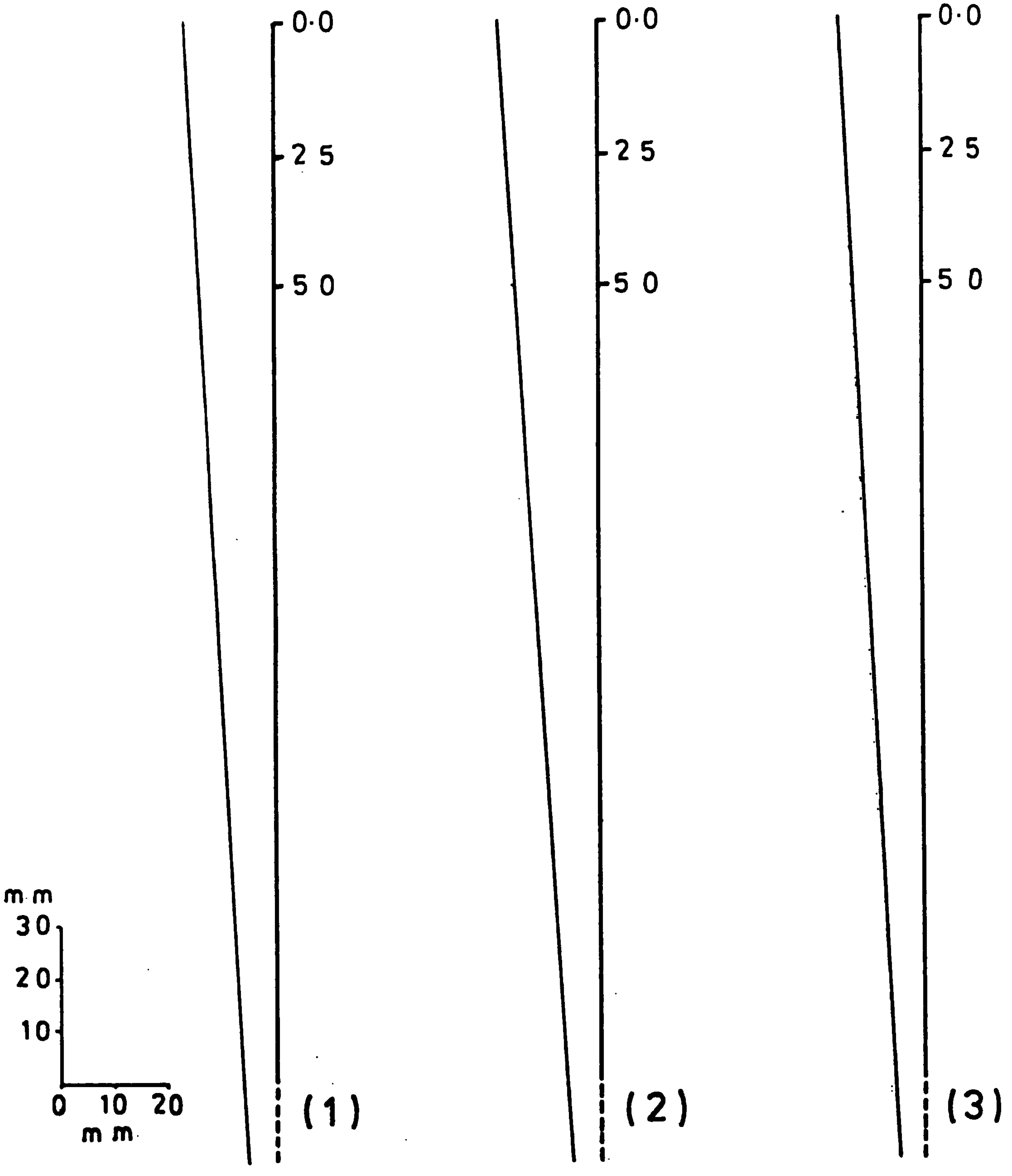


Fig. 6.2 : Anderson's tubes : bodily movement (Plot 1 of sites 1, 2 & 3)

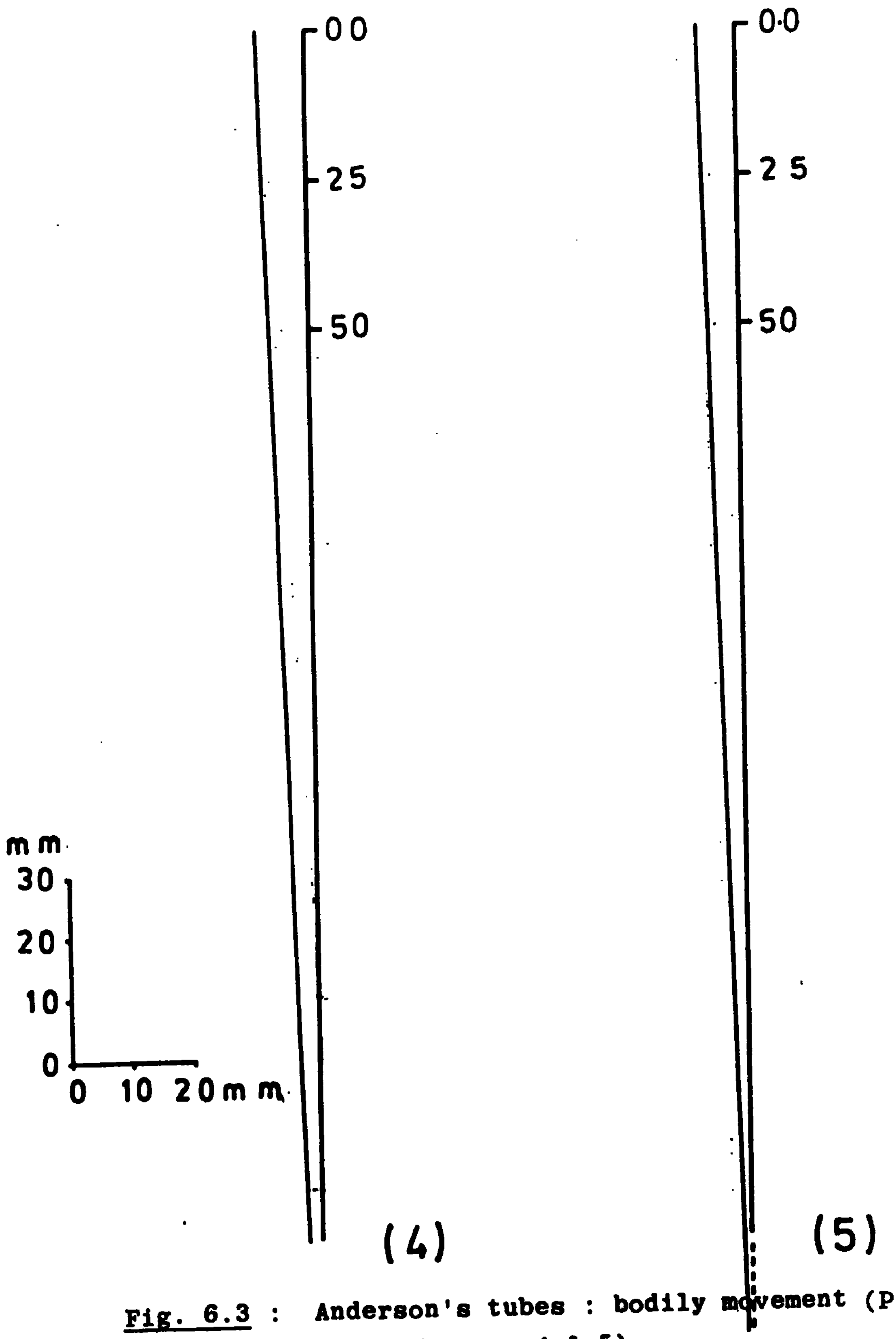


Fig. 6.3 : Anderson's tubes : bodily movement (Plot 1 of sites 4 & 5)

Table 6.2f Annual linear creep rate obtained by Anderson's tubes for 35 plots

Plot No. / Site No.	1	2	3	4	5	6	7	8	9	10	11
1	1.66	1.69	-	-	2.68	2.14	1.80	-	1.74	2.73	-
2	1.87	0.75	2.55	-	-	-	0.68	-	-	1.8	0.72
3	1.57	-	1.68	-	-	1.55	1.26	-	-	-	-
4	0.83	0.97	0.85	0.62	0.7	-	0.88	0.90	1.55	2.63	-
5	0.68	-	0.7	0.72	1.88	1.75	1.84	2.16	1.85	1.72	-

6.4 Wooden pillars

Following the procedure described in Chapter two, six readings of this instrument were obtained between 4th November 1980 and 7th May, 1982 (Table 6.3). These data represent changes in the rod's position caused by soil movement. Regarding the length of rods the layer of soil affected varied between 50-150 mm. This measurement was not sufficient to determine the rods' pivot points, and therefore bodily movement is not calculable. The data were used just to estimate and compare the rate of soil movement with depth upon the rods. With the exception of plot b (100 mm depth) at sample 3, the rate of movement in all plots decreased with depth, i.e. maximum movement occurred at the top layer of the soil, which is contrary to the results taken from other instruments. This can be justified :

a. The dense, intertwined root mat at this sampling site is a more important control of soil creep in the upper soil layers.

b. It is likely that this plot has been affected by tree roots or other agents. The results of this instrument for five sampling sites are given in Table 6.3 and Figures 6.4, 6.5, 6.6, 6.7, 6.8.

Table 6.3 Soil movement at study area (wooden pillars)

Sampling site	1	2	3	4	5
Mean annual movement mm	1.5	1.77	1.35	0.75	0.66
Standard deviation	0.19	0.27	0.16	0.19	0.16

Table 6.3a

The wooden pillars record form

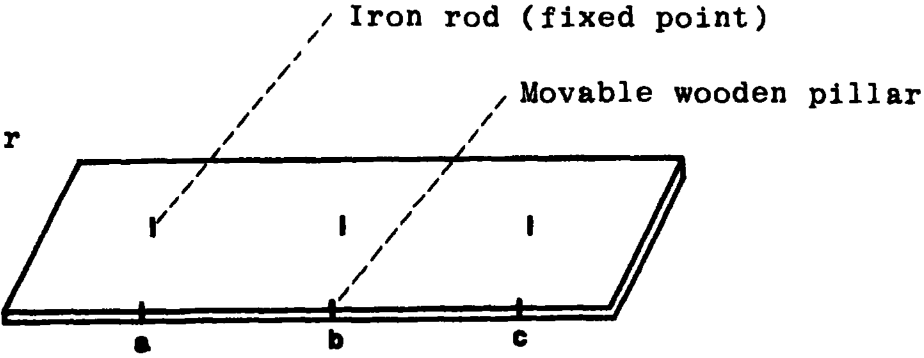
Sample No. 1

Length of wooden pillar insertion

a = 0.05 m

b = 0.10 m

c = 0.15 m



Date of initial reading 5.11.1980

Plot	a	b	c
	Movement in mm	Movement in mm	Movement in mm
* Initial reading mm	40.0	40.0	40.0
6.1.81	0.4	0.4	0.3
4.4.81	0.7	0.6	0.5
2.7.81	0.3	0.3	0.2
1.11.81	0.4	0.3	0.3
7.5.82	0.8	0.7	0.6
Total movement	2.6	2.3	1.9
Annual linear movement	1.73	1.53	1.26

Mean 1.5

Standard deviation 0.19

* Wooden pillars distance from fixed points

Table 6.3b

The wooden pillars record form

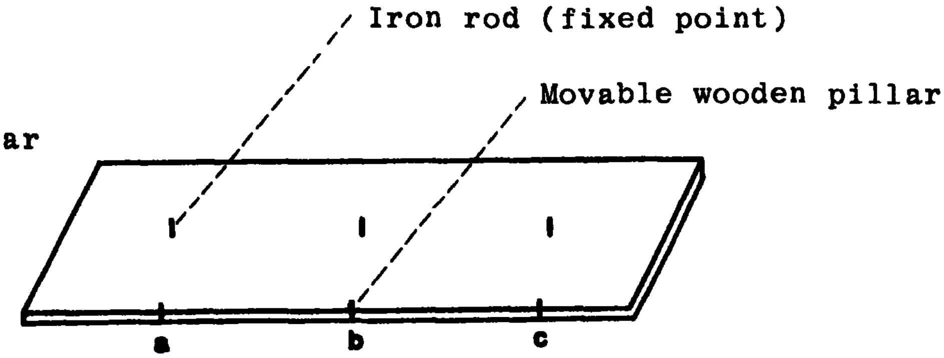
Sample No. 2

Length of wooden pillar insertion

a = 0.05 **m**

b = 0.10 **m**

c = 0.15 **m**



Date of initial reading 5.11.1980

Plot	a	b	c
	Movement in mm	Movement in mm	Movement in mm
* Initial reading mm	40.0	40.0	40.0
6.1.81	0.4	0.3	0.3
4.4.81	0.8	0.7	0.6
2.7.81	0.4	0.3	0.2
1.11.81	0.7	0.7	0.5
7.5.82	0.9	0.7	0.6
Total movement	3.2	2.6	2.2
Annual linear movement	2.13	1.73	1.46

Mean 1.77

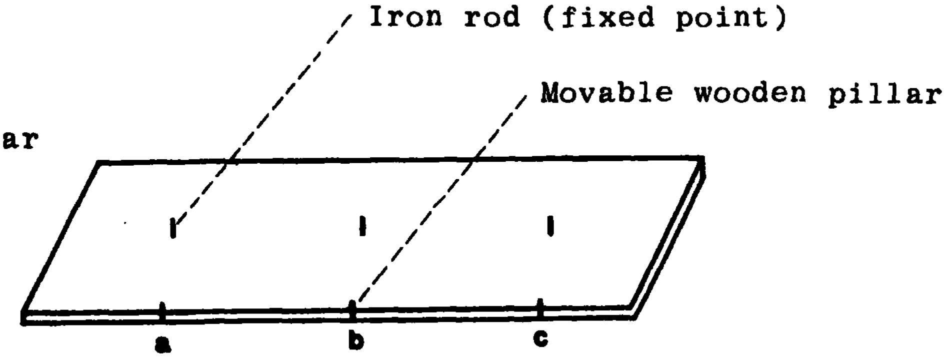
Standard deviation 0.27

* **Wooden pillars distance from fixed points**

Table 6.3c

The wooden pillars record form

Sample No. 3



Length of wooden pillar insertion

a = 0.05 m

b = 0.10 m

c = 0.15 m

Date of initial reading 5.11.1980

Plot	a	b	c
	Movement in mm	Movement in mm	Movement in mm
* Initial reading mm	40.0	40.0	40.0
6.1.81	0.3	0.4	0.2
4.4.81	0.5	0.5	0.5
2.7.81	0.3	0.4	0.2
1.11.81	0.3	0.4	0.3
7.5.82	0.7	0.6	0.5
Total movement	2.1	2.3	1.7
Annual linear movement	1.4	1.53	1.13

Mean 1.35

Standard deviation 0.16

* Wooden pillars distance from fixed points

Table 6.3d

The wooden pillars record form

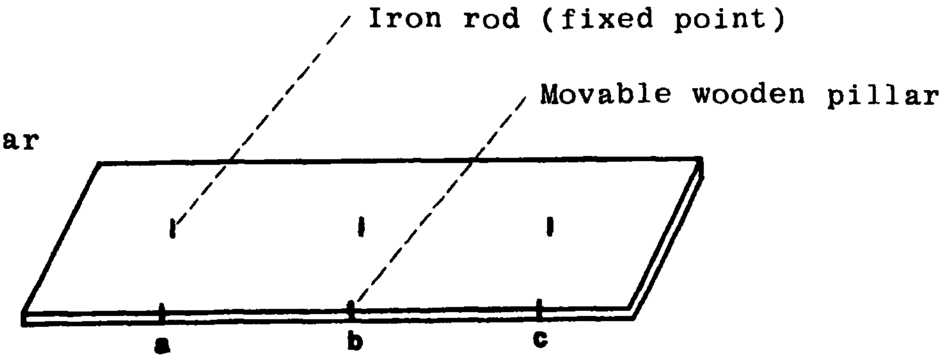
Sample No. 4

Length of wooden pillar insertion

a = 0.05 m

b = 0.10 m

c = 0.15 m



Date of initial reading 5.11.1980

Plot	a	b	c
	Movement in mm	Movement in mm	Movement in mm
* Initial reading mm	40.0	40.0	40.0
6.1.81	0.2	0.1	0.1
4.4.81	0.3	0.3	0.2
2.7.81	0.2	0.2	0.1
1.11.81	0.3	0.1	0.1
7.5.82	0.5	0.4	0.3
Total movement	1.5	1.1	0.8
Annual linear movement	1.0	0.73	0.53

Mean 0.75

Standard deviation 0.19

* Wooden pillars distance from fixed points

Table 6.3e

The wooden pillars record form

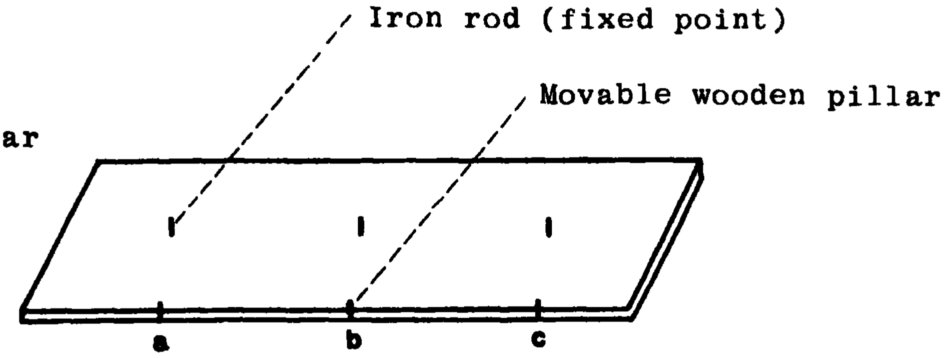
Sample No. 5

Length of wooden pillar insertion

a = 0.05 m

b = 0.10 m

c = 0.15 m



Date of initial reading 5.11.1980

Plot	a	b	c
	Movement in mm	Movement in mm	Movement in mm
* Initial reading mm	40.0	40.0	40.0
6.1.81	0.2	0.1	0.1
4.4.81	0.3	0.3	0.2
2.7.81	0.2	0.1	0.1
1.11.81	0.2	0.2	0.1
7.5.82	0.4	0.3	0.2
Total movement	1.3	1.0	0.7
Annual linear movement	0.86	0.66	0.46

Mean 0.66

Standard deviation 0.16

* Wooden pillars distance from fixed points

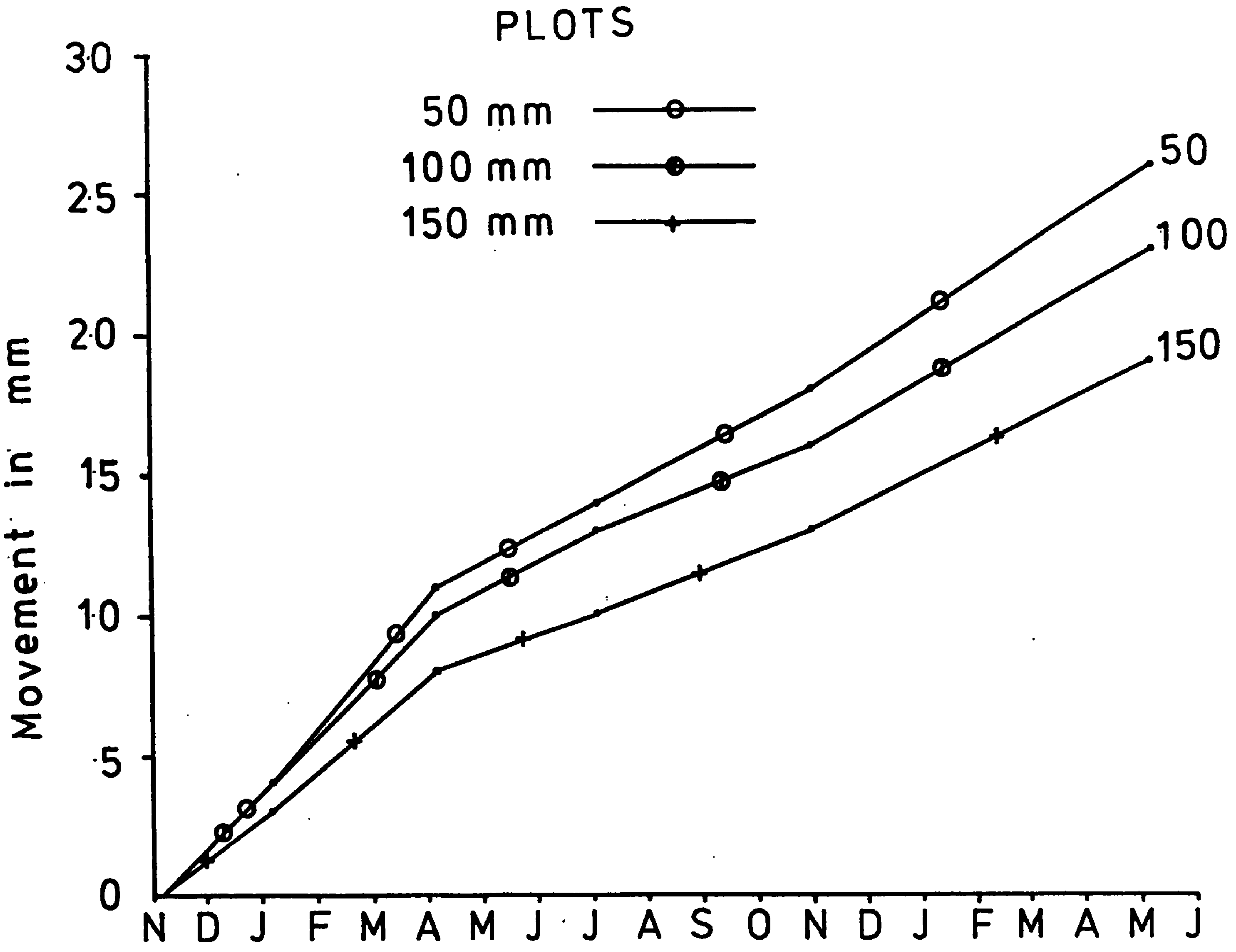


Fig. 6.4 : Creep rate measurements for sampling station No.1 (Wooden pillars)

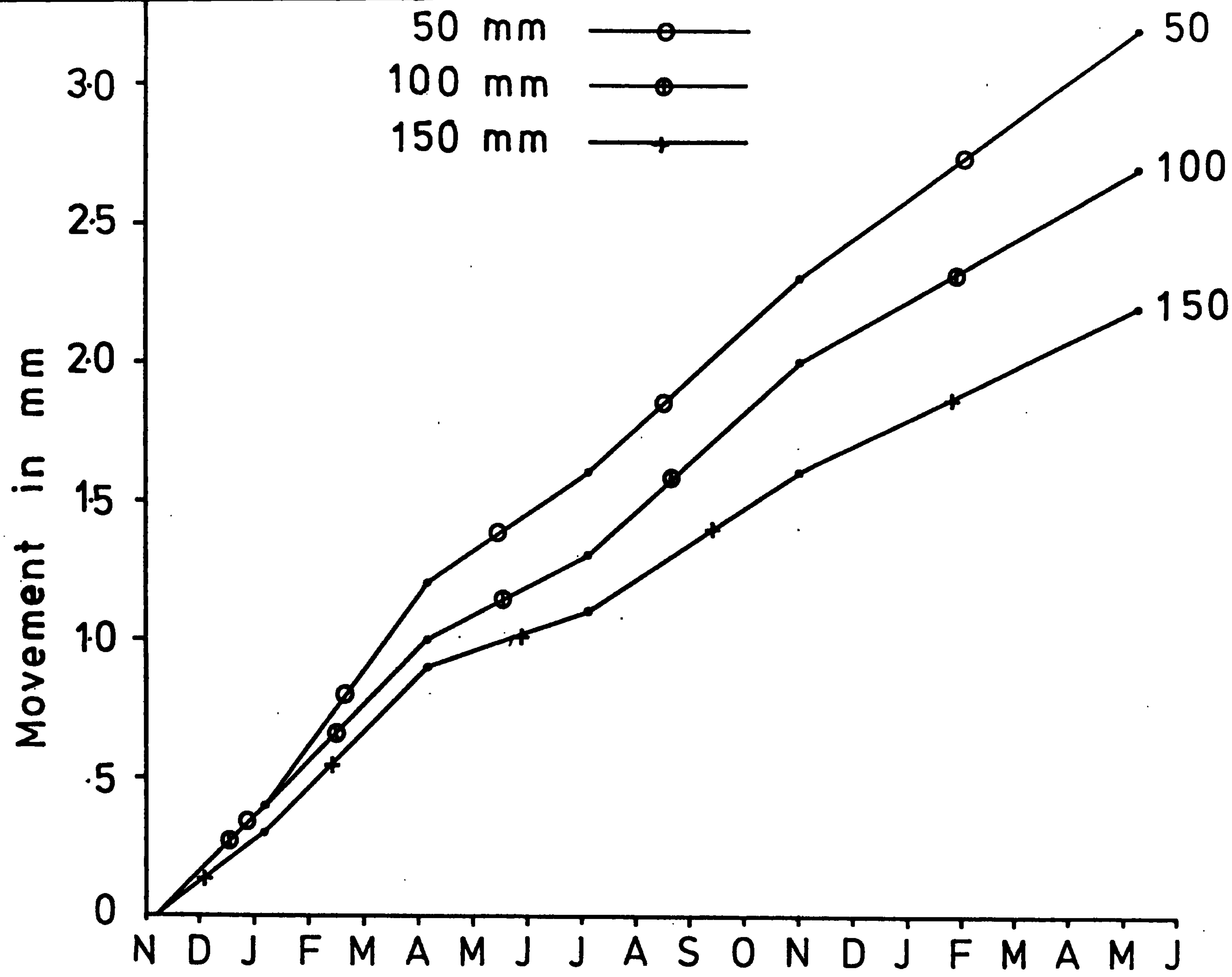


Fig. 6.5 : **Creep rate** measurements for sampling station No.2.

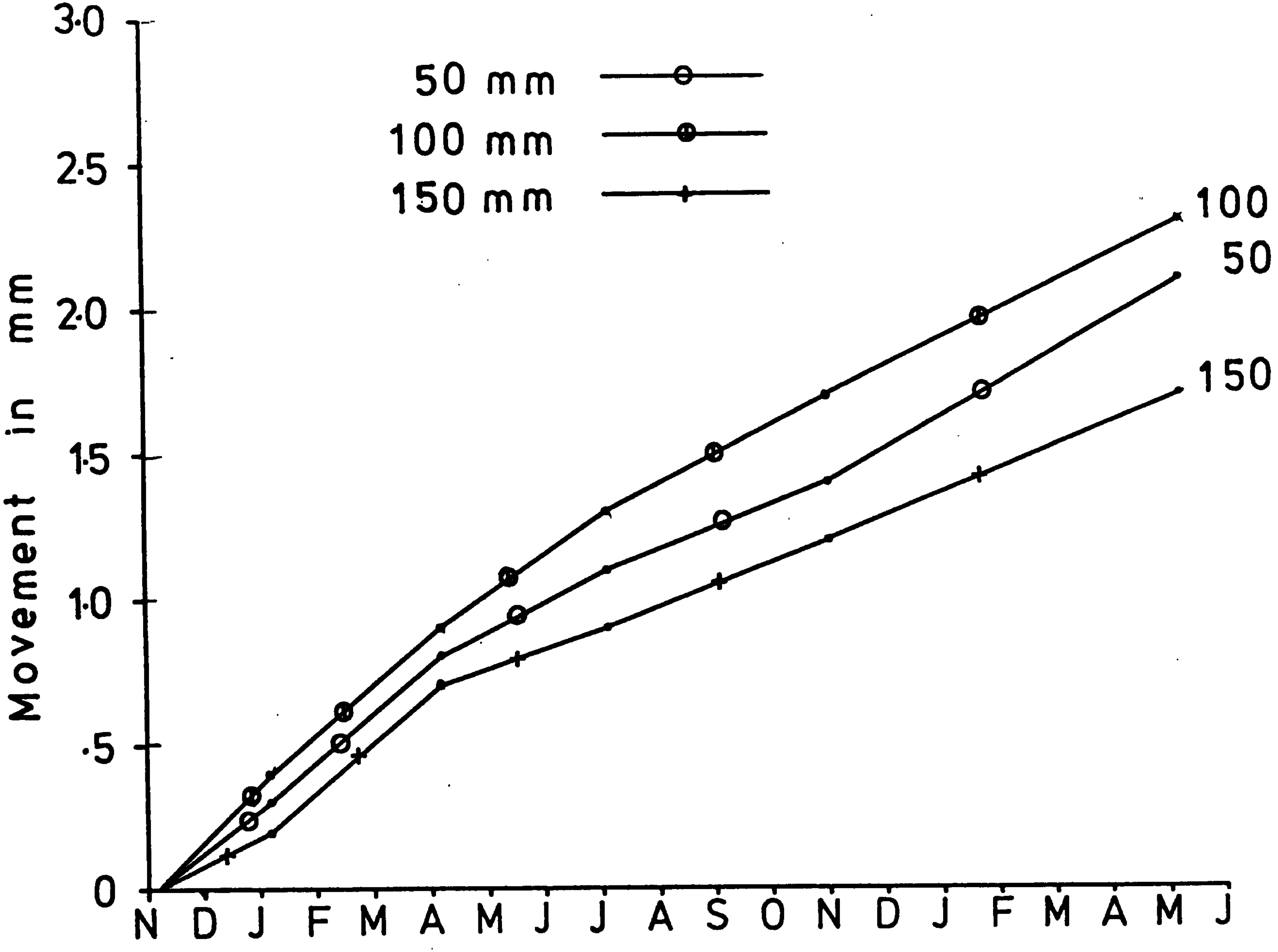


Fig. 6.6 : **Creep rate** measurements for sampling station No.3.

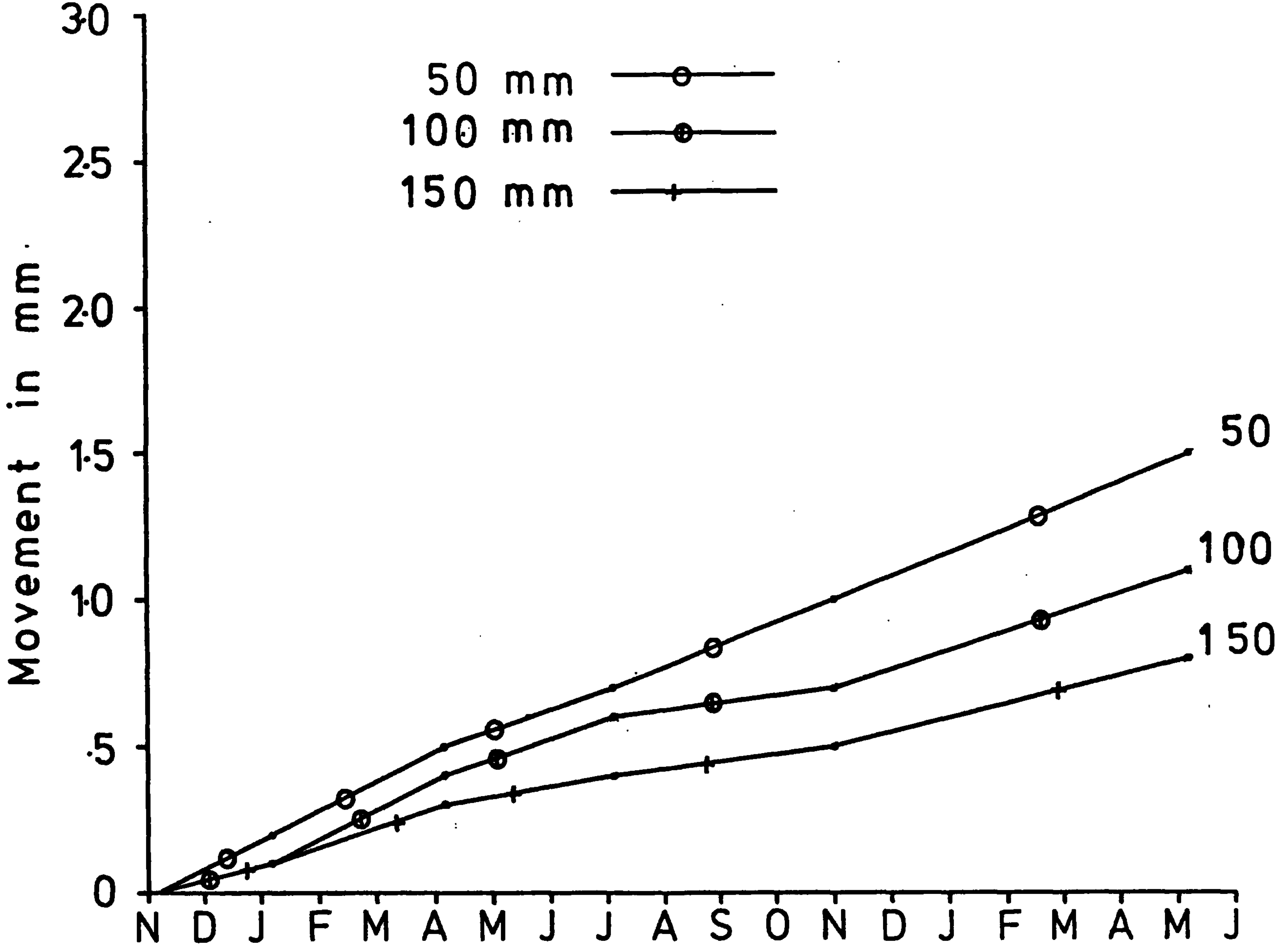


Fig. 6.7 : Creep rate measurements for sampling station No.4.

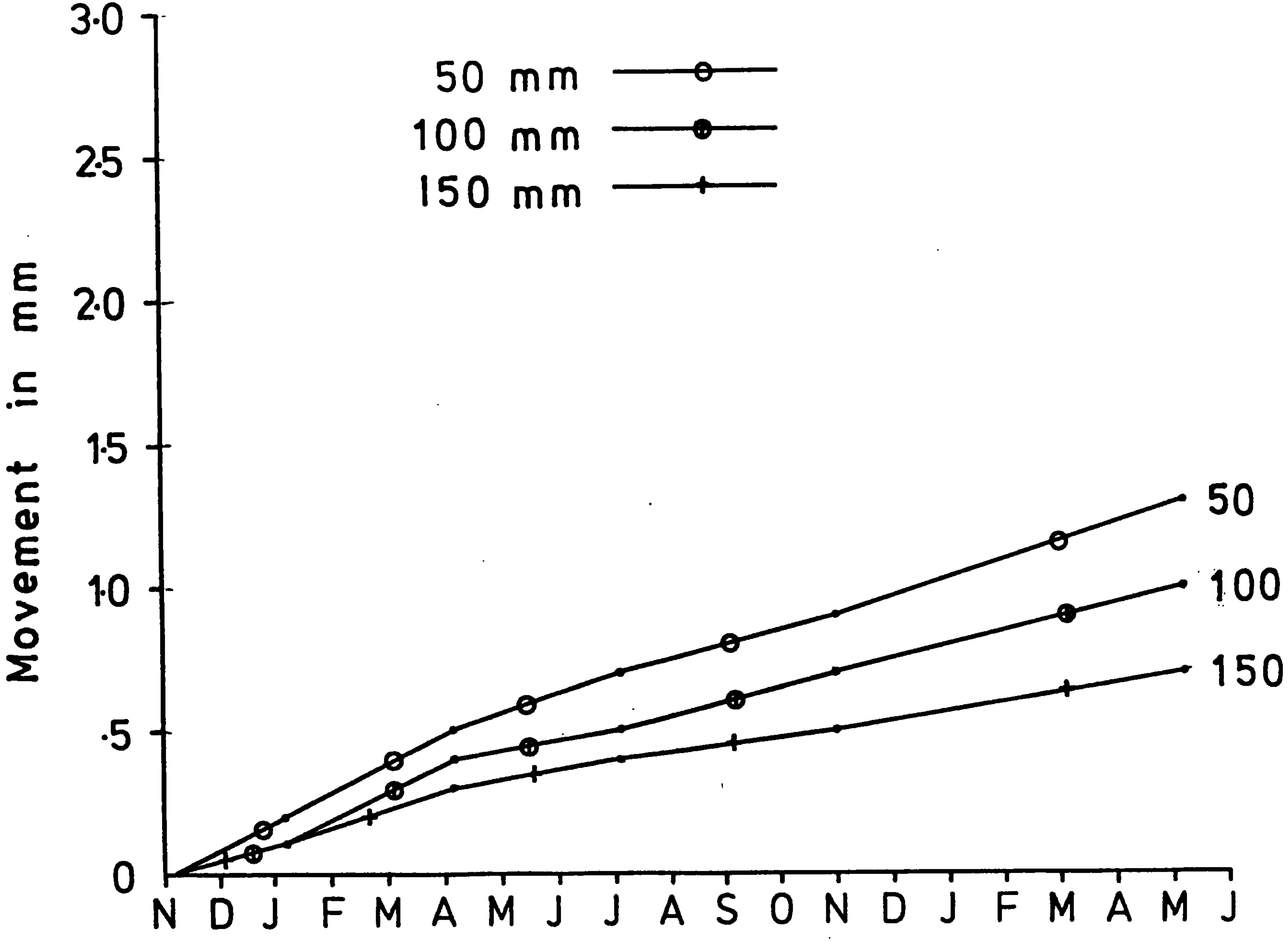


Fig. 6.8 : **Creep rate** measurements for sampling station No.5.

6.5 Young's pit

The Young's pit is a long term technique and it cannot be read over short time periods. As described in Chapter two, it is possible to use circular sampling plots, and to take more than one reading during the period of study. But, because of the short period available for collecting data (18 months), it was felt that one reading from each site would be reasonable. All samples were re-excavated with great care at one visit (5th May 1982), for measurements to be made. It should be noted that measuring the new position of the wires from a suspended plumb line was not easy or accurate; therefore a part of the sectional aluminium gauge (Rashidian's technique) was fitted tangential to the plumb line and used as a stationary point. Measurements of the new position of wires was taken with reference to the gauge. The results of measurements for all samples are listed in Table 6.4 and portrayed in Figure 6.9.

6.6 Results for all instruments

When measuring the creep rate, difficulties occur because the four different methods used (in each control station) produced different results. Since the true rate of soil creep is unknown, there is the problem of not knowing which method has recorded the most accurate result. Data analysis must concentrate on the consistency of the results obtained, to see if any particular method of measurement seems to be more or less consistent. One statistical method of trying to work on this problem is by using the standard deviation which will show how far results are removed from or close to the mean. To facilitate comparison between the

Table 6.4 Young's pit readings in study area

Sample No / Depth mm	1	2	3	4	5	mean	sd
	Movement mm	Movement mm	Movement mm	Movement mm	Movement mm	mm	mm
25	3.1	2.6	2.1	1.6	1.4	2.16	0.62
50	3.0	2.7	2.4	2.3	1.6	2.4	0.46
75	3.0	3.1	2.8	2.0	1.8	2.54	0.53
100	3.1	3.5	2.8	1.6	1.7	2.54	0.76
125	3.1	3.7	2.6	1.5	1.1	2.4	0.97
150	2.3	2.8	2.2	0.4	0.9	1.72	0.91
175	1.6	2.3	1.5	0.2	0.5	1.22	0.76
200	0.7	1.5	0.9	–	0.3	0.85	0.43
225	0.4	1.0	0.7	–	–	0.7	0.24
Mean	2.25	2.57	2.0	1.37	1.16	1.87	0.53
Median	3.0	2.7	2.2	1.6	1.1		
Sd	1.02	0.82	0.74	0.72	0.52		
Mean Ann.rate of movement mm	1.5	1.71	1.33	0.91	0.77		0.39

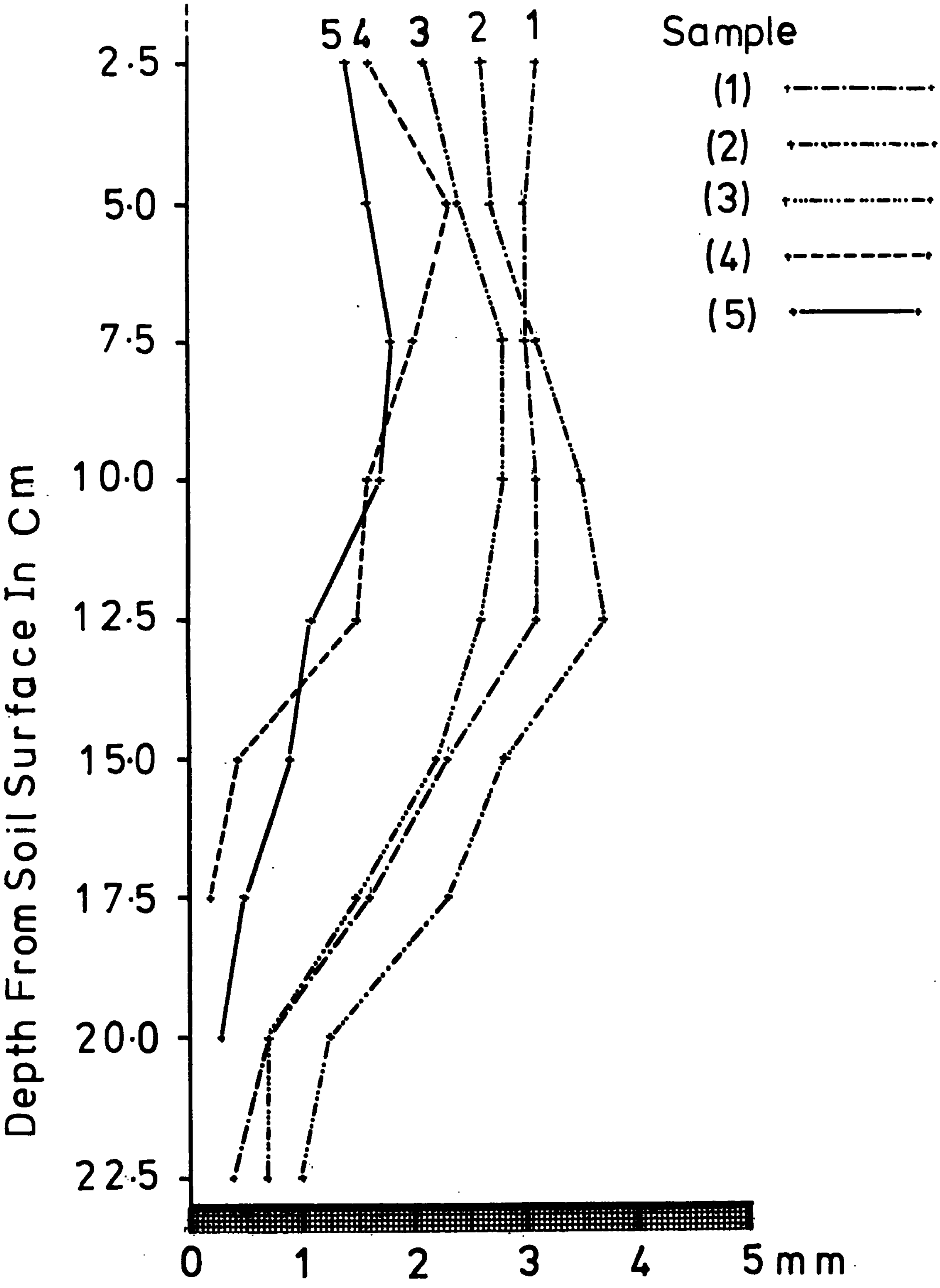


Fig. 6.9 : A comparison of the rate of movement in sampling sites, (Young's pit).

annual creep rates obtained by each instrument, they are listed together for all instruments in Table 6.5 (see also Fig. 6.10). It should be noted that the Anderson's tubes value only represents the linear movement of the tube used in each control station.

Table 6.5 Summary of annual linear movement (mm) obtained by all instruments in sampling stations

Sample Site No	Rashidian's Technique	Young's pit	Anderson's tube	Wooden pillars	Mean	Sd
1	1.39	1.5	1.66	1.5	1.51	0.09
2	1.52	1.71	1.86	1.77	1.71	0.12
3	1.33	1.33	1.55	1.35	1.39	0.09
4	0.69	0.91	0.86	0.75	0.80	0.08
5	0.58	0.77	0.66	0.66	0.66	0.06
Mean	1.10	1.24	1.31	1.20	1.21	
Sd	0.43	0.39	0.52	0.48		

It can be seen that all techniques give slightly greater movement at site 2. The Rashidian technique results are very close to those obtained from the Young's pit and wooden pillars at sample site 1, 3 and to those from Anderson's tubes and Wooden pillars also at sample sites 4 and 5. The results of Young's pit, Wooden pillars and Rashidian technique are very close to the mean for sample sites 1, 2 and 3. But in the case of sample sites 4 and 5, Anderson's tubes results are very close to the mean. This suggests that depending on the soil conditions one of the instruments is more accurate

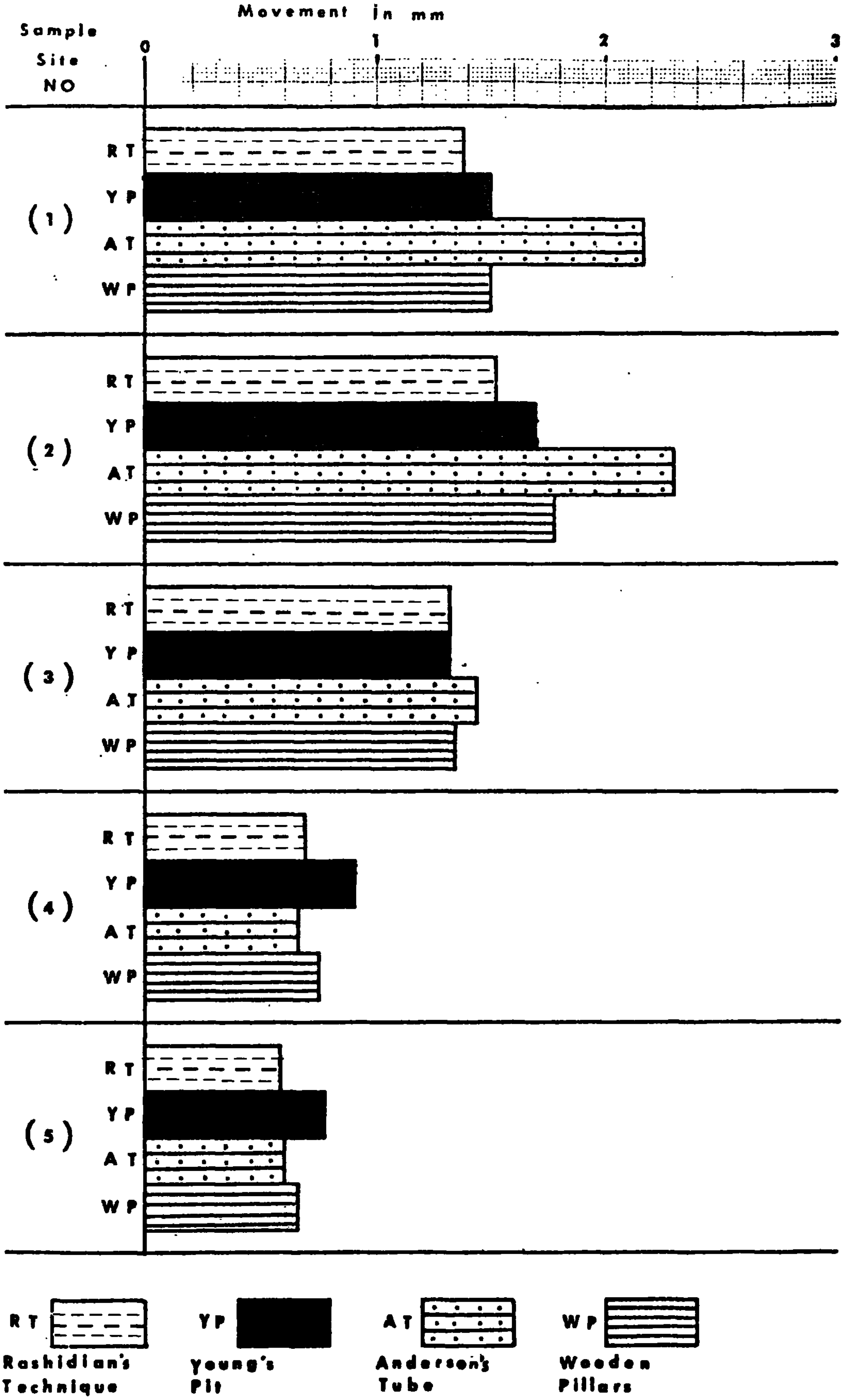


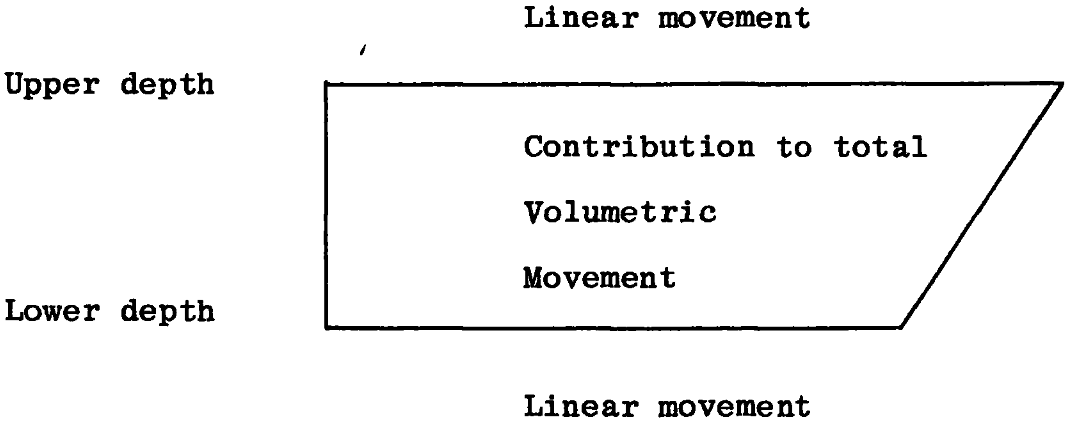
Fig. 6.10 Annual Linear creep rates in sampling stations (four instruments).

and useful than the others, bearing in mind that the soil characters at each site can vary. Also, the type of vegetation covering each sampling site is not the same. Standard deviation within the plots in each sample and between the samples indicates a comparatively high spread of results about the mean. Examination of results shows that differences between the plot means at each sample and between samples are also substantial.

6.7 Volumetric rates of creep

6.7.1 Introduction

The unit for measuring volumetric downslope movement of soil is the volume moved annually across a plane perpendicular to the ground surface and parallel to the contour of the slope, per unit horizontal distance along the plane; it is expressed in cm^2a^{-1} (Young, 1972). This can be calculated as the sum of areas of trapezia, in which the parallels represent linear movements at two adjacent depths, separated by the difference in depths, as in this scheme:



Or, to put it another way,

$$\text{Volumetric rate} = \left(\begin{array}{c}\text{total thickness of}\\ \text{moving soil}\end{array}\right) \times \left(\begin{array}{c}\text{depth-averaged}\\ \text{linear rate}\end{array}\right)$$

6.7.2 The Rashidian technique

Using this technique produced a profile of movement with depth, caused by soil movement over each plot. The volumetric rate of creep was calculated for each site (Table 6.6). Note that there is no record for the first 30 mm depth from the soil surface, because of uncertainty about plot disturbances by rain wash or other agents. The method used to overcome this difficulty was to assume that the rate for 0-30 mm equalled that observed for 30-60 mm. This is, of course, a crude approximation, but it seems the simplest assumption to make. The maximum depth measured for this study was 270 mm from the surface (samples 1, 2 and 3). According to the Anderson's tubes results, maximum depth at which soil moves for sample sites 1, 2, and 3 is respectively 300, 300 and 310 mm. In the case of samples 4 and 5, the maximum depth of soil moving has been calculated.

Table 6.6 Annual volumetric movement in study area cm^2a^{-1} (Rashidian's technique)

Sample No. Soil depth mm	1	2	3	4	5
0.0 - 30	0.5	0.56	0.48	0.27	0.22
30 - 60	0.5	0.56	0.48	0.27	0.22
60 - 90	0.58	0.61	0.61	0.33	0.25
90 - 120	0.66	0.69	0.68	0.28	0.20
120 - 150	0.56	0.61	0.61	0.14	0.14
150 - 180	0.40	0.47	0.44	0.06	0.13
180 - 210	0.30	0.36	0.27	0.0	0.10
210 - 240	0.22	0.24	0.16	0.0	0.0
240 - 270	0.16	0.16	0.06	0.0	0.0
Total movement cm^2a^{-1}	3.88	4.26	3.79	1.35	1.26

6.7.3 Young's pit

According to the data obtained from Young's pit measurements, the movement of wires from the reference varies. The maximum depth measured for this study was 225 mm from the surface. There is no record for the first 25 mm depth from the soil surface. As with the Rashidian technique, it is assumed that the rate of movement for this layer equalled that for the layer below. The results of calculations of volumetric rates of creep for this method are given in Table 6.7.

Table 6.7 Annual volumetric rate of creep in study area cm^2a^{-1} (Young's pit)

Sample No. / Depth mm	1	2	3	4	5
0.0 - 25	0.76	0.66	0.56	0.48	0.37
25 - 50	0.76	0.66	0.56	0.48	0.37
50 - 75	0.75	0.72	0.65	0.53	0.42
75 - 100	0.75	0.82	0.70	0.45	0.43
100 - 125	0.77	0.80	0.67	0.38	0.35
125 - 150	0.67	0.81	0.60	0.23	0.25
150 - 175	0.48	0.63	0.46	0.07	0.17
175 - 200	0.28	0.47	0.30	0.02	0.1
200 - 225	0.13	0.31	0.20	0.0	0.03
Total movement cm^2a^{-1}	5.35	5.98	4.7	2.64	2.49

6.7.4 The Anderson's Tubes

The significant advantage of using Anderson's tube is that its pivot point can be identified, indicating the maximum depth of soil movement. Using the maximum depth of movement for each plot in control stations in relation to its annual linear creep rate, a volumetric measurement was calculated (Table 6.8). For example, site 1 calculation is (1.66 mm x 300 mm)/(2 x 100) = 2.49 cm^2a^{-1}. Full results of volumetric creep rates for 35 Anderson's tubes plots are tabulated in Table 6.8a.

Table 6.8 Volumetric creep rate (Anderson's tubes)

Sample site No.	1	2	3	4	5
Maximum annual linear movement mm.	1.66	1.86	1.55	0.8	0.66
Maximum depth of movement mm.	300	300	310	280	250
Annual volumetric movement cm^2a^{-1}	2.49	2.80	2.43	1.16	0.85

6.7.5 Wooden pillars

It was assumed that the pillars move bodily because they kept their vertical position during the study period. Therefore volumetric rate of movement for these plots was calculated by the amount of pillar movements x length of pillars. This value calculated for 50 mm, 100 mm and 150 mm at all sampling sites (Table 6.9). The main advantage of this method was to provide the rate of creep in the upper

Table 6.8a Volumetric creep rates $cm^2 a^{-1}$ for 35 Anderson's tubes at 5 sampling sites in study area

Plot No. / Site No.	1	2	3	4	5	6	7	8	9	10	11
1	2.49	2.62	-	-	4.82	3.42	2.70	-	2.87	4.64	-
2	2.80	0.90	4.20	-	-	-	0.85	-	-	2.7	0.86
3	2.43	-	2.35	-	-	2.24	1.57	-	-	-	-
4	1.16	1.31	1.06	0.80	0.87	-	1.19	1.21	2.48	4.34	-
5	0.85	-	0.91	0.93	2.82	2.62	2.85	3.56	2.96	2.77	-

50 mm of soil. Furthermore, if we take the result of the 50 mm plot as base, by subtracting that from the 100 mm plot, volumetric creep rates for the layer between 50 and 100 mm can be determined. With this procedure this volume can also be determined for subsequent depths (between 100 and 150 mm). The results of these calculations are listed in Table 6.10

6.8 Volumetric rate comparison

In the comparison of volumetric movements at different sampling sites, problems arise if the maximum depth of movement indicated by Anderson's tube is assumed for all instruments, because each method reflects variation in movement with depth in a different way (see Tables 6.1, 6.3, 6.4 and Figures 6.1, 6.3, 6.4). So for ease of comparison it was decided to calculate both the annual volumetric rate of creep measured by each instrument for different depths (Table 6.11) and the annual volumetric rate of creep for a known depth of soil for which data are available for all instruments (the upper 15 cm of the soil - Table 6.12, and Figure 6.11). However, since the readings were obtained from different locations, differences of results would be expected (Table 6.11). Furthermore, the instruments' accuracy also differed.

These volumetric measurements can be divided into two groups according to the site characters in sample sites 1, 2, 3 and sample sites 4 and 5. The rates of movement are greater for the first group, i.e. samples 1,2 and 3 and less for the second group i.e. samples 4 and 5 (Table 6.11 and Figure 6.11). Anderson's tube was the only instrument in which calculation

Table 6.9 Annual volumetric movements, cm^2a^{-1} in study area (Wooden pillars)

Sample site No.	Depth of plot mm	Volumetric movement cm^2a^{-1}	Depth of plot mm	Volumetric movement cm^2a^{-1}	Depth of plot mm	Volumetric movement cm^2a^{-1}
1	50	0.86	100	1.53	150	1.89
2	50	1.06	100	1.73	150	2.19
3	50	0.7	100	1.53	150	1.69
4	50	0.5	100	0.73	150	0.79
5	50	0.43	100	0.66	150	0.69

Table 6.10 Volumetric rate of creep of certain depth (Wooden pillars)

Sample site No.	Certain Depth mm	Volumetric movement cm^2a^{-1}	Certain Depth mm	Volumetric movement cm^2a^{-1}	Certain Depth mm	Volumetric movement cm^2a^{-1}	Annual volumetric movement cm^2a^{-1}
1	0.0-50	0.86	50-100	0.67	100-150	0.36	1.89
2	0.0-50	1.06	50-100	0.67	100-150	0.46	2.19
3	0.0-50	0.7	50-100	0.83	100-150	0.16	1.69
4	0.0-50	0.5	50-100	0.23	100-150	0.06	0.79
5	0.0-50	0.43	50-100	0.23	100-150	0.03	0.69

for volumetric rate of creep has been made on the base of the pivot point (i.e. 250-310 mm), whereas volumetric rates of creep were made on the base of maximum depth of plots used for other instruments (i.e. Rashidian's technique 180-270 mm, Young's pit 175-225 mm, and wooden pillars 150 mm). Note that the rate of movement declines with depth. On the other hand maximum depths of movement were not highly correlated with creep rate.

Table 6.11 A comparison of annual volumetric movements measured by each instrument for different depths in study area cm^2a^{-1}

Sample site No. / Instrument	1	2	3	4	5	mean
Rashidian's technique	3.88	4.26	3.79	1.35	1.26	2.90
Young's pit	5.35	5.98	4.70	2.64	2.49	4.23
Anderson's tube	2.49	2.80	2.43	1.16	0.85	1.94
Wooden pillars	1.89	2.19	1.69	0.79	0.69	1.45
Mean	3.40	3.80	3.15	1.48	1.32	2.63

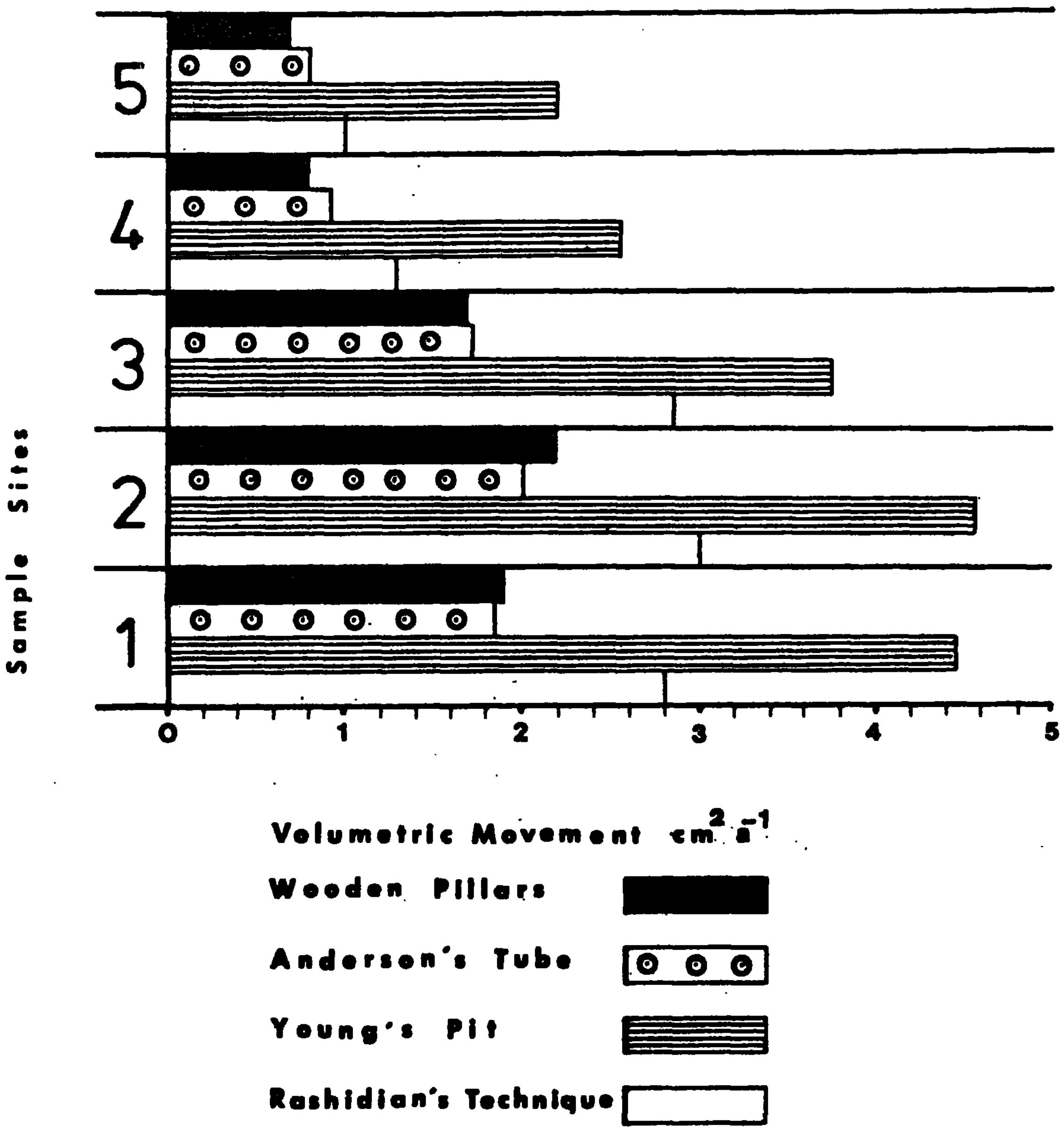


Fig. 6.11 : A comparison of annual volumetric movements for upper 15 cm of soil in study area (all instruments).

Table 6.12 A comparison of annual volumetric movements for upper 15 cm of soil $cm^2 a^{-1}$ in study area (all instruments)

Sample site No / Instrument	1	2	3	4	5	mean
Rashidian's technique	2.8	3.02	2.86	1.29	1.03	2.20
Young's pit	4.46	4.57	3.74	2.55	2.19	3.50
Anderson's tube	1.86	2.09	1.72	0.92	0.79	1.47
Wooden pillars	1.89	2.19	1.69	0.79	0.69	1.45
Mean	2.75	2.97	2.50	1.38	1.17	2.15

6.9 Comparison with other results

There is a concurrence of results that in humid temperate climates, surface movement is of the order of 1-3 mm a^{-1} and volumetric movement of 0.1-10.0 $cm^2 a^{-1}$; the calculation of both linear and volumetric annual rates of creep obtained from this study allows comparison with the results of other workers. This is difficult because of the environmental differences, the inconsistency with which results are often reported and the variety of measurement techniques that have been used. This comparison has been made in this study with due attention to the following principles:

a. Among the results given by several workers Owens (1969), Slaymaker (1972),Leopold and Emmett (1972), Everett (1963), Kojan (1967,Schumm(1964),Williams(1973),Day(1977),Sala (1981), Young (1960,1963a), Kirkby (1964,1967),Evans (1974), Finlayson (1979) and Anderson (1977) only those obtained under broadly similar geomorphological conditions are comparable. Therefore, the results recorded by Young in Alport Dale, a valley in the Southern Pennines, Derbyshire, at 350 m altitude, Evans in the Upper Derwent valley, Derbyshire, at 305 m altitude, Kirkby in the Water of Deugh drainage basin, southwest Scotland, at 450 m altitude, and Anderson in the Rookhope basin, Upper Weardale, at 427 m altitude, are of concern.

b. For ease in comparison it was decided to take just records produced for annual linear rate for the upper 50 mm of soil.

c. The mean value of all sampling stations produced by the Rashidian technique has been adopted for this comparison (Table 6.13).

Table 6.13 Comparison of annual creep rates obtained by Rashidian's technique and others

Source	Method	Location	Climate	Rock	Altitude m	Creep rate mm
Young (1960, 1963a)	Surface and buried pegs	Alport Dale	Temperate maritime	Palaeozoic sedimentaries	350	1-2
Evans (1974)	Surface pegs	Derwent Valley	Temperate maritime	Palaeozoic sedimentaries	305 - 457	0.6
Kirkby (1963, 1967)	Surface and buried pegs	Water of Deugh basin	Temperate maritime	Palaeozoic shales	310 - 480	1.2
Anderson (1977)	Tubes and surface pegs	Rookhope basin	Temperate maritime	Palaeozoic sedimentaries	367 - 485	1.2
Rashidian (1983)	Buried wooden blocks	Killhope basin	Temperate maritime	Palaeozoic sedimentaries	442 - 620	1.37

Further information and data given by other workers (including those given in Table 6.13) are shown in Table 6.14 and Figure 6.12. It can be seen that the rate of movement as measured by the Rashidian technique are close to the average and to those measured by Young (1963), Kirkby (1972), and Anderson (1975). Differences are expected since measurements were for different locations and times. The higher creep rates probably occur as a result of freeze-thaw action and might more properly be regarded as periglacial and solifluction movements (Skempton & Hutchinson, 1969).

Table 6.14 Comparison of annual creep rates obtained by the Rashidian technique and others

Source	Method	Location	Climate	Rock	Altitude m	Creep rate mma^{-1}
1 Rashidian (1984)	Rashidian's technique	Killhope basin N.E.England	Temperate maritime	Carboniferous sedimentaries	442-620	1.37
2 Anderson E.W(1977)	six methods	Weardale N.E.England	Temperate maritime	Carboniferous sedimentaries	367-485	1.3
3 Young, A. (1960-1963)	pegs	Alport Dale S. Pennines	Temperate maritime	Paleozoic sedimentaries	350	1-2
4 Kirkby (1963,1967)	pegs	S.W.Scotland	Temperate maritime	Palaeozoic shales	310-480	1.2
5 Slaymaker (1972)	Young's pit	Wales	Temperate maritime			2.7
6 Day, M.J. (1977)	Young's	Aberystwyth Wales	Temperate maritime	Silurian		0.3-6
7 Evans,R. (1974)	pegs	Derwent Valley	Temperate maritime	Palaeozoic sedimentaries	305-457	0.6
8 Leopold & Emmett (1972)	Young's pit	Maryland U.S.A.	Temperate maritime			0.5
9 Sala, M (1981)	Young's pit	Catalan Ranges Spain	Mediterranean	Granite		1.7
10 Williams, M.A.J. (1973)	Young's pit	N.S.W. Australia	Sub-tropical	Granite sandstone		1.9

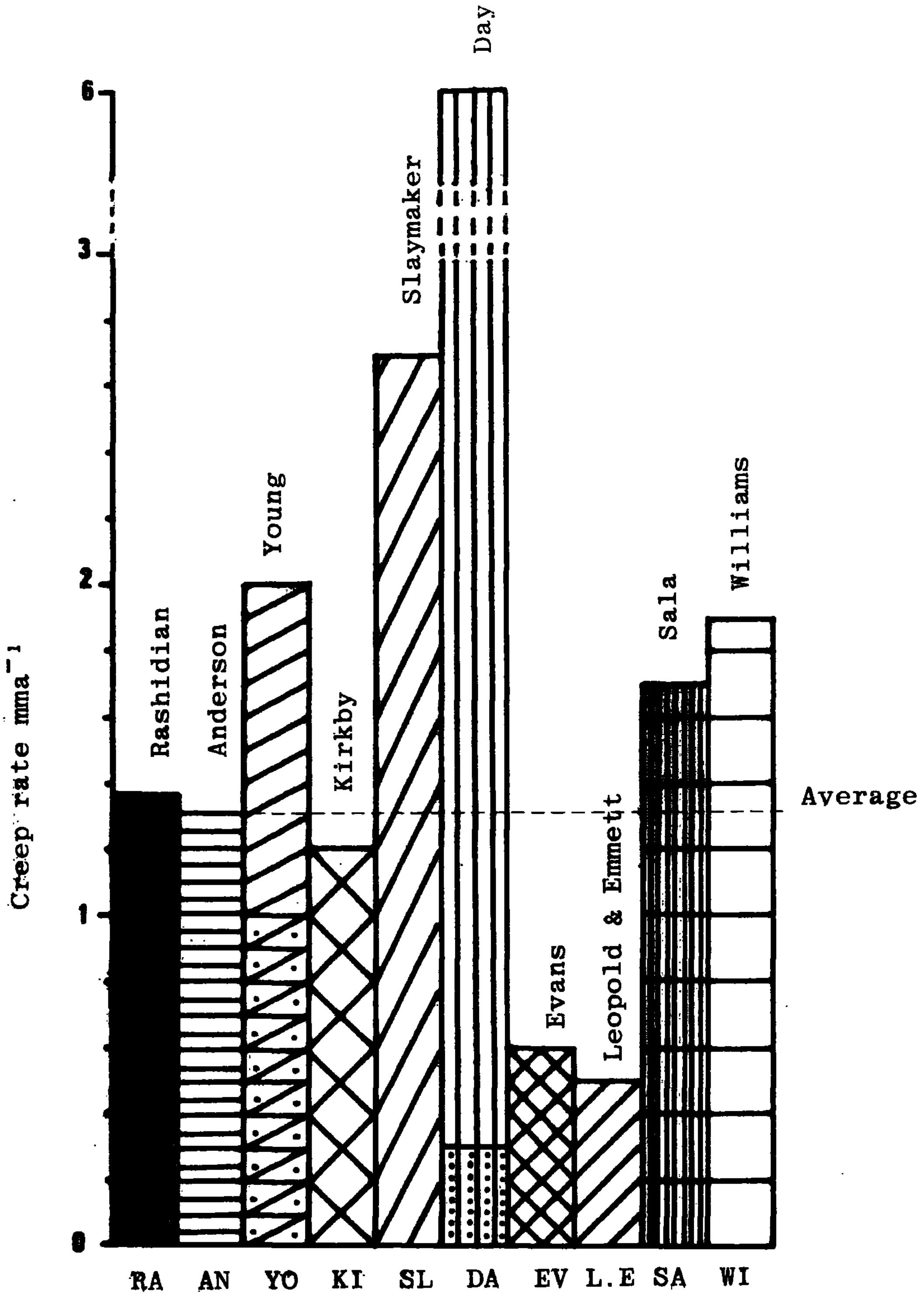


Fig.6.12 : Bar chart showing annual creep rates obtained by workers

CHAPTER SEVEN

DATA ANALYSIS : CONTROLS OF LINEAR CREEP RATES

CHAPTER 7

DATA ANALYSIS : CONTROLS OF LINEAR CREEP RATES

7.1 Introduction

Soil creep occurs when the forces operating to move soil on a slope exceed the resistance of the soil to movement. Since both tractive force and resistance vary not only in space (between sampling plots), but also in time, time should be regarded as an important factor involved in the soil creep process (Chapter 6). The remaining objective is the identification of the relationships between the basin controls and the creep process. However, the main intent of this study was to establish the correlations between creep rate and controlling variables and a comparison between the results from all instruments for each sampling station.

The two measures of creep rate, linear creep rate and volumetric creep rate, for the study area are strongly related to each other as would be expected ($r = 0.99$). Such a very high correlation implies that both values, as response variables, are basically parallel. Linear rate ranges from 0.62 to 2.73 mm a^{-1} with a mean of 1.49 mm a^{-1} and standard deviation of 0.65. Volumetric creep rate ranges from 0.80 to 4.82 cm^2a^{-1} with a mean of 2.26 cm^2a^{-1} and standard deviation of 1.19.

Measurements were made of all the major variables considered crucial in controlling soil creep with the exception of those related to large scale climatic differences. Clearly the extent of the field area precludes such climatic considerations. It is realised that other workers may produce a slightly different list of key variables but a limitation on numbers must be set. Variables measured in the field and laboratory were : sine of slope angle, altitude, depth of soil, soil moisture content (dry and wet seasons), soil texture (clay %, sand %), liquid limit, plastic limit, plasticity index, shear strength, bulk density, dry bulk density, specific gravity, porosity and void ratio. An attempt has been made to maintain a standard procedure for the measurement of variables at each sampling plot, and between all tests at the five sampling sites in the study area. For example, all soil samples were taken on the same date, all laboratory testing was performed on one soil sample for each plot, and the same method was applied for each particular test. It is only through sampling on one specific date that results for variables which constantly change (e.g. soil moisture) can be compared.

For ease of understanding soil creep behaviour, it was decided to produce:

a. Comparison of results from different instruments used on each sampling station.

b. Correlations with controlling variables.

c. Correlations with meteorological data of the region.

d. Interrelationships between controlling variables and Anderson's tube rates.

e. Discussion of variables controlling soil creep rates.

Finally, as a check, certain measurements were made at the end of a further ten months (October 1982 - March 1983) for Rashidian's technique. These measurements were not included in the detailed analysis, for these reasons:

(i) They were incomplete : only 3 sites were totally intact and this would not have allowed complete comparison.

(ii) They relate to just ten months and comparable seasonal rates cannot be calculated.

7.2 Comparisons between instruments

7.2.1 Correlations between annual rates from four different instruments

Annual creep rates measured by all instruments (i.e. Rashidian's technique, Young's pit, Anderson's tube and wooden pillars) are compared with each other. This illustrates aspects of the variability which depend upon field measurement.

The correlation matrix revealed that the results from all the instruments are strongly correlated with each other. (Table 7.1). Although the number of observations of average annual creep rates is small, the correlations are definitely significant and the consistency between instruments is reassuringly high.

Table 7.1 Correlation coefficients between all four instruments in five sampling stations

(n = 5. Significance level : 95% = 0.88; 99% = 0.96)

	Variables	R.T	Y.P	A.T	W.P
R.T.	Rashidian's technique	1.00			
Y.P	Young's pit	0.98	1.00		
A.T	Anderson's tube	0.99	0.99	1.00	
W.P	Wooden pillars	0.98	0.99	0.99	1.00

7.2.2 Correlations between seasonal rates from Rashidian's technique and annual rates from this and three other instruments at five sampling stations

The measurements for three seasons (i.e. from November 1980 to May 1982) by the Rashidian technique are compared with the annual rate measured by the same technique and three other instruments, all used at five sampling stations. The correlation coefficients represent strong relationships; for Rashidian's technique r = 0.87, Young's pit r = 0.84, Anderson's tube r = 0.86, and wooden pillars r = 0.85. (scattergram Figures 7.1a, b and 7.2 a,b) for n = 15, significance levels are 0.51 (95% confidence) and 0.64 (99%).

It was revealed that:

i. Such strong correlations between seasonal creep rates obtained by the four instruments indicate that the instruments are measuring the same phenomenon.

ii. Maximum creep rates recorded by Rashidian's technique for winter 1981 coincide with those recorded by the other instruments for winter 1981.

iii. Higher creep rate values were recorded by all instruments observed at sampling station No.2, 1 and 3 and lower values for sampling station No. 4 and 5.

iv. Lack of data for middle values of creep rates is explained by the limited number of sampling sites and therefore range of soil material.

v. An interesting point is the great absolute range of creep rate values between summer and winter 1981 for sampling stations Nos. 1, 2, 3 compared with 4 and 5.

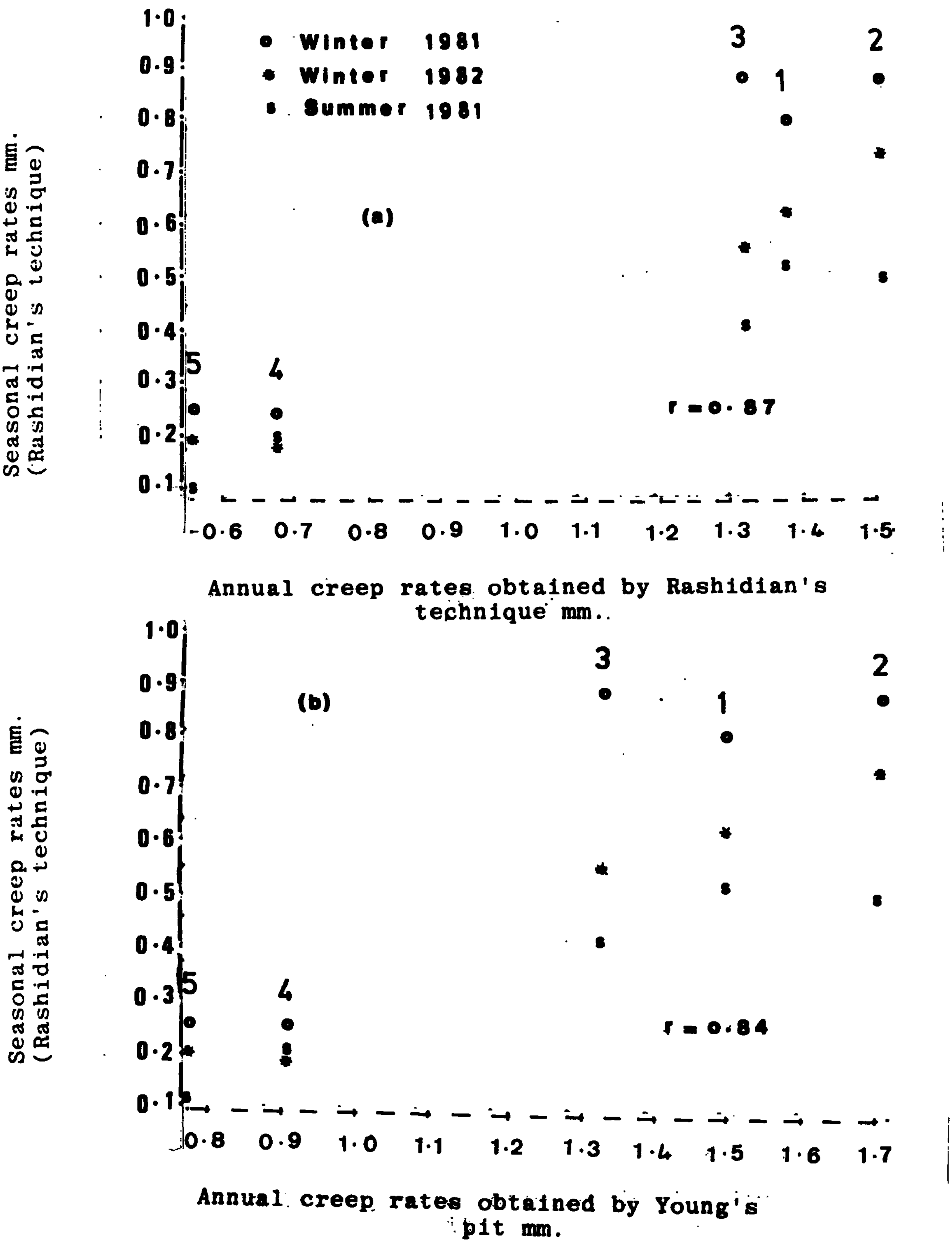


Fig. 7.1 : Scattergram showing correlations between creep rates obtained by Rashidian's technique for three seasons and annual creep rates obtained by a. Rashidian's technique, b. Young's pit.

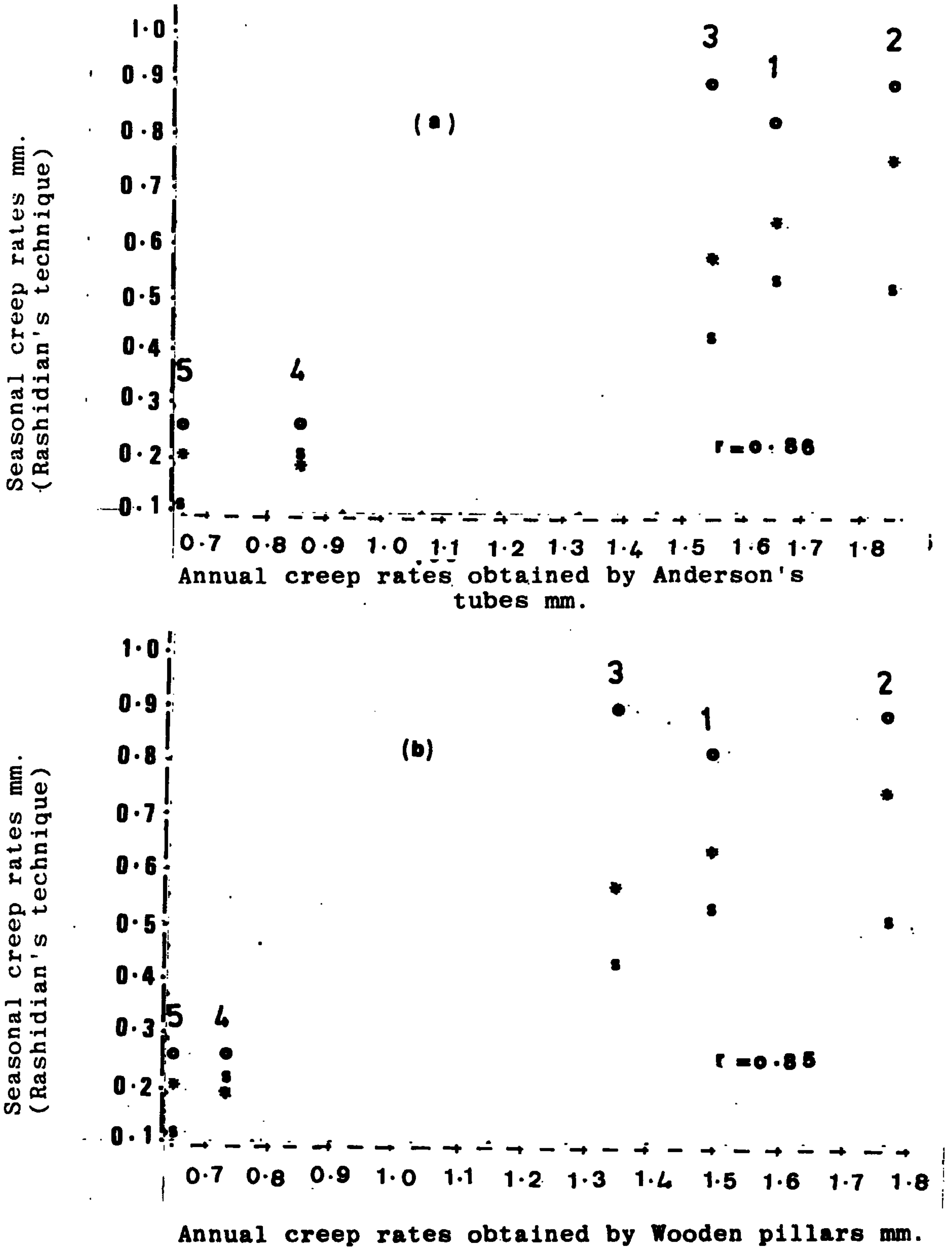


Fig. 7.2 : Scattergram showing correlations between creep rates obtained by Rashidian's technique for three seasons and annual creep rates obtained by a. Anderson's tube, b. Wooden pillars.

vi. It must be borne in mind that the soil depth susceptible to movement at sampling stations Nos.1,2, and 3 was greater than that at sampling stations 4 and 5. Also vegetation cover at sampling stations 1 and 2 was *Calluna vulgaris* at sampling station 3 was *Festuca ovina* and at sampling station 4 and 5, *Poa pratensis* was dominant.

7.3 Correlations with controlling variables

7.3.1 Correlations between annual creep rates (from four instruments) and sixteen controlling variables

The annual creep rates measured by all four instruments at the five sampling stations are correlated with all variables in turn (n = 5). This provides a picture for annual creep rates. The correlations between annual linear creep rates obtained by Rashidian's technique, Young's pit, Anderson's tubes, Wooden pillars and the set of sixteen controlling variables are given in Table 7.2.

The strongest positive correlations are with soil depth. The negative correlations are with plasticity index, bulk density, dry density and shear strength.

These relationships are shown in Table 7.2 and Figures 7.3 to 7.18. The key symbols used at scatter plots for instruments are as follows:

Rashidian Technique	⏻
Young's pit	△
Anderson's tube	+
Wooden pillars	X

Table 7.2 Correlation coefficients between annual creep rates obtained by four instruments and sixteen variables at 5 sampling stations. (n = 5 : significance levels : 95%, 0.88; 99%, 0.96)

Variables \ Instrument	R.T.	Y.P.	A.T.	W.P.
Sine of slope angle	0.05	0.10	0.09	0.03
Soil depth cm	0.89	0.83	0.88	0.82
Moisture content% (wet season)	0.52	0.40	0.49	0.44
Moisture content% (dry season)	0.45	0.33	0.42	0.37
Organic matter% (loss in ignition)	0.65	0.59	0.63	0.62
Clay%	-0.29	-0.22	-0.28	-0.27
Sand%	0.05	-0.08	0.01	-0.23
Bulk density mg/m^3	-0.57	-0.58	-0.57	-0.61
Dry bulk density mg/m^3	-0.55	-0.54	-0.55	-0.57
Porosity%	0.38	0.28	0.36	0.31
Void ratio%	0.39	0.27	0.36	0.31
Liquid limit	0.12	0.30	0.17	0.28
Plastic limit	0.65	0.75	0.69	0.72
Plasticity index	-0.65	-0.62	-0.66	-0.60
Shear strength KN/m^2	0.25	0.21	0.22	0.21
Specific gravity	-0.45	-0.30	-0.41	-0.34

R.T.	Rashidian's Technique
Y.P.	Young's Pit
A.T.	Anderson's Tubes
W.P.	Wooden Pillars

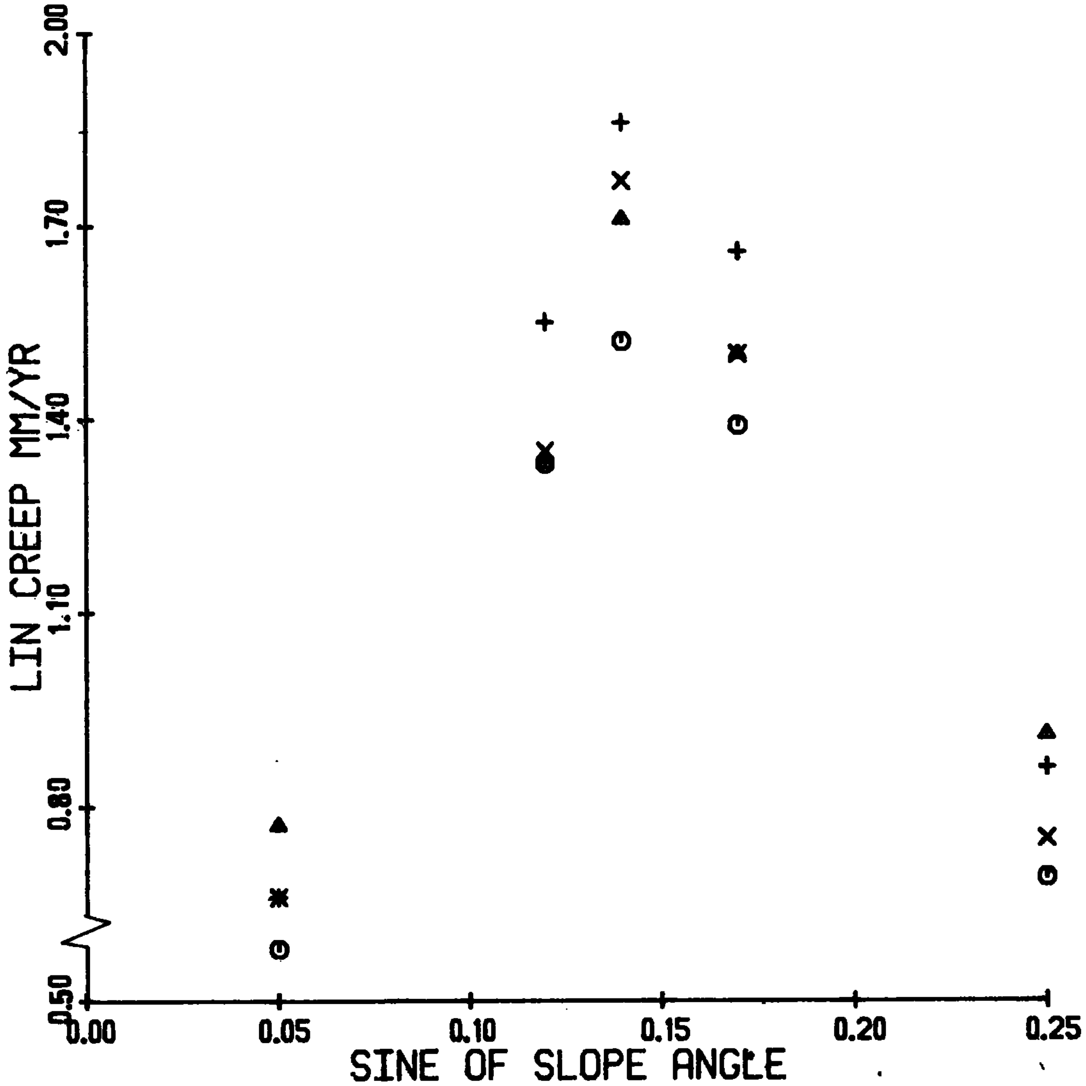
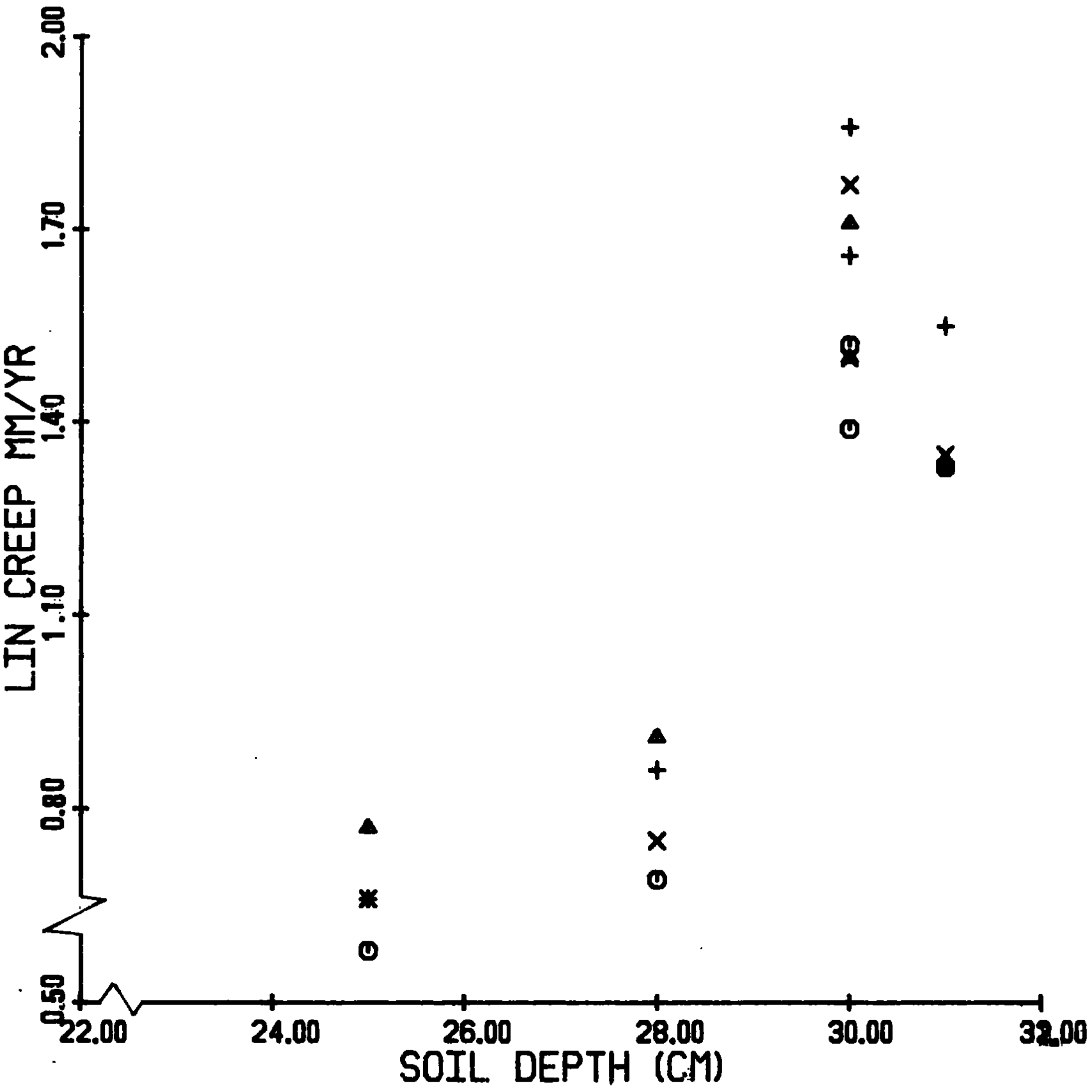


Fig. 7.3 : Scatter plot : Linear creep rate (four instruments) and sine of slope angle.



<u>Fig. 7.4</u> : Scatter plot : Linear creep rate (four instruments) and soil depth.

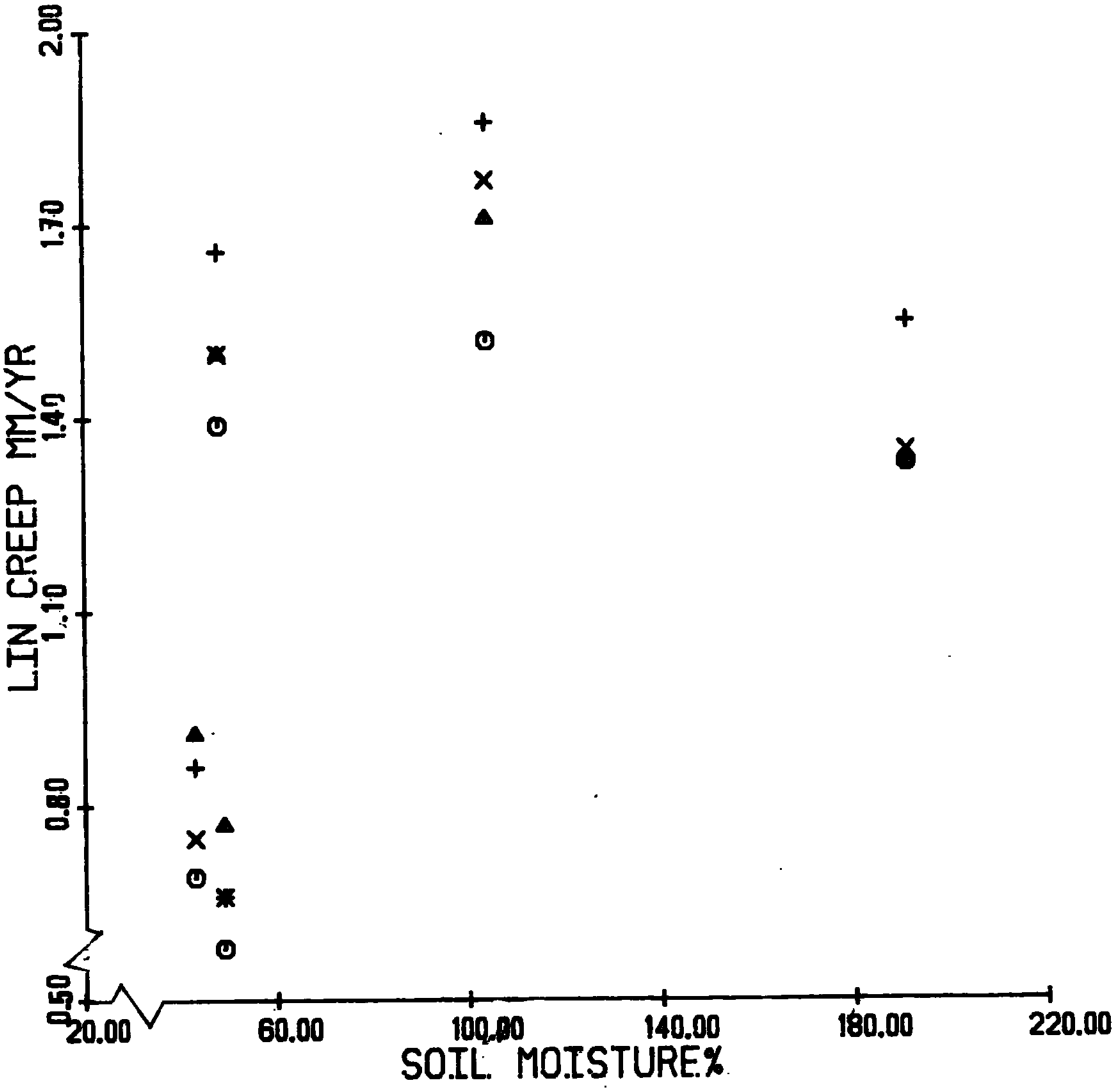


Fig. 7.5 : Scatter plot : Linear creep rate (four instruments) and soil moisture (wet season).

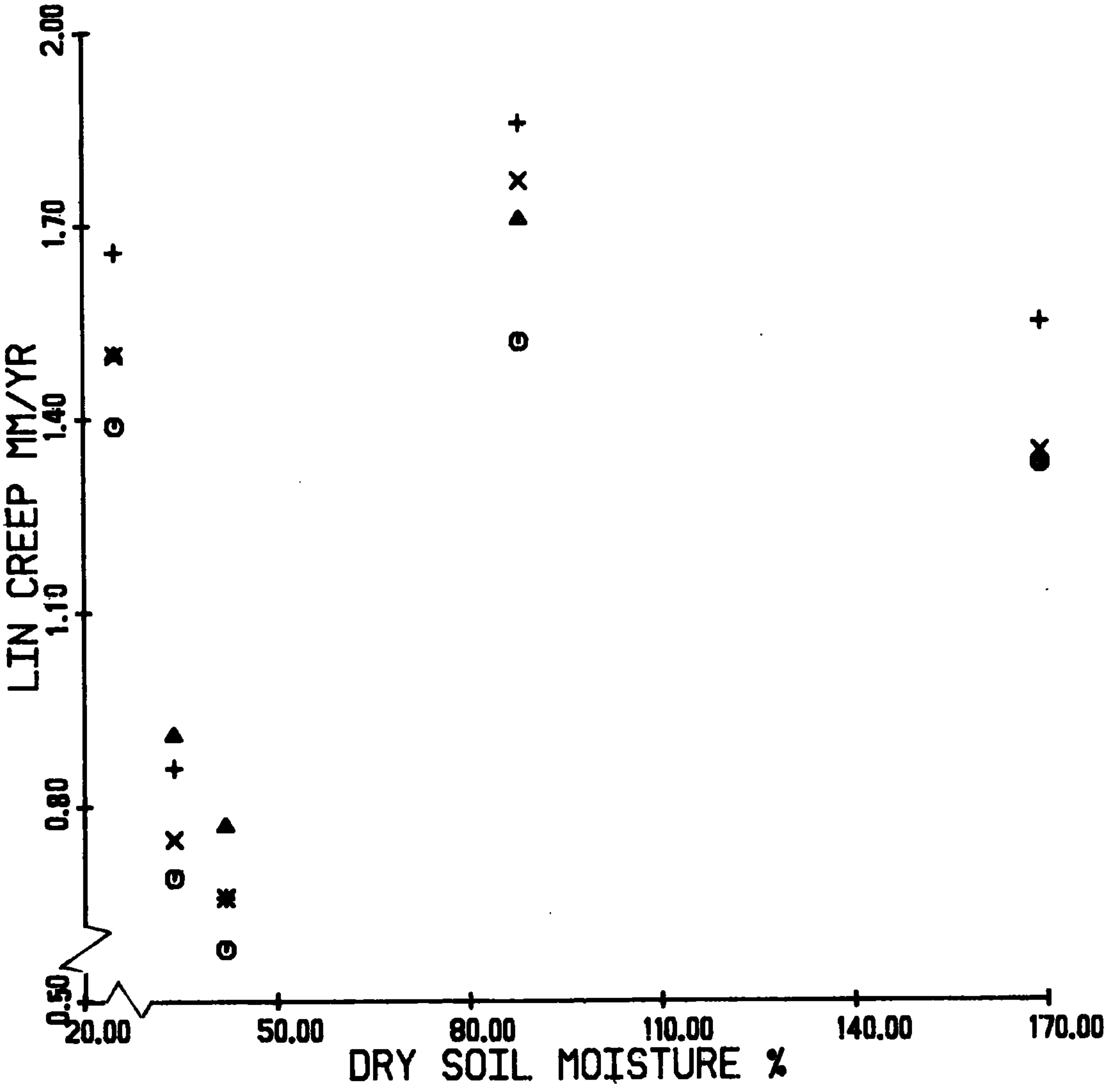


Fig. 7.6 : Scatter plot : Linear creep rate (four instruments) and soil moisture (dry season).

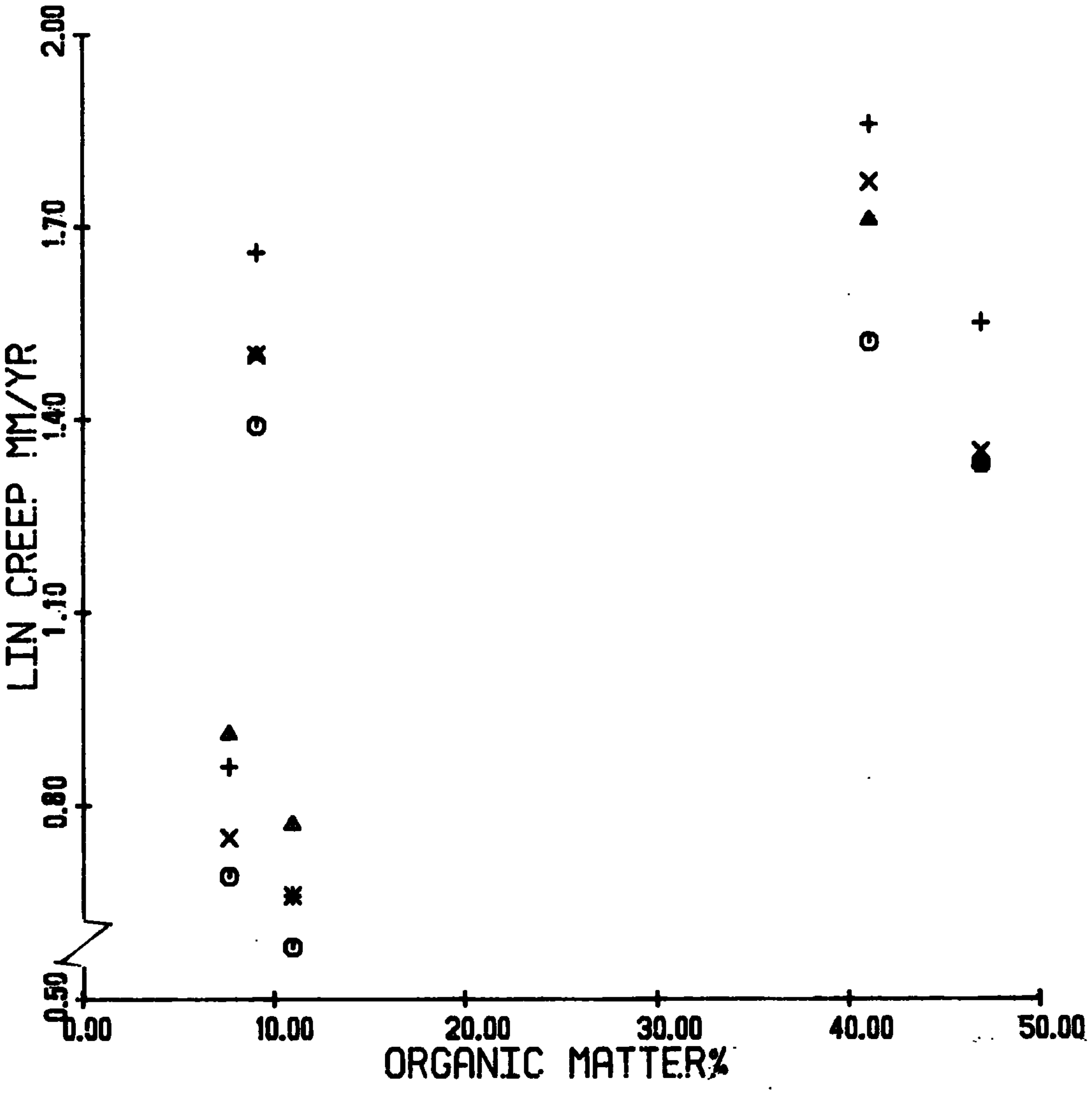
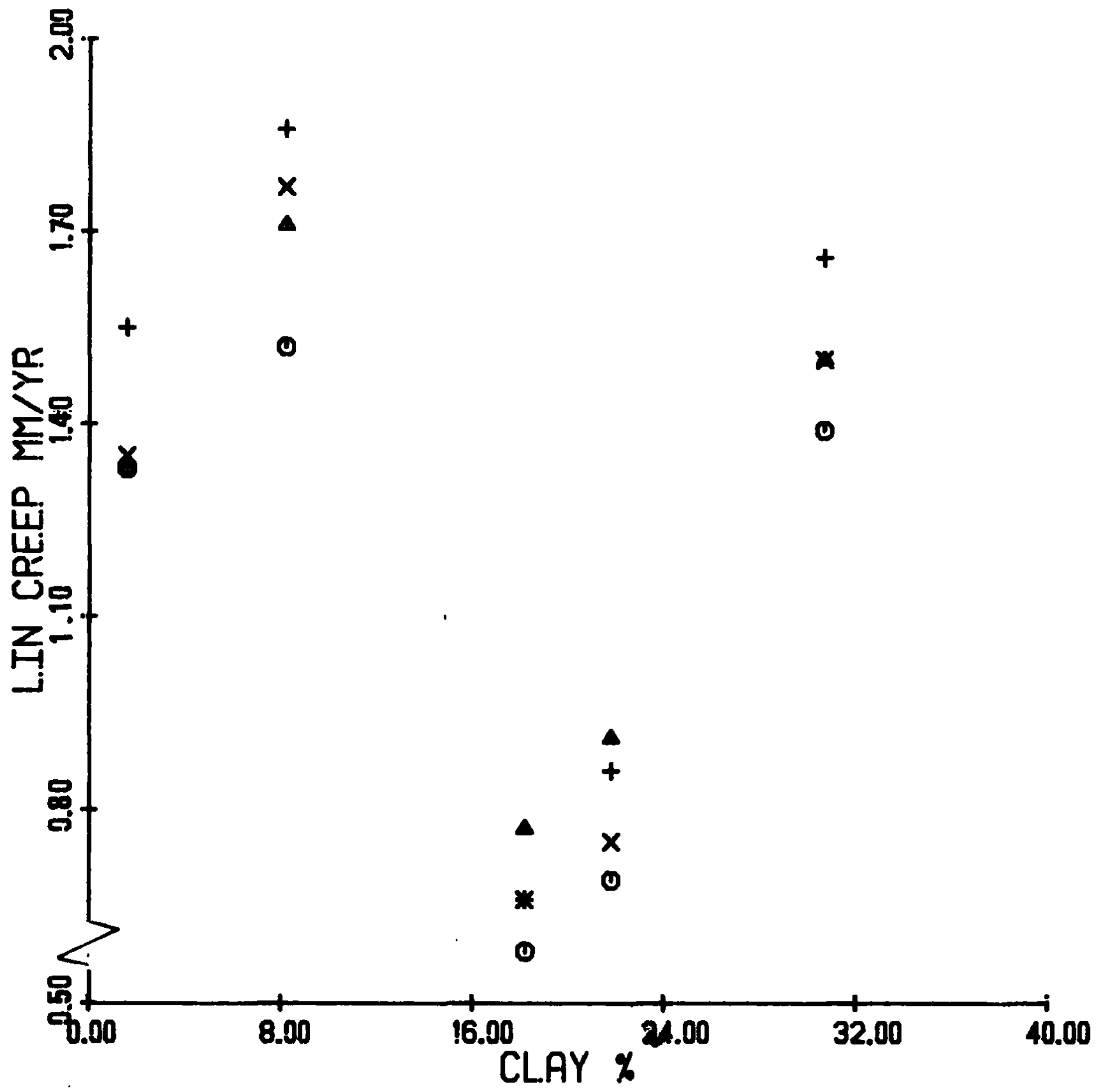


Fig. 7.7 : Scatter plot : Linear creep rate (four instruments) and organic matter.



<u>Fig. 7.8</u> : Scatter plot : Linear creep rate (four instruments) and percentage of clay.

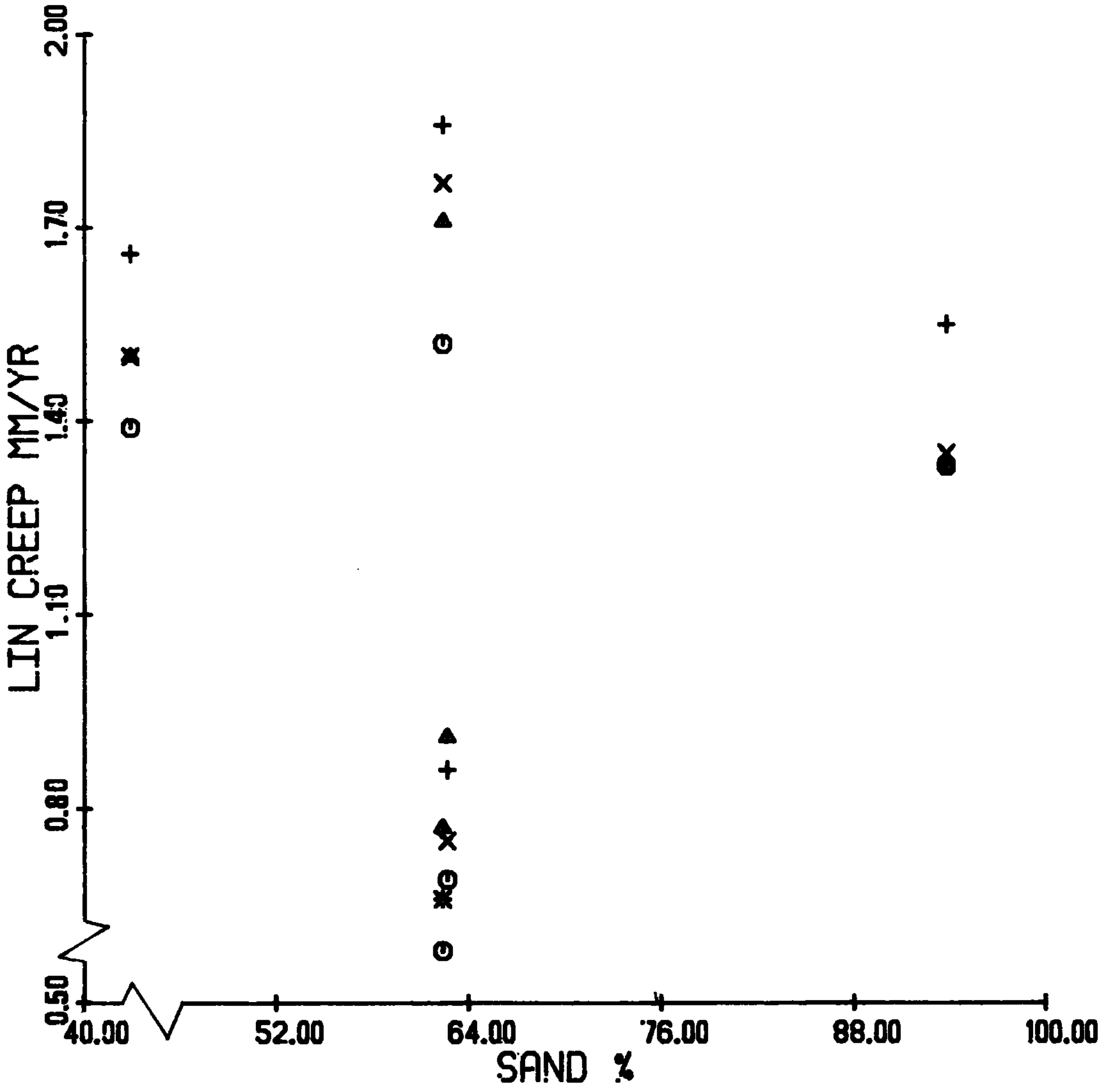


Fig. 7.9 : Scatter plot : Linear creep rate (four instruments) and percentage of sand.

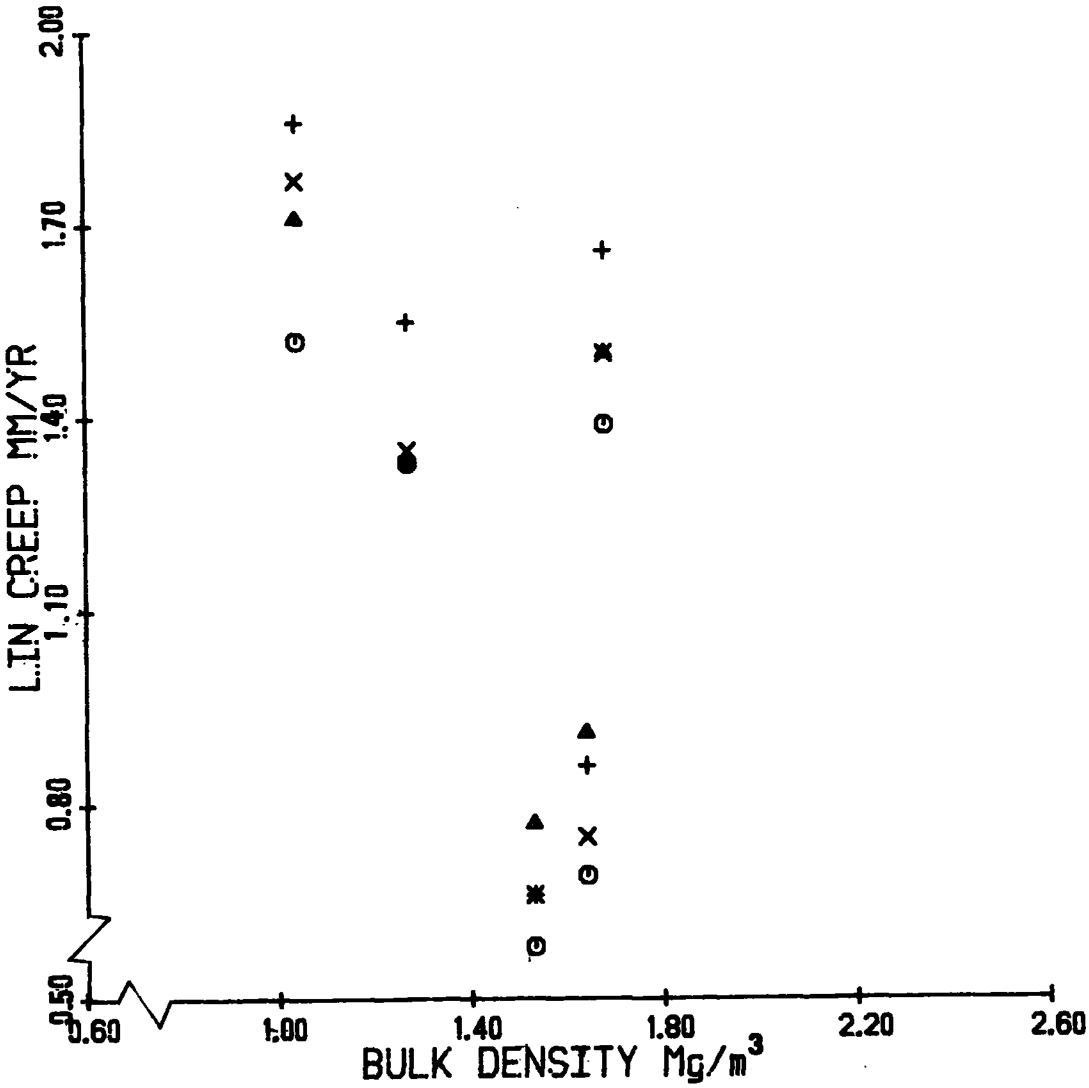


Fig. 7.10 : Scatter plot : Linear creep rate (four instruments) and bulk density.

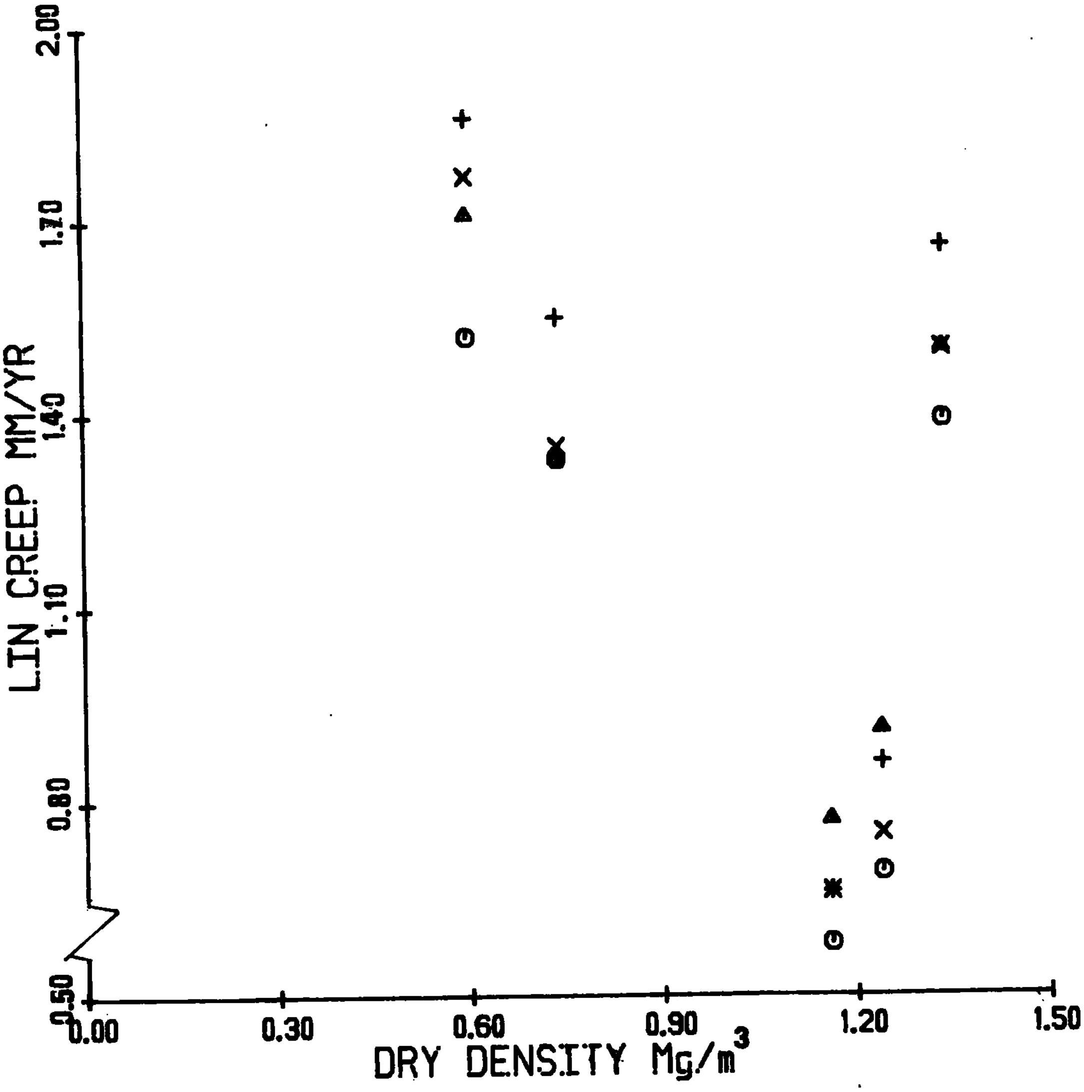


Fig. 7.11 : Scatter plot : Linear creep rate (four instruments) and dry bulk density.

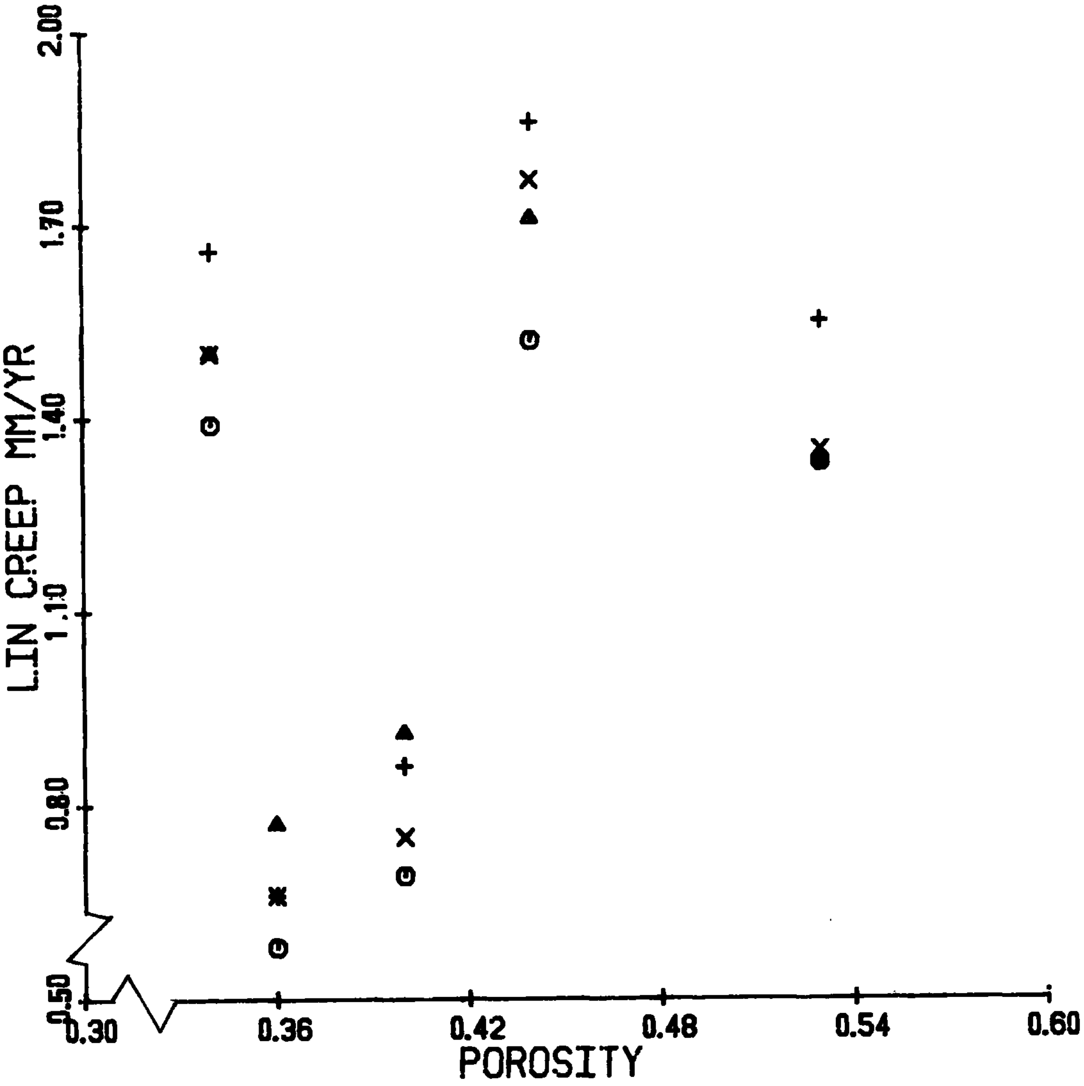


Fig. 7.12 : Scatter plot : Linear creep rate (four instruments) and porosity.

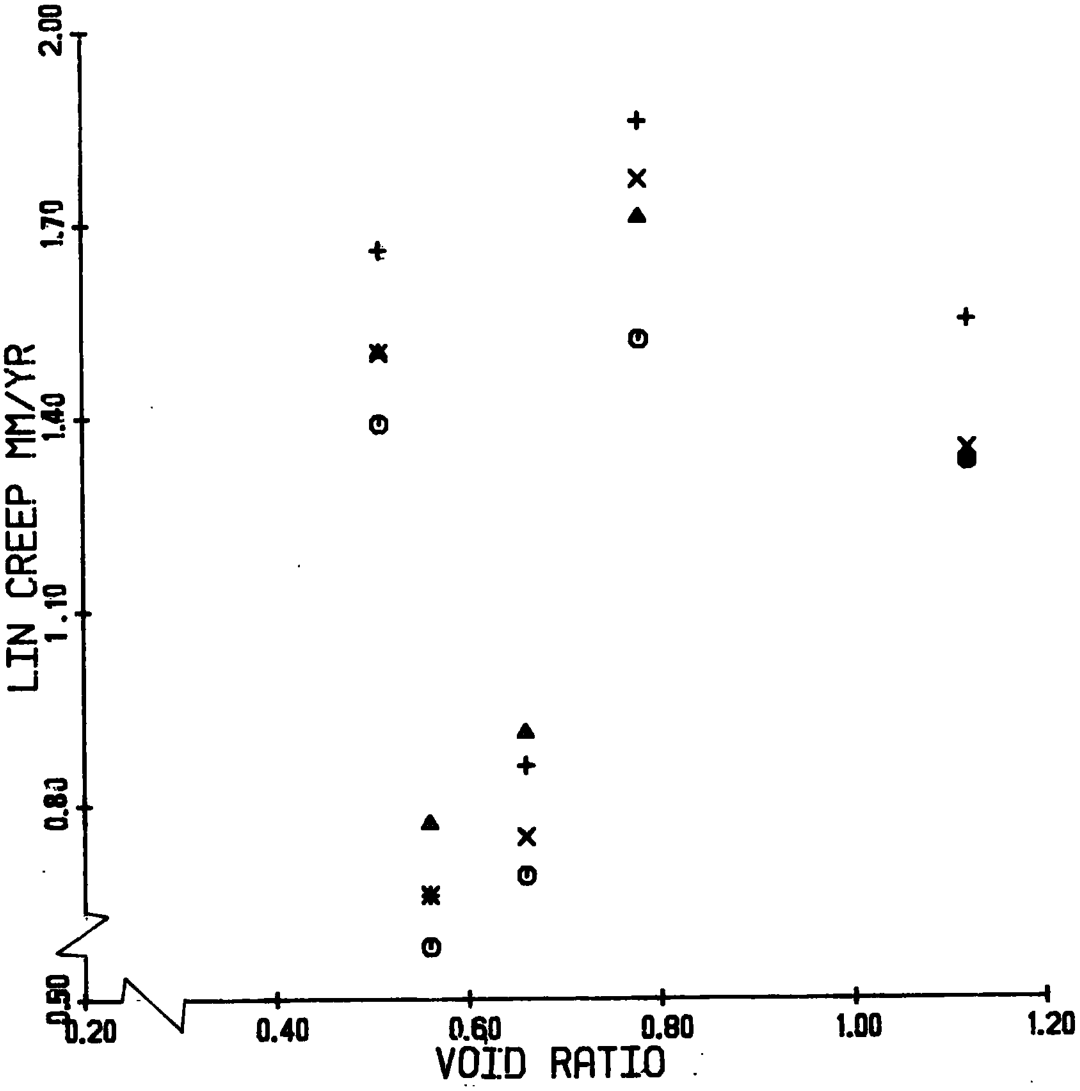


Fig. 7.13 : Scatter plots : Linear creep rate (four instruments) and void ratio.

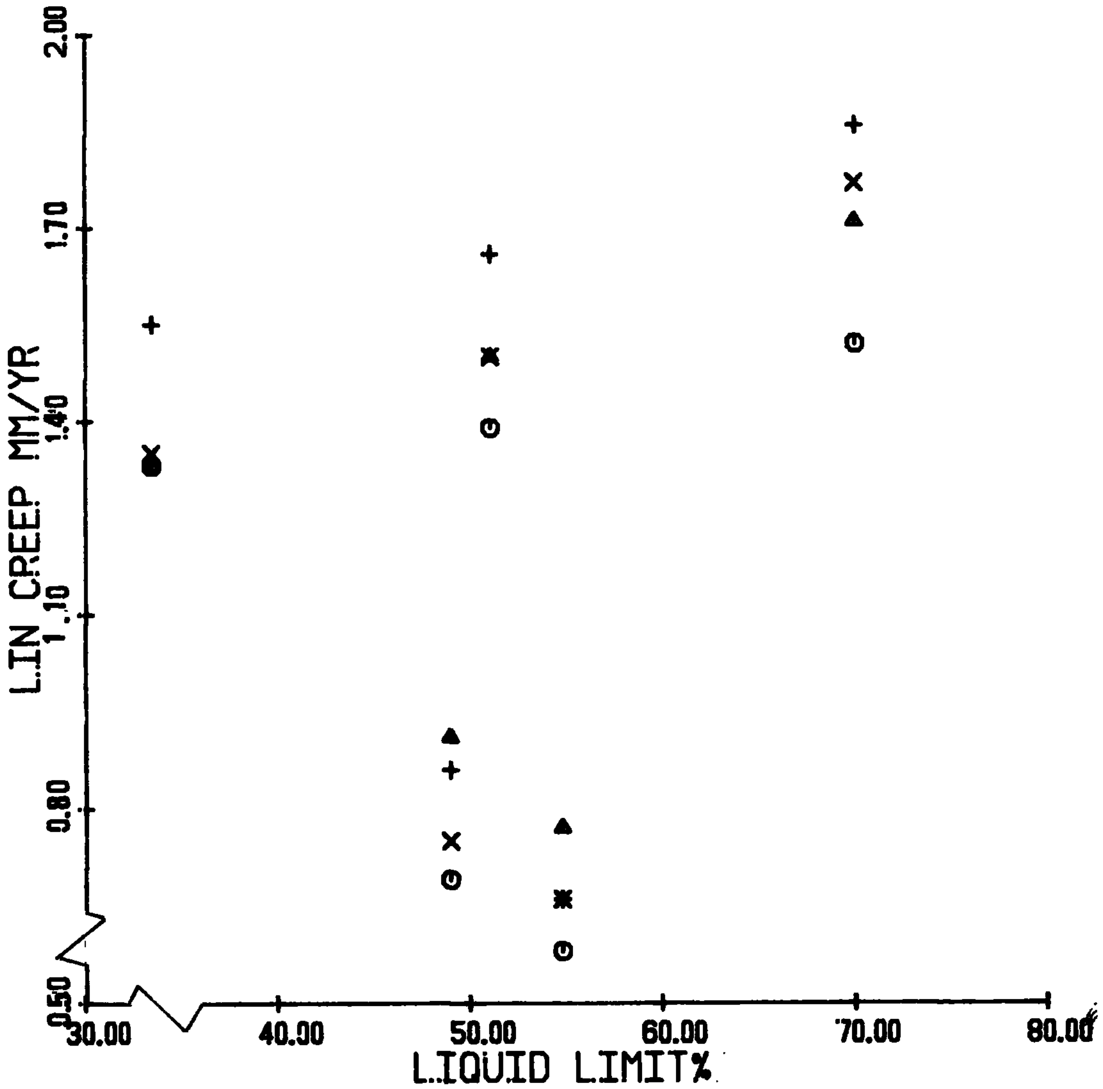
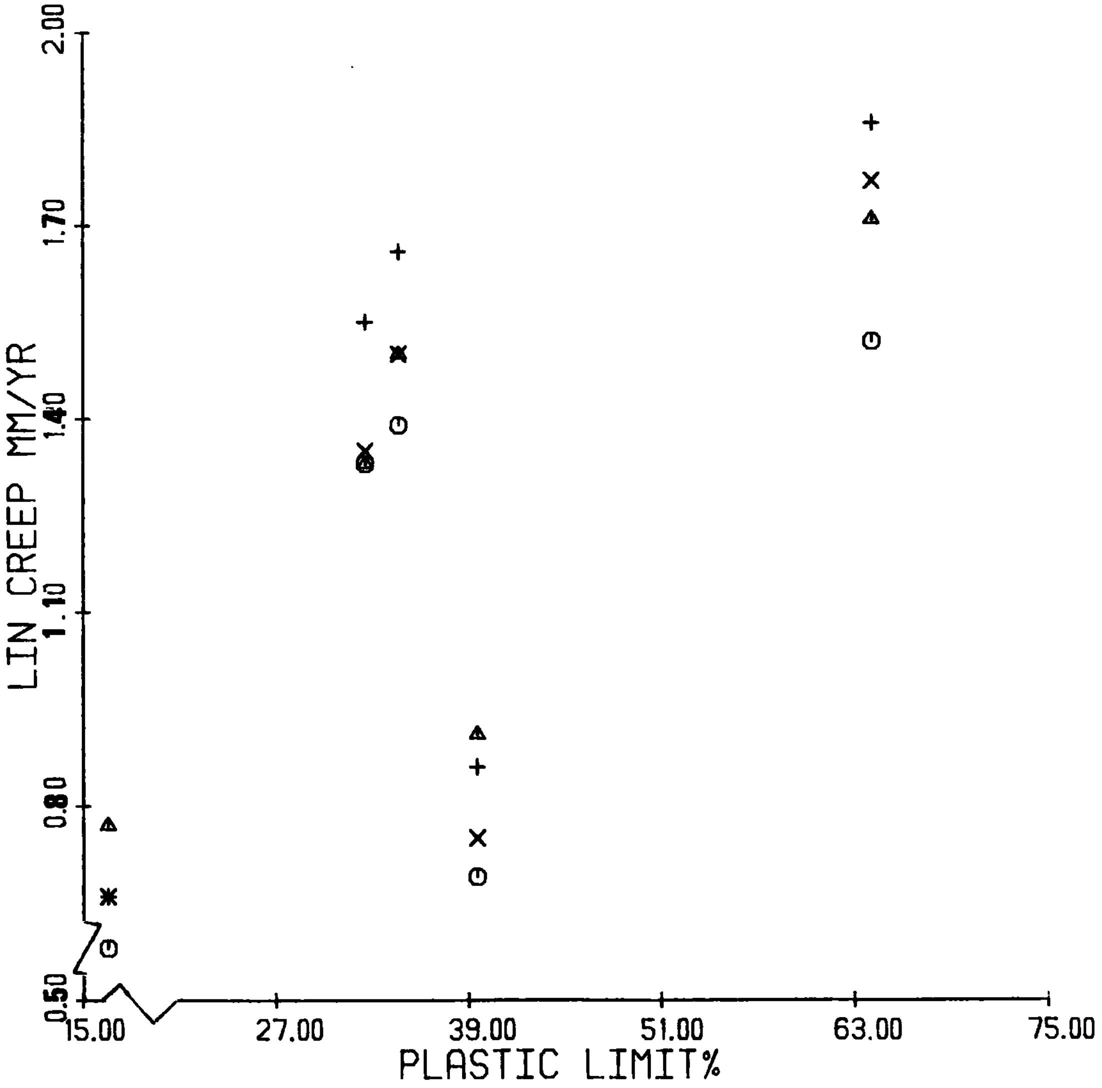


Fig 7.14 : Scatter plot : Linear creep rate (four instruments) and liquid limit.



<u>Fig. 7.15</u> : Scatter plot : Linear creep rate (four instruments) and plastic limit.

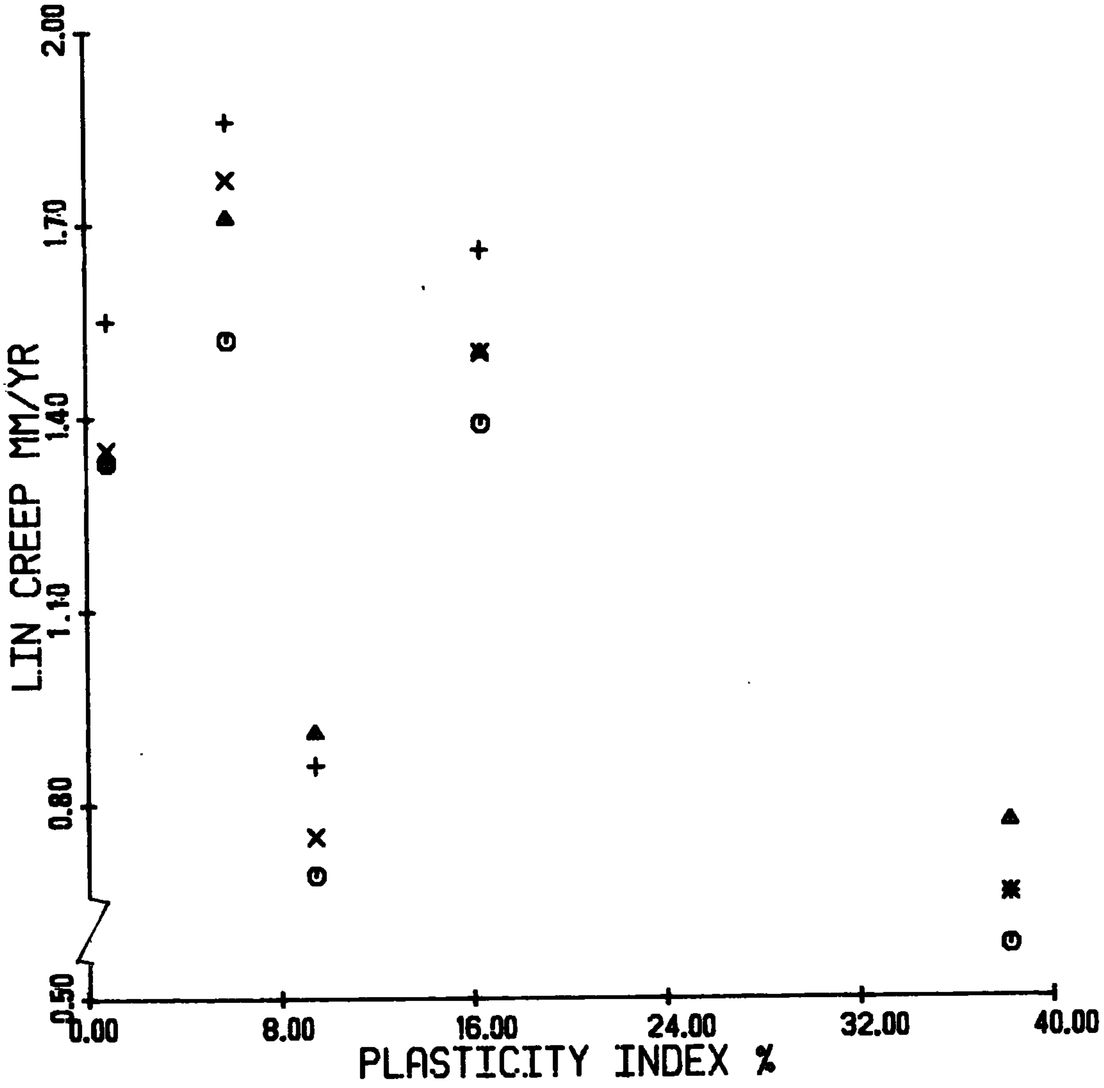


Fig. 7.16 : Scatter plot : Linear creep rate (four instruments) and plasticity index.

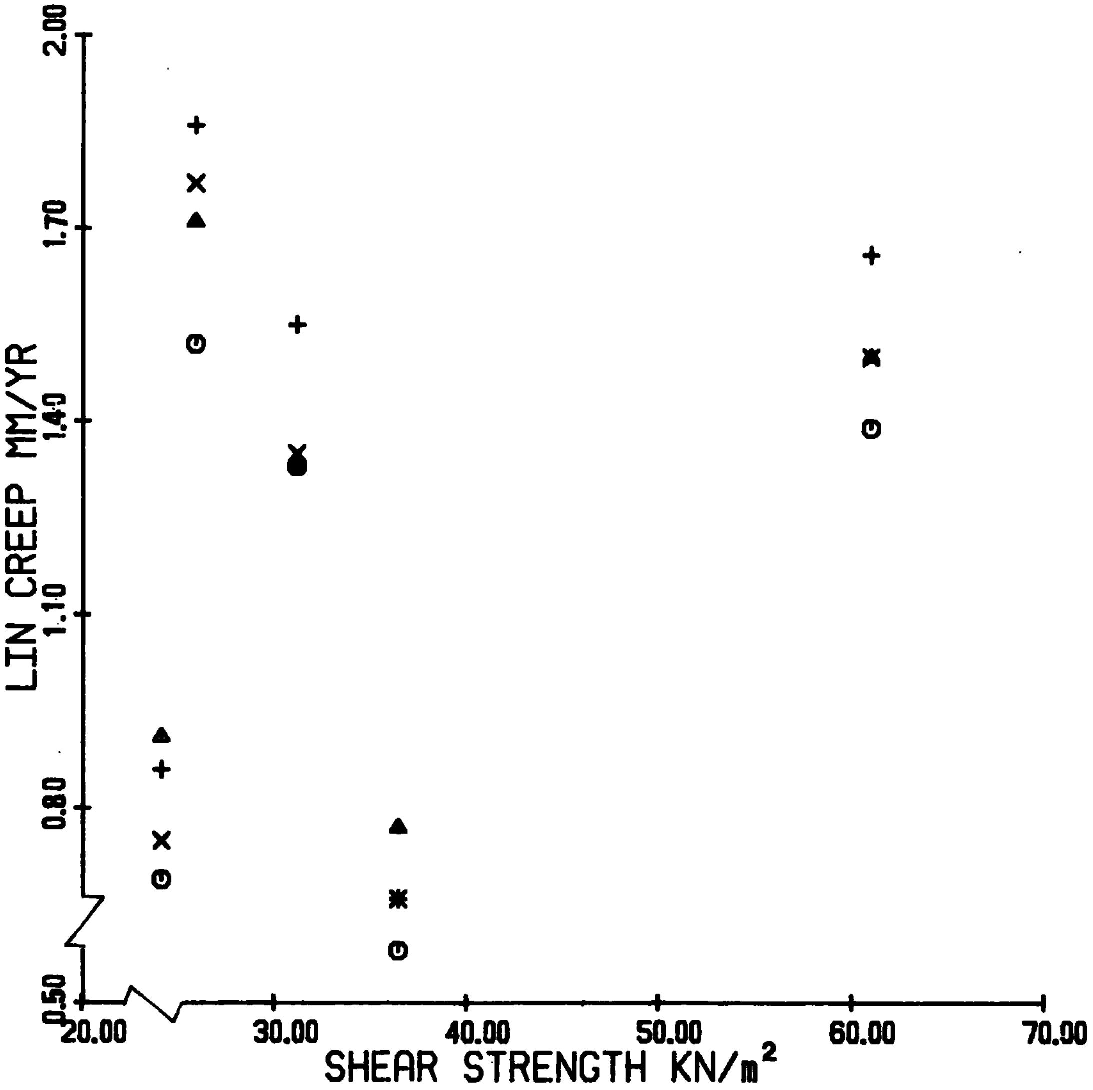


Fig. 7.17 : Scatter plot : Linear creep rate (four instruments) and shear strength.

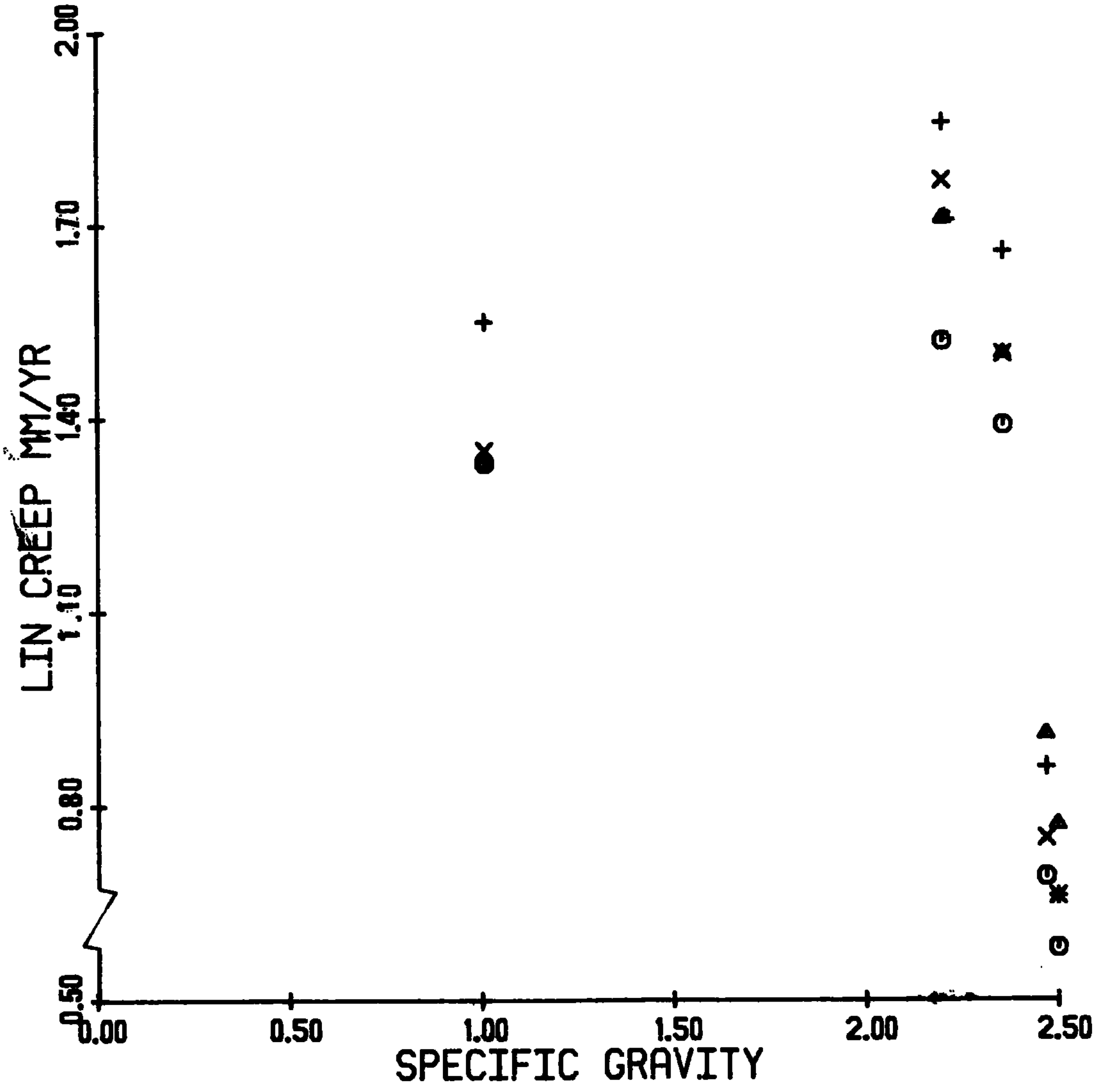


Fig. 7.18 : Scatter plot : Linear creep rate (four instruments) and specific gravity.

7.3.2 Correlations between the meteorological data of the region (Moor House) and a profile of creep rate with depth (Rashidian's technique).

The Young's pit and the Rashidian technique are both capable of producing a profile of soil movement with depth. Strong correlations between the results obtained by both techniques (r = 0.98) permitted one of these to be selected for analysis. Rashidian's technique was selected because there are monthly readings for 18 months whereas there is not more than one reading for the Young's pits.

From the meteorological factors; maximum monthly temperature; minimum monthly temperature; mid-monthly temperature; mean monthly earth temperature (30 cm, 9.0 am); monthly rainfall, days of snow lying and days of ground frost were taken for calculation and analysis. (Table 5-20)

Among these, minimum temperature, earth temperature and frost (days) were found to be the most important factors controlling creep rates.

It should be borne in mind that vegetation, like snow cover, provides an insulation layer between the atmosphere and the ground surface and therefore modifies the heat exchanges between them. Also, because of the large variability in vegetation type and soil properties and their observed influences on soil temperatures, the assessment of rates and depths of penetration of freezing and thawing is not easy.

The plot sections range from 30 mm to 270 mm below the soil surface with a reading interval of 30 mm. Table 7.3 gives correlation coefficients between monthly minimum temperature and profile of creep rates with depth.

The strongest correlations between creep rate and minimum temperature were found for sampling station No.1 at 90 mm (r = 0.58), sampling station No.2 at 240 mm (r = 0.74), sampling station No.3 at 210 mm (r = 0.73), sampling station No. 4 at 150 mm (r = 0.59), and sampling station No.5 at 90 mm (r = -0.63),

Table 7.3 Correlation coefficients between monthly minimum temperature and profile of creep rates with depth. (Rashidian's technique). N = 12 significance level: 95% = 0.57; 99% = 0.70.

Depth mm Site No.	30	60	90	120	150	180	210	240	270
1	-0.54	-0.56	-0.58*	-0.55	-0.44	-0.40	-0.44	-0.35	-0.37
2	-0.40	-0.49	-0.64	-0.70	-0.65	-0.68	-0.66	-0.74*	-0.58
3	-0.58	-0.58	-0.61	-0.69	-0.72	-0.67	-0.73*	-0.72	-
4	-0.32	-0.51	-0.52	-0.56	-0.59*	-0.47	-	-	-
5	-0.53	-0.50	-0.63*	-0.50	-0.35	-0.35	-0.49	-	-

* Maximum correlation for each site.

In the case of earth temperature, moderately strong negative correlations for sampling stations 1, 2, 3, 4 and 5 respectively were found at 120 mm depth (r = 0.56), 120 mm (r = 0.71), 240 mm (r = -0.76), 120 mm (r = -0.58), 90 mm (r = -0.62), Table 7.4.

High correlations between creep rates and soil temperature occurred at depths of 90 - 120 mm from the surface for sampling sites 1, 2, 4, 5 with depths of 300, 300, 280 and 250 mm of soil depth susceptible to creep. The strongest correlation for sampling site No.3 with 310 mm of soil depth was found at the lower section (210 mm). This revealed a relationship between earth temperature and soil depth susceptible to movement. In Table 7.4 the maximum correlation for each station has been identified by *. Figs. 7.19 - 7.23 represent the highest correlation between creep rate and earth temperature for each site.

Table 7.4 Correlation coefficients between mean monthly earth temperature (0.3 m, 0.900) and profile of creep rates with depth (Rashidian's technique) N = 12, significance level : 95% = 57; 99% = 70

Depth mm / Site No.	30	60	90	120	150	180	210	240	270
1	-0.53	-0.54	-0.54	-0.56*	-0.45	-0.39	-0.49	-0.40	-0.38
2	-0.38	-0.48	-0.64	-0.71*	-0.65	-0.66	-0.64	-0.69	-0.62
3	-0.59	-0.60	-0.63	-0.71	-0.74	-0.72	-0.76*	-0.33	-
4	-0.29	-0.52	-0.53	-0.58*	-0.48	-0.39	-	-	-
5	-0.58	-0.54	-0.62*	-0.51	-0.32	-0.32	-0.51	-	-

* Maximum correlation for each site

Frost days had significant correlations with the profile of creep rates. McGaw (1972) investigated the influence of depth to the water table on the rate of frost heave for given rates of frost penetration. His results clearly illustrate that frost heaving is reduced as the depth of the water table is increased. It was found in this study that the correlation between creep rate and frost days has a strong relationship with the soil moisture content.

The strongest correlation between creep rates and frost days is shown by sampling sites No. 2 and 3 (r = 0.75 and

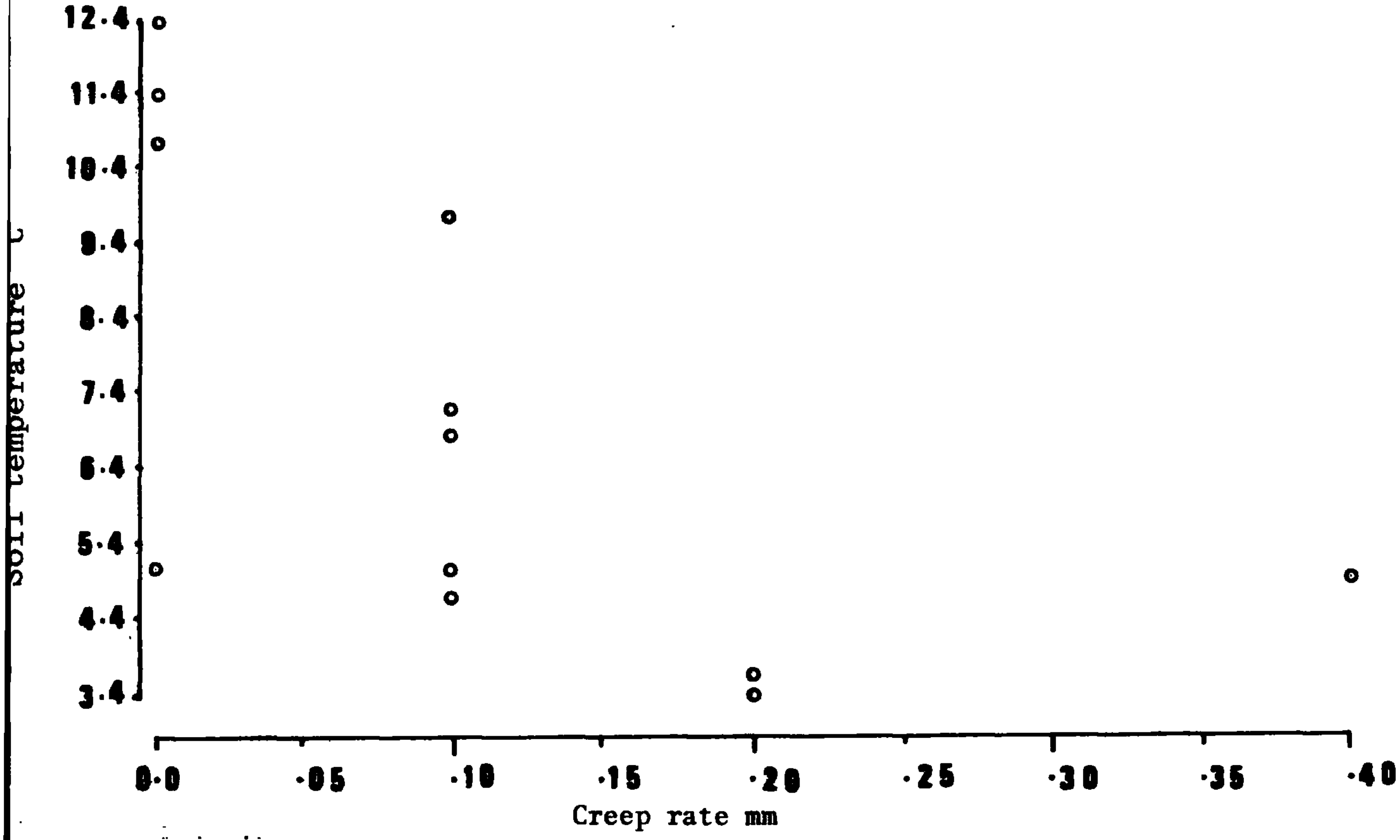


Fig. 7.19 : Scatter plot of monthly creep rates and mean monthly earth temperature for sampling site No.5 at 90 mm depth (maximum correlation).

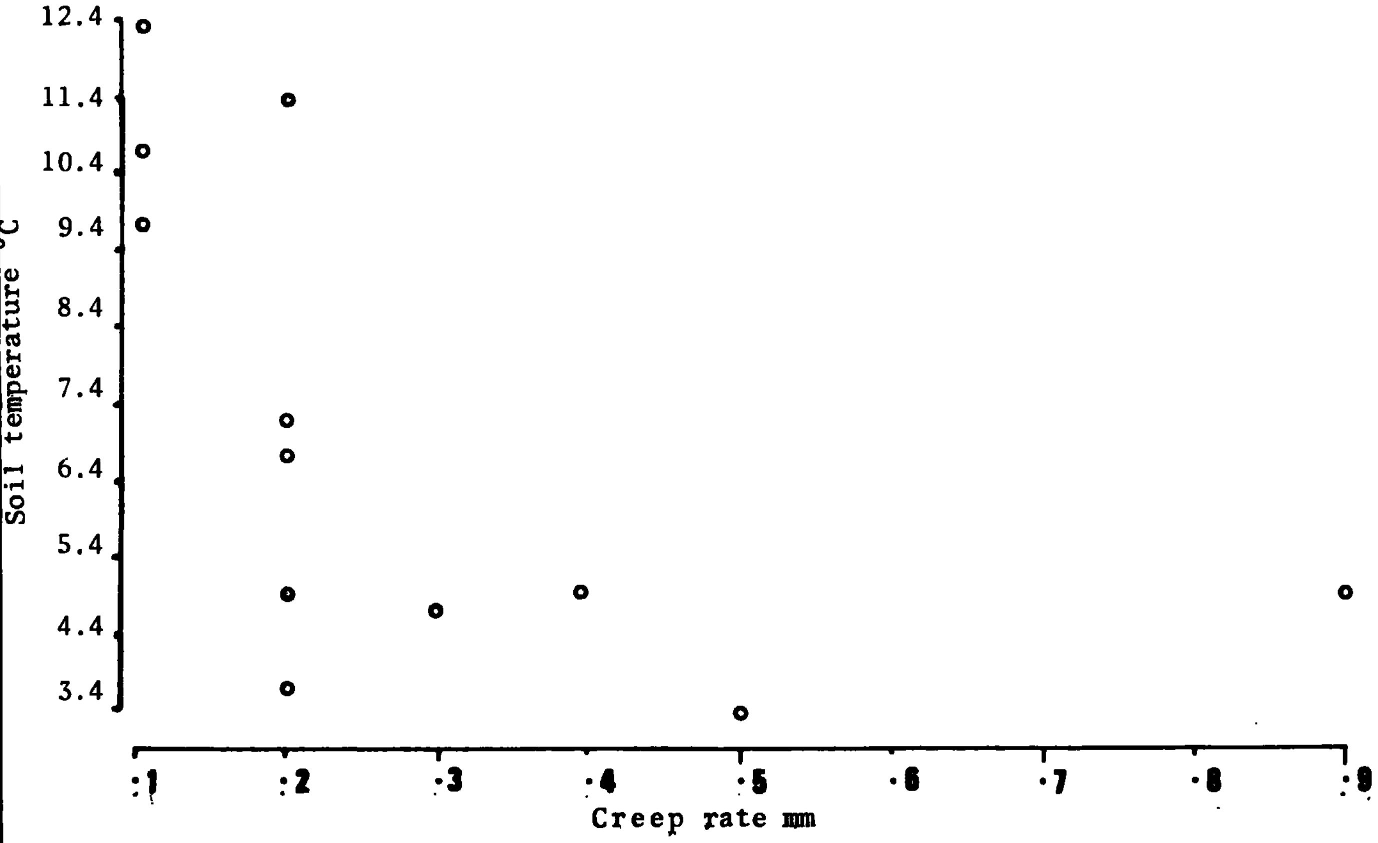


Fig. 7.20 : Scatter plot of monthly creep rates and mean monthly earth temperature for sampling site No.1 at 120 mm depth (maximum correlation).

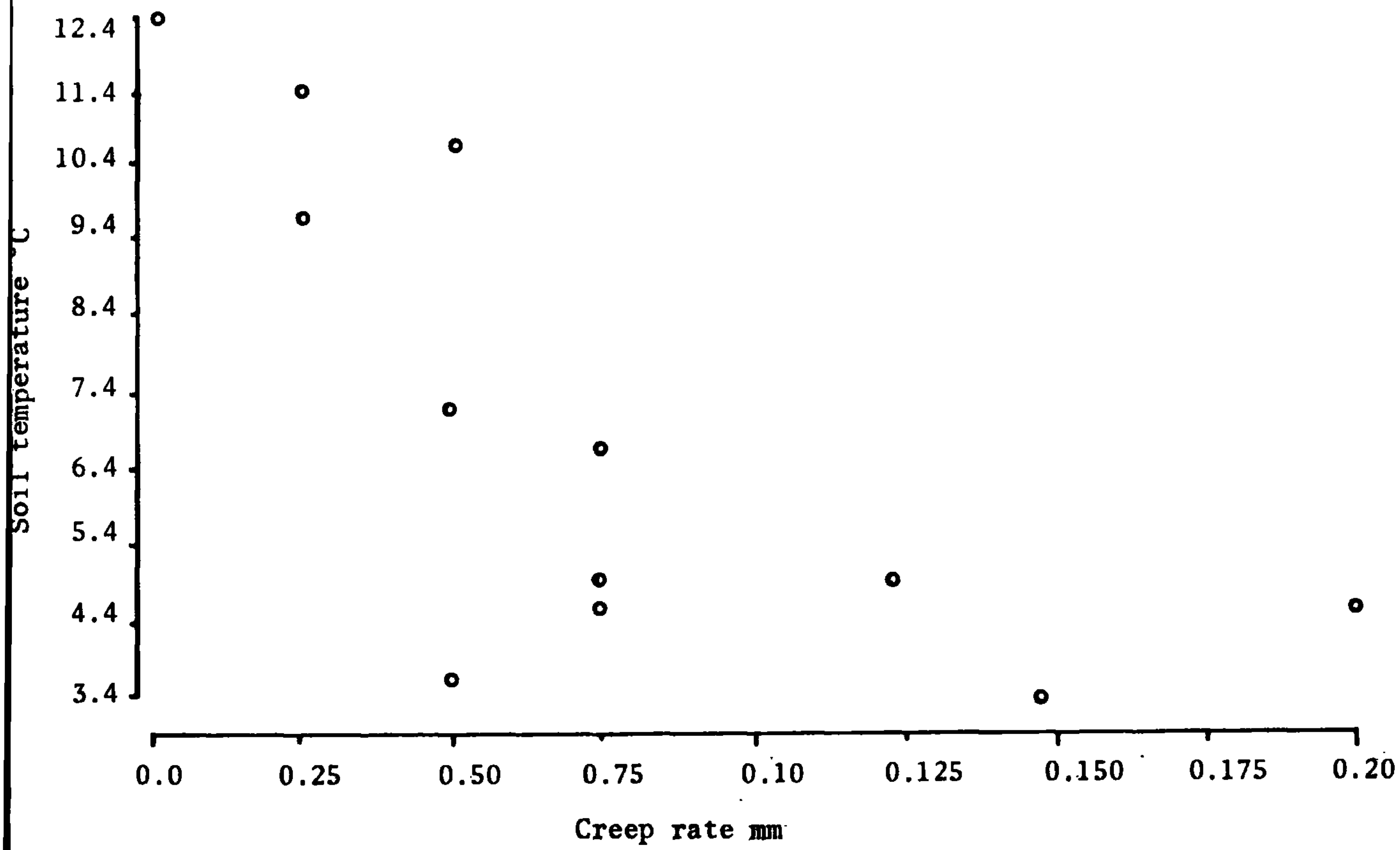


Fig. 7.21 : Scatter plot of monthly creep rates and mean monthly earth temperature for sampling site No.2 at 120 mm depth (maximum correlation).

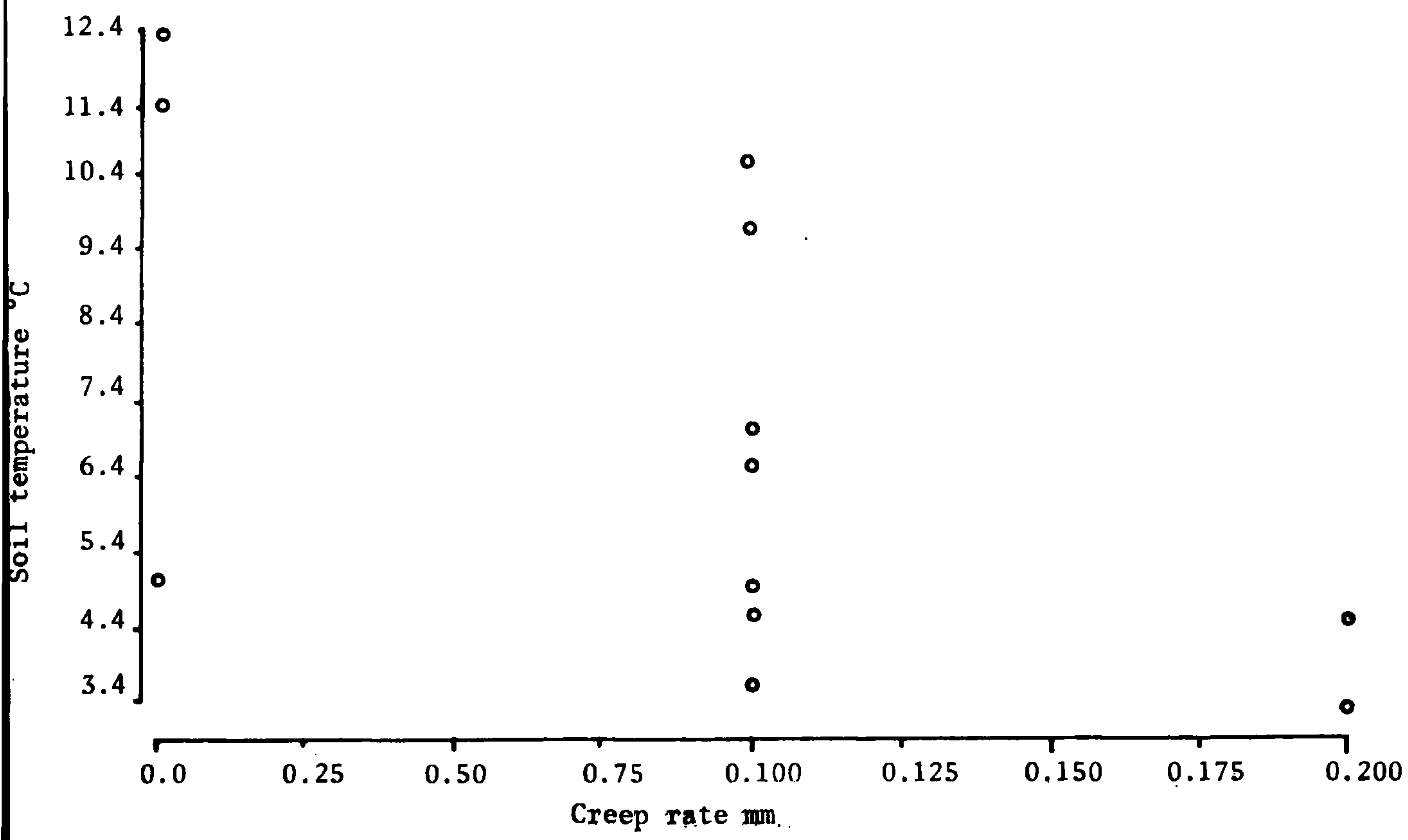


Fig. 7.22 : Scatter plot of monthly creep rates and mean monthly earth temperature for sampling site No.4 at 120 mm depth (maximum correlation).

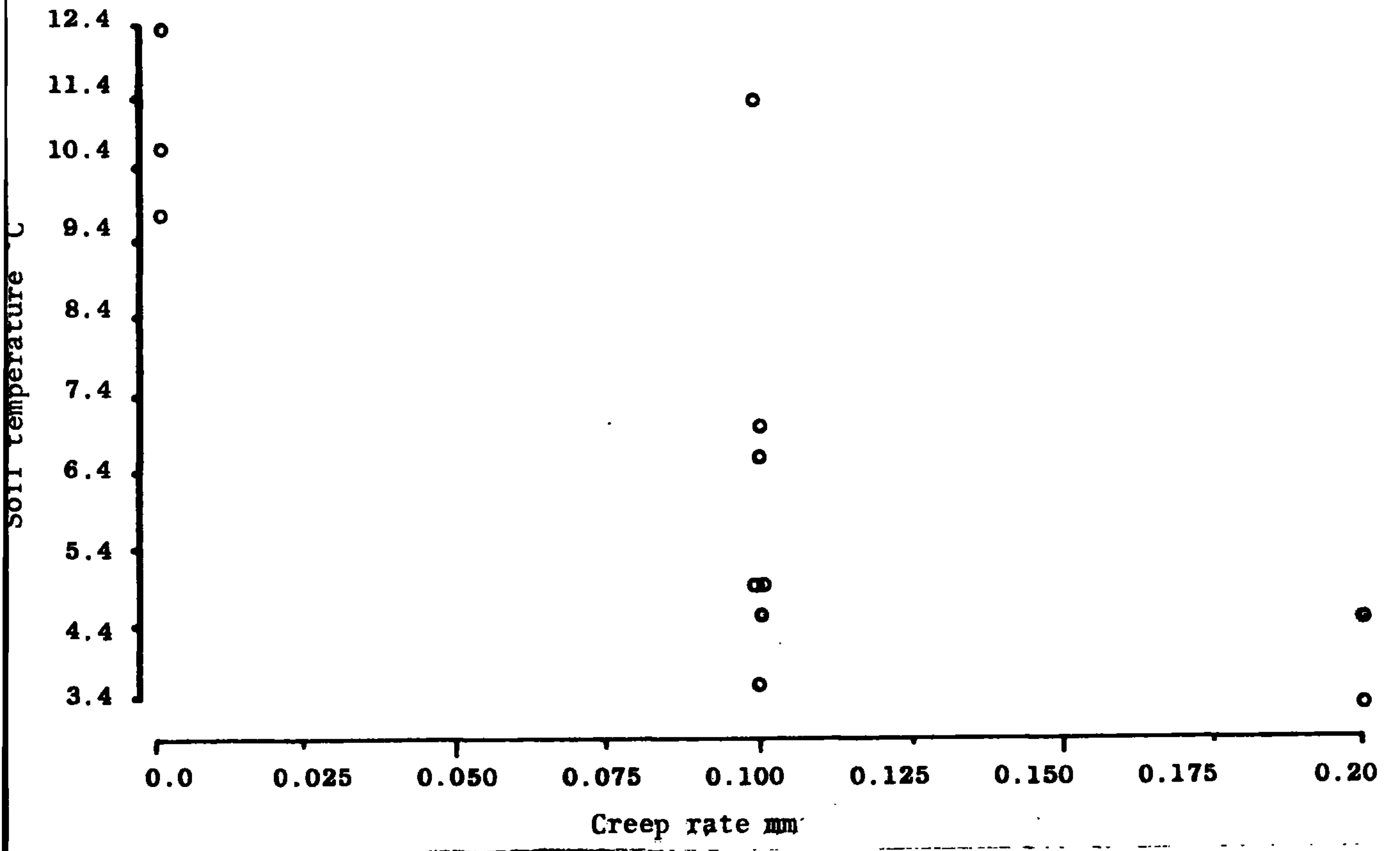


Fig. 7.23 : Scatter plot of monthly creep rates and mean monthly earth temperature for sampling site No.3 at 210 mm depth (maximum correlation).

0.70) for 240 mm and 210 mm depth, Table 7.5. The maximum soil moisture contents were also found on sites 3 and 2 (190 and 104 per cent) whereas a less significant correlation was shown by sampling sites 1 and 5 (r = 0.62 and 0.57) both for 90 mm depth, with 48 and 49 per cent soil moisture content. This supports McGaw's results. Figs. 7.24 - 7.28 represent the highest correlation between creep rate and frost days for each site.

Table 7.5 Correlation coefficientsbetween monthly frost days and profile of creep rates with depth (Rashidian's technique) N = 12 significance level : 95% = 57; 99% = 70

Depth mm Site No.	30	60	90	120	150	180	210	240	270
1	0.53	0.57	0.62*	0.56	0.52	0.47	0.43	0.31	0.42
2	0.40	0.50	0.66	0.70	0.66	0.71	0.67	0.75*	0.58
3	0.55	0.57	0.60	0.65	0.67	0.64	0.70*	0.30	-
4	0.36	0.47	0.52	0.54	0.69*	0.53	-	-	-
5	0.44	0.44	0.57*	0.44	0.32	0.32	0.43	-	-

* Maximum correlation for each site

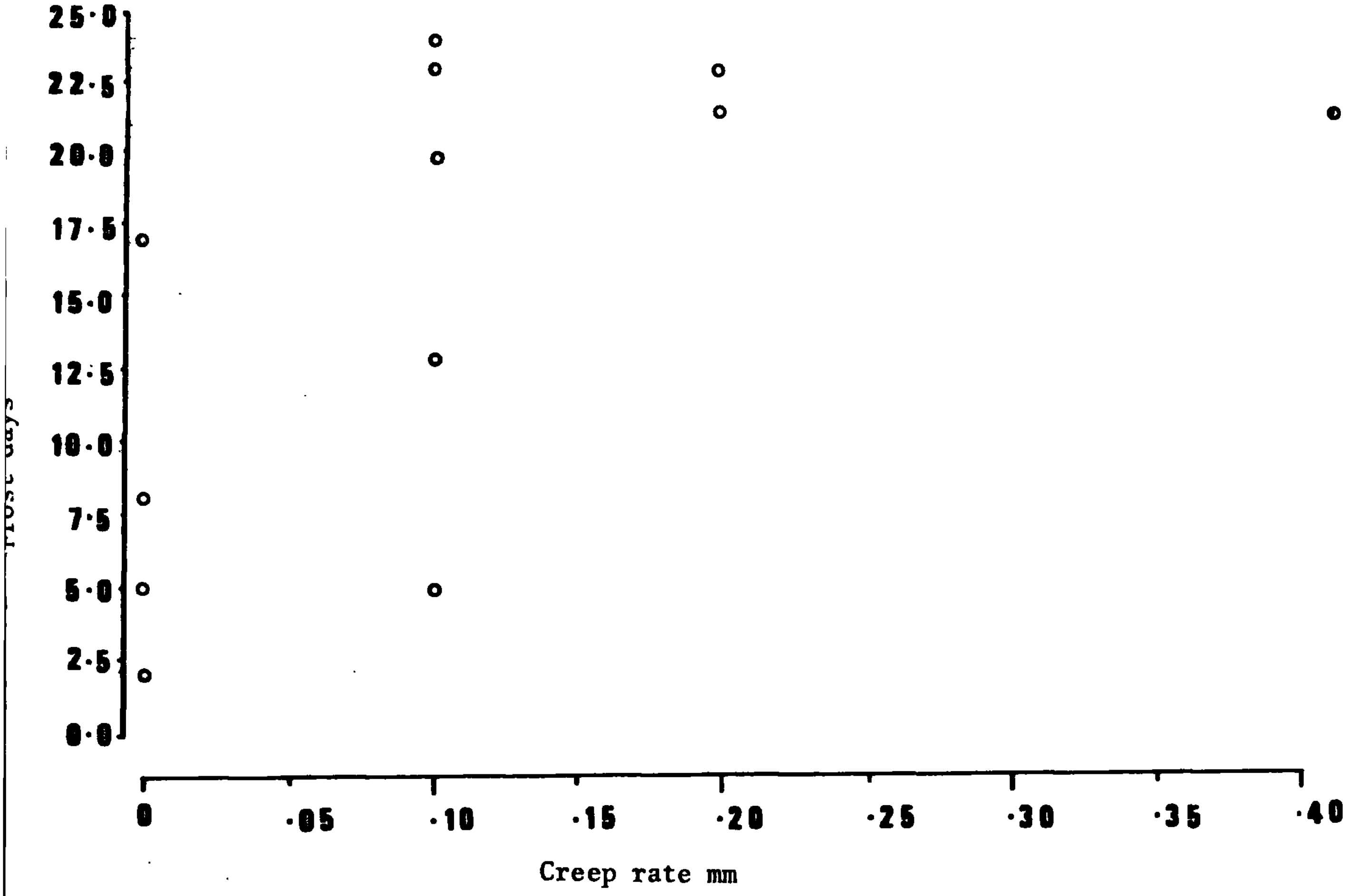


Fig. 7.24 : Scatter plot of monthly creep rates and frost days at sampling site No.5 for 90 mm depth (maximum correlation).

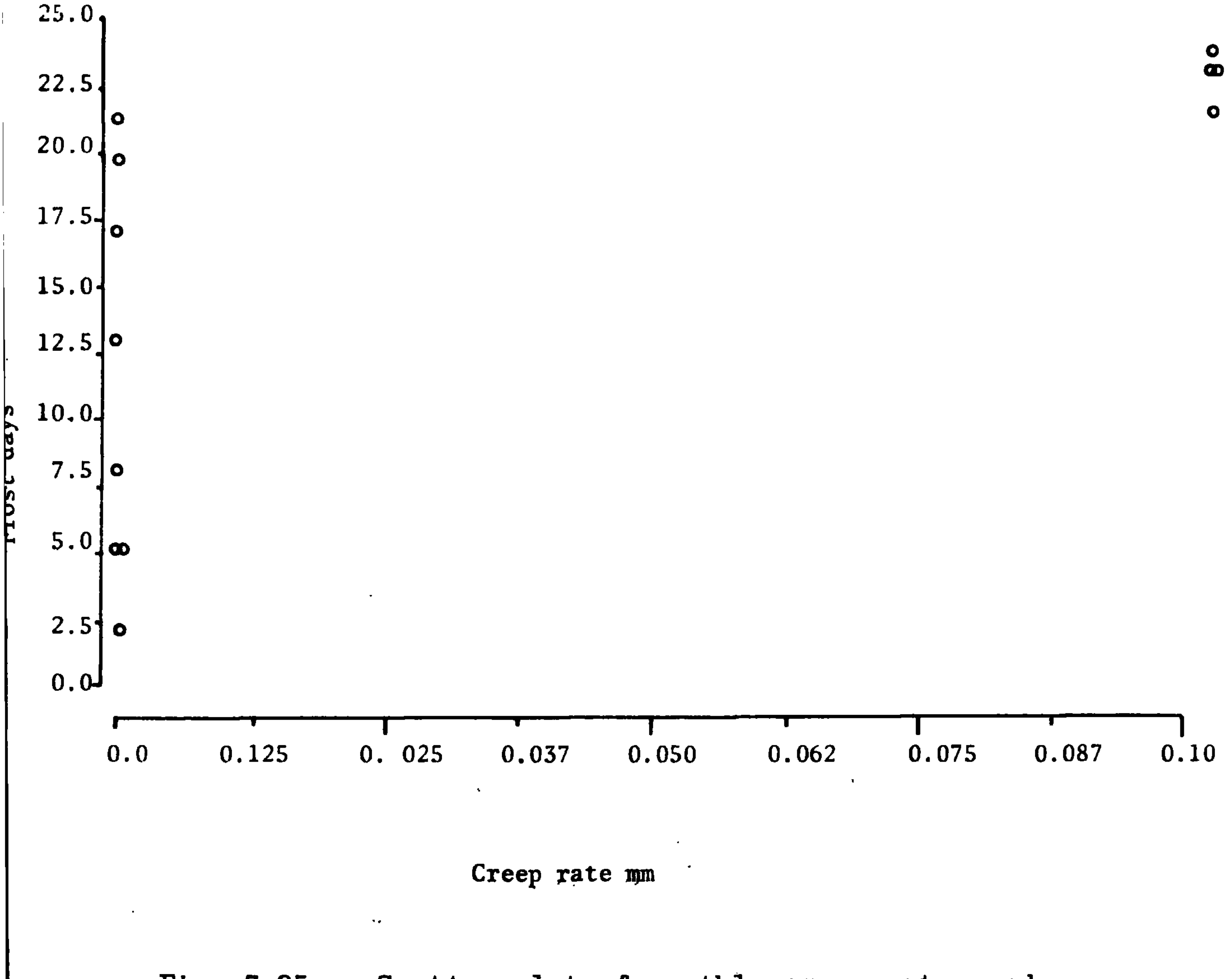


Fig. 7.25 : Scatter plot of monthly creep rates and frost days at sampling site No. 4 for 150 mm depth (maximum correlation)

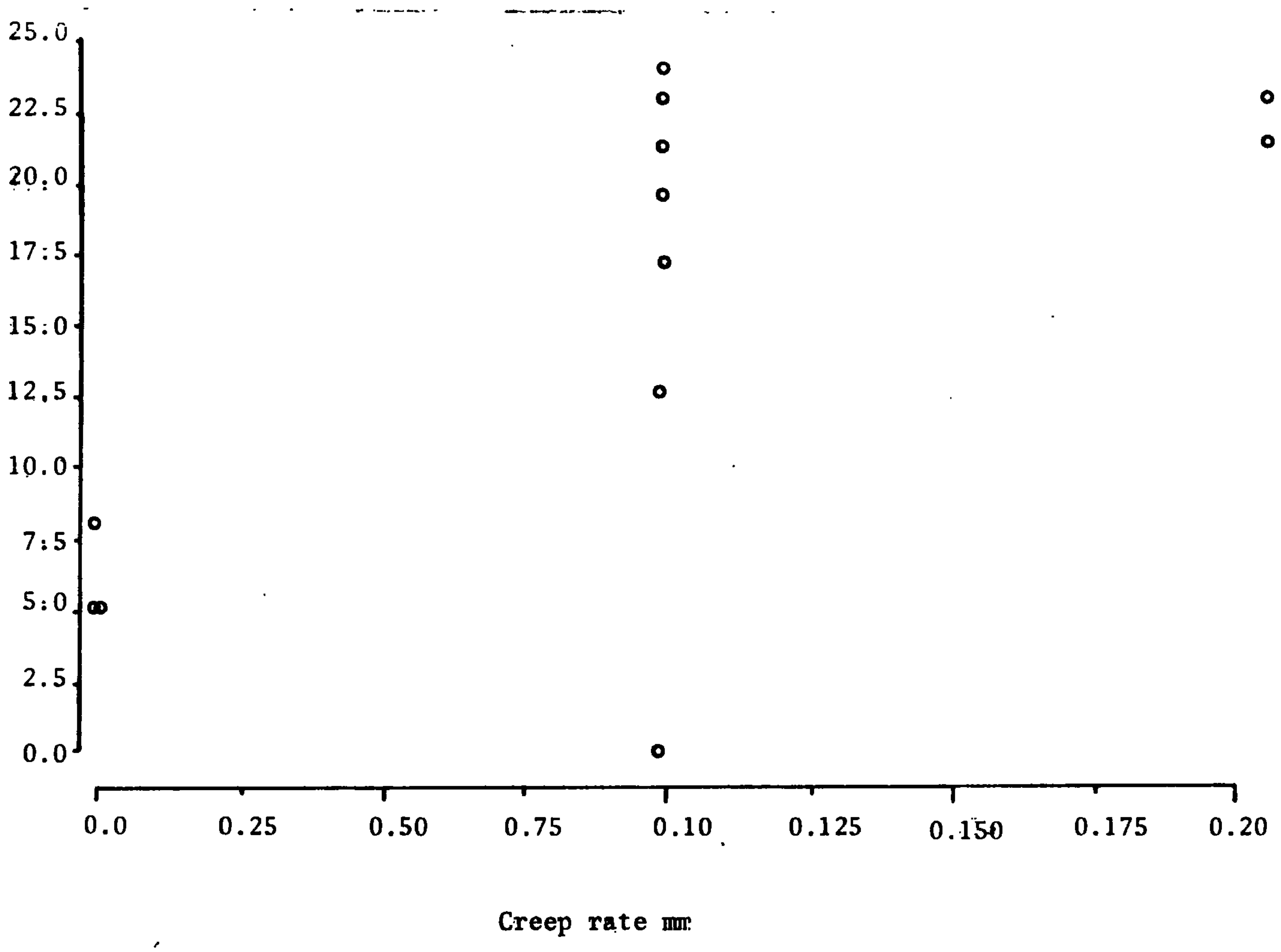
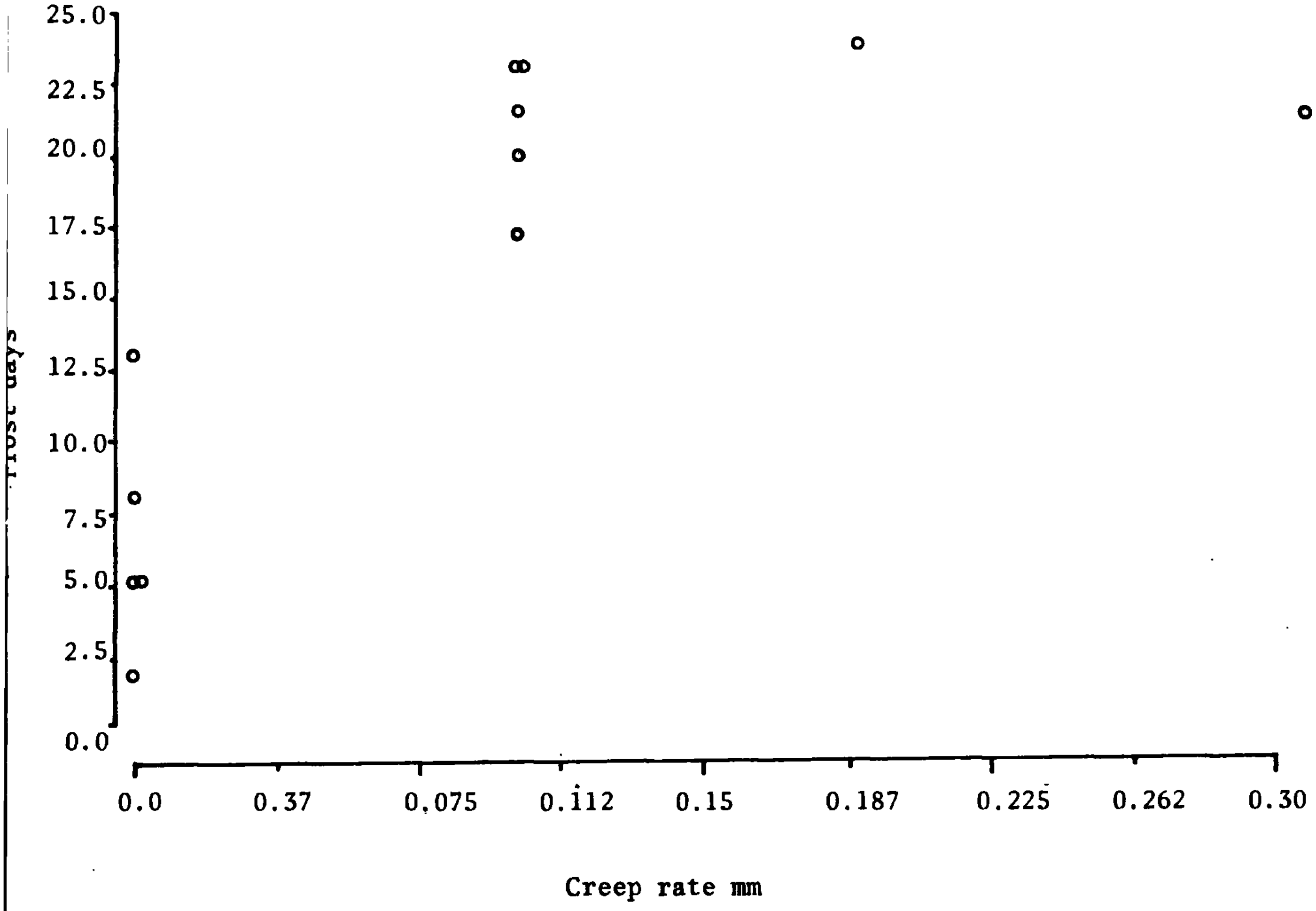


Fig. 7.26 : Scatter plot of monthly creep rates and frost days at sampling site No.3 for 210 mm depth (maximum correlation).



<u>Fig. 7.27</u> : Scatter plot of monthly creep rates and frost days at sampling site No.2 for 240 mm depth (maximum correlation).

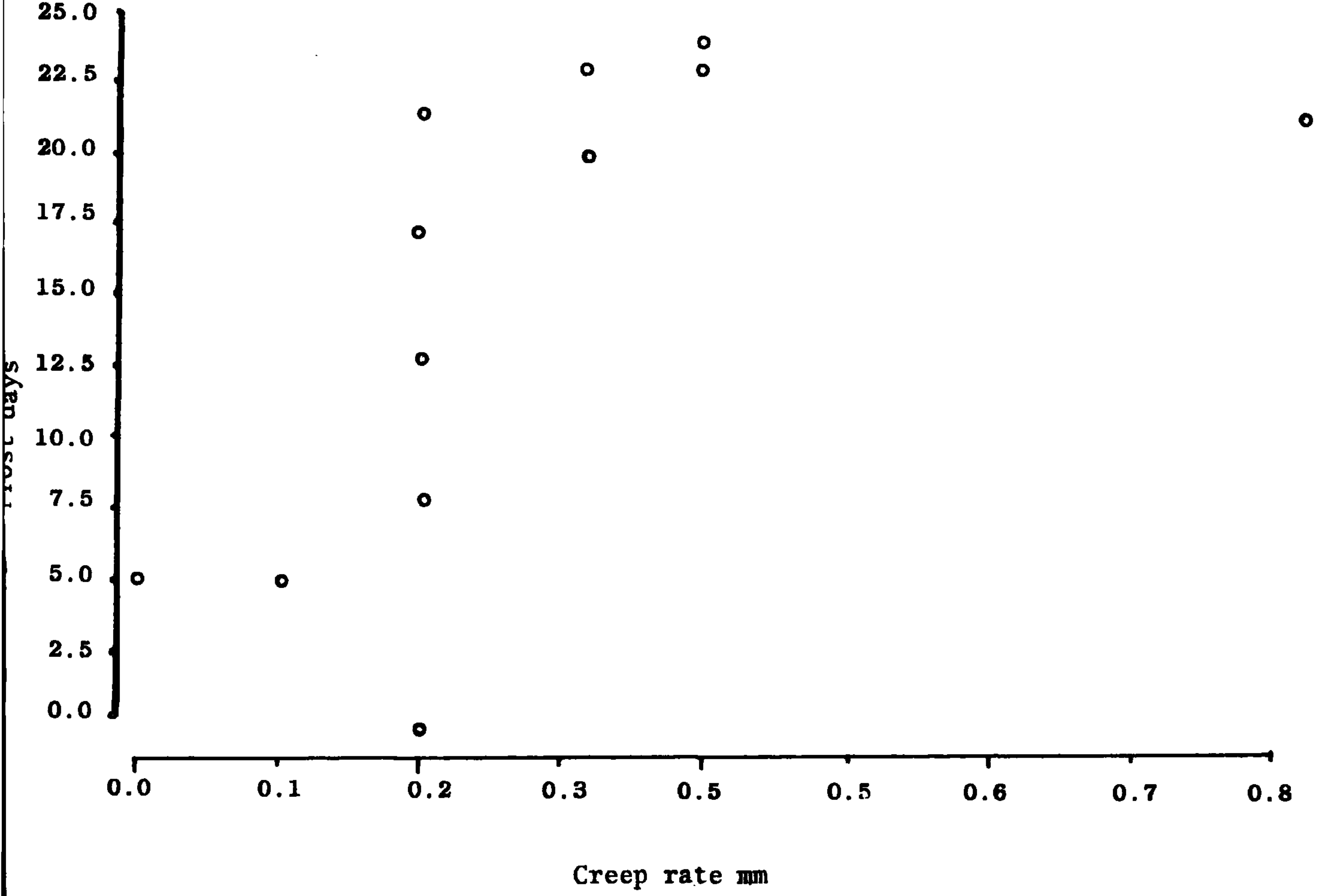


Fig. 7.28 : Scatter plot of monthly creep rates and frost days at sampling site No.1 for 90 mm depth (maximum correlation).

7.3.3 Correlation between volumetric creep rates from Anderson's tubes (35 plots) and fifteen controlling variables

Linear and volumetric creep rates measured by the Anderson's Tubes have been correlated with the controlling variables over 35 plots. The strongest correlations (above 0.38 in magnitude) are with soil depth, soil moisture content (dry and wet seasons), void ratio, porosity and shear strength (negative). The correlations with sine of slope angle stand out as the weakest observed (r = 0.02, 0.022).

From these correlations it follows that the bivariate regressions for several controlling variables have r^2 values of 0.50 to 0.86.

For the sine of the slope angle (Fig. 7.30) no observable pattern can be seen, with an even scatter throughout the range of this independent variable. Figure 7.31 shows a very strong linear trend, with no observed pattern in the residuals. Therefore a linear relationship with soil depth seems a good summary. The restricted range of the independent variable - indicated by a standard deviation of 3.23 cm can somewhat limit the predictive power of this model outside the present data set. In particular, a linear relationship predicts no movement for soil shallower than 36 cm : the full relationship is probably concave up on this plot.

The strong correlations with soil moisture content (wet and dry season) indicate that wetter plots produce much higher creep rates. Stronger correlations between volumetric creep rates and wet season moisture content (r = 0.51) in comparison with dry season moisture content (r = 0.47) indicate that when total saturation is reached soil creep is at maximum and this reflects the influence of higher soil moisture content. On Figures 7.32 and 7.33 two outliers were observed for plots 5 and 10 sampling site No. 1 with low moisture content and high creep rates. These may be accounted for by specific 'on site' conditions. (Three of five plots located on the same slope were diversely moved. It was assumed that this has been caused by processes other than creep).

There seems to be a substantial difference in the behaviour of inorganic and organic soils, especially above 30% organic matter. Figure 7.34 shows a linear trend with a large scatter of residuals at low organic%. Other granulometric properties of the soil matrix are clearly important, especially at low organic per cent values where either high clay per cent or high sand per cent may dominate. Scatterplot Figure 7.34 has also two clear outliers which are similar to those on the scatterplots Figures 7.32 and 7.33.

A negative correlation between creep rates and clay per cent and positive correlation with sand per cent indicate that the ability of soil to resist displacement is dependent on the proportion of clay and sand. Clay and sand have the opposite effect on creeping soils. The correlations between volumetric creep rates and clay per cent (r = 0.35) and sand per cent (r = 0.37) are shown in scatterplots Figure 7.35 and 7.36 with two obvious outliers reveals high residuals at low clay per cent with scatter plot Figure 7.36. There is no consistent pattern to the residuals. (Particle size analysis could not be reliably performed on peaty soils (> 62% organic matter), therefore, scatterplots represented in this study are on the basis of 27 plots).

Obviously, there is no strong relationship between creep rates and soil density (bulk density and dry bulk density). Omitting outliers, there appears to be a relatively strong negative relationship. The correlation coefficient with dry bulk density is stronger than that for bulk density, as water holding capability is removed from the variable. Related to the soil materials, plots are scattered in two groups : organic with low bulk density ranged from 0.98 to 1.35 mg/m^3 with high creep rates, and inorganic ranged from 1.45 to 2.05 mg/m^3 with lower creep rates, (two outliers are omitted), (scatterplots Figures 7.37 and 7.38). It would be expected that the most compact soils would have the greatest internal friction and thus move less .

Porosity and void ratio have positive relationships with creep rates, r = 0.41 for porosity and r = 0.44 for void ratio. Such relationships indicate that soils with the largest proportion of porosity and voids show the highest rates of creep (scatter plots Figure 7.39 and 7.40). (This factor has not been empirically recognised).

In contrast to plastic limit with a weak and insignificant positive relation with creep rates (r = 0.33) liquid limit has a negligible positive correlation (r = 0.13). This indicates that creep behaviour is more sensitive to plastic limit than liquid limit. The two 'outliers' appearing on scatter plots (Figures 7.41, 7.42 and 7.43)are the same outliers as in other scatter plots,(i.e. Figures 7.32, 7.33 and 7.34.)

The negative correlation between creep rate and plasticity index indicates that organic soils have the lowest plasticity index. Thus only very small differences in moisture content separate plastic and liquid behaviour. Soils with low plasticity indices show the highest creep rates (scatter plot Fig. 7.43), but some of them also have low rates. (It should be noted that the liquid limit, plastic limit, and plasticity index tests could not be reliably performed on several of the sandy and peaty samples. Therefore scatterplots are on the basis of 27 plots).

A negative correlation between creep rates and shear strength (r = -0.39) as expected, indicates that soils with high shear strength are more resistant to creep. All soils with low values of shear strength have a high proportion of organic matter and a high moisture content, and are, therefore, more susceptible to creep; soils with high proportions of clay are more coherent with high values for shear strength, and are resistant to creep. The two outliers in scatter plot Figure 7.44 again appear. The correlation coefficients between annual creep rates (linear and volumetric) and controlling variables are shown in Table 7.6.

The appearance of two anomalous 'outliers' (plots No.5 and No.10 at sampling site No.1) in most of scatter plots, suggests that soil movement in these plots occurred not only by the seasonal creep process, but another process has effectively been involved (probably slump). No indication of any other disturbance was found for these plots.

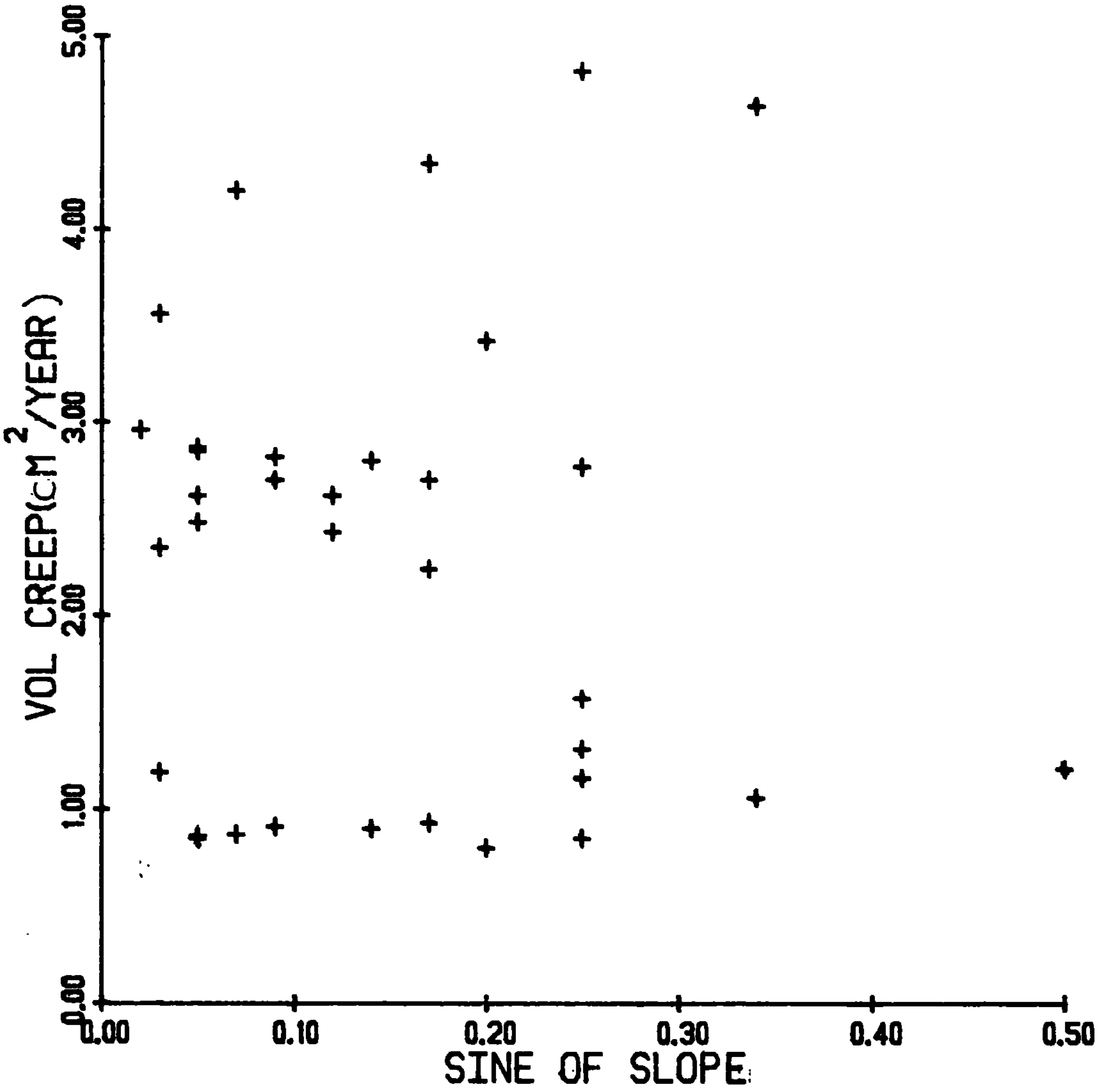


Fig. 7.30 : Volumetric creep rates and sine of slope angle.

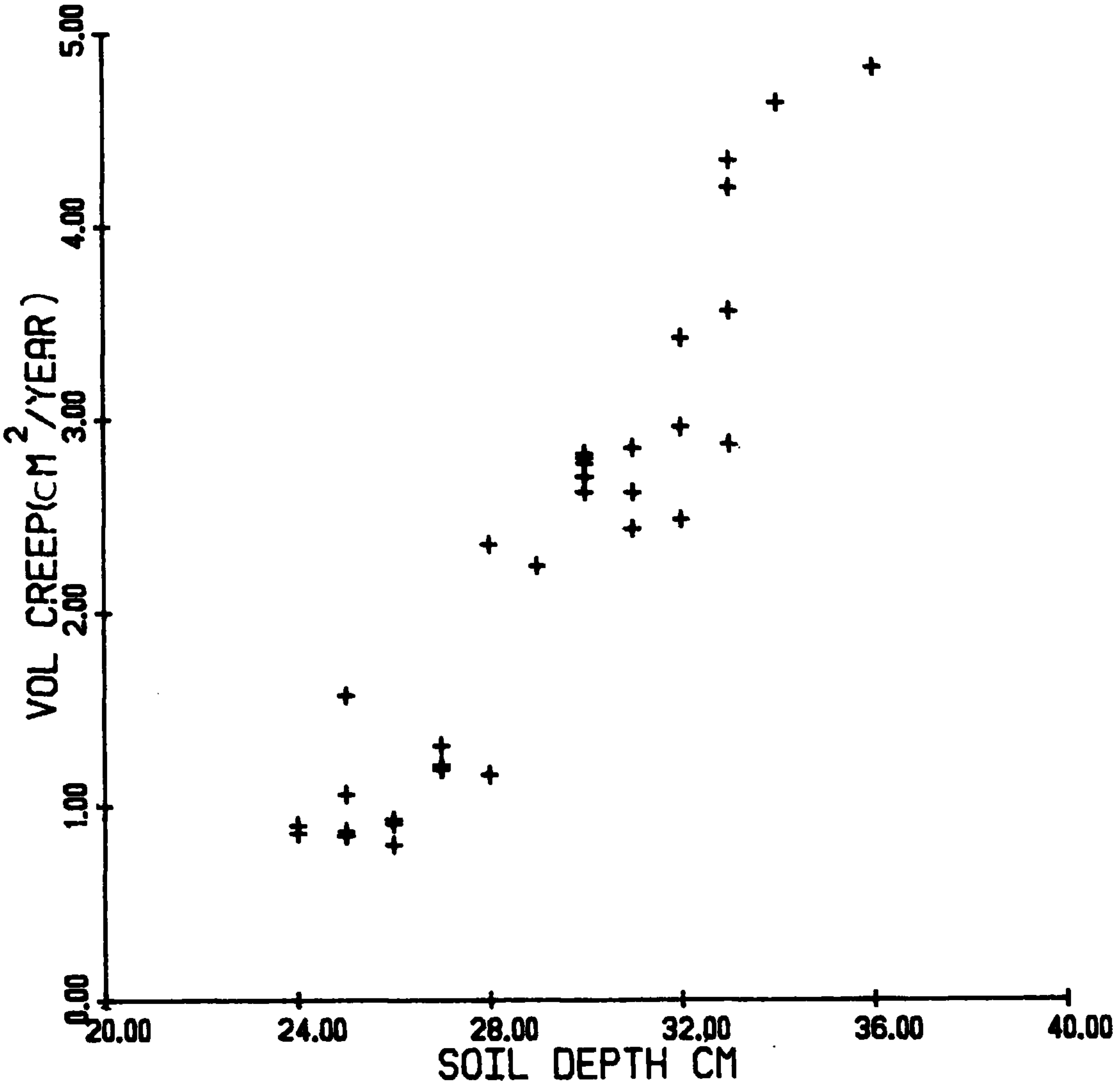


Fig. 7.31 : Volumetric creep rates and soil depth susceptible to movement.

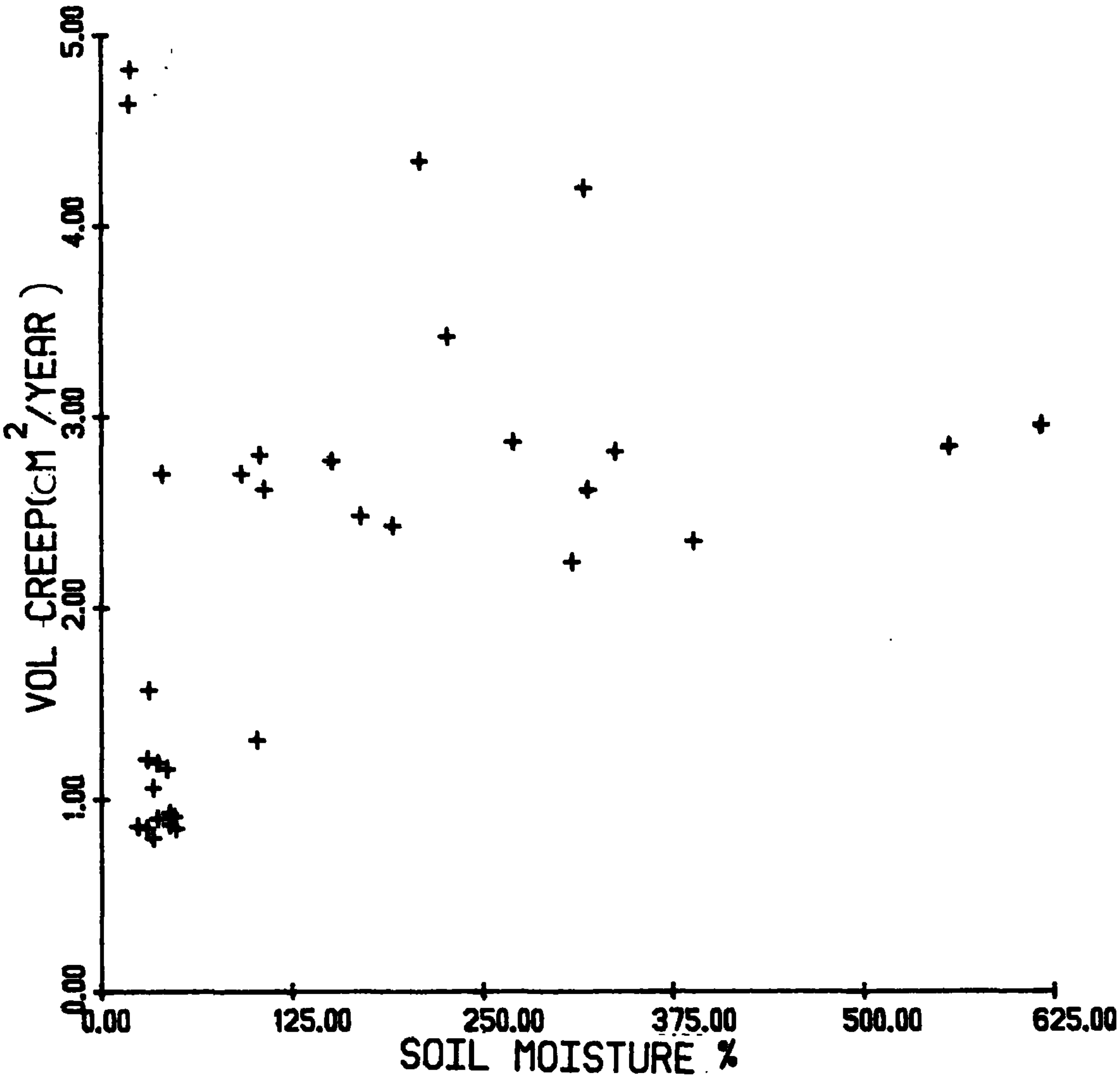


Fig. 7.32 : Volumetric creep rates and soil moisture content (wet season).

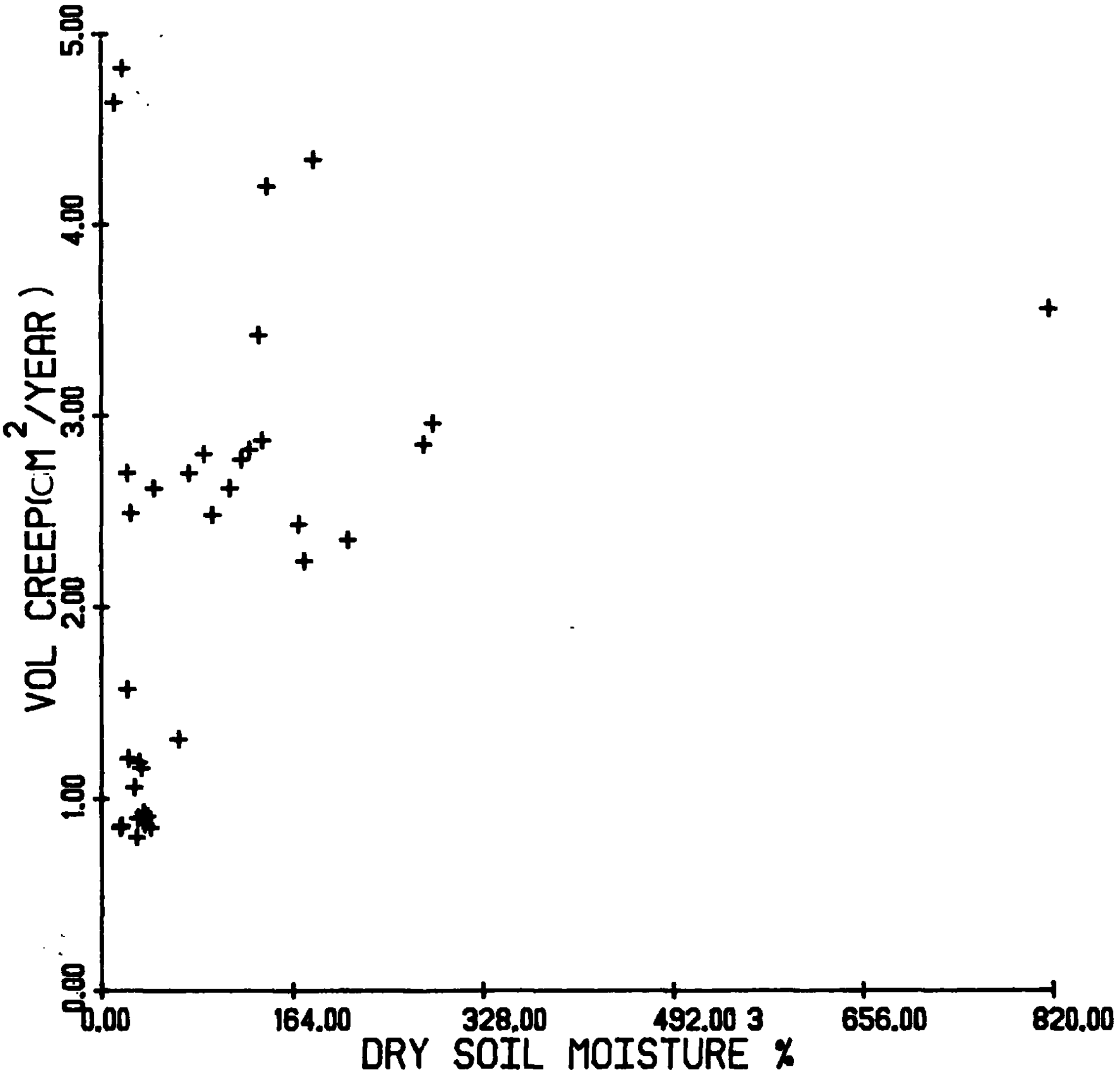


Fig. 7.33 : Volumetric creep rates and soil moisture content (dry season).

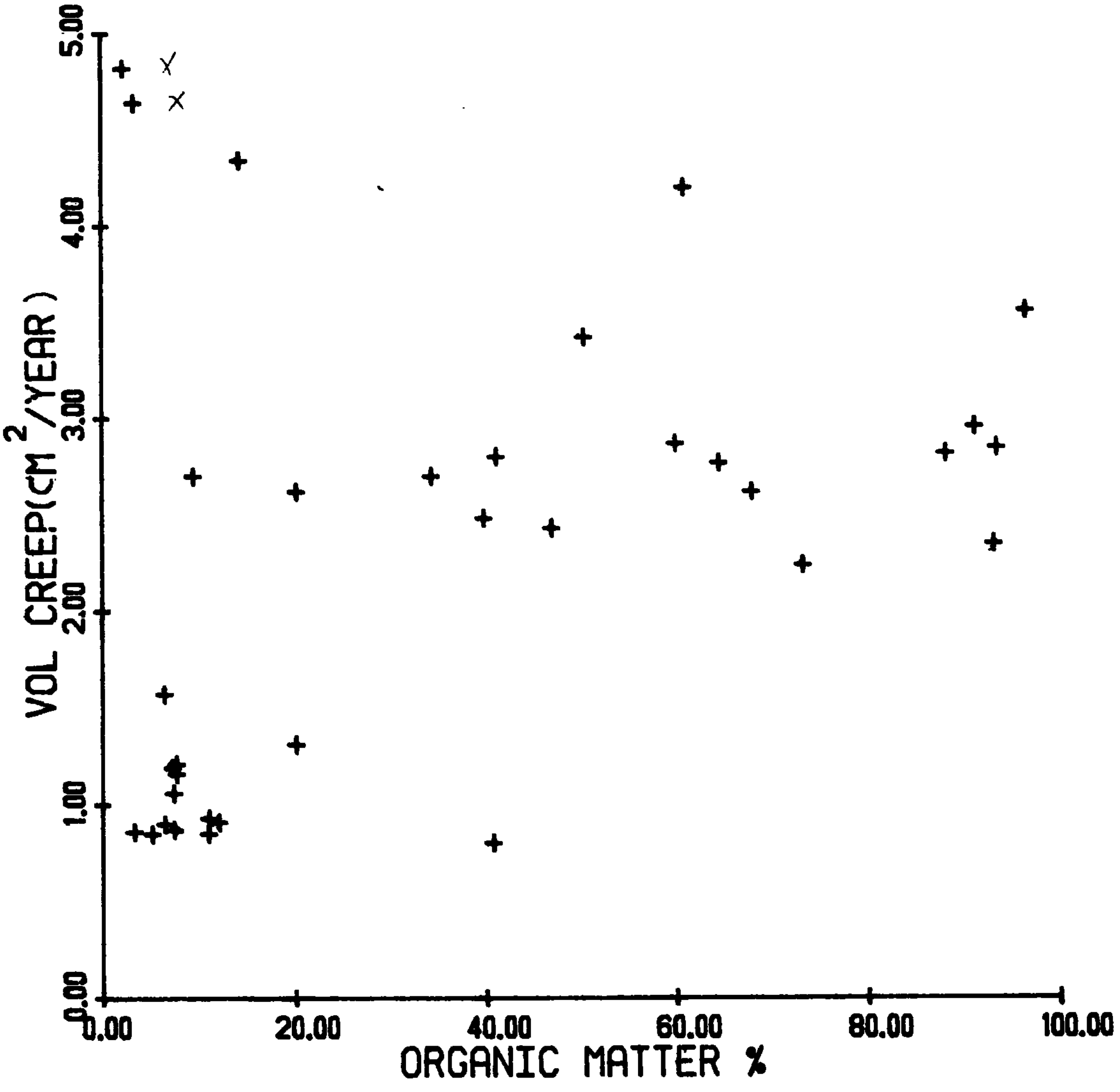


Fig. 7.34 : Volumetric creep rates and soil organic matter.

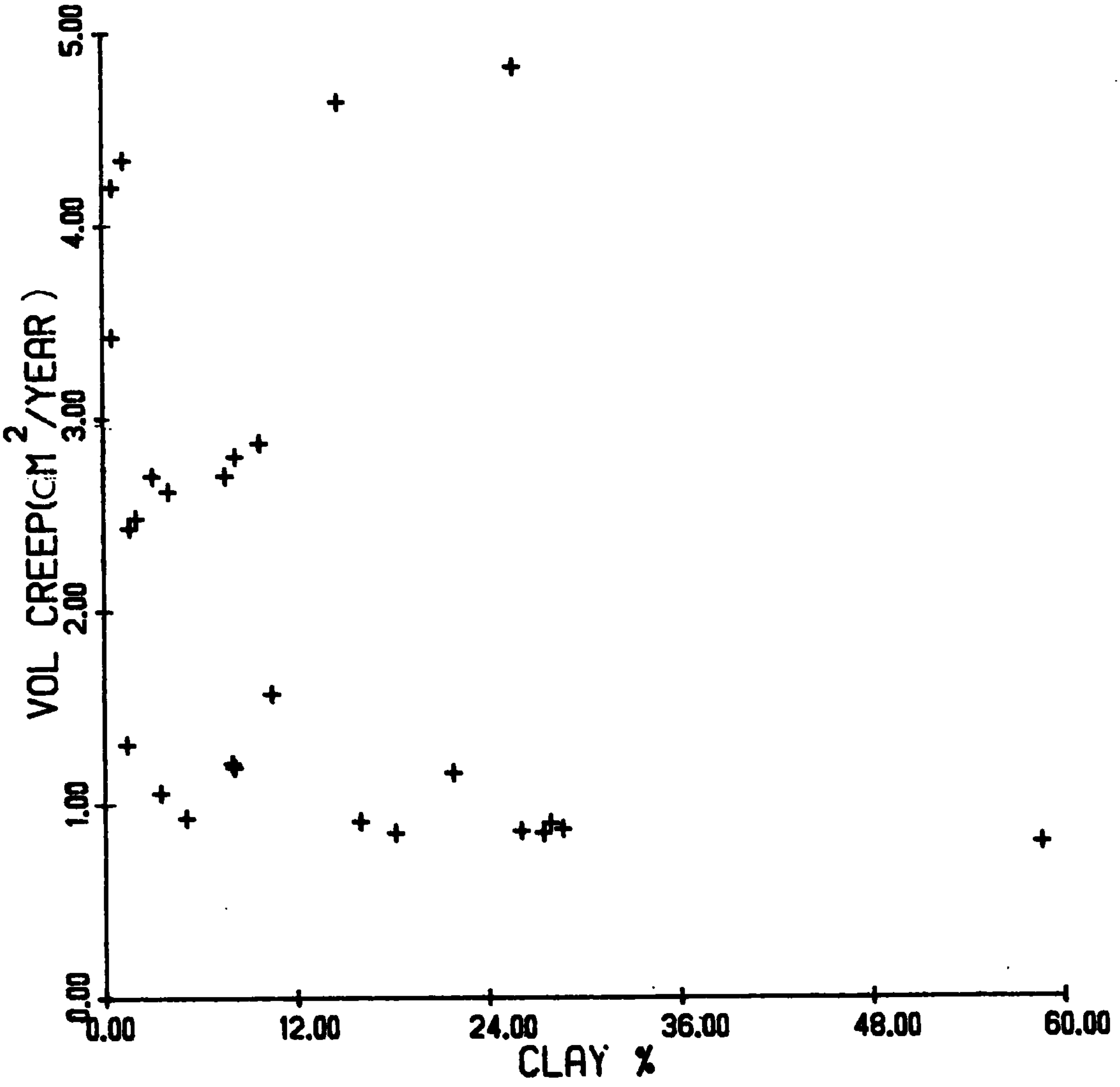


Fig. 7.35 : Volumetric creep rates and soil texture (clay%).

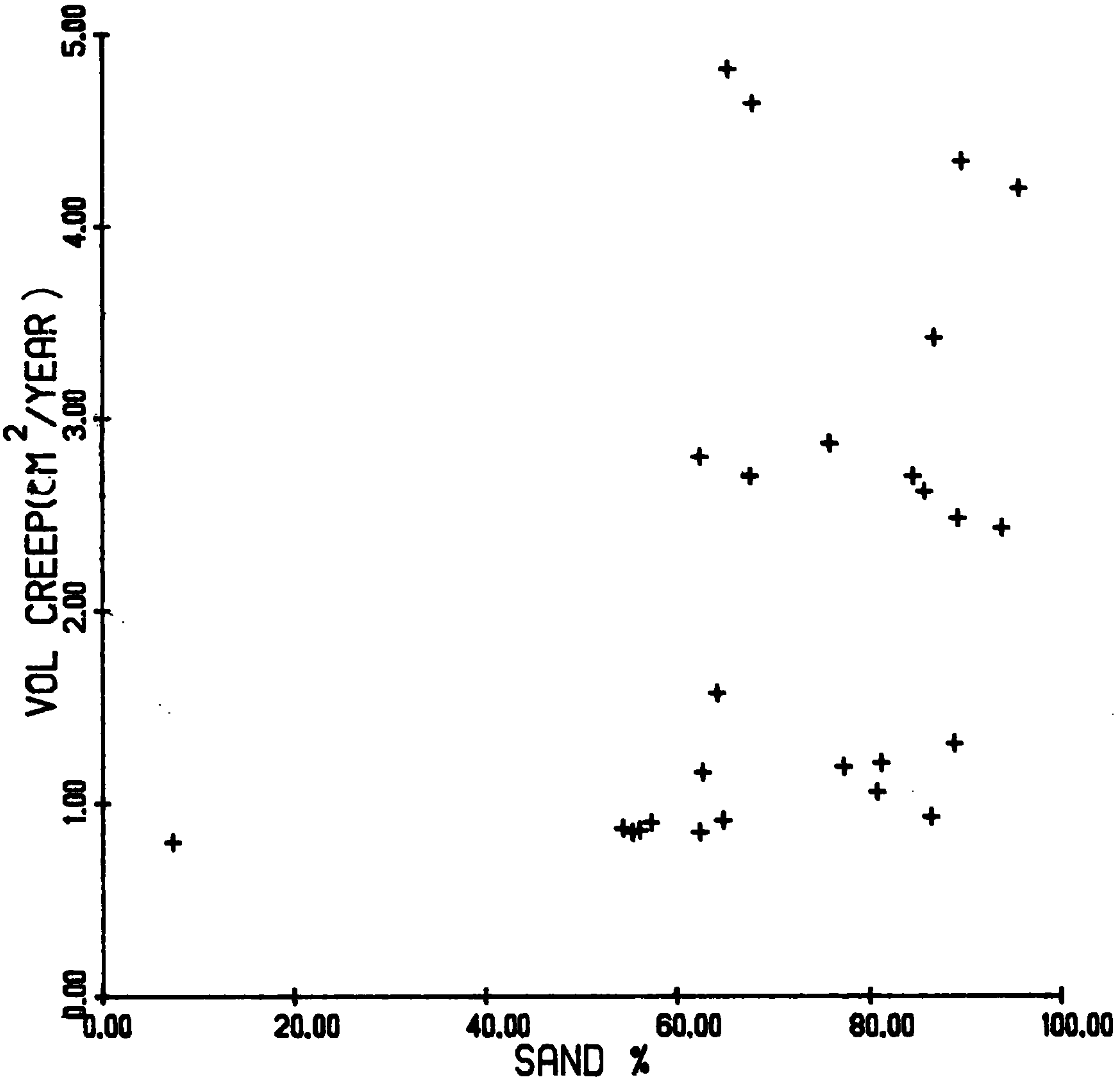


Fig. 7.36 : Volumetric creep rates and soil texture (sand%).

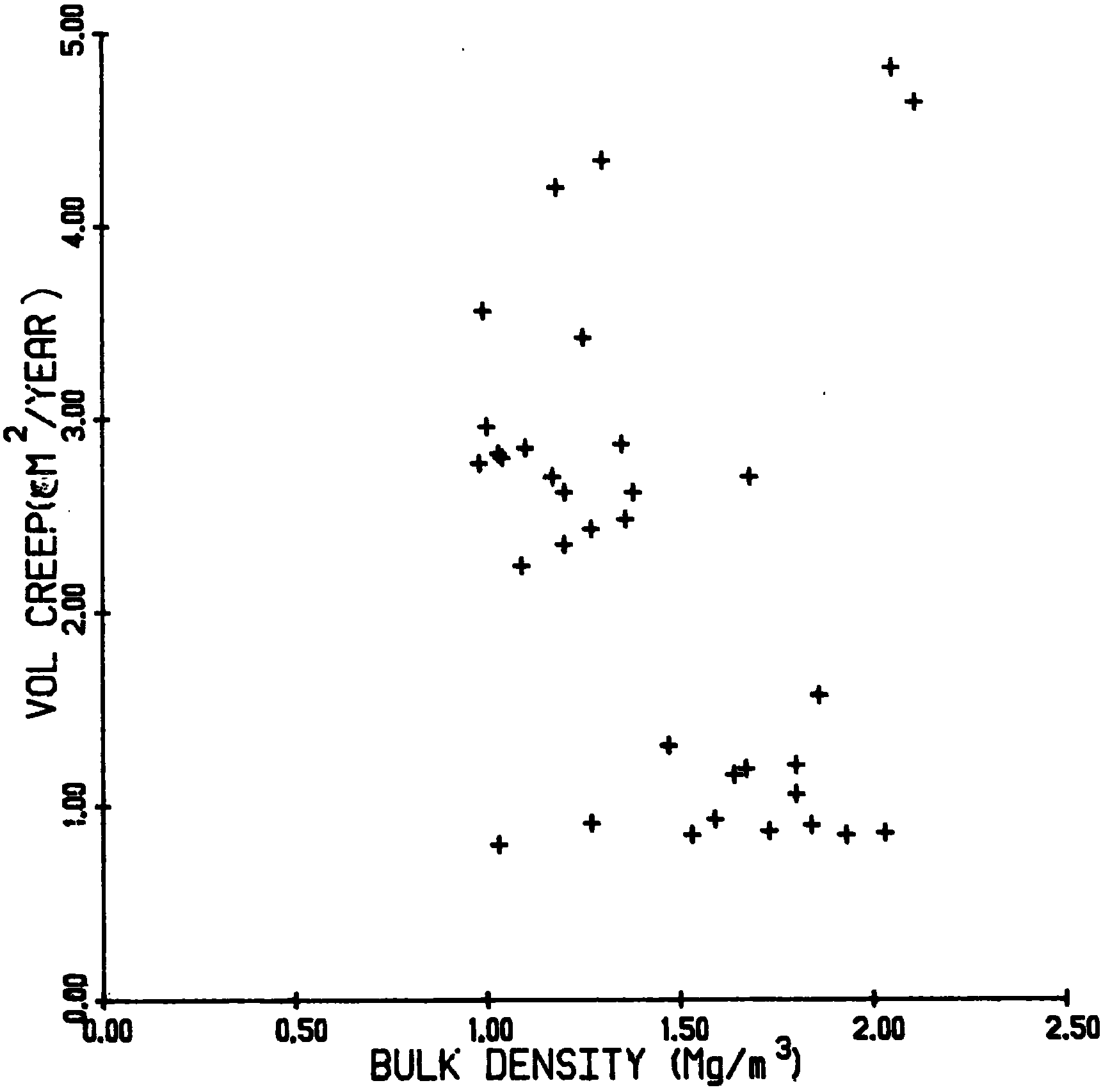


Fig. 7.37 : Volumetric creep rates and bulk density.

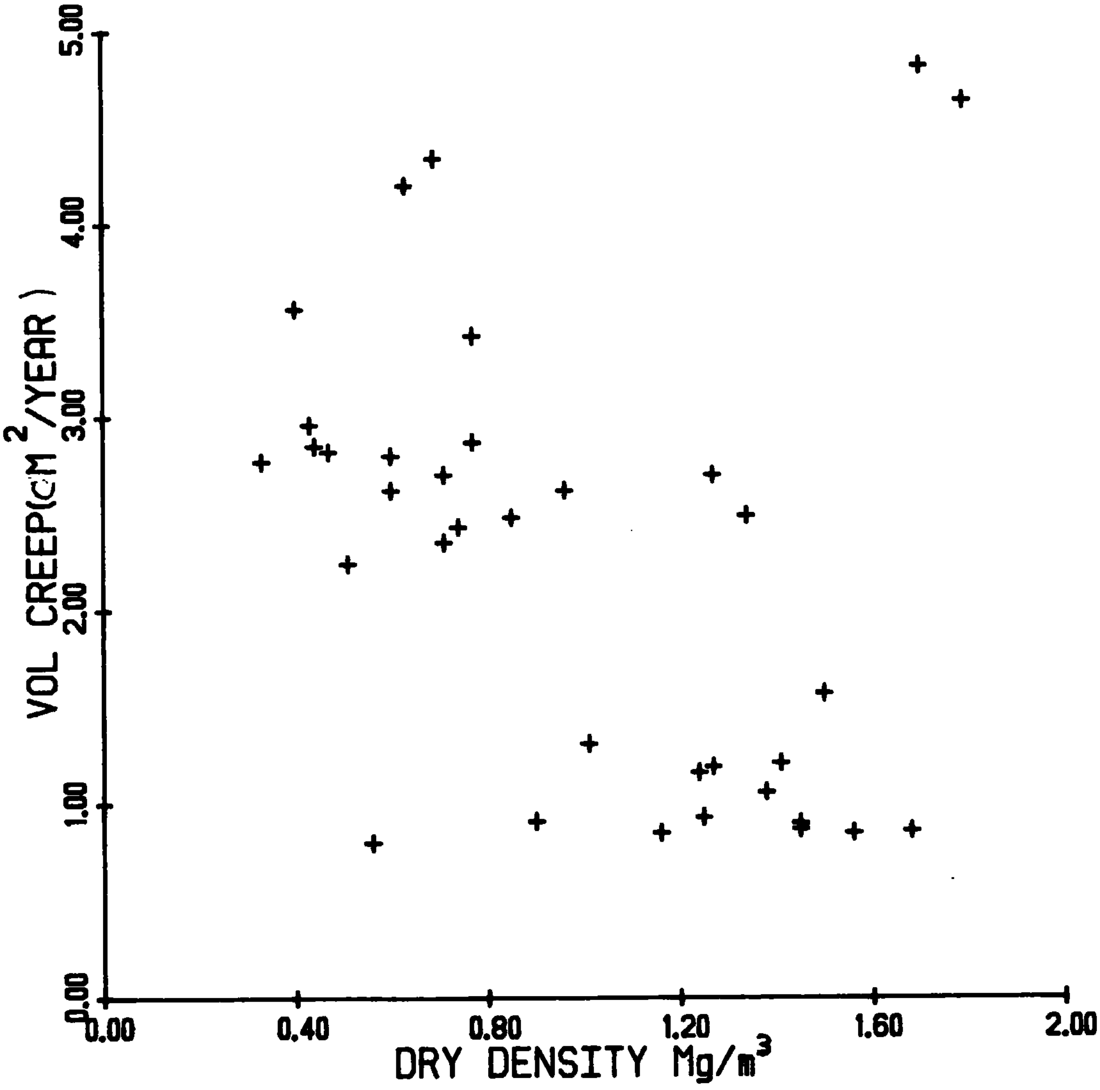


Fig. 7.38 : Volumetric creep rates and dry bulk density.

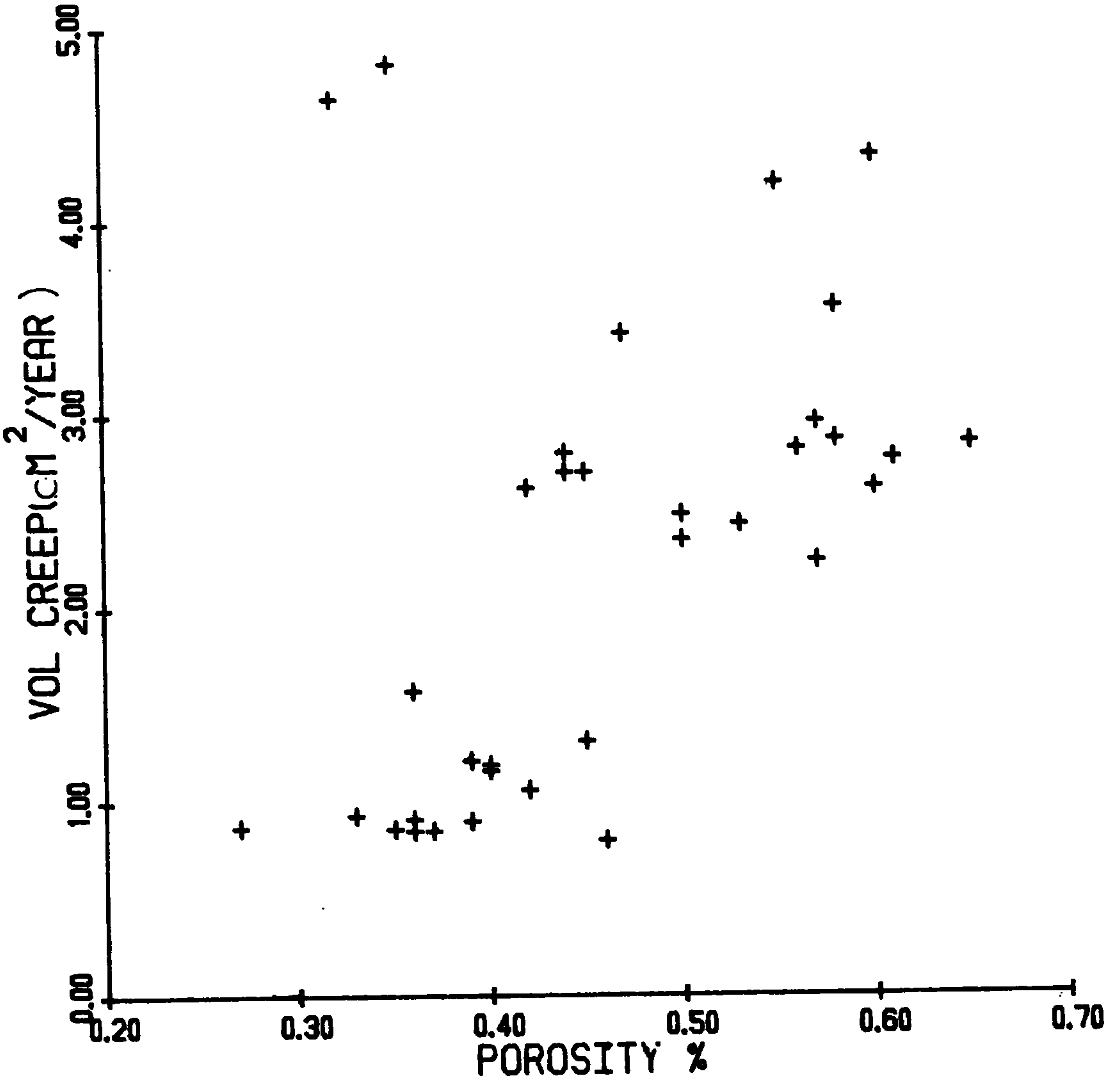


Fig. 7.39 : Volumetric creep rates and porosity.

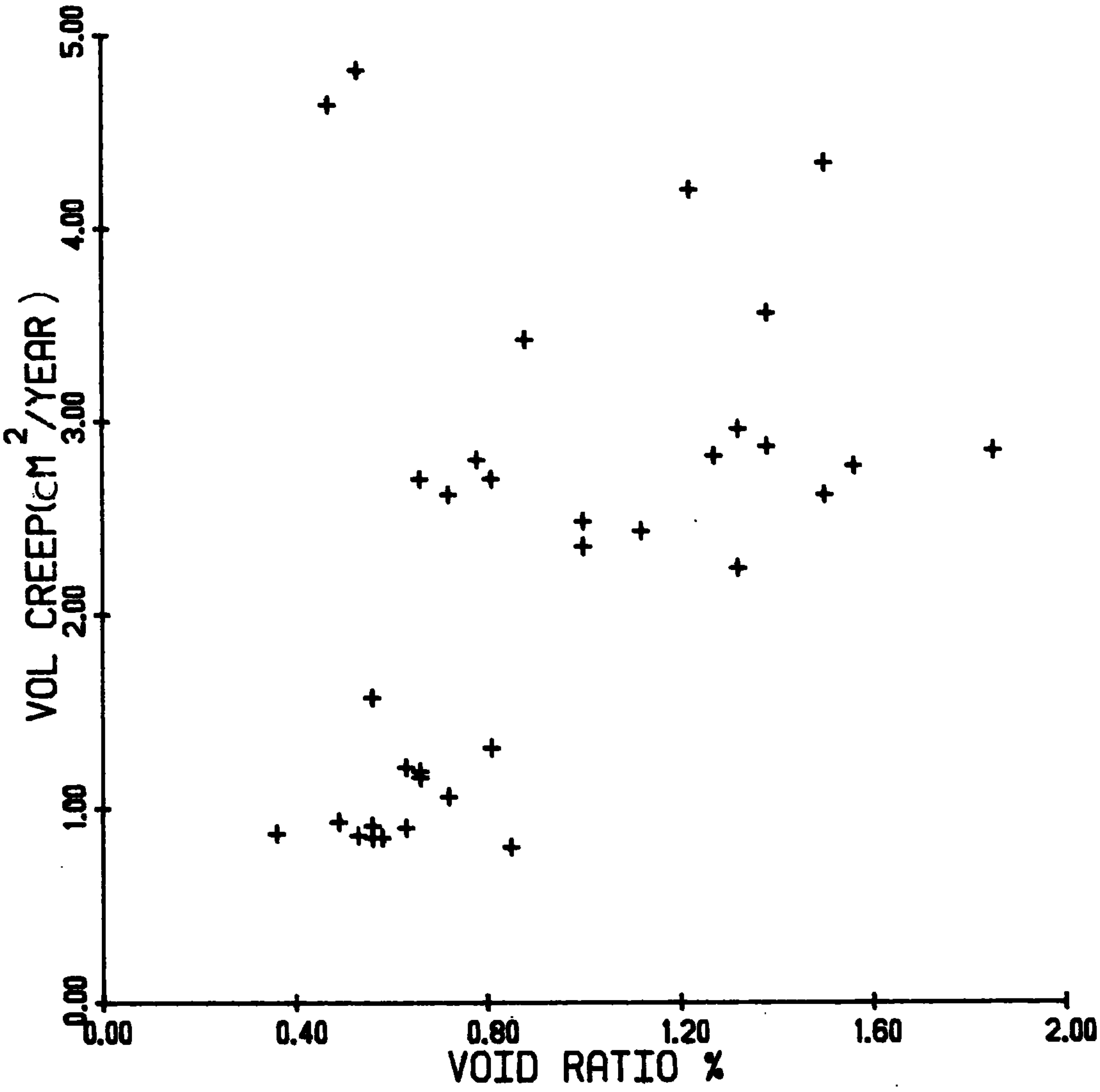


Fig. 7.40 : Volumetric creep rates and void ratio.

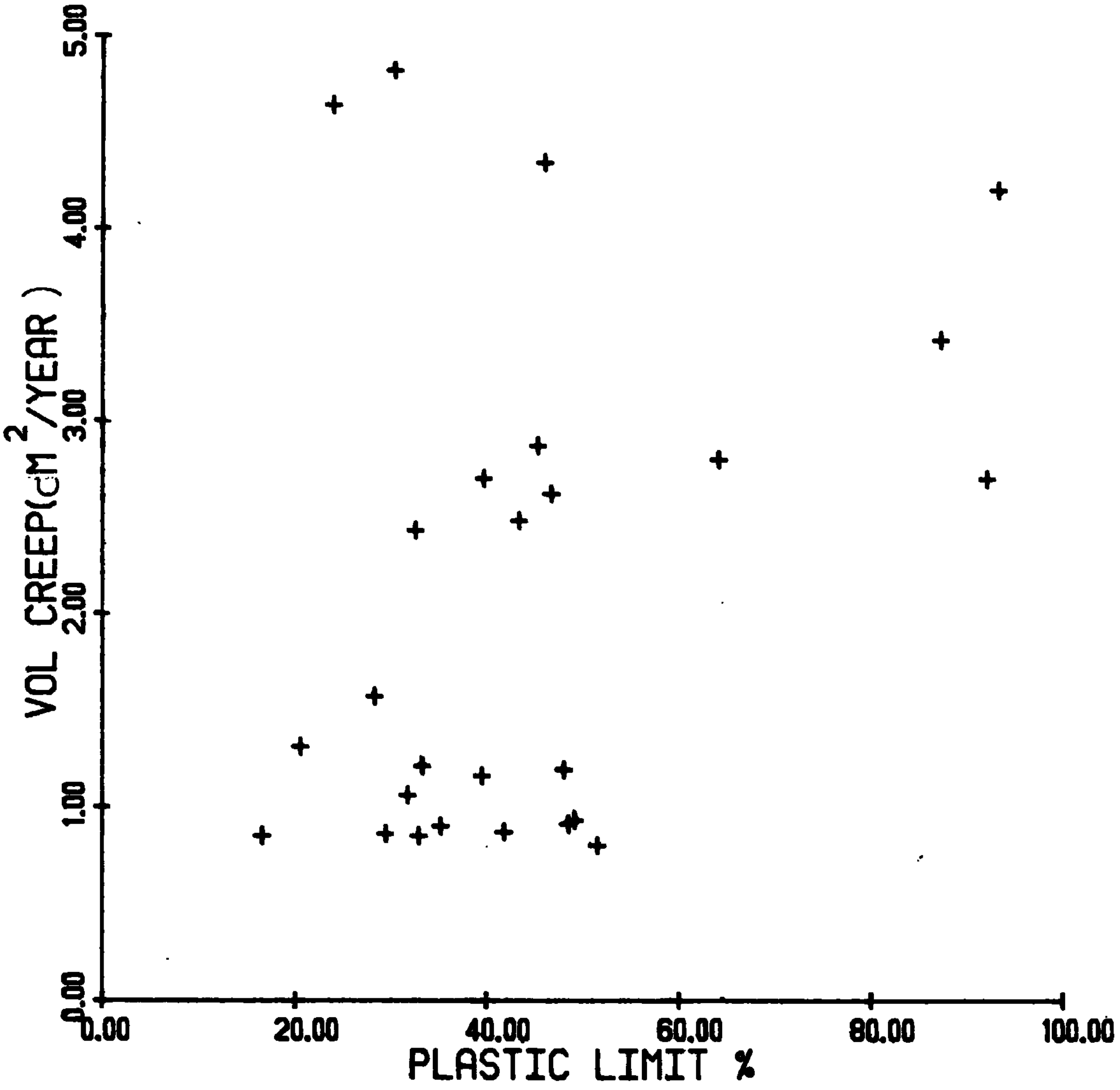


Fig. 7.41 : Volumetric creep rates and plastic limit.

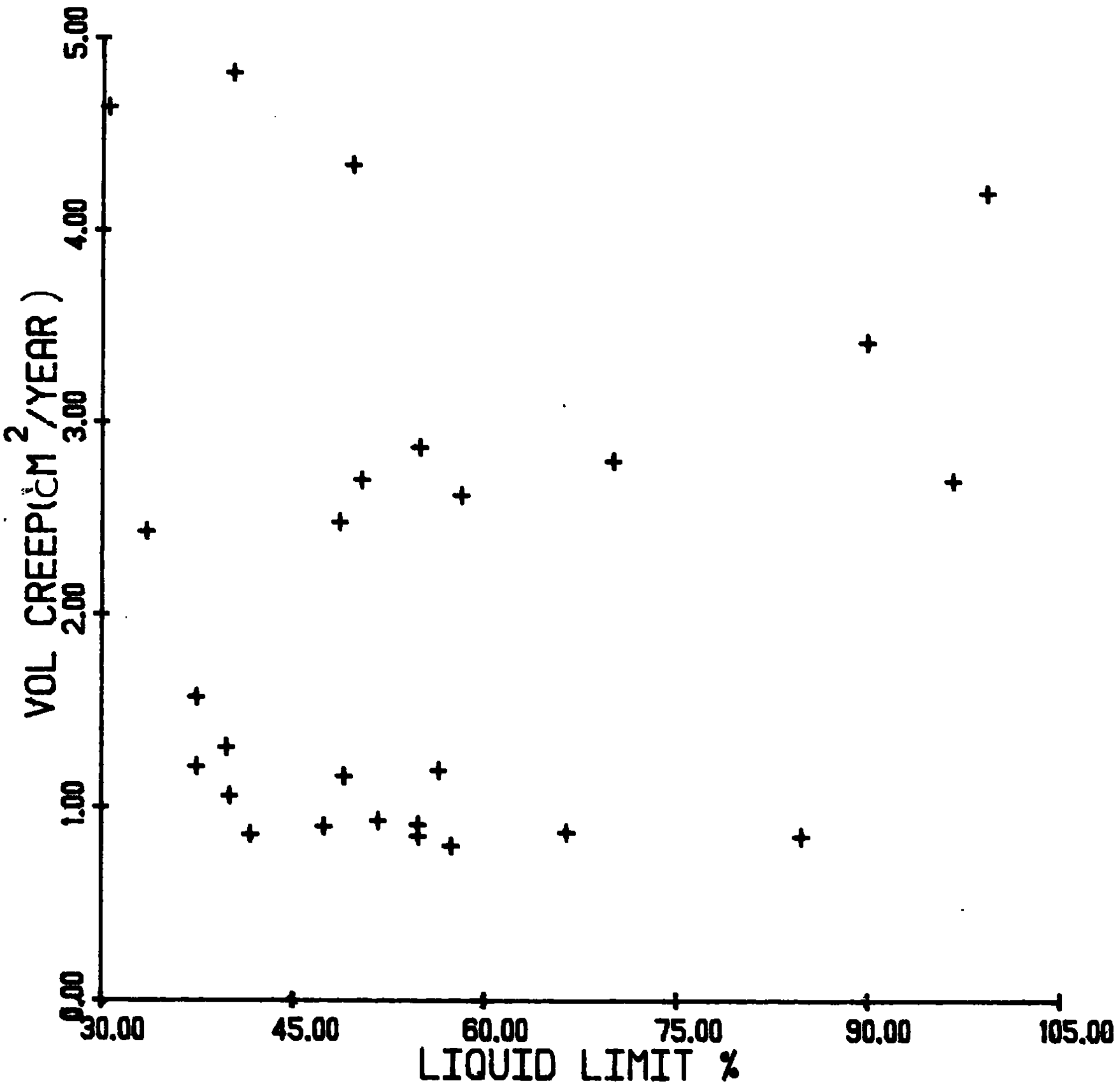


Fig. 7.42 : Volumetric creep rates and liquid limit.

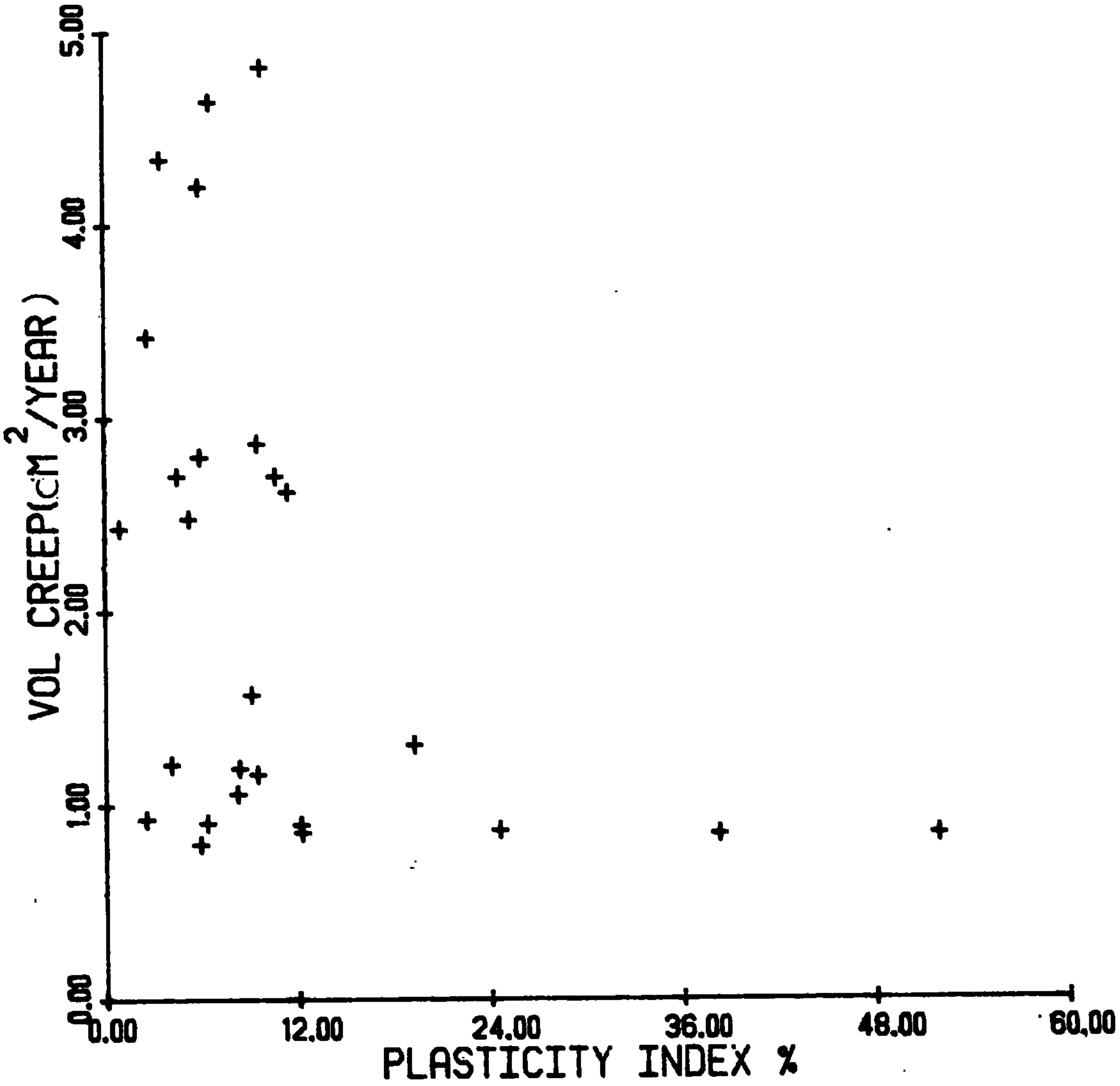


Fig. 7.43 : Volumetric creep rates and plasticity index.

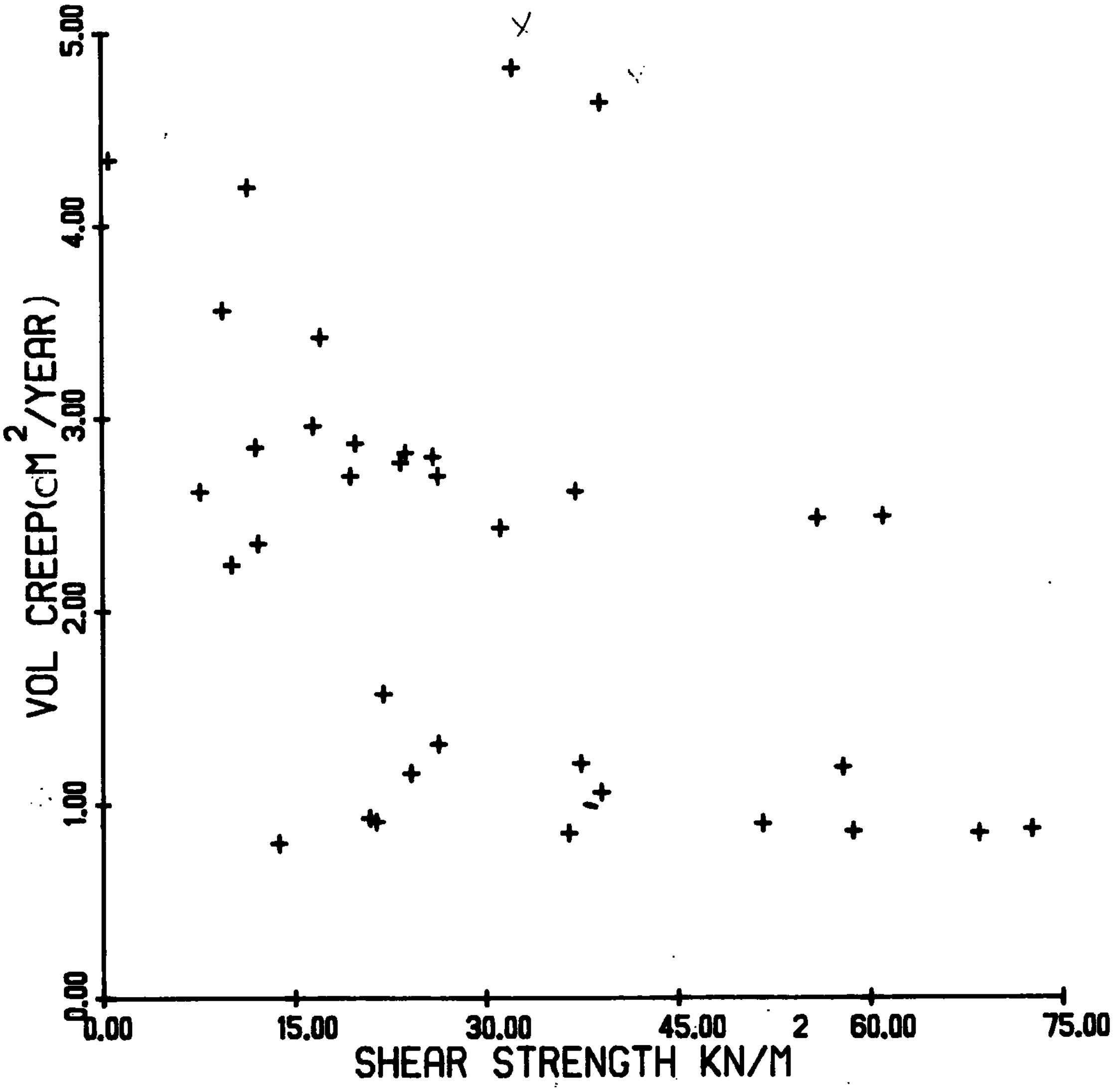


Fig. 7.44 : Volumetric creep rates and shear strength.

Table 7.6 Correlation coefficients between annual creep rates and controlling variables
(Significance level, 95% = 0.38; 99% = 0.49)

Variable	Linear creep rate $mm\ a^{-1}$	Volumetric creep rate $cm^2\ a^{-1}$
1. Sine of slope angle	0.02	0.02
2. Soil depth Cm	0.92	0.94
3. Soil moisture% (wet season)	0.52	0.51
4. Soil moisture% (dry season)	0.49	0.47
5. Organic matter% (loss on ignition)	0.34	0.34
6. Clay%	-0.38	-0.35
7. Sand%	0.38	0.37
8. Bulk density Mg/m^3	-0.14	-0.12
9. Dry density Mg/m^3	-0.20	-0.19
10. Porosity %	0.42	0.41
11. Void ratio %	0.45	0.44
12. Liquid limit	0.15	0.13
13. Plastic limit	0.35	0.33
14. Plasticity index	-0.38	-0.37
15. Shear strength KN/m^2	-0.40	-0.39

CR = Volumetric creep rate $cm^2\ a^{-1}$
SD = Soil depth cm
WM = Soil moisture% (wet season)
DM = Soil moisture% (dry season)
VO = Void ratio
PO = Porosity
SA = Sand%
OR = Organic%
PL = Plastic limit

LL = Liquid limit
SS = Sine of slope
BD = Bulk density
DB = Dry bulk density
CL = Clay%
PI = Plasticity index
SH = Shear strength

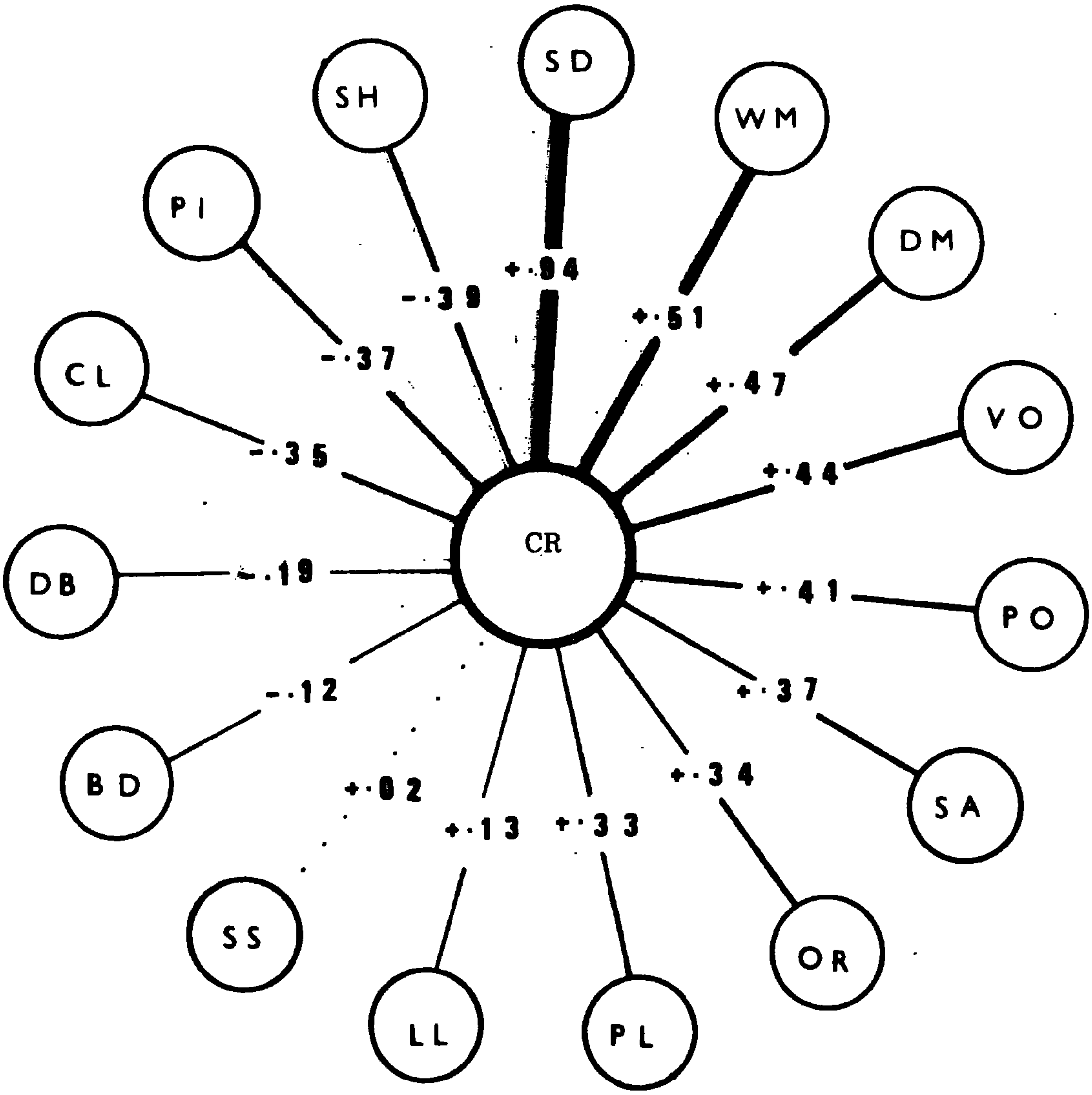


Fig. 7.45 : A portrait of correlation between creep rate and fifteen possible controlling variables in the study area. Stronger correlations are at the top : positive correlations are on the right.

7.4 Interrelationships between possible controls

The relationships between the variables measured at each plot within the study area can be displayed in a correlation matrix. This is expressed by Pearson's product moment correlation coefficients. See Table 7.7 and Figure 7.46.

With a sample size of n = 27, correlations above ±0.38 are significant at the 95% confidence level (the chance that they could be produced by random selection from a population with zero correlation is less than 5%), and those stronger than ±0.48 are significant at the 99% confidence level.

A core group of seven variables is strongly intercorrelated. For six of these all intercorrelations exceed ±0.68 : these are porosity, void ratio, moisture content (dry and wet seasons), organic matter (all positive intercorrelated) and dry density and bulk density (negatively correlated with the other four). Shear strength is also correlated ±0.50 or better with each of the seven variables.

Two further variables, plastic limit and liquid limit, which correlate +0.83 with each other are on the fringe of this main group in that plastic limit is significantly correlated with moisture content, organic matter, bulk density, dry density and shear strength, with four correlations exceeding ±0.55. This core group, then, represents soil looseness, plasticity and moisture content, and includes several variables which are simply different ways of measuring the same thing. The looser, wetter, less resistant soils are also deeper.

Another two variables, clay% and sand% are strongly negatively correlate with each other and form an 'outer fringe' in being correlated significantly with four variables, of the ten mentioned so far : but these correlations are only moderate and neither variable correlates significantly with organic matter and density. Clay's only other notable correlation is with shear strength (+0.32, which is below the 95% significance threshold).

Finally, the sine of the slope angle and plasticity index tend to be the weaker variables correlated with the others. The sine of the slope angle's strongest relationships are 0.46 with bulk density, -0.45 with moisture content (wet season) and organic matter. Plasticity's strongest relationships are -0.46 with plastic limit, -0.43 with porosity and -0.40 with void ratio.

The general pattern, then is of a core of closely-knit variables, with fringe fading into a chain of variables with mainly weak correlations.

The main conclusions from this correlation analysis are: If we look at the strongest correlations (r = 0.48) between the variables we can find a cluster of variables closely related to each other (Table 7.7 Fig. 7.46), soil moisture content (wet and dry seasons), organic matter, porosity, void ratio and soil density. Wetter soils tend to be deeper, and deeper soils tend to be more porous. Also denser soils tend to be more resistant (higher shear strength). The strong but negative relationship between clay per cent and soil moisture content; bulk density, dry bulk density and liquid limit and plastic limit, also bulk density, dry bulk density and porosity and void ratio and between shear strength and porosity and void ratio revealed that the following relations occur:

i. Higher moisture content with less clay per cent.

ii. Denser soils with low plastic limit, low liquid limit and low proportion of porosity and voids.

iii. High shear strength with low porosity and void ratio.

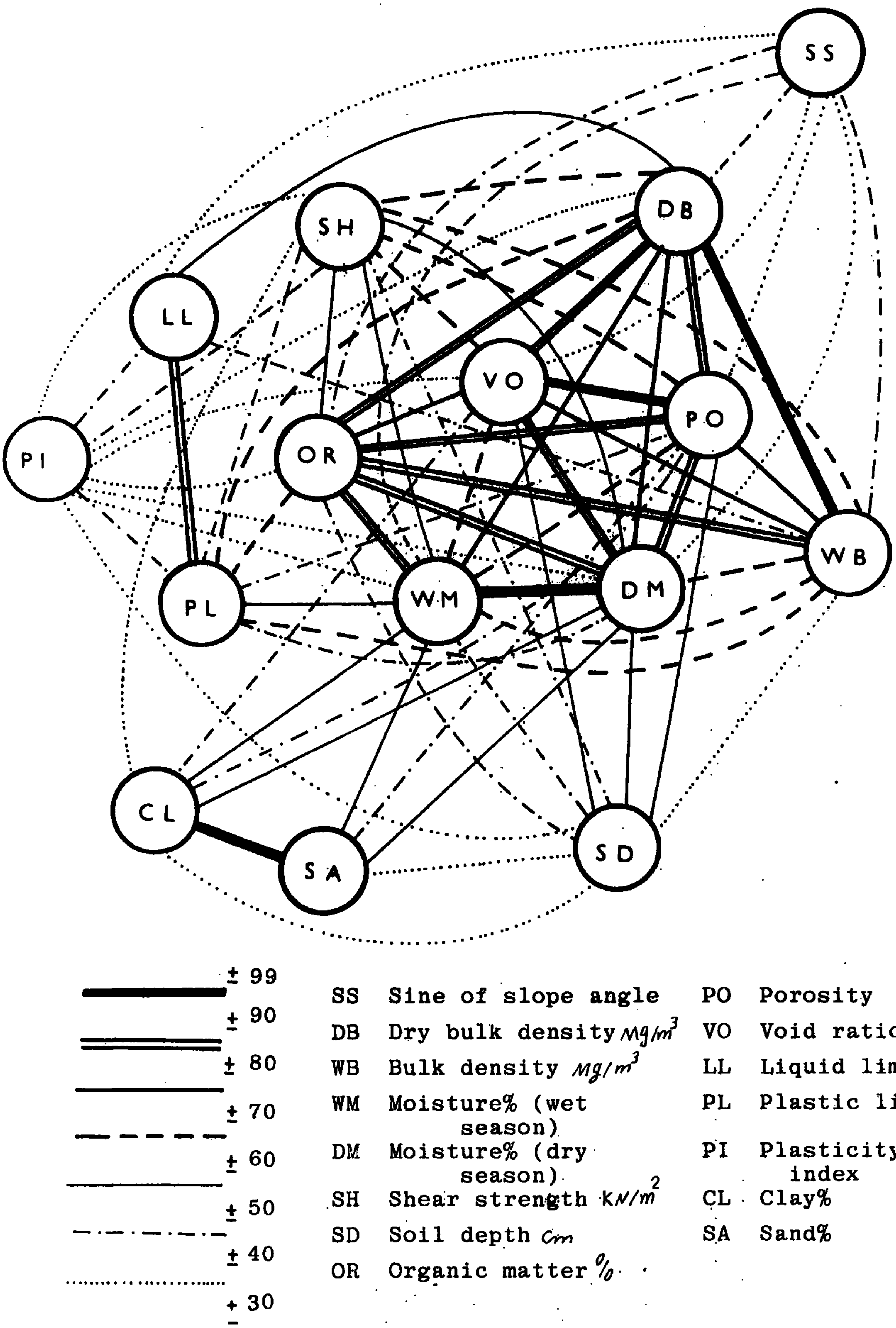
iv. Less dense soils with high organic matter.

Bringing together correlations between creep rates and possible controlling variables measured for this study and interrelationships among the variables revealed that those variables which are strongly correlated with creep rates are generally strongly correlated with each other. This supports the idea "that any attempt to go beyond single-predictor regressions is unlikely to be very successful, since there does not appear to be any component of variation in creep that is uncorrelated with moisture-related variables". (Anderson and Cox1981).

Table 7.7

Basin factors : Correlation matrix n = 27 significance level : 95% = .38; 99% = .48

Variable																		
1.V1	1.00																	
2.V2	-.04	1.00																
3.V3	-.36	.57	1.00															
4.V4	-.35	.45	.85	1.00														
5.V5	.04	-.36	-.51	-.28	1.00													
6.V6	-.05	.39	.55	.27	-.95	1.00												
7.V7	.41	-.28	-.62	-.79	.22	-.16	1.00											
8.V8	-.21	.49	.84	.75	-.43	.44	-.65	1.00										
9.V9	-.23	.51	.87	.73	-.41	.43	-.62	.98	1.00									
10.V10	-.36	.10	.42	.49	-.08	.08	-.49	.22	.20	1.00								
11.V11	-.30	.32	.56	.65	-.27	.25	-.65	.41	.38	.83	1.00							
12.V12	-.06	-.40	-.30	-.34	.34	-.32	.34	-.37	-.35	.18	-.40	1.00						
13.V13	-.10	-.37	-.45	-.45	.32	-.26	.57	-.57	-.56	-.12	-.42	.53	1.00					
14.V14	.39	-.30	-.71	-.83	.28	-.23	.99	-.76	-.73	-.46	-.63	.36	.60	1.00				
15.V15	-.32	.52	.92	.76	-.52	.55	-.66	.85	.89	.29	.47	-.35	-.50	-.75	1.00			
16.V16	.02	.92	.52	.34	-.38	.38	-.14	.42	.45	.15	.35	-.38	-.40	-.20	.49	1.00		
17.V17	.02	.94	.51	.33	-.35	.37	-.12	.41	.44	.13	.33	-.37	-.39	-.18	.47	.99	1.00	
18.V18	-.15	.63	.57	.47	-.43	.42	-.33	.51	.49	.24	.43	-.35	-.17	-.38	.54	.59	.58	1.00
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.
	V1	V2	V3	V4	V5	V6	V6	V8	V9	V10	V11	V12	V13	V14	V15	V16	V17	V18
	SS	S.DI	WM	OR	CL	SA	BD	PO	VO	LL	PL	PLI	SH	DD	DM	LCR	VCR	S D2



SS	Sine of slope angle	PO	Porosity
DB	Dry bulk density Mg/m^3	VO	Void ratio
WB	Bulk density Mg/m^3	LL	Liquid limit
WM	Moisture% (wet season)	PL	Plastic limit
DM	Moisture% (dry season)	PI	Plasticity index
SH	Shear strength KN/m^2	CL	Clay%
SD	Soil depth cm	SA	Sand%
OR	Organic matter %		

Fig. 7.46 : Possible variables controlling soil creep
K. Rashidian 1984.

7.5 Discussion of variables controlling soil creep rates

Annual creep measured in the study area provided a basis for evaluating the effect of different environmental factors on rates of soil creep. Despite the obvious interrelationships between some of the soil properties, they are considered firstly as separate factors.

7.5.1 Soil moisture content

The data analysis for 35 plots in the study area revealed a strong relationship between soil moisture content at two conditions (wet and dry seasons) and creep rates. The stronger correlations with wet season condition express the influences of soil water content. The soil water content is affected by several surface conditions of the slope which serve to increase the infiltration rate. These include abundant shallow-rooted vegetation, a thin layer of litter, and animal burrows (Campbell 1975). Apart from the two anomalous plots, the highest values of creep rate occurred in the wettest plots. This indicates that the wetter plots tend to be more mobile and susceptible to movement. The importance of soil moisture for soil creep was postulated by a number of workers, e.g. Kirkby (1963, 1967), Young (1958), Evans (1974), Everett (1963), Owens (1969), Benedict (1970) and Anderson (1977). Hence it can be assumed that soil moisture is the most important factor governing soil creep, particularly in temperate climates. It is difficult to isolate the effect of soil moisture on soil creep from that of other soil properties because of the strong interrelationships discussed in the previous section.

7.5.2 Soil texture

To clarify the relationship of creep rates and soil texture and its importance it was decided:

(a) To group the plots measured for this study into four classes (in order of the percentage of clay and sand and soil texture).

(b) To calculate the mean of creep rates for each class.

For this purpose no standard procedure is available. Therefore, values for class intervals for clay and sand per cent are arbitrarily selected. Tables 7.8 and 7.9.

Table 7.8 Classification of clay per cent for plots measured for this study and mean creep creep rates mm a^{-1}.

Clay%	0-9	10-19	>20	peat
No.of plots	15	4	8	8
Mean creep rate mma	1.58	1.34	1.08	1.80
Variance	0.34	0.69	0.46	0.03
Standard deviation	0.59	0.83	0.68	0.17

This table confirms the inverse relationship between creep rates and clay per cent. The mean creep rate for fifteen plots containing 0-9 per cent clay was 1.58 mm a^{-1} whereas for 8 plots containing more than 20 per cent clay it was 1.08 mm a^{-1}. Compared with the highly organic soils, soils with a high proportion of clay are less susceptible to creeping.

Table 7.9 Classification of sand per cent for plots measured for this study and mean creep rates mm a^{-1}

Sand%	<65	65-85	>85	Peat
No.of plots	11	8	8	8
Mean creep rate mm a^{-1}	0.95	1.67	1.72	1.8
Variance	0.18	0.51	0.41	0.03
Standard deviation	0.42	0.71	0.64	0.17

The high rate of creep observed was for the group of plots containing more than 85% sand, and the lowest creep rate occurred for the group of plots with less than 65% sand. This indicates that sandy soil is more susceptible to movement. This is supported by a correlation of 0.38 between creep rates and sand per cent, which is on the 95% threshold of significance.

Table 7.10 Classification of soil texture for plots measured for this study and mean creep rates mm a^{-1}

Texture	No.of plots	Mean creep rate mma^{-1}	Variance	Standard deviation
Peat	8	1.8	0.03	0.17
Sand, loamy sand	13	1.54	0.38	0.62
Loam, silty loam	7	1.41	0.5	0.7
Silty clay, silty clay loam	7	1.11	0.52	0.72

The sand and loamy sand plots with a mean of 1.54 mma^{-1} shows the highest values and the silty clay and silty clay loam with a mean of 1.11 mma^{-1} represent the lowest values for mineral plots. Again the mean creep rate value for 'peat' (soil with over 62% organic matter) is significantly higher than that for mineral soils.

Sandy soils have a high angle of internal friction and are most permeable. Clay and silty clay soils have low angles of internal friction and are generally impermeable. Consequently, saturation or soil moisture content as a major control of soil creep is dependent on soil texture. Also, according to the laboratory evidence in the context of a force or resistance model, the behaviour of clay particles is complex (Skempton, 1953). The important points arising in this context can be summarized:

(a) The size percentage of soil particles appear to be important factors controlling soil creep. Sand increases soil creep by permitting higher water contents.

(b) Highly organic soils (peat) are more susceptible to frost action in which creep is faster than in mineral soils.

(c) Over certain ranges of moisture content, clays generally show plastic properties, but when dry, clays show little or no plasticity.

As a result soil texture may affect many soil properties controlling the creep rate, such as plasticity index, shrinkage limit, permeability etc.

7.5.3 Slope angle

The influence of slope angle on creep rate has been widely argued : Kirkby (1963), emphasized the importance of slope angle in the creep process (Carson and Kirkby, 1972 p.289). Evans (1974) stated "there is no proof to support the hypothesis that slope angle is of major importance in governing soil creep" (p.167). Anderson and Cox (1981) are of the opinion that sine of slope angle is not an important factor controlling creep rate for soils in the Rookhope catchment and found a low negative correlation between creep rate and sine of slope angle (r = -0.44).

The negligible correlation between sine of slope angle and creep rate found in this study (r = 0.02), over the range 0.02 to 0.5 on the sine scale, i.e. 1 to 30 degrees, supports this opinion and reinforces Young's statement "If theoretical considerations are ignored, and only the results of field measurements taken, the hypothesis that in humid climates soil creep varies with slope angle is not proven." (1958, p.52). The same results emerge from other workers (Kojan, 1967; Owens, 1969; Williams, 1973); all show either no relationship to slope angle or a very weak one at best.

7.5.4 Soil depth susceptible to movement

The thicker soil layers generally tend to maintain more moisture in the soil and allow the extension of plant roots. This has two different results:

(a) A dense root mat concentrated in the upper soil layers increases resistance by binding the soil.

(b) The root mat drains the soil and decomposes to increase susceptibility to creep.

Probably, the first situation applies to those plots in which the soil depth is not more than 0.3m, and the second alternative is applicable to the plots with a soil depth of >0.4m. Young (1963) measured movement deeper than 0.3m, Everett (1963) at 0.15 m, and Kirkby (1967) at o.2 m below the soil surface.

In this study the soil depth susceptible to movement ranged from 0.23 m to 0.36 m below the surface.

At sampling stations most profiles show decreasing rates of movement with depth (below 0.18 m) due to the fact that changes in soil moisture, the major cause of seasonal creep, are greater near the soil surface. The strong correlation coefficient between soil depth susceptible to movement and creep rates (r = 0.94) reveals the importance of this variable as a control of the soil creep process. It corresponds closely to the thickness of the soil layer.

7.5.5 Organic matter

The creep pattern in the high organic soils (peat) is obviously different from that in mineral soils. This is to be expected since the mechanical properties of the peat are very different from those of mineral soils and the wetting and drying cycles are also different.

The moderate correlation coefficient between organic matter and creep rate (r = 0.34) might be explained by the complicated reaction of plant roots and soil fauna to creep, i.e. growth of plant roots, movement of worms and other faunal activity contribute directly or indirectly to the creep processes. In this study the greatest creep rates occurred in high organic soil (containing more than 62% organic matter), and the lowest in mineral soils (less than 30% organic matter) Rates in mixed soils (30-62% organic) are almost as high as those in peat.

Table 7.11 Classification of organic matter for plots measured for this study and mean creep rate mm a^{-1}

Organic matter	30% >	30-62%	>62% (peat)
No.of plots	19	8	8
Mean creep rate mm a^{-1}	1.26	1.73	1.80
	0.50	0.29	0.02
	0.70	0.54	0.16

It should be noted that decaying roots may cause changes in soil properties (e.g. soil texture, specific gravity, bulk density, porosity and void ratio, plastic limit and liquid limit, and shear strength).

7.5.6 Liquid limit and plastic limit and plasticity index

These variables are regarded as associated with forces facilitating soil movements (i.e. the soil creep rate is higher when the liquid limit and plastic limit of the soil are higher. Omitting the high organic plots (more than 62% organic matter), the results obtained from this study indicate a weak correlation between creep rate and plastic limit ($r = 0.35$). The value for liquid limit was much lower ($r = 0.15$).

Note that liquid limit increases with plastic limit, both liquid and plastic limit increase with organic content, and soils with high moisture content have high liquid and plastic limits.

The plasticity index is classified as a resistance factor; high values (over 31) being associated with an increased resistance of the soil to movement, Table 7.12, and therefore producing lower creep rates (0.68 mma^{-1}). Plots with a lower plasticity index (non plastic) which implies less resistance, display faster movement with mean creep rate of 1.76 $mm\,a^{-1}$.

Table 7.12 Classification of plasticity index for plots measured for this study and mean creep rate $mm\,a^{-1}$

Value	0-3 (non plastic)	4-15 Slightly plastic	16-30 Medium plastic	31+ High plastic	Peat
No.of plots	4	18	3	2	8
Mean creep rate mma^{-1}	1.76	1.44	1.11	0.68	1.80
Variance	0.50	0.48	0.16	-	0.02
Standard deviation	0.71	0.69	0.40	-	0.17

Plasticity index tends to decrease with an increase in organic content. Thus the organic content appears to contribute little to the plasticity of the material but much to the water-holding capacity. The correlation coefficient between creep rate and plasticity index found for 27 plots measured in this study was -0.38.

7.5.7 Porosity and void ratio

The correlations between linear creep rates and porosity and void ratio ($r = 0.42$ and $r = 0.45$) indicate that high porosity and void ratio increase soil permeability. High permeability tends to increase the susceptibility of soil to movement. In other words where a pore or a void is present a disturbed particle can move freely into it. The disturbed particle will apply stresses to the adjacent particles causing movement. Thus stresses may be transmitted through part of a soil layer. Strong correlations between porosity and void ratio and soil moisture content indicate that the amount of water available for freezing is dependent on the size, shape and percentage of the soil's pores and the void ratio.

In this study maximum porosity and void ratio occur in plots at which the maximum creep rates were observed and minimum porosity and void ratio were found for plots at which minimum movement occurred, Tables 7.13 and 7.14.

Table 7.13 Classification of porosity at 35 plots measured for this study and mean creep rates mm a^{-1}

Values	0.27-0.39	0.40-0.49	0.5 +
No.of plots	12	11	12
Mean creep rate mm a^{-1}	1.18	1.38	1.89
Variance	0.54	0.27	0.12
Standard deviation	0.74	0.52	0.35

Table 7.14 Classification of void ratio at 35 plots measured for this study and mean creep rate mm a^{-1}

Values	0.36-0.59	0.60-0.99	100+
No.of plots	10	12	13
Mean creep rate mma^{-1}	1.25	1.26	1.88
Variance	0.62	0.27	0.12
Standard deviation	0.79	0.52	0.34

7.5.8 Bulk density and dry bulk density

Bulk density varies with soil moisture content and therefore will be affected by moisture. Dry bulk density is constant and can be regarded as an independent variable controlling soil creep.

Bulk density and dry bulk density are classified as resistance factors; large values for dry density will result in less susceptibility to movement. The fact that bulk density shows a similar but weaker trend to dry bulk density indicates that the more compact the soil the greater resistance to movement. The mean annual creep rate for 19 plots with dry bulk density less than 1.00 Mg/m^3 was 1.75 mma^{-1}, whereas the value for 16 plots with dry bulk density more than 1.00 Mg/m^3 was 1.17 mma^{-1} (Table 7.15).

Table 7.15 Classification of dry density for 35 plots measured in this study and mean creep rates

Value	below 1.0 Mg/m^3	over 1.0 Mg/m^3
No.of plots	19	16
Mean creep rate mma^{-1}	1.75	1.17
Variance	0.22	0.44
Standard deviation	0.47	0.66

7.5.9 Shear strength

A significant negative correlation was found between creep rate and shear strength (r =-0.40). This indicates that the shear strength is also regarded as a resistance factor to soil creep. In fact, when the shearing force has increased beyond the shear strength of the soil, particle displacement is initiated.

The significant negative correlation between shear strength and soil moisture content (r = -0.45 for wet season and -0.50 for dry season), are justified by the study of Hollingsworth and Kovacs (1981) who show that the cohesion which results from intergranular air-water surface tension is reduced as shear resistance reduces when water replaces air in the soil pores. This study clearly explains the effect of water content in soil susceptibility to movement. Also significant negative correlations were observed between shear strength and organic matter which indicate that the higher the organic matter, the less resistance there is to movement. The same explanation can be applied as for porosity and void ratio.

Table 7.16 shows that maximum creep rates occurred at plots with less than 20 kN/m^2 and minimum creep rates were observed at plots with more than 50 kN/m^2.

Table 7.16 Classification of shear strength for 35 plots measured at this study and mean annual creep rate

Value	<20 kN/m^2	20-50 kN/m^2	>50 kN/m^2
No.of plots	12	16	7
Mean creep rate mma^{-1}	1.86	1.42	0.99
Variance	0.24	0.42	0.15
Standard deviation	0.49	0.65	0.39

7.6 Conclusions

The influence of slope angle (in the range 1 to 30 degrees) on soil creep is not obvious. Perhaps this is because it is not important or is masked by other factors such as soil moisture. Moisture content in a soil is dependent on several factors such as clay%, presence of hard pans, rock permeability, organic content, density and depth of the root mat. It is also affected (negatively) by slope angle and therefore the effects of moisture content and slope angle are interrelated. The opposition between these two factors may account for the weak relationship between slope angle and soil creep. This nevertheless implies that moisture is the dominant control and slope angle is subordinate.

However, the importance of soil moisture found in this study agrees with the conclusions found by other workers such as Kirkby (1967), Evans (1974), Anderson (1977) and Anderson and Cox (1981).

Since the range of moisture content may not increase downslope (away from divides)(Carson and Kirkby, 1972), creep process may be independent of distance as stated by Gilbert (1909). Whilst the potential of soil instability depends on a high moisture content, the critical level varies from soil to soil.

Finally, the creep rates during winter periods (from November to May) are higher than creep rates for summer (i.e. from May to November). An interesting point is that despite the severe winter cold in 1982, maximum creep occurred in winter 1981. This is probably because of unexpectedly heavy snowfall on 21 March 1981 and the fact that snow was lying until May 1981 in the study area. Thus heavy snow melt resulted.

7.7 Supplementary readings (incomplete)

On 14th March 1983 a supplementary reading was taken from the sampling sites to check the continuity of previously recorded creep rates. Sample stationNo.1 was completely disturbed; therefore there are no records from this station. Two of the nine plots for the Rashidian instrument at sample station No.2 were also disturbed. These two disturbed plots were ignored in the calculation of the mean value from this station. The other sampling sites remained undisturbed and readings are presented in Table 7.17.

Table 7.17 Supplementary measurement of sampling sites in mm (three instruments)

Instrument \ Sampling site	1	2	3	4	5
Rashidian's Technique	*	1.25	1.13	0.56	0.44
Anderson's tube	*	1.65	1.45	0.70	0.53
Wooden pillars	*	1.48	1.26	0.63	0.50

* No measurements have been taken because of plot disturbances

7.7.1 Comparison between main reading and supplementary reading (three instruments)

The measurements from the supplementary ten months period (May 1982 - March 1983) can be extrapolated to twelve months in order to make comparisons with annual creep rates. Table 7.18 and Figure 7.35.

Table 7.18 Supplementary and main linear creep rate in sampling sites in mm (three instruments)

Instrument \ Sampling site		1	2	3	4	5
Rashidian's technique	A	1.39	1.52	1.33	0.69	0.58
	S	*	1.50	1.36	0.67	0.53
	D	*	-0.02	+0.03	-0.02	-0.05
Anderson's tube	A	1.66	1.86	1.55	0.86	0.66
	S	*	1.98	1.74	0.84	0.64
	D	*	+0.12	+0.19	-0.02	-0.02
Wooden pillars	A	1.5	1.77	1.35	0.75	0.66
	S	*	1.78	1.51	0.76	0.60
	D	*	+0.01	+0.16	+0.01	-0.06

A = Annual linear creep rate
S = Supplementary linear creep rate
D = Deviation

* Disturbed plot

From Table 7.18 and Figure 7.47, it is clear that the two creep rates are almost identical at all recorded sites. For Rashidian's technique the two rates show very close agreement. The deviations between the main reading and the supplementary reading lie between 0.02 and 0.05 mm. Those for wooden pillars lie between 0.01 and 0.16 mm, and for Anderson's tubes, between 0.02 and 0.19 mm. The maximum deviations for all techniques occur in sample site No.3 where the creep rates for the supplementary reading seem to be higher than the main creep rates. It appears, then, that the 1983 winter has been intermediate to those of 1981 and 1982 in its effects on creep rate.

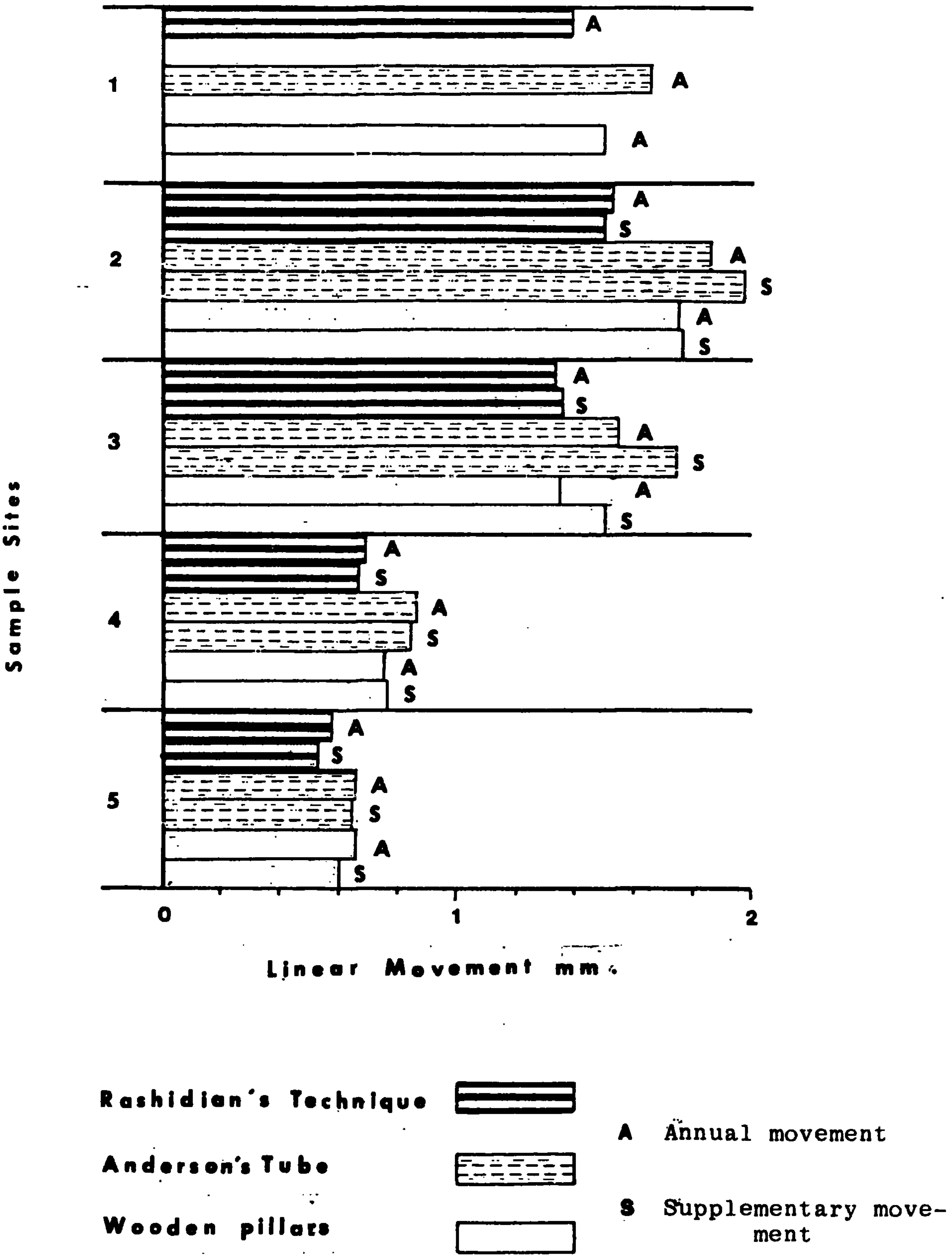


Fig. 7.47 : A comparison between annual soil movement and supplementary movement in study area. (three instruments)

CHAPTER EIGHT

CONCLUSIONS

CHAPTER 8

CONCLUSIONS

8.1 Summary of Thesis

The results reported in this thesis from seasonal soil creep monitoring in the Killhope basin (Upper Weardale), and their relations to controlling variables, can be summarized as follows:

1. Research on soil creep is difficult for several reasons, but particularly because soil movement is an intermittent process. It is therefore difficult to observe the creep process itself, and so in most cases, only the consequences of creep are investigated, and can be assessed only by comparing the original situation with a subsequent situation created by this process.

2. A major problem in soil creep research is the fact that the creep process does not occur as an isolated phenomenon, but takes place together with other processes, such as wash and solifluction. Also it is difficult to differentiate between creep and shear. The values represented for creep in this study are a reflection of changing soil position (soil movement) during the study period.

3. Seasonal soil creep as a process was monitored for three years using four different methods and instruments including Anderson tubes, Young's pits, modified wooden pillars, and a new technique designed for this purpose by the author. The differences in rate of soil creep recorded by the different instruments in each sampling station were small. The linear rates of soil creep measured by the

Rashidian technique in the five sampling stations within the study area varied from 0.58 mma^{-1} to 1.52 mma^{-1} and the average linear creep rate obtained by the four different techniques ranged from 0.66 mma^{-1} to 1.71 mma^{-1}. This demonstrates the consistency of the three established techniques and provides validation for the Rashidian technique.

The average linear creep rate for the 35 plots obtained by Anderson's tubes was 1.49 mma^{-1}. These values are comparable with those published by workers for similar environments, such as Young (1960-1963) 1-2 mma^{-1}, Kirkby (1963-1967) 1-2 mma^{-1}, Evans (1974) 0.6 mma^{-1}, and Anderson (1977) 1.2 mma^{-1}.

4. The results of this study showed that the creep rate is very much faster in the uppermost 120 mm of soil than in the deeper layer. The occurrence of maximum creep rates varies from soil to soil, and it occurs between 60 and 120 mm from the soil surface. Below 120 mm, creep rates decrease with increasing depth. This probably is connected with the decreasing fluctuation of soil moisture content and soil temperature and with the decreasing frequency of freeze-thaw cycles.

5. Definite relationships were demonstrated between creep rates and possible controlling variables measured in the field and the laboratory. Data analysis indicated that a number of variables influence the soil creep process; among these, soil depth, soil moisture content, soil texture, shear strength, plasticity index, porosity and void ratio are most important. These variables were also strongly

intercorrelated. Because the slope angle and soil texture remain virtually constant over a short period of time, changes in creep rates with time are a reflection of changing moisture conditions.

6. Soil moisture content as a main control of seasonal soil creep is dependent on several factors such as: mineralogical composition of soil (shape or size of particles and texture), density of root mat, vegetation cover, slope angle, and meteorological elements. Furthermore the soil moisture change mechanism is restricted to the zone of soil influenced by evapotranspiration and drainage.

7. Since snow depths in winter not only affect soil freezing rates and depths but also greatly influence the soil moisture content during the spring thaw, it must be concluded that the distribution of snow is an important factor in controlling rates of soil creep.

8. Soil creep occurring predominantly during April to May can be explained by the high saturation of the soil by water from thawing snow and melting frozen ground and the fluctuation of soil temperature during this period. All these cause changes in the volume of soil (expansion and contraction).

9. No measurements recorded showed any tendency to upslope ('retrograde') movement. This was probably because soil with a high moisture content loses cohesion and consequently under the influence of gravity begins to move downwards.

10. The influence of meteorological elements on soil characteristics and the interrelationships between soil

properties suggests that none of the variables controlling soil creep acts alone.

11. The interesting point arising in this study concerning the effect of percentage of clay and sand on creep rates was that:

Inspite of higher internal friction between sand particles in comparison with clay, sandy soils were found more susceptible to movement than clay. This can be explained by:

(a) Sandy soils containing more pores and voids are more susceptible to movement when water replaces the air.

(b) The sand particles tend to separate because of pore pressure as the saturated soil is frozen.

(c) Clay particles are susceptible to movement only when the soil is highly saturated and its cohesion is reduced. Otherwise clay per cent can be regarded as a factor of resistance to movements.

12. The results obtained from the Rashidian technique revealed that maximum soil creep rates do not occur on the surface but occur between 0.09-0.12 m from the surface, and decline sharply below 0.21 m from the soil surface.

8.2 Suggestions for further work

1. Since the monitoring and measuring of soil creep in this study took place over a period of three years, the results must be interpreted with that in mind: measurements over a longer period would be more useful.

2. If soil creep plots were established near a suitable operational meteorological station, they might give a better indication of the dependence of seasonal soil creep on fluctuation of temperature and rainfall.

3. The Rashidian Technique designed for this study to produce a profile of soil movement with depth is recommended for further work.

4. Field monitoring and measurements show plot disturbance to be a major problem; thus it is important to replicate instruments. When several instruments are used within one plot replication also provides a valuable check on instrument accuracy. Instrument disturbance can often be detected by comparing the consistency of measurements from all the instruments within the plot. When disturbance is detected or suspected in an instrument this result can be omitted from further analysis, thus minimising the effect of small scale disturbances on soil creep measurements.

5. Since several successful detailed studies of soil creep rates have now been made, it should be possible to attempt a standardization of instruments.

6. With standardized measuring techniques, studies could then concentrate on large scale landscapes.

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