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Engineering geology of cohesive soils associated with ophiolites with particular reference to Cyprus

Engineering geology of the Kannaviou, 'Mélange' and Mamonia Complex formations—Phiti/Statos area, S W Cyprus

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EXECUTIVE SUMMARY

This report attempts to describe the characteristic engineering properties and behaviour of the cohesive soils of, or derived from, the Kannaviou, Melange, and Mamonia Complex Formations which occur in close proximity to the Troodos ophiolite in the Paphos region of SW Cyprus. The investigation was concentrated in two study areas located in the landslide-prone highlands adjacent to the updomed Troodos Massif.

An extensive mineralogical and geotechnical data base of over 3000 discrete test data has been established. Analysis of the test results show that the argillaceous Kannaviou sediments may be classified as overconsolidated, stiff, sheared (or 'tectonised') montmorillonitic clays of high to extremely high plasticity; and the tectonically undeformed sedimentary Melange as an overconsolidated, firm to stiff, fissured montmorillonitic silty clay (matrix) of intermediate to high plasticity, with embedded rock clasts of all sizes. The engineering behaviour of the Melange is dominated by its matrix component which shows a marked uniformity in geotechnical properties despite the lithological variety of included clasts. A discontinuously-developed pervasive shear fabric has been recognized in the Melange matrix which appears to be related to Recent landsliding. A 'Superficial Melange' deposit has been identified which is, at least in part, derived by subaerial weathering of the Mamonia Complex rocks. Generally of low to intermediate plasticity, this deposit is highly variable in clast:matrix ratios with local clast/matrix lithologies being closely related to underlying or adjacent Mamonia rock types. As such, its regional geotechnical behaviour is unpredictable.

Strength determinations of the sheared Kannaviou clays suggests that the in-situ mass shear strength is largely controlled by the undrained shear strength of the discontinuities, and is substantially less than 'peak' laboratory values but above residual strengths found on continuous pre-existing slip surfaces. Difficulties in determining the strength and consolidation parameters of sheared clays from complex tectonic environments are highlighted, and further determinations of 'field' strength values by back-analysis of first-time landslides in conjunction with seasonal monitoring of moisture content variations is recommended.

Two 1:10 000 scale engineering geology maps, prepared for each study area, show that major slope stability problems occur where weak, sheared montmorillonitic clays and Melange deposits crop out on steep slopes in areas of high relief; with landslide development exacerbated by high winter rainfalls, permeable cap-rocks, earthquake shocks, and active erosion associated with continued uplift of Troodos. Limited analyses of slope angle and residual strength data indicate that limiting slope angles for shallow mass movements in the Kannaviou and Melange clays are c. 8.5° and 11°, respectively. Deep-seated slope failures are shown to be largely associated with faults.

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LIST OF SYMBOLS & ABBREVIATIONS

Ac	Activity (= PI / %Clay).
Af	Pore pressure coefficient A $[=\delta u/\delta(\sigma_1-\sigma_3)]$, at failure in triaxial test.
App.	Appendix.
BGS	British Geological Survey.
BH	Borehole.
BS	British Standard.
BSCS	British Standard classification of soils
Ca	Calcium
Co	Cobalt
c.	Coarse
c	Apparent cohesion
c'	Cohesion intercept based on effective stresses
c_u	Apparent cohesion in terms of total stress
c_r'	Cohesion intercept for residual condition
Chi	Coefficient of isotropic consolidation-horizontal drainage (m^2/yr)
Cv	Coefficient of consolidation - vertical drainage (m^2/yr)
Cvi	Coefficient of isotropic consolidation - vertical drainage (m^2/yr)
CALC.	Calcite
CHL.	Chlorite
CLAY	Size fraction <0.002 mm
CLIN.	Clinoptilolite
CU	Consolidated undrained triaxial test
D	Diameter (mm)
e	Voids ratio
Eff.	Effective
Extr.	Extremely
f.	fine
Felds.	Feldspar
Fig.	Figure
Fissd	Fissured
GR	Grid reference (Eastings first)
Gr.	Grain (F.gr.= fine grained; M.gr = medium grained)
GSD	Geological Survey Department, Nicosia, Cyprus
Gs	Specific gravity (alternative SG)
H	Drainage path length (mm)
Inter.	Intermediate
KAN.,KANN	Kannaviou Formation, Cyprus
Ko	Coefficient of earth pressure at rest
k	Coefficient of permeability
k_h	Horizontal coefficient of permeability
LI	Liquidity index
LL	Liquid limit
LS	Linear shrinkage
MAM.	Mamonia Formation, Cyprus
Mca.	Mica
MEL.	Melange, Cyprus
MONT	Montmorillonite
m	Metres
mm	Millimetres
m/c	Moisture content
m_v	Coefficient of volume compressibility (m^2/MN)
m_{vi}	Coefficient of isotropic volume compressibility (m^2/MN)
N	Standard Penetration Test - Number of blows per 300mm
n	Number of observations

n	Porosity
Nat.	Natural
OCR	Overconsolidation ratio (max. previous overburden ÷ present overburden)
Pr.	Pressure
Psw	Maximum swelling pressure
PL	Plastic limit
PI	Plasticity index
QZ.,QTZ.	Quartz
r	Coefficient of correlation (statistics)
SAND	Size fraction 0.06mm - 2mm
SILT	Size fraction 0.002mm - 0.06mm
SILTST.	Siltstone
SST	Sandstone
STRAT.MAM.	Stratified (sedimentary) Mamonia Formation, Cyprus
SD	Standard deviation (statistics)
SG	Specific gravity (alternatively Gs)
SPT	Standard Penetration Test
Sr	Degree of saturation
Superf.	Superficial
s_u	Undrained shear strength
s'	Effective shear strength
t	Temperature
t_{50}	Time to reach 50% pore pressure dissipation in Swelling Pressure Test
u	Pore pressure
V	Specific volume
v.	Very
x	Arithmetic mean
XRD	X-Ray diffraction
γ_b	Bulk density (Mg/m^3)
γ_d	Dry density (Mg/m^3)
δ	Cumulative change
σ_n'	Effective normal stress
$(\sigma_1 - \sigma_3)$	Deviator stress
τ	Shear stress
ϕ_u (degrees)	Angle of shear resistance in terms of total stress
ϕ'	Angle of shear resistance based on effective stress (degrees)
ϕ'_r	Residual angle of shear resistance (degrees)

1. INTRODUCTION

This report describes the results of work carried out in the Paphos District of SW Cyprus during 1984-85 and forms the fourth phase of a four-year research programme funded by the Overseas Development Administration into the engineering geology of cohesive soils associated with ophiolites. The study has resulted from collaboration between staff of the British Geological Survey and the Geological Survey Department of Cyprus.

The three earlier phases of the research programme describe the engineering geology and geotechnical properties of the Pliocene Marl in Nicosia (BGS Report No: EGARP KW/86/1, GSD Report No: G/EG/12); the Moni Formation clays in the Pendakomo area, Southern Cyprus (EGARP KW/86/2, G/EG/13); and the Pliocene Marl in the Polis area, western Cyprus (EGARP KW/86/3, G/EG/14). The final phase of the study, carried out concurrently with the Paphos project work in 1985, describes mineralogical and geotechnical properties for supplementary 'external samples' obtained from a regional sampling programme outside the main study areas at selected sites across Cyprus. The supplementary data, with accompanying location maps of the sampled cohesive soil formations, are presented in Report No. EGARP/86/5, G/EG/16.

The overall aims of the research programme were to identify and classify the soils in engineering terms, and to ensure that potential geological hazards to development are recognized prior to detailed planning, ground investigation and construction.

SW Cyprus is characterized by extensive outcrops of Late Cretaceous bentonitic clays, mudstones, and volcaniclastic sandstones of the Kannaviou Formation and an allochthonous, highly-deformed assemblage of Triassic-Cretaceous rocks (the Mamonia Complex) thought to have been emplaced by large-scale gravity sliding brought about by collision of Troodos oceanic crust with a distal continental margin. In many areas these formations are overlain by a sedimentary melange (the Kathikas

Formation of Swarbrick & Robertson, 1980) derived by erosion of the Mamonia Complex rocks and deposited as a series of Late Cretaceous submarine debris flows. Where these formations crop out in the highlands of the region, a high relief, steep slopes and intense winter rainfalls, in addition to periodic earthquake shocks, have combined to form the most landslide-prone area in Cyprus.

The investigation of these clay and rock formations and their role in the development of widespread slope instabilities in the region's highlands (which have necessitated the resiting of numerous villages and continue to harrass communication routes and agricultural land) form the basis of the present study. Centred on the villages of Phiti (Study Area 1) and Statos (Study Area 2), the investigation encompassed an area of approximately 103 km^2 located adjacent to the western margin of the Troodos Ophiolite.

The report essentially consists of four parts. Firstly, the general topographic, geological and climatic setting of SW Cyprus is discussed (Chapter 3) and an historical outline given of geologically related engineering problems in the region (Chapter 4). The second part of the report describes the survey methods and techniques undertaken in the two study areas (Chapter 5), and discusses in detail their geology (Chapter 6) and the mineralogical/geotechnical properties and engineering behaviour of the cohesive soil formations (Chapter 7). An assessment of the slope instability problems given in Chapter 8 refers extensively to two 1:10 000 scale engineering geology maps of the Phiti and Statos Study Areas which accompany this report; the production of these maps formed a major aspect of the investigation. Conclusions and recommendations for future work are given in Chapter 9. The third part of the report consists of a comprehensive bibliography (Chapter 10). Finally, four appendices are presented which give details of the logs of boreholes drilled during the survey of Study Area 1, annotated sections of trial pit excavations, a full listing of sample information, and tabulated and graphical summaries of all mineralogical and geotechnical laboratory test results.

2. OBJECTIVES

The main objectives of the present study were:

a) To determine the characteristic geotechnical properties and engineering behaviour of the cohesive soils of, or derived from, the Kannaviou, 'Melange' and Mammonia Complex Formations in the Paphos District, SW Cyprus.

b) To assess the slope stability problems associated with these formations in the two selected study areas, and establish the main causal factors; and to indicate, in map form, areas of present and potential instability.

It was intended that the geotechnical appraisal and methodology of landslip assessment established in the study areas would be applicable to similar terrains, in Cyprus and elsewhere, and be used to guide engineers and planners concerned with foundations on expansive montmorillonitic clays and with regional urban and agricultural development in areas prone to landslides.

3. TOPOGRAPHICAL AND GEOLOGICAL SETTING OF THE PAPHOS REGION

3.1 General Topography and Drainage

The Paphos region, as defined in the present study, extends northeastwards from the southwestern coastal zone centred on Paphos town to the highlands of the Troodos Massif. As shown in Fig. 3.1, the region may be divided into five main topographical zones, ranging from the coastal plains of less than 200m elevation to the massif highlands with elevations in excess of 1200m AMSL.

The coastal plain occupies a zone some 3-4km wide, its landward margin broadly representing the outcrop boundary between the Neogene and older formations and the more recent Pleistocene and Holocene deposits. Within the coastal zone, two marine terrace surfaces have been recognised, extending NW-SE between the villages of Kissonerga - Kouklia and Emba - Yeroskipou at average elevations of 75m and 140m AMSL, respectively (Hadjistavrinou and Afrodisis, 1969).

Inland from the southwestern coastal zone, the gently inclined topography rises abruptly to a high scarp approximately 400m AMSL. Between this elevation and c.6-800m AMSL, the region is characterised by a deeply dissected plateau, dominated by U. Cretaceous-Miocene chalks and marls incised by numerous streams which form deep and steep-sided valleys. In the vicinity of Pano Panayia village [GR 665 643] a higher plateau surface rises above the general topography to an elevation of around 1100m AMSL.

To the NNE, the inland margin of the region is marked by the updomed Troodos massif. The crystalline massif forms the backbone of the Troodos mountains and, topographically, consists of a deeply dissected block of basic and ultra-basic rocks with elevations in excess of 1200m AMSL (Fig. 3.1). The updomed massif is centred on the summit of Mount Olympus which forms the highest point in Cyprus at an elevation of 1951m AMSL.

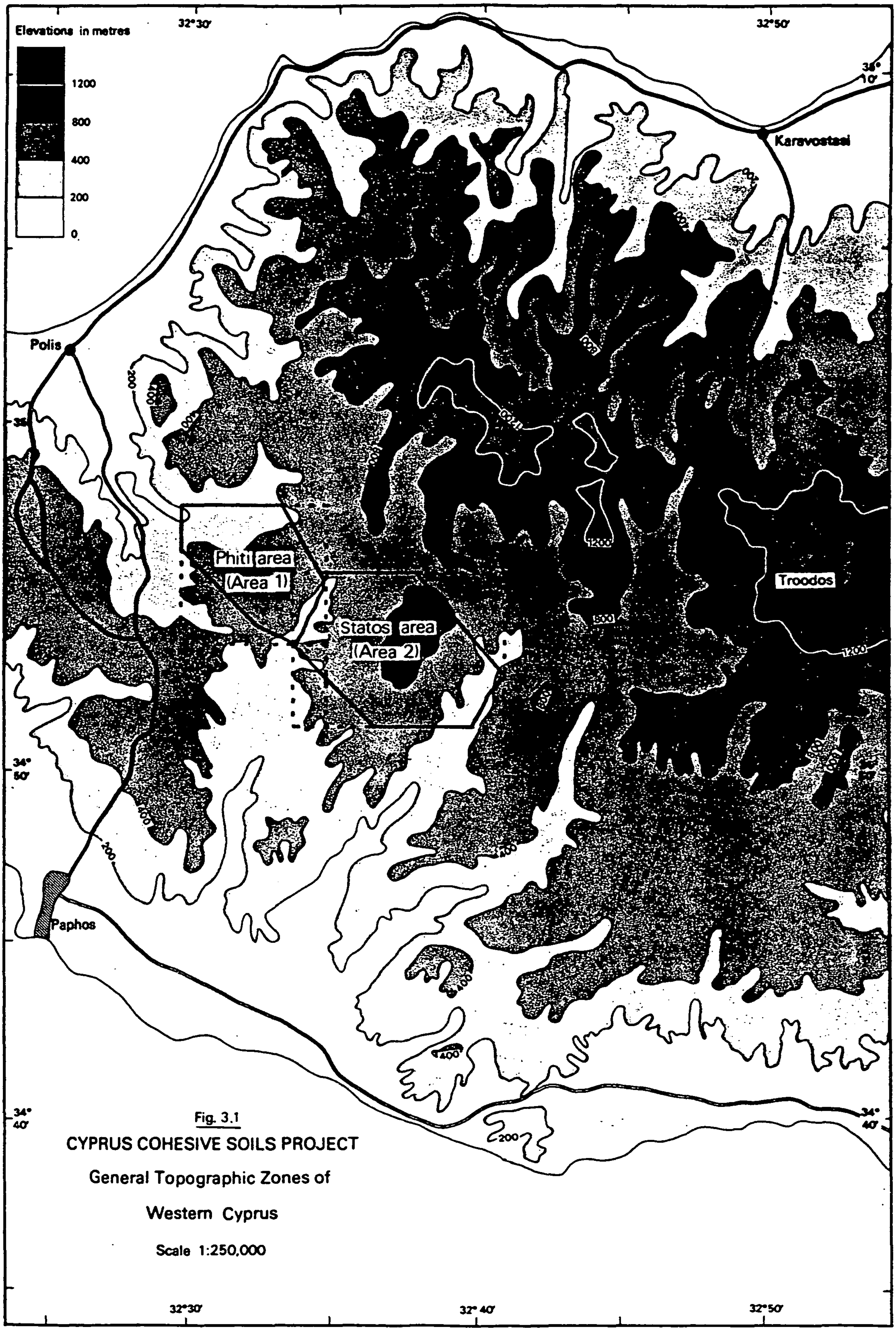


Fig. 3.1

CYPRUS COHESIVE SOILS PROJECT

General Topographic Zones of Western Cyprus

Scale 1:250,000

The drainage of W and SW Cyprus is centred in the Troodos mountains with the main rivers draining radially towards the sea. In the Paphos region, the trend of the major river valleys is NNE-SSW with the central and SW parts of the area being drained by the usually perennial Ezousas, Xeros and Dhiarizos rivers which flow towards the SSW. In the highlands the rivers are entrenched in deep valleys which broaden towards the coastal plain where the main river courses are separated by low ridges. At a number of locations, the main valley side slopes are interrupted by discontinuous terrace surfaces (op.cit., 1969) which mark former stream levels and are indicative of episodic periods of uplift and renewed denudation of the Troodos massif.

3.2 Climate and Rainfall

Since Late Glacial times, the climate of Cyprus has been one of increasing desiccation, with temporary reversals of the trend at c. 9000 and 5000 BC (Butzer, 1958). The present day climate of the Paphos region is of extreme Mediterranean type, characterised by hot dry summers and generally mild winters. Average daily summer temperatures range from 21° - 30°C (lowlands) to 19° - 28°C (highlands) and in winter from 10° - 17°C to 4.5° - 10°C in the lowlands and highlands, respectively. Even in winter the humidity is low, and loss of water by evaporation is high.

Fig. 3.2a shows that precipitation in Cyprus correlates to the physiography of the island, with the highest average annual rainfall occurring over the higher parts of the Troodos mountains and the lowest on the Central Lowland. In the Paphos region, records from several stations across the area show the 50-year average rainfall ranging from 400mm at the coastal plain to 600mm in the 'central' highlands. The 70-year mean monthly rainfall plot (Fig. 3.2b) recorded at Pano Panayia, located near the NE margin of the region south of the Troodos massif, also indicates that no, or very little, rainfall is epected from mid June - mid September. Rainfall is confined almost entirely to the winter and spring months, when vegetation cover is at a

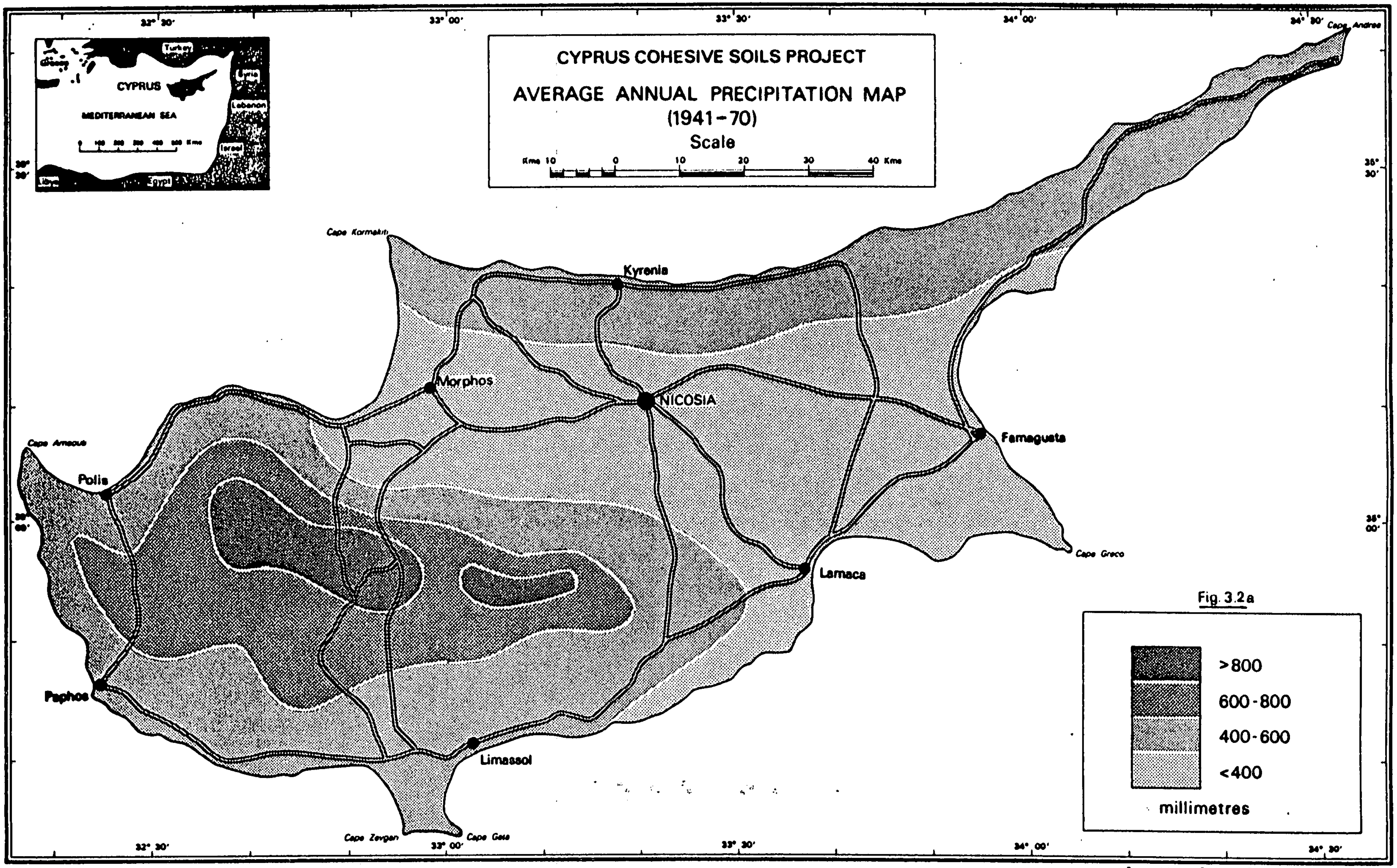
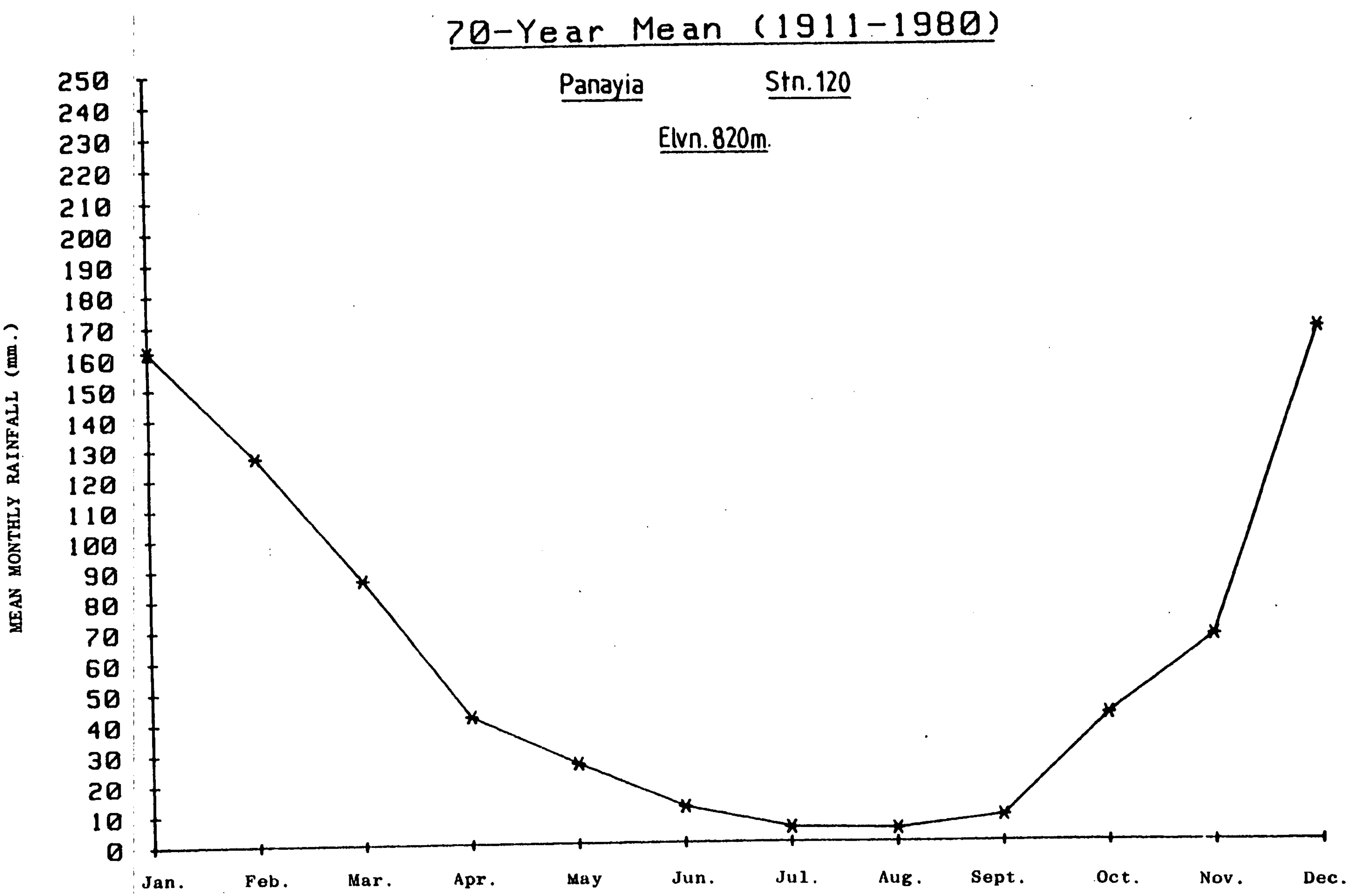


Fig. 3.2a

Prepared by the Geological Survey Department, Cyprus, 1986

Fig. 3.2b



70-Year Mean (1911-1980)
Panayia
Stn.120
Elvn.820m.
MEAN MONTHLY RAINFALL (mm.)
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Jan.
Feb.
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sept.
Oct.
Nov.
Dec.

minimum. Of particular significance with regards to slope erosion and stability is that the rains occur as heavy erosive downpours and even in spring and summer, occasional torrential cloudbursts may cause considerable damage. Water held as snow on the highest parts of Troodos is released beneficially in spring, but the amount is too little to persist into summer, and for most of the year the majority of rivers are dry.

3.3 Vegetation

The SW coastal zone is virtually completely given over to the cultivation of cereal and vegetable crops and plantations of citrus, banana and carob. Agricultural development has been enhanced in recent years following completion and operation of the major Paphos Irrigation Project that relies on water supplied from the Asprokremmos dam located some 13km SW of Paphos town.

Vineyards cover large areas of the upland chalk plateau with terracing common on the steeper cultivated slopes. The ground is unirrigated and stony, with the vine roots seeming to have little binding effect. Relatively small citrus plantations and vegetable crops are cultivated in restricted areas irrigated by water from rivers, springs and a limited number of boreholes. On the more 'heavy clay' soils in the plateau highlands, related to the older formations underlying the chalk capping, cereal crops are grown in small fields confined to the flatter areas and shallow slopes. Within this terrain, the ground is subjected to frequent slope movements and permanent plantations are limited. On land too poor, rocky or steep for agriculture the vegetation comprises shrubs, small stunted trees, dwarf scrub and annual grasses, and is grazed by flocks of sheep and goats. On the steepest hillsides there is no vegetation mat and therefore practically no binding influence at ground level. Small bushes and grass tufts often support masses of loose rock on their uphill side, indicative of the continual movement of loose debris.

Most of the Troodos highlands are forested. The main forests are state-owned and consist of coniferous high forest with an understorey of broad-leaved species (Burdon, 1951).

3.4 Seismicity

Cyprus is seismically active and a number of damaging earthquakes have been documented in the historic past. A seismic map of Cyprus prepared by the Geological Survey Department (Fig. 3.3), shows that the most severe earthquake events occur along the south coast which includes the southwest part of Paphos region.

The most severe recorded earthquake to hit SW Cyprus (with a wave magnitude of 6.16) occurred in September, 1953. The epicentre was located offshore about 35 kms southwest of the coast, and damage in the Paphos region was severe. Forty fatalities were reported and over 100 people seriously injured, and many villages in the region were completely destroyed.

3.5 General geological setting

The geological evolution of Cyprus has been the subject of much research, particularly in recent years following the work of Moores and Vine (1971) on the Troodos Massif which provided the basis for the modern definition of an ophiolite as adopted by the 1972 Penrose Ophiolite Conference. It is now generally accepted that the basic-ultrabasic rock sequences represent land-bound fragments of ocean lithosphere formed at fossil constructive plate margins. Opinions still vary markedly, however, as to the tectonic environment in which the Troodos ophiolite was formed and its mode of emplacement. Characteristic of SW Cyprus is the highly deformed assemblage of rocks now known as the Mamonia Complex, which has similarly attracted much research and controversy. Are these rocks, for example, wholly or only in part allochthonous; how were they emplaced; and what is their

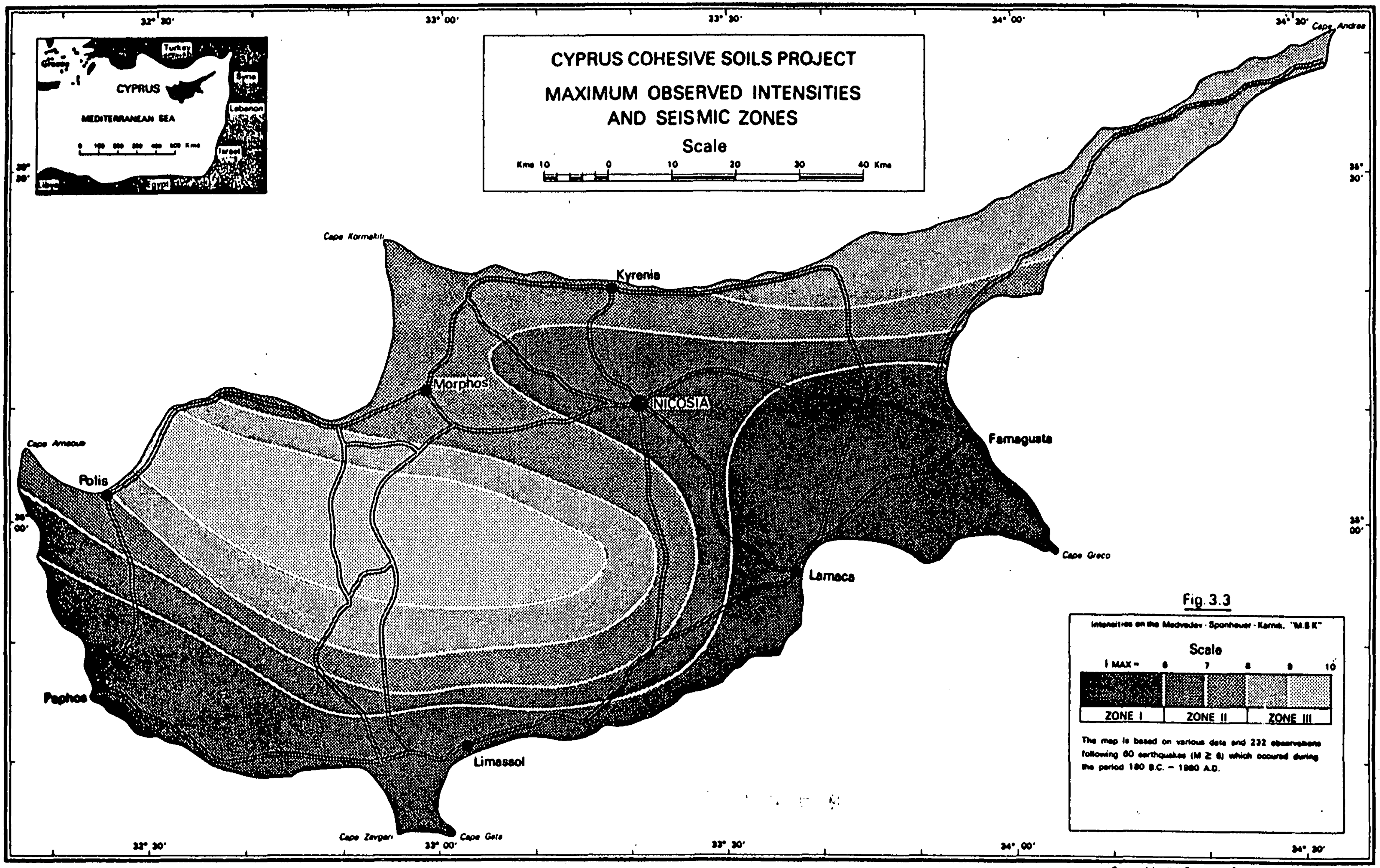


Fig. 3.3

Prepared by the Geological Survey Department, Cyprus, 1988 relationship to the Troodos ophiolite? In attempting to answer these and other problems, confusion has arisen to some degree in the published literature as a result of ambiguities in stratigraphical nomenclature. Further elucidation of these questions related to the early tectonic evolution of Troodos and SW Cyprus in particular is beyond the remit of the present study. A general scenario of the evolutionary history of SW Cyprus is, however, given below, followed by a description of the rocks comprising the major geological formations in the region (Sections 3.5.1 to 3.1.4). The latter sections of this chapter attempt to summarise the main published works related to the origin of the Troodos ophiolite (Section 3.6) and emplacement of the Mamonia Complex rocks (Section 3.7).

Following the formation of the Troodos ophiolite at an E-W spreading axis in the Late Cretaceous, a subduction zone dipping northwards towards Troodos began, in the Early Campanian, to consume oceanic crust of the Afro-arabian Plate or a microplate situated SSW of present-day Cyprus. As a result of this subduction, the continental margin of the Afro-arabian Plate was approaching Troodos. In the marine basin between the relatively elevated Troodos to the north and the continental margin to the south-southwest, the Kannaviou bentonitic clays were deposited. Volcanic activity related to the Afro-arabian shelf or a microcontinenent produced the volcaniclastic material deposited within the Kannaviou clay sequence.

By the end of the Campanian the continental margin and the subduction trench had collided with Troodos. This collision resulted in the shedding of gravity slices (the Mamonia Complex Rocks) from the descending continental plate onto the Troodos. Following the emplacement of the Mamonia Complex (which was completed by the Late Maestrichtian), parts of the Mamonia were then rapidly eroded and the derived material deposited as a series of submarine debris flows to form an extensive cover of melange.

By the end of the Maestrichtian, major tectonic movements ceased and deep-water calcareous sediments began to blanket the whole area, accompanied during the Tertiary by subsequent progressive uplift of Troodos. The driving force behind this uplift is believed to be due to the hydration of deep seated mantle rocks to produce serpentinite; the hydrating fluids involved in this serpentinization possibly being liberated from the northward dipping subduction zone beneath Cyprus. A pulse of accelerated uplift in the Miocene was associated with the deposition of both clastic material and chalks and marls in subsiding basins to the south, and culminated in the localized development of reef limestones and gypsum deposition. Major uplift again occurred in the Pleistocene resulting in the deposition of fanglomerates.

A major event in the evolution of Cyprus is its 90° counter-clockwise rotation which has occurred since the Campanian. Precise details of when this event took place and what actually rotated has still yet to be resolved, however, an outline of recent theoretical models are given in Section 3.6, below. The driving force for this tectonic rotation could have been the oblique consumption of oceanic crust in the subduction zone below Troodos, and a transform fault representing a possible zone of weakness along which rotation occurred. This fault is possibly preserved as the Arakapas transform fault seen in southern Cyprus, the northwesterly extension of which reaches the Paphos region.

Several workers have mapped areas of limited extent in the Paphos region (e.g. Gass, 1960; Pantazis, 1969; Kluyver, 1969; Turner, 1971; Swarbrick, 1979). However, the most comprehensive geological mapping of SW Cyprus was carried out by H. Lapierre (1966-1970) which culminated in the publication of the 1:50 000 scale "Geological map of the Polis-Paphos Area" by the Geological Survey of Cyprus in 1971.

A simplified geological map of Cyprus is shown in Fig. 3.4, and for the purposes of the current report, the rock formations in the region are considered as comprising four main groups:

1. The Troodos ophiolite
2. Circum-Troodos sedimentary rocks prior to the emplacement of the Mamonia Complex.
3. The Mamonia Complex and related sediments
4. Circum-Troodos sedimentary rocks post emplacement of the Mamonia Complex.

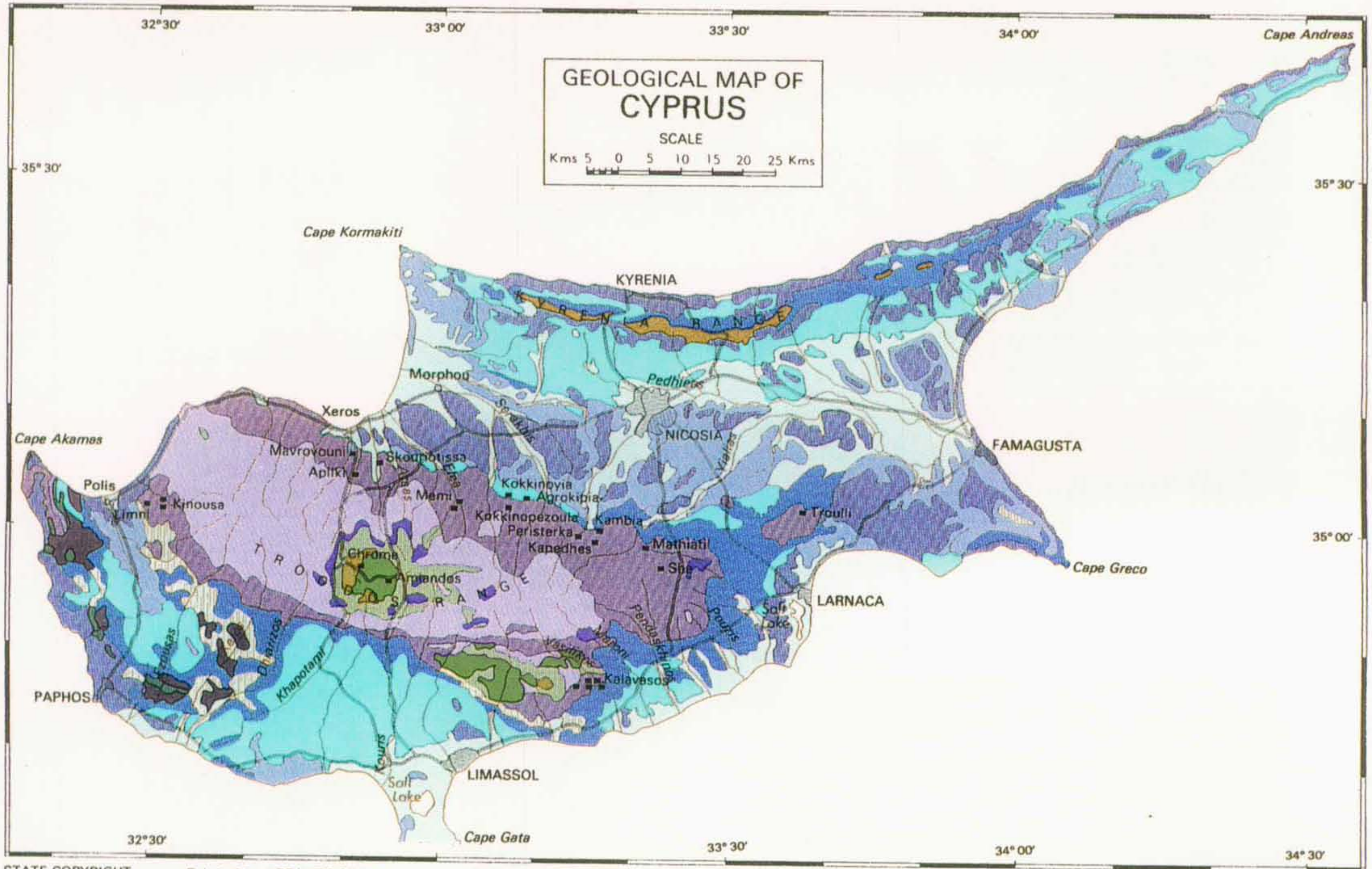
3.5.1 The Troodos Ophiolite

The Troodos Ophiolite occupies the south central part of the island, forming an elongated east-west orientated dome centred on Mount Olympus. In the Paphos region, as defined in the present study, the ophiolite (dominantly lavas) crops out in the highland areas forming the northeastern margin. A small ophiolite outcrop, separated from the main Troodos body, occurs in the Akamas Peninsula to the northwest and other isolated small outcrops are present in other areas of the region.

The Troodos massif comprises Uppermost Cretaceous basic and ultrabasic rocks, forming a complete and underformed ophiolite sequence from pillow lavas, through a sheeted dyke complex, cumulate gabbros, and ultrabasic rocks ranging from peridotites to tectonized harzburgite. Although the Troodos ophiolite is represented in the Paphos region mainly by the Pillow Lavas, the sheeted Dyke Complex, and limited Gabbro, a description of the whole sequence of the Troodos Ophiolite is, however, given here to emphasize its role as an important source material for much of the associated cohesive sediments which form the main subject of the current report.

The serpentinites found in the Paphos region are associated both with the Mamonia Complex rocks and with the Troodos ophiolite and are discussed in more detail together with the former in Section 3.5.3.3.

The Tertiary uplift of the Troodos massif and subsequent erosion resulted in exposure of the deepest stratigraphic units in the central, highest part of the dome with the younger units



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LEGEND

SEDIMENTARY FORMATIONS

Formation	Age
Alluvium	RECENT
Fanglomerate, Terrace Deposits	PLEISTOCENE
Nicosia - Athalassa Formations	PLIO-PLEISTOCENE
Kalavasos, Koronia, Pakhna and Kythrea Formations	MIDDLE-UPPER MIOCENE
Terra, Lefkara, Ardana-Kalogrea and Lapithos Formations	MAESTRICHTIAN - LOWER MIOCENE
Moni, Kannaviou and Perapedhi Formations	CAMPANIAN-MAESTRICHTIAN
Hilarion, Sykhari, Dhikomo and Kantara Formations	PERMO-CARBONIFEROUS TO LOWER CRETACEOUS
Mamonia Complex	TRIASSIC TO LOWER CRETACEOUS

TROODOS OPHIOLITE (PRE-CAMPANIAN)

Rock	Unit
Upper and Lower Pillow Lavas and Basal Group	PILLOW LAVA SERIES
Diabase	SHEETED DYKE COMPLEX
Plagiogranite	PLAGIOGRANITE
Gabbro	GABBRO
Pyroxenite, Wehrlite, Dunite	ULTRAMAFICS
Harzburgite, Serpentinite	ULTRAMAFICS
Serpentinite (Mamonia Complex)	ULTRAMAFICS
▪ Mine	

Fig. 3.4

outcropping concentrically around them. In the centre of the ophiolite, around Mount Olympus, the dominant rock outcrop is tectonized harzburgite which is largely serpentinized. Around the central harzburgite core, cumulate ultramafic rocks (mainly dunite, wehrlites and pyroxenites) are present, outcropping to the west and southwest of the harzburgite. Towards the periphery of Troodos, these rocks are overlain by a sequence of gabbros, with melagabbros at the base followed upward by olivine gabbros to diorites and plagiogranites.

The Sheeted Dyke Complex crops out over most of the Troodos mountains and separates the plutonic complex from the extrusive lavas. At the bottom of the sequence, screens of plagiogranite and gabbros are included in the dykes, whilst at the top of the succession, pillow lava screens are encountered.

The sheeted complex grades upwards into an extrusive sequence which crops out in a discontinuous belt around the margins of the Troodos massif. Pillow lavas dominate the sequence but massive flows, thin sheet flows, flow breccias, and hyaloclastites are common. Early workers divided the lavas into two units. The Upper Pillow Lavas and the Lower Pillow Lavas, the contact between the two units being an unconformity. The Upper Pillow Lavas are dominantly olivine basalts with limburgitic and picritic units whilst the Lower Pillow Lavas comprise oversaturated basalts, andesites, and dacites showing evidence of extensive silica metasomatism. The main lava types are occasionally separated by thin weathered layers of umberiferous sediments or haematitic shales. Similar deposits, referred to as the Perapedhi Formation and considered to be, in part, the products of submarine weathering, also occur in patchy outcrops above the pillow lavas.

3.5.2 Circum-Troodos sedimentary rocks prior to the emplacement of the Mamonia Complex

The circum-Troodos autochthonous sediments, deposited over the Troodos Massif prior to the emplacement of the Mamonia

Complex, are grouped into two formations: the Perapedhi Formation and the Kannaviou Formation (Fig. 3.4).

3.5.2.1 The Perapedhi Formation

The Perapedhi Formation is considered to be the earliest sedimentation after extrusion of the Troodos Pillow Lavas. Lithologically the Formation comprises dark brown iron- and manganese-rich shales (Umbers) and reddish radiolanian mudstones with occassional interbedded cherts. The outcrops are patchy and usually occur within topographic depressions on the Upper Pillow Lavas. Their thickness is very limited and rarely exceeds 10 metres, and in SW Cyprus are represented by thin isolated patches of umbers overlying the Troodos Lavas.

3.5.2.2 The Kannaviou Formation

The Kannaviou Formation was named by Lapierre (1968, 1975) after the village of Kannaviou, situated in the east-central part of the region close to the western periphery of the Troodos Massif. These sediments were previously included in the 'Moni Formation' of Pantazis (1967).

The Formation sediments consist of Lower Campanian to Mid Maestrichtian bentonitic clays, radiolarian mudstones and volcaniclastic siltstones and sandstones. They conformably overlie the Perapedhi Formation, where it is present, or rest unconformably on the Troodos Pillow Lavas. The Kannaviou Formation is overlain by the Mamonia Complex rocks, the Kathikas Formation (the 'Melange', in this study), the Lefkara Formation, or (in S Cyprus) the Moni Formation. In S and SW Cyprus the Kannaviou sediments are very extensive, reaching 650m in thickness, whilst around the northern and eastern margins of the Troodos Massif they are thin and erratic. In SW Cyprus, two main regions of Kannaviou outcrops can be distinguished. In the Akamas Peninsula, Marathounda and Archimandrita areas, the Kannaviou sediments crop out as tectonic windows through the over-thrusted Mamonia Complex; whilst in the Kannaviou-Statos area (in which the Study Areas are located), they outcrop around the uplifted margin of the Troodos Massif.

Typical sequences in the Kannaviou - Statos area consist of basal non-calcareous clays and conglomeratic sandstones which include material derived from the submarine erosion of the Troodos lavas. Higher up the succession, volcaniclistic sandstones and siltstones interbedded with clays and mudstones are present; their lithological and sedimentological charcteristics indicating much more rapid deposition on a steeply-sloping sea floor by a combination of mass flow and minor turbidity currents. The volcaniclastic sandstones contain pumice and volcanic material, with clasts of various sedimentary and metamorphic rock types possibly comparable to those found in the Mamonia Complex.

The presence of radiolaria and foraminifera fauna indicates that the Kannaviou Formation was deposited in a deep marine environment. The general upward passage from non-calcareous to calcareous clays, followed by volcaniclastic sandstones, rich in plant material, indicates an overall change to a shallower, but still fully open, marine environment of deposition. Troodos, which was situated to the north of the depositional basin, was probably elevated, as indicated by the presence of Troodos-derived breccias and sediments derived from the submarine erosion of Troodos-type rocks at the base of the Kannaviou Formation. The mineral assemblage in the volcanogenic rocks indicates an andesitic magmatic source thought not to be related with Troodos, but with an island arc area located off-shore of present-day Cyprus (Cleintuar et al. 1977). Taking into consideration the post-Campanian rotation of Cyprus, Robertson (1977) suggests that this source area was from the present N, NW and NE.

3.5.3. The Mamonia Complex

The Mamonia Complex of SW Cyprus comprises a diverse and structurally complex assemblage of allochthonous Upper Triassic to Lower Cretaceous sedimentary rocks and Upper Triassic mafic igneous rocks. Serpentinites and metamorphics are also found associated with the Mamonia rocks.

The Mamonia Complex is very extensive in Paphos region, and crops out in two broad zones. The northwest zone extends from the Akamas Peninsula in the north and continues SSE to the area around Mavrokolymbos Dam on the west coast. The southeast zone forms a broad E-W belt extending eastwards from the Marathounda area (west of Paphos Town) to the area around Mamonia village in the Dhiarizos River valley, before swinging northwards through the areas around Ayia Marina, Pendalia, and Ayios Photios-Statos villages. Elsewhere, the Mamonia Complex rocks are exposed in limited outcrops in S and SE Cyprus, near Limassol and Paralimni; they are completely absent to the north and east of the Troodos Massif (Fig. 3.4).

Over large areas of SW Cyprus, an autochthonous sedimentary melange (the Kathikas Formation) overlies the deformed Mamonia Complex rocks and/or the underlying Kannaviou sediments. This melange is stratigraphically grouped as part of the Mamonia Complex as its derivation as an erosion product of the Mamonia rocks is directly related to the emplacement of the Mamonia Complex onto the Troodos igneous massif.

The Mamonia Complex has posed particular problems in stratigraphic classification which has resulted in a plethora of stratigraphic terms arising in the literature, all of which are not discussed here. Lapierre (1968a) was the first to realize the fundamental distinction between an in-situ Troodos sedimentary cover and an allochthonous sequence composed mostly of Mesozoic sedimentary and igneous rocks. Within the Mamonia Complex, Lapierre (op cit.) recognized two distinct, wholly allochthonous, units which were interpreted as separate 'nappes'. These were (a) the '<u>Mamonia Formation</u>' (Upper Nappe), which was virtually entirely sedimentary and (b) the <u>Petra tou Romiou Formation</u> (Lower Nappe), mostly igneous but with some sedimentary lithologies. Robertson and Woodcock (1979), in common with Lapierre, subdivided the Mamonia Complex into two separate stratigraphical groups: the <u>Ayios Photios Group</u>, an entirely sedimentary assemblage of continental margin type rocks (corresponding to the Mamonia Formation of Lapierre); and the Dhiarizos Group, a predominantly mafic assemblage dominated by late Triassic ophiolite rocks (corresponding to Lapierre's Petra tou Romiou Formation). This stratification is basically the same as that proposed by Swarbrick and Robertson (1980) in an attempt to revise the stratigraphy of the Mesozoic rocks of Southern Cyprus (Fig. 3.5). This paper is used as the basis for the stratigraphical nomenclature employed in this report, and is the main source for the description of the Mamonia Complex rock formations given below.

3.5.3.1. Ayios Photios Group

The Ayios Photios Group is a Middle Triassic to Lower Cretaceous sedimentary sequence about 235m thick, named after Ayios Photios village located in the centre of Study Area 2. It is divided into three formations: the Vlambouros, the Marona and the Episkopi Formations.

The Vlambouros Formation normally tectonically overlies the Dhiarizos Group but, locally, may be intercalated with the Phasoula lavas of the latter. It consists of up to 50m of medium- to coarse-grained sandstones and thinly bedded finer-grained sandstones interbedded with radiolarian mudstones and calcilutites. It passes conformably upwards into the Marona or Episkopi Formation.

The Marona Formation passes transitionally upwards into the Episkopi Formation and consists of a sequence, reaching 20m in thickness, of grey fine-grained limestone, partially recrystallised and silicified with interbeds of mudstones siltstones and shales.

The Episkopi Formation forms the highest stratigraphical levels of the Ayios Photios Group. It comprises a 120m thick sequence of chert, silicified radiolarian mudstone, red shale, grey bituminous shale and black iron-manganese siltstones. Coarser facies include massive or thinly bedded sandstone,

FIG. 3.5: Stratigraphical Classification of the Mesozoic rocks of SW Cyprus

		LAPIERRE 1975		SWARBRICK and ROBERTSON 1980			
CRETACEOUS	Upper	LEFKARA FM		LEFKARA FM			
		MONI FM		KATHIKAS FM			
		KANNAVIOU FM		KANNAVIOU FM			
		TROODOS COMPLEX		TROODOS COMPLEX			
	Lower	MAMONIA COMPLEX		MAMONIA COMPLEX			
				DHIARIZOS GROUP			AYIOS PHOTIOS GROUP
		PETRA TOU ROMIOU FM	MAMONIA FM				AKAMAS MEMBER
JURASSIC	Upper		CHERT UNIT	MAVROKOLYMBOS FM			EPISKOPI FM
	Middle						
	Lower		HALOBIA LIMESTONE UNIT		KHOLETRIA MEMBER		MARONA FM
TRIASSIC	Upper	LIMESTONE, CHERTS, LAVAS, BRECCIAS		PHASOULA FM	LOUTRA TIS APHRODITIS FM	PETRA TOU ROMIOU FM	
			SANDSTONE WITH FOSSIL PLANT UNIT				
	Middle						VLAMBOUROS FM
				Also AYIA VARVARA FM: Metamorphics			

FM= Formation

gritstone, calcarenite, conglomerates and orthoquartzite.

In addition to the above formations, isolated sandstone blocks up to 40m in diameter exist in the Akamas Peninsula which are generally absent in other areas of SW Cyprus, or appear as interbeds in the upper part of the Episkopi Formation or as olistoliths in the Moni Formation melange in S Cyprus. The sandstones are yellow to reddish, massive and structureless, consisting mainly of quartz. Because of its erratic and limited occurrence, the Akamas sandstones are not considered as a separate Formation (Swarbrick and Robertson, op cit.) but as a Member of the Episkopi Formation.

3.5.3.2. The Dhiarizos Group

The Dhiarizos Group consists of a Middle to Upper Triassic igneous and sedimentary sequence. It forms the base rocks of the Mamonia Complex and is tectonically overlain by the Ayios Photios Group. The Dhiarizos Group is subdivided into four formations: the Phasoula, Loutra tis Afroditis, Petra tou Romiou and Mavrokolymbos Formations, and the Kholetria Member.

The Phasoula Formation exceeds 250m in thickness and consists mainly of pillowed and massive lavas with some doleritic sills and dykes. The lavas are commonly porphyritic, highly vesicular, and are much more alkaline and richer in TiO_2 than the Troodos lavas. In SW Cyprus, the Phasoula Formation is frequently structurally associated with masses of serpentinite, Troodos igneous rocks, and metamorphics.

The Loutra tis Afroditis Formation is best developed in the coastal areas of SW Cyprus, whilst elsewhere it is known to occur only as small detached blocks. It consists of lava breccias, volcaniclastic breccias with subordinate volcaniclastic siltstones, and some manganiferous radiolarian mudstones.

Both the Phasoula and Loutra tis Afroditis Formations are intercalated with pink and grey chert-bearing and manganiferous calcilutites which comprise the Kholetria Member, recognised as a separate lithological unit by Swarbrick and Robertson (op cit.).

The Mavrokolymbos Formation comprises thinly-bedded radiolarian mudstones, manganiferous siltstones, calcilutites and white radiolarian siltstones, with a maximum thickness of c. 45m. Its lower boundary is exposed only in the Kholetria Member of the Phasoula Formation. The upper boundary is in tectonic contact with the Ayios Photios Group.

Closely associated with the Dhiarizos Group rocks are the metamorphic rocks of the Ayia Varvara Formation, comprising an assemblage of amphibolites, schists and marbles. The maximum estimated thickness of these metamorphics is around 200m in the type area North of Ayia Varvara village.

3.5.3.3. The serpentinites

In S and SW Cyprus, the Mamonia Complex is associated with extensive sheets of serpentinite and related mafic and ultramafic rocks, the origin of which are uncertain. They generally rest tectonically on the Kannaviou Formation or the Troodos Complex rocks and in several places are in turn tectonically overlain by rocks of the Ayios Photios or Dhiarizos Groups. In SW Cyprus, the serpentinite sheets form a major arcuate belt extending from the Akamas Peninsula in the north, through the Mavrokolymbos and Ayia Varvara area to near Archimandrita (Fig. 3.4). Most of the serpentinites are highly sheared, but serpentinite protoliths of harzburgite and dunite from less underformed outcrops, may indicate a relation to similar serpentinite found within the main Troodos Massif. Xenolithic blocks and slivers of both Troodos and Mamonia lavas, diabase, and gabbro, as well as sedimentary rocks of the Mamonia complex, have been observed within the serpentinites mainly along shear zones.

3.5.3.4. The Melange

The Moni Formation, named after Moni village in S Cyprus, was the term suggested by Pantazis (1967) to describe a series of strongly sheared gypsiferous clays intercalated in places with radiolarian siliceous, chalky and tuffaceous beds which occurred at the base of the Lefkara Formation. Within these clays in S Cyprus there is a zone of 'melange' (the 'Moni Melange'; Pantazis, op cit.) with numerous incorporated exotic blocks of various sizes. Lapierre (1975) used the term 'Moni Formation' to include the Upper Cretaceous 'melange' consisting of blocks of Mamonia Complex rocks in a clay matrix. The equivalent formation was termed the 'Trypa melange' by Turner (1971) and 'Mamonia melange' by Ealey and Knox (1975).

The confusion of terms used for the melange of S and SW Cyprus was clarified by Swarbrick and Naylor (1980) who introduced the term 'Kathikas Formation' (after the type locality near Kathikas village) for the characteristic melange which discontinuously overlies the Kannaviou, Mamonia Complex, and Troodos rocks in SW Cyprus and locally in S Cyprus. Predominantly derived from erosion of the Mamonia Complex rocks, the deposition of the Kathikas melange was interpreted as a series of submarine debris flows which reach a maximum estimated thickness of c. 270m. It is generally overlain by the chalks and marls of the Lefkara Formation. The term 'Moni Formation' is restricted to the markedly different melange found only in S Cyprus (see Report No. EGARP-KW/86/2; GSD Rep. No. G/EG/13, this series), which is distinct from the Kathikas melange in that highly-sheared, bentonitic Kannaviou Formation clays form its supportive matrix, in contrast to the dominantly Mamonia-derived reddish-brown silt-clay matrix of the Kathikas melange. In addition, the Moni melange includes some clast lithologies not seen in the Kathikas melange and the clasts are generally larger (Robertson 1977).

This distinction between the Moni melange and Kathikas melange is recommended by Swarbrick and Robertson (1980) in their stratigraphic revision of the Mesozoic rocks in Cyprus. We believe that this distinction is correct and justified, and that the general use of the Moni Formation is confusing (e.g. as employed on the 1978 1:25 000 scale geological map of Cyprus published by GSD).

The Kathikas Formation, as one of the major cohesive soil formations associated with the ophiolite terrain of SW Cyprus, is discussed in detail in succeeding sections of this report, where it is generally referred to simply as the 'Melange'.

3.5.4. The Circum-Troodos Sedimentary rocks post emplacement of the Mamonia Complex

By the end of the Maestrichtian, the major tectonic movements which resulted in the emplacement of the Mamonia Complex had ceased , and the entire south margin of Troodos came under deep-water calcareous sedimentation, accompanied by later progressive uplift of the Troodos Massif.

The Maestrichtian to early Cainozoic stratigraphical units of the circum-Troodos sediments comprise widespread sequences of pelagic carbonates. The Lefkara Formation (Upper Maestrichtian-Oligocene), consisting predominantly of chalks and subordinate marls and cherts, is successively overlain by Terra Formation reef limestones (Lower Miocene); alternating sequences of chalk, marl, marly chalk, and calcarenite of the Pakhna Formation (Middle Miocene); locally developed reef limestones of the Koronia Formation and gypsum, marly chalk, and marl of the Upper Miocene.

The Pliocene is represented by the Nicosia Formation (which in SW Cyprus crops out extensively in the Polis Basin in the north-central part of the Paphos region) comprising marl and subordinate arenitic deposits. This is overlain by biocalcarenites and marls of the Athalassa Formation.

The upper parts of the circum-Troodos sedimentary succession are represented by Pleistocene-Recent fanglomerates; marine and river terrace deposits of sand, silt and gravel; chalk talus deposits around the highland plateaux areas; and river alluvium.

3.6 The origin of the Troodos Ophiolite

Early studies of Troodos (Bishop 1952, Wilson 1959) recognised the Troodos Compex as a slice of ocean crust, but it was only following the work of Moores and Vine (1971) that it was redefined as an ophiolite, formed during the development of the Tethyan Sea. Fossil datings of interlava sediments and radiometric age determinations on igneous members of the complex indicate a pre-Maestrichtian age; the Upper Pillow Lavas are probably Cenomanian, based on radiolaria in the Peraphedi Formation (Mantis, 1970; 1971).

Although there is general agreement that it represents an uplifted sequence of ocean lithosphere, the origin of the Troodos ophiolite, the tectonic environment in which it was formed, and the mode of its emplacement has been the subject of controversy for many years.

Based on gravity measurements, Gass and Masson Smith (1963), proposed a model consisting of a rectangular slice of high density ocean crust in which a gravity low coincides with the exposure of the serpentinised harzburgite. The present-day structure of the Troodos Massif has resulted from progressive uplift (the majority of which has occurred since the Lower Miocene) possibly caused by the serpentinization of the deep-seated ultramafic rocks.

On the basis of the N-S strike and preferential chilling of the sheeted dykes, indications are that the Troodos ophiolite was produced at a N-S constructive margin located to the west of the present-day massif. However, this is in contrast with the spreading axis of the Tethyan ocean system which is orientated E-W. In 1971, Moores and Vine postulated a 90° anticlockwise rotation of the massif (based on palaeomagnetic data) and an original E-W orientation for the Troodos spreading axis. Thus the structural scenario for Troodos at the time of its formation (summarized by Gass, 1980) was an E-W spreading axis that lay to the north of the present-day massif. To the west lay a transform fault, now preserved as the Arakapas Fault Zone and Limassol Forest Area. The fact that the oceanic layers of Troodos are much thinner than the present day major ocean basins, together with geochemical data, indicates that Troodos was part of an oceanic lithosphere produced at a minor constructive margin in a marginal back-arc basin above a paleosubduction zone.

Due to the lack of information regarding the nature of the Troodos basement (i.e. is it oceanic or continental crust?) Gass & Masson Smith (1963) and Gass (1980) suggested two models for the emplacement of Troodos. The first model postulates a northerly inclined slab of high density mantle under-thrust and detached by the northward movement of continental Africa. The second model postulates an under-thrusted ocean crust basement below Troodos, with the latter formed under back-arc conditions.

Gass (1980) favours the idea that Troodos is essentially autochthonous and attached to a subjacent mantle of high density rocks at least 30km thick. However, following identification of the undoubted allochthonous Semail ophiolite in Oman and its similarities to Troodos, the autochthoneity of the Troodos ophiolite is still open to question. Biju-Duval et al. (1976) and Coleman (1977) postulate that the Troodos ophiolite is a rootless slab of oceanic crust resting on African continental crust.

Robertson and Woodcock (1980) suggest that the Troodos is part of a sizeable ocean basin which originated by intra-continental rifting in the Late Triassic. Troodos was created by a major pulse of Late Cretaceous ocean floor spreading related with a subduction zone. Consumption of oceanic crust eventually juxtaposed the Troodos with the Turkish margin resulting in large scale, localised down margin sliding (of the Mamonia complex). After collision of the Arabian with the Turkish plates in the Late Cretaceous, Turkey was probably expelled westwards leading to the 90° anticlockwise rotation of Cyprus in Middle Miocene.

Moores et al., 1984 (taking into account geochemical evidence that suggests involvement of a subduction zone, the thin oceanic crust, the extensional environment indicated by sheeted dykes, the existence of fault zones perpendicular to the inferred spreading axes, and the discontinuous nature of the ophiolite exposures around the Arabian block), find similarities between Troodos and other Mid-east ophiolites and the Andaman Sea region of the Indian ocean. They suggest a model in which each of the ophiolites from Troodos to Semail, were formed in a series of short spreading segments separated by transform faults, all located over a north-dipping subduction zone. A highly oblique collision of Troodos with a microcontinent (possibly now part of the Antalya Complex in S Turkey) resulted in uplift and the shedding of gravity slices onto Troodos. In Late Miocene time, the collision of another microcontinent or possibly the continental margin of the African Plate with the subduction zone south of Cyprus, caused the rotation and uplift of the Troodos Complex. In a recent study, however, Clube, et al. (1985) postulate that the rotation occured relatively quickly in the Late Cretaceous - Lower Eocene, and was completed by the end of the Lower Eocene. Although their is little doubt that this remarkable rotation took place, exactly when this event occurred and precisely what rotated has still to be resolved.

3.7 The origin of the Mamonia Complex and its emplacement on the Troodos Ophiolite

Most workers agree that the Ayios Photios Group records the Mesozoic evolution of a passive continental margin whereas the volcanic suite of the Dhiarizos Group mainly shows affinities to intra-plate volcanism (Ealey & Knox, 1975; Robertson & Woodcock 1979; Swarbrick, 1980). The mode of emplacement of the Mamonia Complex is, however, still the subject of some controversy.

Earlier workers have postulated that the Mamonia Complex was derived from the northeast and thrust over the Troodos and its sedimentary cover, the Kannaviou Formation, as a series of nappes. Lapierre (1975), argues that the base of the Mamonia Complex is a sheet of serpentinised harzburgite and the nappes were large folds verging a in southwesterly direction. The presence of Kannaviou and Troodos Complex rocks detached from the main massif were interpreted as tectonic windows to the Troodos basement. Turner (1973) essentially agrees with this hypothesis and postulates a Late Cretaceous subduction of oceanic crust beneath a continental margin then located to the NW of Cyprus in Southern Turkey. In the Maastrichtian, this subduction culminated in a major collision of oceanic crust with the continental margin triggering off major oceanward gravity sliding of the continental margin rocks.

Cleintuar et al. (1979) and Searle & Panayiotou (1980) suggest that the Mamonia complex rocks formed part of the Afro-arabian continental margin that escaped the fate of being under-thrust along the N-dipping subduction zone below Troodos in the Upper Cretaceous, and were later emplaced by gravity sliding onto the leading edge of Troodos.

Robertson and Woodcock (1979) refer to the close similarity of the Antalya Complex of SW Turkey with the Ayios Photios Group of the Mamonia Complex, which is considered to represent the relatively autochthonous remnants of the northern continental margin of an ocean basin. The Troodos is a remnant of the southern part of this oceanic basin and the Dhiarizos igneous rocks represent a marginal strip between Troodos and the continental margin. Swarbrick (1980) proposed the emplacement of the Ayios Photios Group onto the Dhiarizos Group by gravity sliding and suggested that both of groups were then juxtaposed with the Troodos Complex along large SW-NE strike slip faults.

As noted in Section 3.5.6, Moores et al (1984) suggested that a highly oblique collision of Troodos with a microcontinent (possibly now part of the Anatalya complex in Southern Turkey) resulted in the uplift of the Mamonia continental margin and the shedding of gravity slides onto the Troodos Complex.

The authors of the current report concur with Swarbrick & Naylor (1980) and Swarbrick & Robertson (1980) that the deposition of the Melange (Kathikas Formation) occurred as a series of submarine debris flows following emplacement and erosion of the Mamonia Complex rocks. It should be noted, however, that Ealey and Knox (1975) argue that a large part of the melange debris was formed as a result of mylonisation and tectonic fragmentation which accompanied the emplacement of the allochthonous Mamonia rocks.

For more detailed accounts of the theories pertaining to the origin and emplacement of the Mamonia rocks of SW Cyprus and the Troodos ophiolite, the reader is referred to the comprehensive bibliography given in Chapter 10.

4. HISTORY OF GEOLOGICALLY RELATED ENGINEERING PROBLEMS IN THE PAPHOS REGION

Large parts of the Paphos region can be described as vast outdoor museums exhibiting various forms of engineering problems related mainly to the behaviour of cohesive soils. Ruins or remnants of old villages are found scattered over areas of extensive outcrops of the Kannaviou Formation, the Melange and the Superficial Melange, especially in the more mountainous areas, depicting a long history of mass movements affecting the old dwellings. Historically, the villages are situated at or very close to the contact of the argillaceous cohesive soils and overlying chalks, where natural springs provided the water supply of the settlements. Successive shallow or large scale landslides repeatedly ruined the old villages and until the middle of this century such events were considered as "God sent". People simply moved to what they considered to be safer grounds, rebuilding their houses close to the original position of the village so as to be near their fields and water supply. Landslides adversely affected not only villages but also extensive tracts of agricutural land which, due to the slope movements, was rendered unsuitable for any permanent cultivation (vines, almond or olive trees) and was thus left as pasture land. In 1953 a strong earthquake with a surface wave magnitude of 6.16 hit south western Cyprus with catastrophic results. Paphos was the worst affected area and five villages suffered damage of the order of 90% and over, 38 villages suffered damage of 50-90% while 48 villages had suffered more minor damage ranging from 10-50%. Analysis of these damages by the Geological Survey Department showed that although a large number were the direct result of the earth tremor combined with poor construction of the buildings, there was a strong correlation between the earth tremor and the triggering of landslides, which in turn caused considerable damage. This catastrophic event was the impetus for more organised work into the causes of mass movements and the issue of landslides in the cohesive soil formations started coming into focus.

The need to know the extent, and to understand the mechanisms, of mass movements in the broader Paphos region became critical issues from the early 1960's onwards with the instigation of large-scale development projects involving the construction of new permanent roads, communication lines, and large water utilization projects (dams, ponds, conveyors). In parallel, traditional agriculture (vines in the more stable areas and pastures in the unstable areas) was gradually being replaced by more intense agricultural methods involving terracing of slopes and the cultivation of fruit trees and other permanent plantations. Houses of more "modern" construction were also being built, and demands for more reliable locations led to the resiting of many old villages (e.g. Statos, Ayios Photios, Kholetria, Theletra and others) to areas of more stable foundation conditions.

Landslides were no longer affecting remote, badly constructed villages but large expensive structures such as, for example, the Mavrokolymbos dam, where repeated landslides into the reservoir threatened its integrity and necessitated expensive remedial works. Proposed dam sites at Kapslos on the Dhiarizos river, at Pitargou and Ayia Varvara on the Ezousa river, and the Hoglagovounos dam site on the Khapotami river, were rejected, after extensive investigations, because of large scale landslides affecting the dam sites and/or their respective reservoirs. These landslides were associated with the rocks and related sediments of the Mamonia Complex and the overlying chalks. Road sections near Yiolou village, Statos-Ayios Photios, and Axylou-Nata were realigned because of extensive damage caused by landslides; and efforts to develop agriculture by modern techniques involving terracing and drip or sprinkler irrigation, were often frustrated by even shallow movements that disrupted the irrigation lines. Resiting villages was no longer a relatively inexpensive solution. From recent experience, resiting a moderate-size village involves expenses in the order of CY £3M, and more if access roads have to be constructed. Even today, villages such as Pendalia and Episkopi demand to be resited because of landslide movements, and in such cases the expenditure involved will be considerable.

In general terms, the geologically related engineering problems in the Paphos region may be divided into two broad categories.

In the first category are the problems that occur often and repeatedly and are of relatively small magnitude. These include problems related to creep, swelling and shrinkage, water logging of the soil, and shallow mass movements, i.e. events closely related to the climatological and topographical conditions of the region. Although individual events may be small, their cumulative effect causes considerable damage which, when regularly repaired, results in annual remedial costs of thousands of pounds. Examples of such damage may be cracking of existing buildings, collapse of terrace walls, destruction of road pavements, and tilting of telephone/electricity poles.

In the second category are the large-scale engineering problems related to events such as strong earthquake shocks (eg. 1953) and/or prolonged periods of high rainfall (e.g. as recorded for selected winter months between 1961 - 1969). Athough of relatively infrequent occurrence, such events may trigger massive foundation and slope failures that could ruin villages, completely disrupt roads, service and communication lines, or threaten large structures. Such catastrophic events, which have caused extensive damage in the recent past, create expenditure of many millions of pounds in addition to raising the critical issue of the threat to human life.

The common denominator in both categories is the fact that the major engineering problems are associated primarily with the cohesive soil formations. For engineering and planning purposes, therefore, it is essential that these soils be identified and their mineralogical and geotechnical properties ascertained in order to predict their anticipated behaviour, and to ensure that any potential geological hazards are recognized prior to local or regional development.

5. THE SURVEY

5.1 Introduction

Following preliminary desk studies and reconnaissance visits to SW Cyprus, two adjacent study areas were selected for the investigation, situated 20 km NE of Ktima (Paphos town) in the highlands of the Paphos region on the southwest perimeter of the updomed Troodos Massif (Fig.5.1a). The study areas were centred on the villages of Phiti (Area 1) and Statos (Area 2) with the NE-SW trending Ezousas river forming a common boundary between the two (Fig. 5.1b). The topographical and geological setting of the two study areas, outlined below, are discussed in detail in Chapter 6.

5.1.1. The Study Areas

The Phiti Study Area (Area 1) comprises an area of approximately 40km^2 bounded by the Stavros tis Psokas river to the north and the Ezousas river to the southeast. The northeast and southwest margins follow broad geological boundaries represented by the Troodos pillow lavas and the in-situ calcareous rocks, mainly Maestrichtian to Lower Miocene chalks and marly chalks, respectively. In general terms, the topography is characterized by a WSW-ENE trending central plateau of Lefkara chalks, reaching a maximum elevation of 700m AMSL, which separates the area into two main northern and southern slopes interrupted by smaller chalk plateaux near Ayios Dhimitrianos [GR 589 632] and Simou [GR 548 668] villages. The chalks, forming the higher ground, overlie an Upper Cretaceous sedimentary melange (the 'Melange' or Kathikas Formation) which crops out to form the upper slopes below the chalk caprock. The Melange overlies sediments of the Kannaviou Formation comprising Lower Campanian to Maastrichtian bentonitic clays, mudstones and volcaniclastic sandstones and siltstones. The Kannaviou forms the greater part of both the main northern and southern slopes and this extensive outcrop was a major factor in the selection of the study area. Contrastingly, outcrops of the Mamonia

Fig. 5.1a

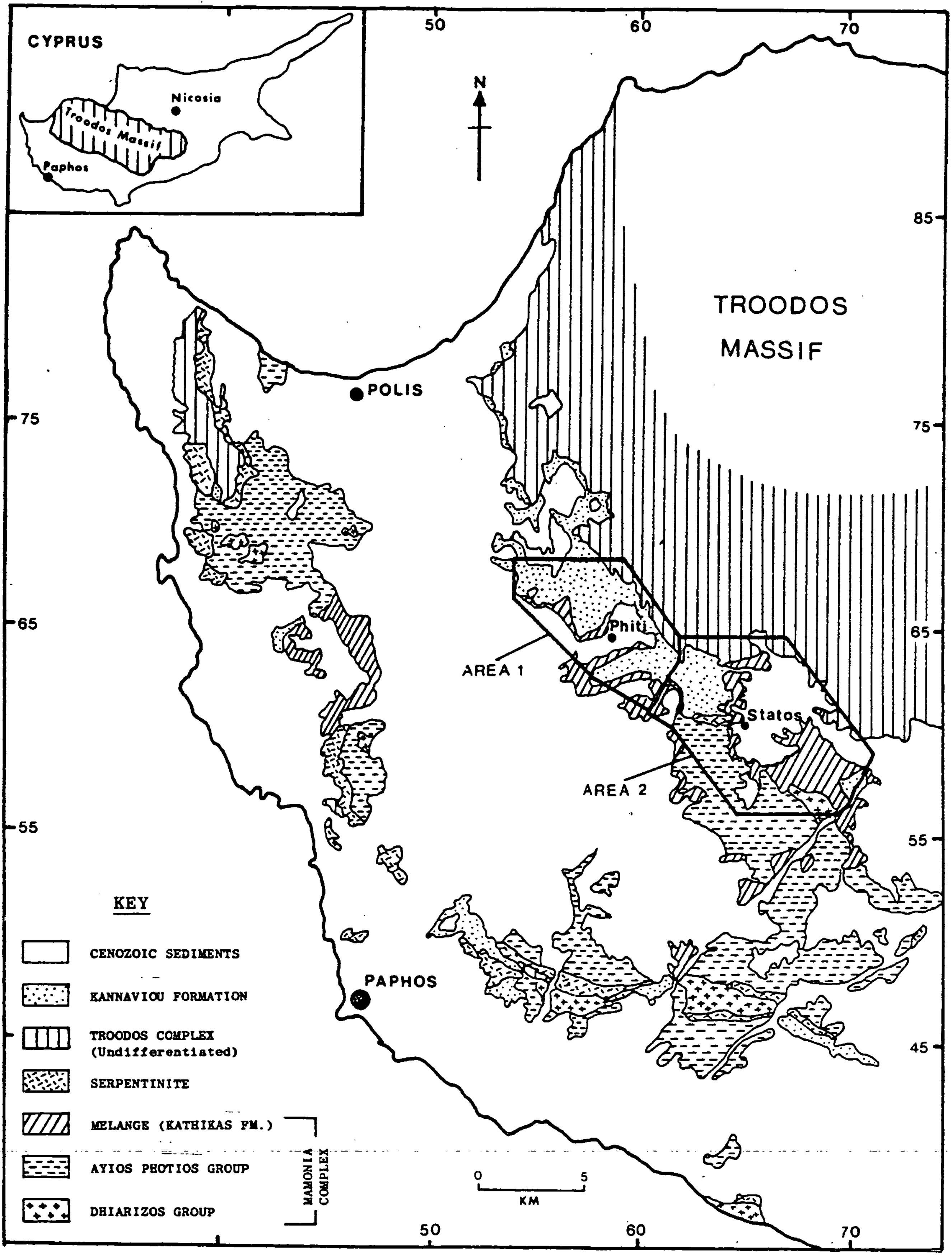


Fig. 5.1a Outline geological map of SW Cyprus showing locations of Study Areas 1 and 2. (Based on Swarbrick & Robertson, 1980; Cenozoic sediments after Lapierre, 1975).

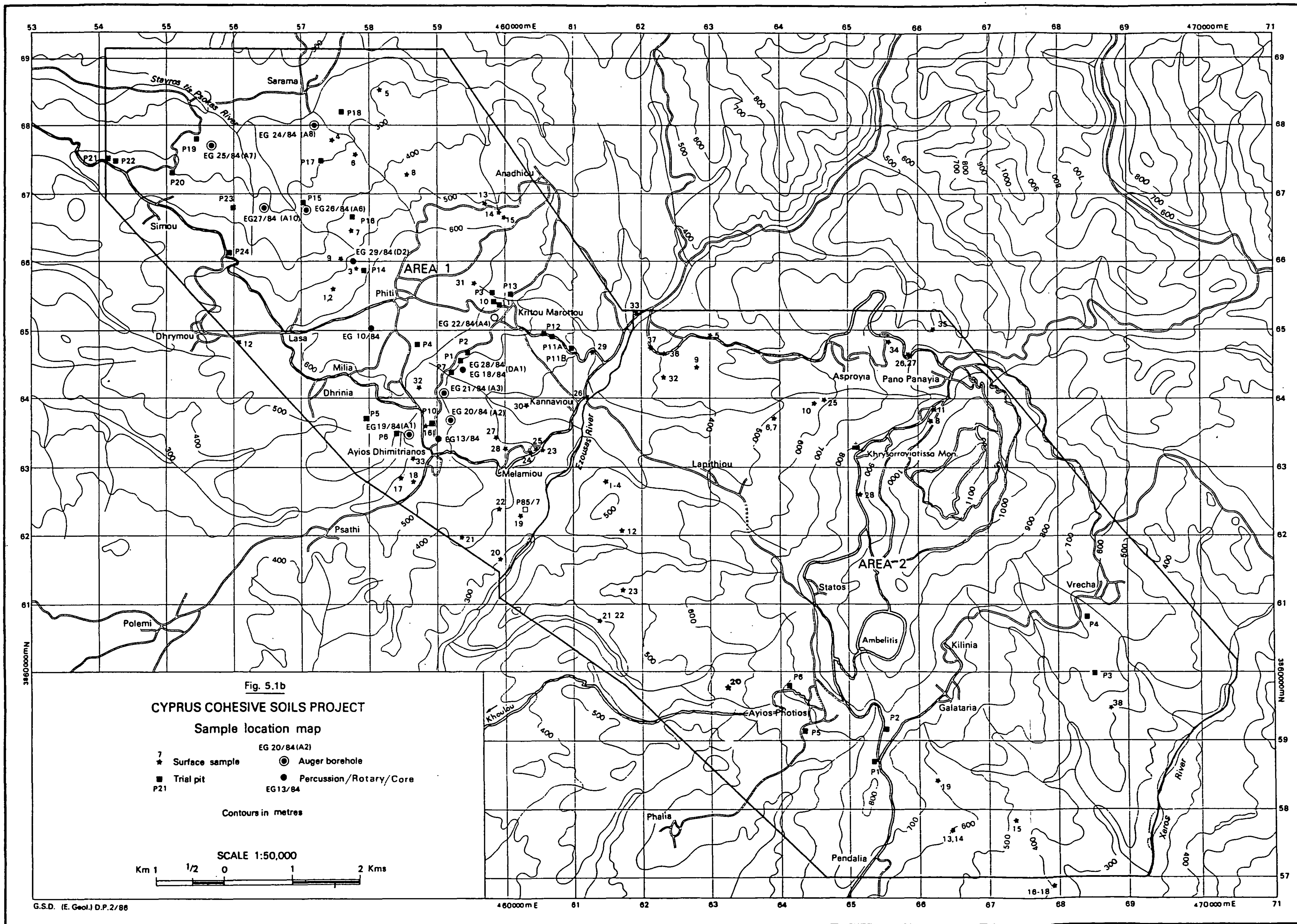


Fig. 5.1b

CYPRUS COHESIVE SOILS PROJECT

Sample location map

Complex rocks are virtually absent but limited exposures in recent landslip scarps may indicate that these rocks underlie the Melange-covered slopes immediately south of Dhrinia village [GR 572 641]. Near the southeast area boundary, 0.5km SW of Kannaviou village, [GR 610 640] highly disturbed Kannaviou sandstone beds are in direct structural contact with a large mass of serpentinite.

Throughout the study area the Kannaviou and Melange clays, and in many places the overlying chalk caprock, are involved in extensive landslides.

<u>The Statos Study Area (Area 2)</u> comprises an area of approximately 63km², bounded by the Xeros river to the southeast and the Ezousas river to the northwest, with the latter forming a common boundary with Area 1. The southern margin follows a straight E-W line from the Xeros river to 0.5km south of Pendalia [GR 652 573] village before continuing towards the NW to meet the Ezousas river approximately 2.5km SW of Kannaviou village to form the southwest boundary line. To the north and northeast, the area boundary broadly follows the outcrop of the Troodos lavas. Topographically more rugged and of higher relief than Area 1, Area 2 is dominated by an extensive NNE-SSW trending central 'chalk' plateau stretching from Pano Panayia village [GR 665 643] in the north to around Ambelitis village [GR 655 605] in the south. The plateau, referred to in this study as the 'Panayia plateau', comprises bedded chalks, interbedded marls and marly chalks of the Lefkara Formation, and reaches a maximum elevation of 1140m AMSL in its central part where it is capped by hard, massively bedded reef limestone of the Terra Formation (L. Miocene) and thin-bedded chalks of the Pakhna Formation (M. Miocene). South of Ambelitis, a 0.5km long, chalk-free, Melange-covered saddle ridge separates the Panayia plateau from a smaller chalk plateau of maximum elevation c. 800m AMSL above Pendalia. The central plateaux separate the area into two extensive WNW- and SE-facing slopes dissected by tributary streams draining to the Ezousas and Xeros rivers. Exposures of the basal Kannaviou sediments are of more limited extent than in Area 1 and crop out in only two areas; on

the western slope in the vicinity of Lapithiou where it is often incorporated in and covered by extensive Melange and chalk landslip debris, and on the lowermost part of the SE slope 2km south of Vrecha [GR 685 612] where it is exposed in a small stream valley cut through the surrounding Melange-covered slopes. Rocks of the Mamonia Complex are widespread in the area, outcropping mainly as extensive 'windows' in the Melange cover in the eastern part of the area below Statos and Ayios Photios and on the SE slope below Pendalia. With the exception of the steep NE slopes of the Panayia Plateau where the chalk directly overlies the Troodos lavas, extensive Melange deposits drape the slopes below the chalk capping to form a cover of variable thickness over the Kannaviou and Mamonia Complex rocks.

An important factor in the selection of the two study areas was a consideration of the history of slope stability problems associated with the Kannaviou and Melange clay formations and the slope deposits derived from the Mamonia Complex rocks, which have been exacerbated by earthquakes and high intensity winter rainfalls. Extensive outcrops of these clays occur in Areas 1 and 2 and mass movements continue to harrass settlements, roads, communication lines and agricultural land. The investigation of the geotechnical properties and engineering behaviour of these cohesive soil formations occuring in close proximity to the Troodos ophiolite, and the associated problems of slope instability in the two study areas (differentiated by a contrast in elevation, relief and geological outcrop), forms the basis of this report.

5.2. Methodology and Techniques

Following selection of the study areas, the investigaton fell broadly into four parts:

(i) A desk study of available data

(ii) Aerial photograph assessment

(iii) Fieldwork

(iv) Laboratory work

5.2.1. Desk Study

A desk study of available data was carried out in the early stages of the project prior to the fieldwork programme and continued throughout the survey period as additional data sources came to light. Major sources of data were the published papers and maps of early and contemporary workers in SW Cyprus and published/unpublished reports and borehole/hydrogeological/ rainfall records held in the GSD archives in Nicosia. Discussions with engineers of the Cyprus Public Works and Water Development Departments provided further data, and GSD personnel provided useful first-hand information on many aspects of the geology and related engineering problems in the Paphos region. The major sources of published and unpublished data are listed in Chapter 10, 'Bibliography'.

5.2.2. Aerial Photograph Assessment

In order to provide an assessment of the type and extent of landslipping in the study areas, it was decided to produce two engineering geological (landslide) maps, one of each area, at a final presentation scale of 1:10 000. The maps were to show landslide details and other relevant data superimposed onto a geological base. For field mapping it was decided to use readily available, high quality 1:5 000 scale topographic base maps supplied by the GSD.

The aerial photographic assessment of Areas 1 and 2 utilized existing panchromatic black and white vertical aerial photography at c. 1:10 000 scale flown in September-October 1963. These photographs, supplied by the GSD, were the most recent available providing full coverage of the two study areas.

To facilitate the field mapping and provide sufficient geological detail for landslip assessment at 1:5 000 scale, the major geological/lithological boundaries were identified from the aerial photographs and marked on transparent overlays. The boundaries were then transferred by hand onto the 1:5 000 scale topographic 'field' maps covering both study areas. Within the identified areas of the Kannaviou and Mamonia Complex rocks, a distinction was made between the major volcaniclastic sandstone outcrops and the dominantly argillaceous sediments of the former, and the sedimentary and igneous rocks (including serpentinites) of the latter. Superficial materials comprising chalk talus deposits, often covering extensive areas below the chalk plateaux scarps, and river alluvium, were also identified and their boundaries transferred to the field maps. The aerial photographs also showed an extensive superficial cover of reworked colluvial material overlying, in particular, large tracts of the Kannaviou and Melange slopes and, to a lesser extent, the sedimentary Mamonia Complex rocks. These often ubiquitous deposits were identified as probable landslip debris. In addition to outcrop boundaries, major lineaments representative of possible fault lines were identified and transferred to the field maps. For the latter exercise the 1:10 000 scale air cover was supplemented by additional assessment of 1:25 000 scale aerial photographs flown in 1957.

In addition to the recognition of geological detail, the 1:10 000 scale photographs provided an invaluable tool in the preliminary identification of landslides, landslide zones and significant geomorphological aspects such as cliffs, major breaks of slope and erosional features within the study areas. Boundaries of individual landslides and areal landslide zones (certain or inferred) were delineated and head and side scarps marked. Within the boundary lines indicating the extent of slip debris, symbols were used to denote direction of movement and whether the movement was primarily by slide or flow failure. Within the limits of the photographic scale, 'block type' deformations indicative of slumped (or backtilted) and translated masses were also noted as was the presence of rockfall debris. As with the geological details, the interpreted landslide information was transferred from transparent overlays onto the 1:5 000 scale topographic map sheets.

The 1963 aerial photographs clearly showed the presence of many fresh or recently active slope movements, distinguished by a disrupted vegetation cover, 'sharp-edged' scarps, terraces and crevices, and clearly defined cracks or fissures at lateral slip margins and immediately behind backscarp crests. These movements almost certainly reflected the triggering effects of the high autumn and winter rainfalls recorded in the region between October 1960 and March 1963. In particular, many areas in the Paphos region were affected by landslides following the high rainfall between October 1961 and March 1962 (Pantazis, 1969). Although these features were noted, no attempt was made to classify the identified landslips with respect to their activity state (whether active or dormant) from the initial aerial photograph assessment prior to field checking (i.e. some 21 years after the air cover was flown).

The field mapping for study Area 1, using the 1:5 000 scale topographic base maps with annotated geological and landslip data, was carried out between May - July 1984, and for study Area 2 between April - June 1985. The details of the fieldwork programme are described in the following Section (5.2.3.). On completion of the field mapping, a further assessment of the aerial photographs was undertaken for each study area to re-confirm or modify geological and landslide boundaries and features identified from field checking. It should be stressed that the quality and reliability of any air photograph interpretation are enhanced in direct ratio to the interpreter's knowledge of the geology and geomorphology of the area under study. With this in mind, the importance of re-assessing the aerial photography with good 'ground control' gained from the walkover field surveys cannot be over-emphasised.

The obvious disadvantage of not having available up-to-date aerial photographic cover, preferably flown immediately prior to the investigation, was that mass movements occurring after September - October 1963 could not be recorded. Also, as mentioned above, a preliminary assessment of the state of current landslide activity could not be carried out with any degree of certainty. The more recent mass movements were, therefore, recorded during the field mapping. Similarly, the assessment of landslip activity, whether active or dormant, was recorded during the field surveys. In contrast, the aerial photographs proved particularly useful for the detection and delineation of landslides and areal landslide zones which, prior to and since 1963, had undergone various degrees of degradation by both natural processes and agricultural activity. In virtually all cases these degraded slides, although often difficult to define from field inspection, showed up clearly on the aerial photographs.

The assessment of aerial photography, coupled with the results of the fieldwork surveys, greatly assisted the preparation of the final 1:10 000 scale engineering geological maps for the Phiti and Statos study areas, the details of which are described in Chapter 8.

Towards the latter stages of the project a number of low-level oblique natural colour and false-colour infrared photographs became available for inspection and assessment. The photographs, taken by a hand-held 35mm SLR camera from a single engine, high-wing light aircraft, were specially commissioned for the project and concentrated on selected localities within the study areas in order to clarify landslip details. Although not available prior to final preparation of the 1:10 000 scale engineering geological maps, the oblique aerial photography provided a useful supplement to the 1:10 000 scale vertical air photographs and field 'ground photographs' as a record of landslipping in the study area. In addition to confirming the presence and extent of disturbed ground, the false-colour infrared photographs also provided indications of surface and near surface drainage conditions and further evidence of the widespread occurrence of superficial colluvial material covering the hillside slopes. The technical advantages and cost effectiveness of this oblique aerial photography in the recognition and assessment of landslides and slide-prone areas is discussed briefly in Chapter 9.

5.2.3. Fieldwork

The fieldwork programme consisted of three phases:

i) Geological (litho-stratigraphic) mapping
ii) Engineering geological (landslide) mapping
iii) Field sampling and testing

Each phase was conducted more-or-less concurrently, with the greater part of the work being carried out during two successive 10-week 'core' field periods, between May-July 1984 for Area 1 and April-June 1985 for Area 2. Although a similar three-phase programme was adopted for both study areas, the field surveys undertaken in the Phiti area (Area 1) was carried out in more detail, particularly with respect to the 'walk-over' geological mapping and subsurface investigation and sampling. A more rapid field reconnaissance technique supported by selected spot checks was undertaken in the more rugged Statos study area which, at approximately 63km^2, was $1^1/_2$ times the size of Area 1.

Vehicular access, mainly utilizing unasphalted agricultural tracks, was generally good in Area 1 but often proved extremely difficult in the more rugged terrain of Area 2. In the latter area, where the 'rapid reconnaissance' technique was employed, the fieldwork survey necessitated the use of a four-wheel drive off-road vehicle.

5.2.3.1. Geological mapping

The geological field mapping primarily entailed the field checking of geological and lithological boundaries interpreted from assessment of the aerial photography and transferred onto the 1:5 000 scale topographic field sheets. The main aim of the work was to produce a sufficiently accurate geological base for presentation of the engineering geological (landslide) details at 1:10 000 scale. For the purposes of the present study, six major litho-stratigraphic divisions, as identified from the aerial photographs, were recognised and mapped in the field as follows:

a) The Troodos pillow lavas, which form the base of the stratigraphic sequence in the study areas.

b) The Kannaviou Formation, with a distinction being made between the major volcaniclastic sandstone outcrops and the dominantly argillaceous sequences.

c) The Mamonia Complex rocks, with a broad two-fold subdivision being made between the sedimentary formations and the igneous formations (including serpentinites).[1]

d) The Melange

e) The 'Chalks', comprising the undifferentiated calcareous rocks of the Lefkara, Terra Limestone, and Pakhna Formations.

f) Superficial deposits, comprising river alluvium and chalk talus.

A superficial cover of landslip colluvium mantled extensive areas of the slopes in both study areas. These materials were mapped as landslip deposits and on the final 1:10 000 scale map sheets were presented as such superimposed on a solid geology base to give an indication of the underlying source rocks from which the colluvium was derived.

Although virtually absent in Area 1, extensive outcrops of the Mamonia Complex formations were present in Area 2. Detailed lithological and structural mapping of this geologically complex terrain with a view to theorizing on its origin and mode and direction of emplacement was beyond the scope of the project objectives. Although broad lithological associations were noted on the field maps, a relatively simple two-fold division between

[1] The origin and mode of emplacement of the serpentinite sheets is not certain. In this study they are grouped with the Mamonia Complex rocks owing to their field associations with the latter in SW and S Cyprus.

the sedimentary (or stratified) and igneous Mamonia Complex formations, broadly equivalent to the Ayios Photios Group and the Dhiarizos Group, respectively, was presented on the 1:10 000 scale geological base maps.

Within the Statos study area, large tracts of the Mamonia Complex rocks appeared from the aerial photographs to be overlain by extensive deposits of Melange. Although this was generally the case, it was clear from the field reconnaissance mapping that over extensive areas a distinction could be made between the characteristic olistostrome Melange (i.e. the Kathikas Formation or Melange as described by Swarbrick & Naylor, 1980 and Swarbrick & Robertson 1980) and a melange-like superficial weathering product derived from the underlying sedimentary Mamonia rocks. This latter deposit, termed 'Superficial Melange' in the present study and described in detail in Chapters 6 and 7, was differentiated in the field from the Melange 'proper' in not generally exceeding a maximum thickness of c. 5 metres and by its variability in lithological constituents, grading, and colour which were commonly reflected in the immediately underlying Mamonia source rocks. The Superficial Melange was mapped in the field and presented on the 1:10 000 scale geological base maps as a distinct superficial deposit in those areas where its estimated thickness exceeded approximately 1 metre. It is stressed, however, that the outcrop boundaries are somewhat arbitrary owing to intermixing of the Melange 'proper' and Superficial Melange by extensive shallow landslipping.

Structural mapping was restricted to selected measurements of bedding and joint orientations and the delineation of significant faults. In the Kannaviou and chalk terrain, the majority of the structural measurements were carried out during the landslide mapping programme in an attempt to distinguish slipped and in-situ strata, as was the continued checking of lithological boundaries.

5.2.3.2. Engineering geological mapping

The main aim of the engineering geological mapping was the identification and classification of the mass movements that occurred extensively throughout the two study areas. In addition, erosional, hydrological and relevant morphological features were also mapped to enable a comprehensive record and assessment of the geodynamic processes acting in the survey areas to be made.

Landslide identification consisted of 'ground truth' checks to verify information derived from the aerial photograph interpretation and primary mapping to identify landslides that had occurred since 1963 and which were not, therefore, shown on the aerial photographs. The morphological details of each landslide were recorded in as much detail as the 1:5 000 scale topographic base maps permitted; also a photographic record of most landslides and any landslide-related damage (to structures, roads, etc) was made. Where appropriate, bedding and joint plane directions were recorded, together with the presence and trend of faults and fissures. In addition, in Area 1, ten selected landslide slope profiles were surveyed using a tape and hand-held clinometer to supplement the mapped landslide details. In Area 2, only two landslide slope profiles were surveyed in the field with additional selected landslide profiles being constructed from the 1:5 000 topographic base map contours.

During the field mapping survey, a classification of the identified mass movements was undertaken based on the systems of Skempton & Hutchinson (1969) and Varnes 1978). The classification utilized readily observable surface morphological features, which could be ascertained from the walk-over surveys and supplemented by aerial photograph interpretation, without recourse to detailed sub-surface investigation and field instrumentation. The chief classification criteria were:

(1) type of movement
(2) type of material and geological formation involved
(3) estimated thickness of slip debris/mass, i.e. depth of slide
(4) activity

The definition and field recognition of these classification criteria and the characteristic types of mass movements identified in the two study areas are described fully in Chapter 8, 'Assessment of Slope Instabilities in the Phiti and Statos Study Areas.

In addition to landslide details, active or fresh erosional features (subdivided into the three categories of sheet erosion, gully erosion and vertical stream erosion) were mapped, as were hydrological features pertaining to marshy areas or ponds (particularly in relation to landslipped ground), water tanks/reservoirs, and active springs. Modifications to stream courses, usually as a result of slope movements, were also mapped where these were found to differ from those shown on the topographic base maps and/or aerial photographs. Other mapped data, assisted considerably by aerial photograph interpretation, included geomorophological features such as prominent ridges, cliffs (slopes in excess c. 55°), breaks of slope and gulleys/depressions.

As far as possible, the symbols used to denote landslide and other details on the map sheets were those recommended by the International Association of Engineering Geology (IAEG) Commission on Engineering Geology Mapping (Matula, 1981) and the Geological Society Engineering Group Working Party Report (Anon, 1972) on the preparation of maps and plans in terms of engineering geology.

5.2.3.3. Field sampling and testing

The main aims of the field sampling and testing programme were to determine the characteristic geological/lithological successions at selected locations in the hillside slopes, to describe these materials in engineering terms, and to obtain 'undisturbed' and 'disturbed' samples for geotechnical and mineralogical testing in the laboratory. Over 300 samples were obtained from boreholes, trial pits and surface outcrop sampling at the locations shown in Figure 5.1b. Approximately 80% of the samples were collected from Area 1 where the most intensive field sampling programme was carried out. In addition, limited sub-surface investigations were also undertaken at two localities in Area 1 using geophysical electrical resistivity surveys.

i) Surface sampling was undertaken at selected outcrops, road/track and stream cuttings, and from landslide scarps during the field mapping surveys. Where appropriate, a spade was used to obtain 'fresh' clay samples below the dried and/or reworked surface soil layer. Approximately forty clay and rock samples were collected from each study area, sealed in plastic bags and transported to the GSD soils laboratory in Nicosia.

ii) Trial pits were dug using a JCB-type back-hoe digger. Twenty-five excavations to an average depth of 2 metres were carried out in Area 1 and six in the more rapidly surveyed Area 2. In each study area, the pits were excavated in both in-situ and slipped material, with the excavations being concentrated in Kannaviou and Melange terrains in Area 1 and in the Melange, Superficial Melange, and sedimentary Mamonia Complex terrains in Area 2. Each pit section was drawn to scale and the lithological and structural details, in particular the presence and orientation of shear surfaces, noted and described (see Appendix IB).

Disturbed bulk samples were collected from each excavation and supplemented in selected pits by undisturbed samples obtained by block sampling and/or from cylindrical steel sampling tubes pushed into the pit base or side. After careful removal from the pits, the undisturbed blocks were trimmed to approximately 250mm square, given a thin coating of melted paraffin wax and wrapped in several layers of tin foil. Several layers of wax-impregnated strong industrial tissue were then applied which, on drying, sealed the sample at natural moisture content and provided protection during transport. Five undisturbed block samples of Kannaviou clay (Area 1) and Melange (Area 2) were collected, with at least one block from each lithology containing shear planes or shear zones resulting from mass movement(s).

Undisturbed Kannaviou and Melange clay samples were taken with limited success from seven excavations in Area 1 by means of U100[1] sample tubes hydraulically pushed into the base of the pits by the excavator bucket. On removal from the pits, the tube ends were sealed with paraffin wax and metal screw caps. In Pit No. 5(85), Area 2, three undisturbed U35[2] samples of soft to firm Melange clay were taken by hand-pushing the sample tubes into the pit sidewall. In several excavations, density ring[3] samples were taken from various depths in the pit sidewalls, sealed and returned to the GSD laboratories for density and moisture content determinations.

In addition to a visual classification of the lithologies examined in the pit sections, quick in-situ field tests using a pocket 'Torvane' shear-meter and penetrometer were carried out in selected excavations to provide a rapid quantitative assessment of the strength and consistency of the clay soils in terms of 'immediate' or undrained shear strength and unconfined compressive strength. The 'field' results are presented on the annotated pit logs in Appendix 1B, where both shear-meter and penetrometer values are shown in terms of undrained shear strength, Su kN/m^2.

iii) <u>Borehole investigations</u> were retricted to the Phiti study area (Area 1). A total of twelve boreholes were drilled in order to ascertain, at selected locations, lithostratigraphic successions, depth of landsliding, groundwater levels in the hillside slopes, and to obtain samples for laboratory testing.

[1]Nominally 100mm dia.x450mm long steel cylinders with detachable cutting shoe.
[2]Nominally 35mm dia. x 230mm long cylindrical steel sample tubes.
[3]Density ring samples comprise undisturbed clay samples obtained by pushing a thin-walled, 50mm diameter cutting ring of known volume into the pit sidewall.

The type and location of all borings are shown on the Phiti area location map, Fig. 5.1b; drilling method, total depth, and sampling interval and technique for each borehole are detailed in Table 5.1. Fully annotated borehole logs are presented in Appendix IA.

Continuous sampling was carried out in all boreholes to obtain a complete descriptive record of lithology and to ensure availability of selected samples for laboratory testing. Of the twelve boreholes drilled, nine were augered to a maximum depth of 18 metres, with alternate undisturbed U4 and SPT samples and disturbed bulk samples being taken over the full borehole depth. Auger hole DA1, near Kritou Marottou was subsequently deepened to 62.7 metres by continuous core drilling through Kannaviou Formation sediments. Three additional deep boreholes were located near the area of Phiti village (B.H.'s D2 and EG 10/84) and Ayios Dhimitrianos (B.H. EG 13/84) for the primary purpose of establishing accurate lithological successions. Borehole D2 was continuously cored to 64.1 metres in Kannaviou clays and sandstones whilst Boreholes EG 10/84 and EG 13/84 were drilled through extensive thicknesses of Melange by percussion and rotary drilling methods, with limited coring being possible only in the underlying Kannaviou deposits.

Within the Kannaviou Formation, nearly all the borings encountered zones or bands of hard, highly sheared montmorillonitic clays. Reasonable undisturbed samples of these horizons were obtained only from the core drilling employing a double-tube sample barrel. On removal from the inner split sample tube, however, the sheared clay easily fragmented along the shears and no undisturbed samples of sufficient quality were obtained for geotechnical strength testing in the laboratory. The influence of sample disturbance on the laboratory shear strength test results are discussed in Chapter 7.

iv) <u>Geophysical electrical resistivity surveys</u>, utilizing an ABEM SAS 300 Terrameter, were carried out at two localities in Area 1 near the villages of Kannaviou [GR 597 638] and Phiti [GR 577 660]. The purpose of the geophysical surveys was to

TABLE 5.1

Borehole drilling and sampling details for Phiti Study Area (Area 1).

BH No.	LOCATION (GRID REF)	BH DEPTH (m)	DRILL RIG TYPE	DRILLING METHOD	DRILL FLUSH	SAMPLING METHOD
E610/84	Phiti (5806.6500)	178.00	Ruston-Bucyrus 60RL Mayhew 1000 "	Percussion (0-68m) Rotary (68-178m) Core (125-127m)	Bentonite mud flush	Bulk samples (1m intervals) Core (125-127m)
E613/84	nr.Ayios Dhimitrianos (5896.6344)	79	Mayhew 1000 "	Rotary (0-79m) Core (30-32m) (42-47m) (61-63m)	Bentonite mud flush	Bulk samples (1m intervals) Core (30-32m) (42-47m) (61-63m)
E618/84 (DA1)	nr.Kritou Marottou (5935.6441)	18	B-53 Mobile Drill	Auger (0-18m)	-	U4 (3m intervals) SPT (alternate 3m intervals) Bulk samples (between SPT/U4)
E628/84 (D1)	"	62.7	B-53 Mobile Drill "	Rotary (0-18m) Core (18-62.7m)	Water flush	Core (18.0-62.7m),continuous
E629/84 (D2)	nr.Phiti (5782.6604)	64.1	B-53 Mobile Drill "	Rotary (0-3m) Core (3-64.1m)	Water flush	Core (3.0-64.1m),continuous
E619/84 (A1)	nr.Ayios Dhimitrianos (5855.6352)	8.05	B-53 Mobile Drill	Auger (0-8.05m)	-	U4 (3m intervals) SPT (alternate 3m intervals) Bulk samples (between SPT/U4)
E620/84 (A2)	nr.Ayios Dhimitrianos (5924.6368)	16.0	B-53 Mobile Drill	Auger (0-16m)	-	U4 (2.0-2.5m),(5.0-5.5m) SPT (3m intervals) Bulk samples (between SPT/U4)
E621/84 (A3)	nr.Kritou Marottou (5905.6412)	8.0	B-53 Mobile Drill	Auger (0-8m)	-	SPT (3.5m,5.0m) Bulk samples (1-2m intervals)
E622/84 (A4)	Kritou Marottou (5993.6516)	18.0m	B-53 Mobile Drill	Auger (0-18m)	-	U4 (3m intervals) SPT (alternate 3m intervals) Bulk samples (between SPT/U4)
E624/84 (A8)	nr.Sarama (5720.6805)	18.0m	B-53 Mobile Drill	Auger (0-18m)	-	U4 (12.5-13.0m) SPT (1.5m intervals) Bulk samples (between SPT/U4)
E625/84 (A7)	nr.Sarama (5573.6774)	18.0m	B-53 Mobile Drill	Auger (0-18m)	-	U4 (3m intervals) SPT (alternate 3m intervals) Bulk samples (between SPT/U4)
E626/84 (A6)	nr.Sarama (5712.6681)	18.0m	B-53 Mobile Drill	Auger (0-18m)	-	U4 (3m intervals) SPT (alternate 3m intervals) Bulk samples (between SPT/U4)
E627/84 (A10)	nr.Simou (5648.6684)	16.0m	B-53 Mobile Drill	Auger (0-16m)	-	U4 (not possible) SPT (1.5m intervals) Bulk samples (between SPT's)

Rotary Drilling: Tricone bit
Core Drilling: Double-tube core barrel,50mm diameter core
Auger Drilling: 12-in. diameter hollow-stem auger flights

determine the into-slope extent of two 15 metre-thick sandstone outcrops occurring within montmorillonitic clays of the Kannaviou Formation. The possibility existed that these and numerous similar sandstone outcrops represented, at least in part, isolated blocks which had been disrupted from more extensive beds and transported limited distances downslope as block-glides. Thus the geophysical study, coupled with borehole information, was expected to provide data on the structural relationships of the outcropping sandstone masses and the adjacent strata. Although acceptable data were obtained, difficulties were encountered in both conducting the geophysical survey and in data interpretation due to the effect of topographic irregularities and steeply sloping ground surfaces.

The resistivity investigations consisted of eleven 'soundings', nine in the vicinity of Kannaviou village and two near Phiti village. The survey findings are discussed in Chapter 8 and the methodology and results are described in detail in GSD report No. G/GP/5/84 (Kramvis, S., 1984).

5.2.4. Laboratory Work

The laboratory testing programme was directed towards the determination of representative geotechnical parameters and mineralogy of the cohesive soils comprising, and derived from, the Kannaviou, Mamonia Complex, and Melange Formations within the two study areas. Of 314 disturbed and undisturbed samples collected from Study Areas 1 and 2 during the field sampling programme, 265 samples were selected for geotechnical and/or mineralogical testing. A summary record of the number and type of tests carried out for each of the major lithological groups is shown in Table 5.2.

The geotechnical and mineralogical testing was carried out both at the Geological Survey Department, Nicosia and the British Geological Survey laboratories, U.K. Throughout the test programme a number of control tests were undertaken on duplicate samples in GSD, Cyprus and BGS, U.K. to ensure testing

TABLE 5.2

Laboratory test record for study Areas 1 (Phiti) and 2 (Statos)

LITHOLOGY	TYPE and NUMBER OF TESTS											
	Moisture Content	Bulk/Dry Density	Liquid & Plastic Limits	Linear Shrinkage	Specific Gravity	Particle Size	Triaxial Shear	Ring Shear	Swelling Pressure	$CaCO_3$ Content	Montmor. Content	Quartz Content
KANNAVIOU FORMATION (clays, mudstones, and sandstones)	44	34	109	6	2	103	6	16	6	112	123	21
MELANGE FORMATION (silty clay matrix)	25	18	82	4	3	84	2 +1 (Melange+Kannaviou Landslip Sample)	13	7	88	88	20
MAMONIA COMPLEX (Sedimentary Mam. rocks incl. 'Superficial Melange'/weathered stratified Mamonia)	-	-	7	2	1	7	-	2	-	12	12	8
CHALKS (Lefkara marly chalk talus slip debris)	6	3	2	-	1	2	-	1	-	-	-	-

ADDITIONAL TESTS(No.):

1. KANNAVIOU CLAY: high pressure (16kPa) oedometer consolidation test (1)
2. MELANGE: falling head permeability test (1)
3. KANNAVIOU SST.: slaking tests (9)
4. KANNAVIOU, MELANGE, CHALKS: selected SEM observations

consistency and reproducibility of results. All geotechnical index testing was carried out in accordance with the test procedures laid down by British Standards BS 1377:1975 and mineralogical testing carried out in accordance with recognised analytical procedures. Mineralogical investigation utilizing x-ray diffractometry supplemented by scanning electron microscope (SEM) observations were undertaken at BGS.

Testing procedures and results are discussed fully in Chapter 7 and a complete summary listing of geotechnical and mineralogical data are presented in Appendix II.

5.3 Data Handling

Sample details and geotechnical and mineralogical data from the GSD and BGS laboratory test programmes were gathered together at BGS and recorded in two ways:

a) A portable CP/M 2.2 system computer was used to record details of all collected samples in terms of sample number, type, depth, location and lithology. Geotechnical and mineralogical data were recorded against each appropriate sample by continuous updating as the test results from the UK and Cyprus laboratories become available. Complete computer listings of sample details and test results are presented in Appendix II.

b) A Hewlett-Packard HP 9845B desktop computer utilizing a sophisticated statistical-graphics software programme was used to produce detailed statistical analyses of all the data and also graphical output in the form of histograms and bivariate X-Y plots. Approximately 3000 discrete test results were dealt with using a matrix of 400 'observations' x 18 'variables'. In addition to test results determined on samples from Study Areas 1 and 2, the data set also included results obtained on supplementary samples collected from outside the main study areas at selected sites across Cyprus. These latter, 'external', samples were collected and tested in order to examine the regional variation in lithology and geotechnical/mineralogical properties of the main cohesive soil formations. These results are discussed and presented in Report No. EGARP KW/86/5, G/EG/16 (this series).

The Hewlett-Packard computer data file was divided into 7 main litho-stratigraphic subfiles for the purposes of statistical and graphical output as follows:

1. Kannaviou Formation
2. Moni Formation (all external to Study Areas 1 and 2)
3. Melange (Kathikas Formation)
4. Stratified Mamonia (including selected sedimentary Mamonia Complex rocks and derived weathered slope deposits, e.g. 'Superficial Melange')
5. Marl (all external to study Areas 1 and 2)
6. Chalk (including Lefkara marly chalk and talus slip debris)
7. Miscellaneous (including serpentinite)

Within each subfile, the samples/test data were grouped primarily into a) those within and b) external to the Phiti and Statos Study Areas, and secondarily into those of similar lithology and/or colour. Where a sample comprised a mixture of formation lithologies (as might be found in a flow-type landslip) it was placed in the subfile corresponding to its dominant component, but in a separate subgroup from the 'uncontaminated' samples.

5.4 Presentation of Results

The results of the survey are presented in the form of:

a) Report text with appended borehole and pit logs, and summary listings of sample and test data.
b) Two 1:10 000 scale engineering geological maps of the Phiti and Statos Study Areas (Area 1 and Area 2, respectively).

6. TOPOGRAPHY AND GEOLOGY OF THE PHITI AND STATOS STUDY AREAS

6.1 Topography

The topographical setting of the Phiti and Statos Study Areas (Areas 1 and 2, respectively) are described in Chapter 5. Located adjacent to the western perimeter of the updomed Troodos Massif (Fig. 5.1a), both areas essentially comprise major NW-SE facing slopes flanking central chalk plateaux, which are dissected by minor rivers and tributary streams draining to the major Stavros tis Psokas, Ezousa and Xeros rivers which flow southwestwards and mark the study area boundaries by their deep river valleys. Downcutting of the rivers is believed to have commenced in early Pleistocene times, and remnants of the original surface survive as plateaux at the higher inter-river ridges which are elongated in a NE-SW direction. Topographically, Study Area 2 differs from Area 1 by its higher elevation, more pronounced relief, and steeper slopes.

In Area 1, the chalk plateau is, for the most part, marked on its NW flank by a steep c. 10-30m high scarp. Below the scarp, the northern dominantly Kannaviou slope is generally characterized by a series of concave segments, underlain by clays and mudstones, between successive 'benches' of sandstone. At outcrop, the sandstone sequences form steep, prominant cliffs from c. 3-15m high in the hummocky clay terrain (Photos. 6.1 and 6.4). With the exception of the smaller, separate chalk plateau near Ayios Dhimitrianos, the SW flank of the central chalk plateau is marked by steep, generally rounded slopes (unlike the continuous north-facing scarp) underlain by steep c. 18-20° slopes of Melange. At many localities, sub-vertical landslip scarps c. 5-15m high mark the contact of the Melange with underlying Kannaviou clays (Photo. 6.2). As on the northern slope, the exposed Kannaviou sandstones on the southern slope of Area 1 form prominent scarps and ridges. Here, however the sandstones tend to dip c.10-12° to the south (downslope), and where eroded and/or faulted give rise to characteristic upslope-facing scarps (Photo. 6.3).

The extensive chalk/limestone forming the central plateau in Area 2 between Pano Panayia and Ambelitis villages (termed the 'Panayia Plateau' of this study) is marked on both its NW and SE flanks by widespread, complex landslides above steep eroded and gulleyed Melange slopes. To the southwest, the main plateau is separated from a smaller chalk plateau near Pendalia village by a chalk-free 'saddle' ridge, again flanked by steep slopes of Melange. Below the capping chalk near Pendalia and below the central plateau west of Ambelitis and Ayios Photios, the terrain comprises steep, dissected irregular slopes underlain by rocks of the Mammonia Complex, which in many areas are covered by variably thick Melange-like colluvium. West of Statos village, a pronounced, rugged ridge of serpentinite and lavas extends E-W for nearly 3km from the chalk cap across the middle-lower slopes. The steep Melange slopes SW of Ambelitis and the irregular colluvium-covered Mamonia slopes below Pendalia are shown in Photo 6.5. The extensive WSW-facing slope of Area 2 between Panayia and Statos villages is shown in Photo. 6.6.

6.2 Seismicity

The general seismicity of the Paphos region is described in Chapter 3. Here, the effects of the severe earthquake which struck SW Cyprus in 1953, with respect to the Phiti and Statos Study Areas, are briefly outlined.

The effects of the 1953 earthquake resulted in widespread damage in both study areas. Many villages, in particular, suffered extensive damage as a result of both poor construction and their precarious locations above steep slopes or on potentially unstable ground. Within the boundaries of the two study area, the following villages were seriously affected:

Lapithiou village, situated in the northwestern part of Area 2 was almost completely destroyed and was rebuilt at a new site in the vicinity of the old village.

The villages of Anadhiou, Mamoundali, Melamiou, Pano Panayia, Statos and Vrecha were seriously damaged, some of which were rebuilt at safer sites.

The villages of Asproyia, Ayios Photios, Dhrinia, Galataria, Kannaviou, Kilinia, Kritou Marottou, Pendalia and Simou were affected less seriously; other villages were only slightly affected.

In addition to the damage to villages, the earthquake triggered several landslides which caused considerable damage to roads, pipe lines and agricultural land.

Prior to the 1953 earthquake, a number of catastrophic earthquakes are mentioned in historical accounts. Local older villagers speak about earthquakes and extensive landslides which disrupted fields and destroyed villages in their youth. Old village ruins scattered throughout the study areas may bear witness to some of these accounts.

6.3 Geological Setting

The geological setting of the broader Paphos region is given in Chapter 3, where the geological formations are grouped into four main groups:

- The Troodos ophiolite
- The circum-Troodos sedimentary rocks prior to the emplacement of the Mamonia Complex
- The Mamonia Complex and related sediments
- The Circum-Troodos sedimentary rocks post emplacement of the Mamonia Complex.

In this Section, the distribution and character of the geological formations found in Areas 1 and 2, and the general geological structure of these areas is described. For the origin and the mode of emplacement of the formations involved, the reader is referred to Chapter 3.

The geological mapping carried out in the two study areas formed the base map details presented on the Phiti and Statos Area, 1:10 000 scale, engineering geology map sheets which accompany this report. On these maps, the geological/lithological formations are presented as follows:

a) The pillow lavas, which comprise part of the Troodos Ophiolite Complex.

b) The bentonitic clays and volcaniclastic sandstones of Kannaviou Formation, forming part of the circum-Troodos sediments prior to the emplacement of the Mamonia Complex.

c) The Mamonia Complex allochthonous rocks and associated serpentinites.

d The Melange (Kathikas Formation), of sedimentary origin related to the emplacement and erosion of the Mamonia Complex.

e) The chalks and other calcareous rocks, which form the circum-Troodos sediments deposited after emplacement of the Mamonia Complex.

f) The alluvium.

The stratigraphy established in the study areas (regardless of the age of deposition and the complicated mode of emplacement for the allochthonous rocks of the Mamonia Complex) is as follows:

The Troodos Pillow Lavas form the base of the stratigraphic sequence and are overlain by the Kannaviou Formation bentonitic clays and volcaniclastic sandstones. Tectonically overlying the Troodos lavas and Kannaviou sediments is the deformed assemblage of allochthonous rocks of the Mamonia Complex. Related to the tectonic emplacement and subsequent erosion of the Mamonia

Complex, is an extensive melange deposit (the Melange) which was probably deposited as a series of submarine debris flows and which discontinuously overlies the Troodos, Kannaviou, and Mamonia rocks. The uppermost part of the stratigraphic succession consists of the calcareous sedimentary rocks (chalk, limestones and marls). Finally, Recent alluvium is found in the river valleys. This complete sequence is, however, not present throughout both study areas.

The relationship between the geological 'grouping' used in this study with the stratigraphical classifications of Lapierre (1975) and Swarbrick & Robertson (1980) are shown in Fig. 6.1.

6.3.1 Phiti Study Area (Area 1)

The complete stratigraphic sequence as described above (Fig. 6.1), is not exposed within Phiti area. The Mamonia Complex rocks are absent with only isolated serpentinite outcrops found near the southernmost margin of the area. Over most of the area, the dominant succession, in ascending order, consists of Troodos pillow lavas, Kannaviou Formation, Melange, and chalks/marly chalks. Two diagrammatic geological cross sections, one across each major N- and S-facing slope, are shown in Fig. 6.2. Landslide debris overlying Kannaviou bedrock along almost the whole length of the slopes, is not shown on the cross sections except where they acquire a substantial thickness.

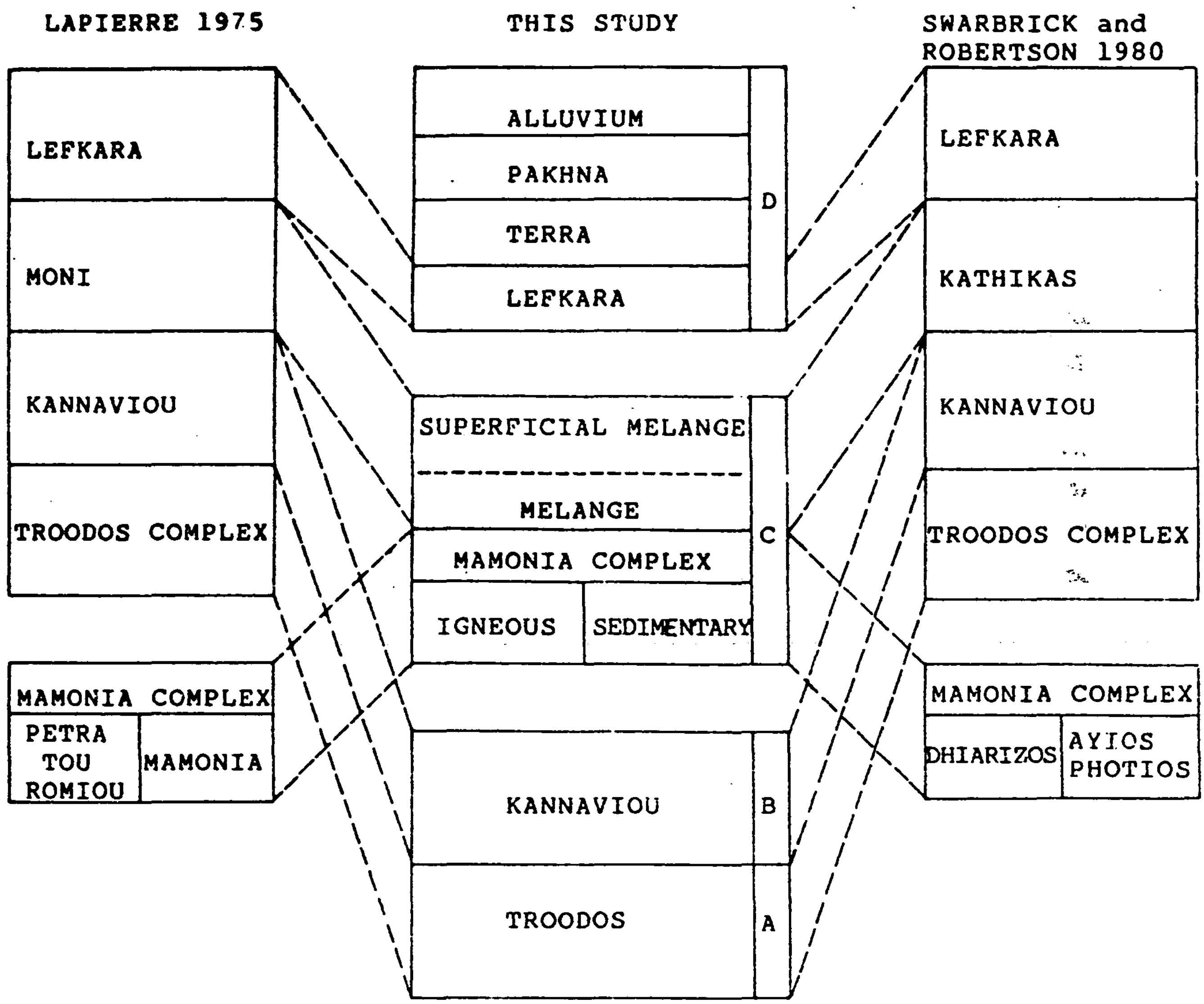
6.3.1.1 The Pillow Lavas

Outcrops of Pillow Lavas mark the eastern and north-eastern area boundary. To the north, they are found in the bottom of the Stavros tis Psokas river valley as isolated outcrops. The lavas are believed to belong to the Upper Pillow Lava unit of the Troodos ophiolite. Locally, on the lava surface, there are up to 5.0m thick deposits of umbers belonging to the Perapedhi Formation. The umbers were not mapped as a separate unit during the present study.

FIG 6.1.

CYPRUS COHESIVE SOILS PROJECT

The relation between the geological formations in this study and the stratigraphical classification of Lapierre and Swarbrick and Robertson

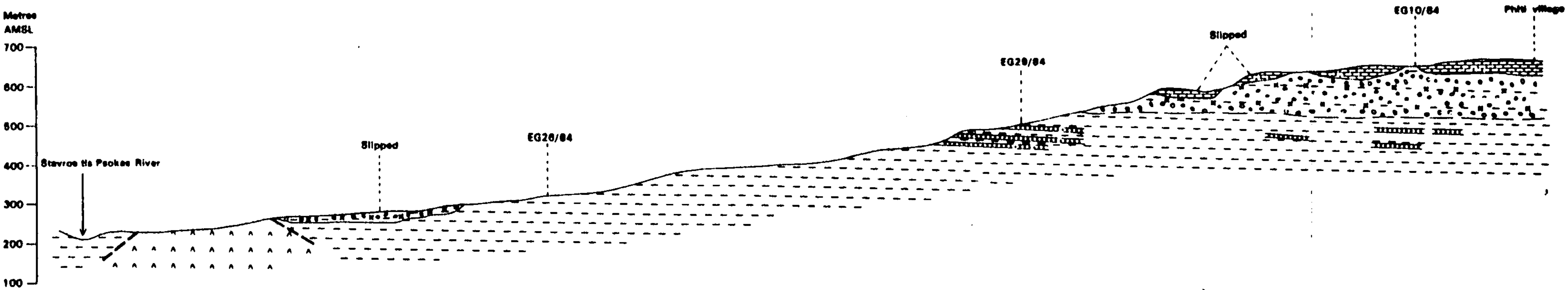


A. Troodos ophiolite.

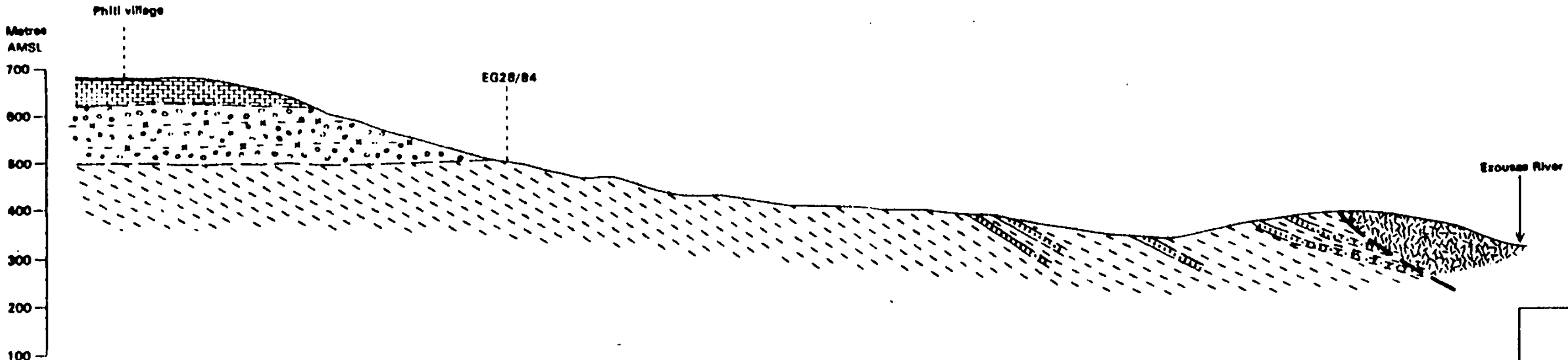
B. Circum Troodos sedimentary rocks prior to the emplacement of the Mamonia Complex.

C. Mamonia Complex and related sediments.

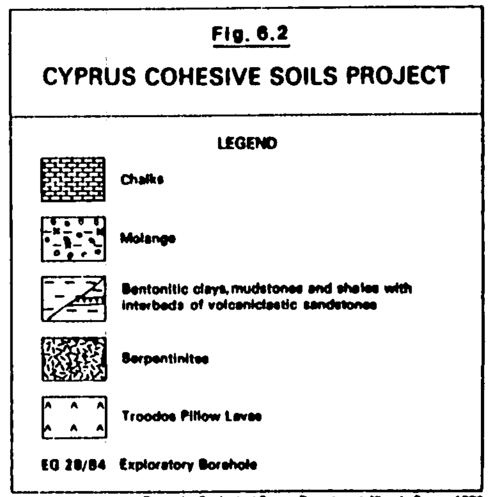
D. Circum Troodos sediments after the emplacement of the Mamonia Complex.



Geological cross section along the northern slope



Geological cross section along the southern slope



Drawn by Geological Survey Department, Nicosia Cyprus 1988

GSD (E Geol) DP 4/88

The Troodos Pillow Lavas are unconformably overlain by the Kannaviou Formation. The contact is clearly observed north of Kannaviou village. In places, e.g. on the bottom of the Stavros tis Psokas river valley, the lavas are discontinuously overlain by Recent landslide deposits of Melange.

6.3.1.2 The Kannaviou Formation

The Kannaviou is the most extensive formation found in the Phiti Study Area, both in surface extent and thickness. It forms the bedrock underlying most of the northern and southern slopes.

Two main lithological units are distinguished on the 1:10 000 scale engineering geology maps: the dominantly argillaceous sequences (Bentonitic Clays) and the volcaniclastic sandstones.

The argillaceous sequences broadly identified as 'Bentonitic Clays' comprise greyish-green, montmorillonitic clays and silty mudstones, and dark greenish-grey laminated shales. At outcrop, the mudstones and shales are generally highly disturbed, weathered and are undergoing breakdown to soft structureless clayey material which, when dry, is highly fissured. At depth, based on borehole information (Appendix IA), they generally form thick sequences with distinct zones which are often highly sheared.

The volcaniclastic sandstones are more abundant in the upper parts of the Kannaviou succession and generally consist of fine to coarse sand-grade material with subordinate silt and clay; they are usually moderately to highly cemented by $CaCO_3$ and contain variable amounts of montmorillonite clay minerals. In the boreholes (Appendix IA), a gradation between coarse sandstones to fine siltstones, and vice versa, was observed. The sandstones generally occur as 5-10m thick bands alternating with mudstones and shales, although thinner bands were frequently observed.

At outcrop, the sandstones form up to 15m high near-vertical cliffs which are outstanding features on the more gentle, hummocky, argillaceous Kannaviou slopes (e.g. Photo. 6.4). Most of the sandstone bands do not outcrop continuously across the Kannaviou slopes as they are interrupted by zones of disturbance (either by folding and/or fault zones) or affected by mass movements. Their outcrops usually occur as lenticular bodies up to c. 300m in breadth. It is possible, however, that the lenticular shape of the sandstones in surface exposures is not everywhere related with tectonics or mass movement disturbance, but it is an original sedimentological feature (Jacres variation). Locally, they can be traced for more than 500m. North of Kannaviou village, although not in a continuous outcrop, a massive, structureless, thick band of sandstone (Photo. 6.3) can be traced for more than 3kms in a westerly direction. The regional dip of the sandstone bands generally ranges between 10° - 20° to the S, SW or SE, with local variations resulting from tectonic disturbances and\or recent mass movements. Southwest of Kannaviou village for example, some sandstones outcrops in tectonic contact with serpentinites show unusually steep 60° to sub-vertical dips.

The upper boundary of the Kannaviou is in contact with the Melange. In some places however, near Ayios Dhimitrianos, Kritou Marottou, Simou and Anadhiou villages the Kannaviou apppears to be overlain by chalks. However, these villages are wholly or partly located on huge displaced masses or blocks of chalk, and the absence of outcropping Melange could be related to major mass movements bringing the chalks into direct contact with the Kannaviou. Also, around the more intact chalk blocks there is usually a thick accumulation of chalk talus which covers the underlying contact with the Kannaviou. It is likely that Melange is present between the Kannaviou and chalks throughout the area despite difficulties in identification of the contact at field outcrop.

6.3.1.3 The serpentinites

The serpentinites are found in the southern part of the area in a relatively extensive outcrop south of Kannaviou village and around Melamiou village. They are highly sheared, altered rocks but in the study area still form sound, solid outcrops. Their contact with the surrounding Kannaviou clays and sandstones is believed to be tectonic.

6.3.1.4 The Melange

The Melange, comprising a thick deposit of variably-sized 'exotic' clasts embedded in an argillaceous matrix discontinuously overies the Kannaviou Formation and/or the serpentinites (the various stratigraphic classifications and nomenclature applied to this deposit in the literature is discussed in Chapter 3).

The maximum thickness of the Melange as established by drilling in Phyti area is 128m (EG 10/84 - Appendix IA). Beneath and close to the periphery of the central chalk plateau, the surface exposures of the Melange and information from boreholes (drilled during this study and for other projects by the Geological Survey Department) indicate that the Melange forms a subhorizontal, tectonically undeformed horizon about 100m thick below the chalks (Fig. 6.2). However, drilling in the southern slope proved that thick Melange is found infilling valley-like depressions in the underlying Kannaviou surface. Borehole EG 13/84 for example showed 60m of Melange in an area bounded by Kannaviou clays outcropping no more than 200m north and south of the borehole. This 'buried valley' filled with Melange continues eastwards, downslope, as proved by borehole EG 20/84. In other areas, landsliding appears to be the slope movement process responsible for the accumulations of relatively thick Melange within the Kannaviou Formation terrain at greater distances below the in-situ Melange/Kannaviou contact. For example, borehole EG 21/84, drilled in a 100m^2 isolated 'patch' of Melange recorded a c. 8m thickness of slipped Melange debris some 300m downslope of the in-situ outcrop.

Some variations in the lithological composition and appearance, and colour of the Melange were observed in the study area. In the majority of outcrops, the Melange comprises a reddish-brown to purple cohesive silty clay matrix with embedded angular-rounded intact clasts of various igneous and sedimentary rock types dominantly of Mamonia origin. In addition, bentonitic clay and sandstones were also observed to occur as clasts and rafts particularly in outcrops close to the Kannaviou Formation (see also Swarbrick and Naylor 1980). The average size of the clasts is c. 15cm but much finer and coarser clasts up to 3m across are also present. From the current investigation, the clasts were estimated to form about 40% of the deposit.

The Melange show some rudimentary bedding features in the form of thin sequences of pelagic chalk, colour banding, and clast-bedding (discussed in more detail in Chapter 7).

Around Melamiou village in the southeastern part of the area, there is an extensive outcrop of Melange in which the matrix is characteristically grey in colour, more clayey, and the clasts are limited both in amount and composition in relation to those present in the more common Melange. The majority of these clasts consist of 'flaggy' blocks of sandstone and siltstone belonging to the Vlambouros? Formation of the Mamonia Complex. This Melange is not, however, differentiated on the engineering geology maps.

In the vicinity of the Dhrinia village, near the southwestern area boundary, the Melange is again somewhat different from the Melange 'proper'. Here, although the colour of the matrix and the lithological composition of the clasts are similar to the Melange elsewhere, there are huge blocks of Mamonia Complex rocks outcropping within the Melange cover. Some of these blocks are hard and intact and others are highly sheared and weathered with their original bedding well preserved (Photo. 6.10). This Melange could be interpreted either as a relatively thin cover over partly exposed Mamonia Complex bedrock or an 'immature melange' (see Swarbrick & Naylor, 1980) transitional between the sheared and disrupted Mamonia rocks and the Melange 'proper'. In the present study, particularly near Dhrinia village, the current authors favour the former interpretation. However, a distinct deposit termed the 'Superficial Melange', similar in many respects to the 'immature melange' of Swarbrick & Naylor, has been identified in Study Area 2 (see Section 6.3.2.4, below, and Chapter 7).

6.3.1.5 The chalks and other calcareous rocks

The circum-Troodos sedimentary rocks, deposited after the emplacement of the Mamonia Complex, consist of chalks, marly chalks, subordinate marl of the Lefkara Formation and younger reef limestones of the Koronia Formation. No effort was made to distinguish between the various formations (i.e. Lefkara, Terra, Pakhna, etc.) on the engineering geology maps. Also, no distinction was made between the various lithologies encountered; all are grouped together in one broad unit of calcareous rocks, generally referred to in this report as 'chalks'.

The chalks form a cap of approximately 50m thickness over the central plateau (Fig. 6.2) between Lasa and Phiti villages, as an extension of the major plateau uplands to the northwest. In the southern part of the area they form the caprock of a second, less extensive plateau around Ayios Dhimitrianos village.

The 'chalks' are bedded rocks comprising c. 20cm thick bands of chalk interbedded with marly chalks and thin marls. Although bedding is, more-or-less, sub-horizontal, they are cut by numerous faults and around the peripheries of the plateaux are displaced by mass movements (see Chapter 8). These displaced chalk masses are found near the villages of Simou, Ayios Dhimitrianos, Kritou Marottou and Old Anadhiou. On both the northern and southern slopes, debris accumulations of broken chalk masses and chalk talus resulting from mass movements are widespread.

In some instances drilling proved the existance of such blocks buried below slipped Melange or Kannaviou bentonitic clays. For example, in borehole EG 22/84, a chalk block more than 8m in thickness was found below 10m of slipped Kannaviou and Melange debris.

6.3.1.6 The Alluvium

River alluvium, of any appreciable extent, is found in the Stavros tis Psokas and Ezousas river valleys. It consists of gravel, boulders, sand and silt, in various proportions. The granular materials within the alluvium appear to be derived mainly from Troodos-type igneous rocks but gravel clasts of Mamonia origin, the harder chalk/limestone lithologies, and Kannaviou sandstone are also present.

6.3.2 <u>The Statos area (Area 2)</u>

The geological setting of Study Area 2 is generally similar to that of Area 1 except for the presence of extensive outcrops of Mamonia Complex rocks.

The complete stratigraphic succession comprises Troodos lavas overlain by bentonitic clays and volcaniclastic sandstones of the Kannaviou Formation. Rocks of the Mamonia Complex tectonically overlie the Kannaviou sediments or Troodos rocks which are, in turn, discontinuously overlain by the Melange. The 'chalks' form the uppermost capping sequence above the Melange. Alluvium is found in the main river valleys.

On the engineering geology map sheets, the Mamonia Complex rocks are divided into the 'Igneous' group (including serpentinites) and the 'Sedimentary' group. This division was made soley on lithological grounds and corresponds, in the main, with the 'Ayios Photios Group' and 'Dhiarizos Group' stratigraphic division of Swarbrick & Robertson (1980) discussed in Chapter 3.

A characteristic superficial deposit ,the 'Superficial Melange', was also recognised in the study area, overlying large tracts of the Mamonia Complex terrain.

6.3.2.1 The Pillow Lavas

The Pillow Lavas form the northern and northeastern boundaries of Study Area 2 and are in all respects similar to those described for Area 1.

Near Statos village there is an elongated E-W trending outcrop of serpentinites and lavas. According to Lapierre (1975) the lavas of this outcrop are of Troodos-type. However, because of their field association with serpentinites, they are mapped, in this study, as part of the Mamonia Complex.

6.3.2.2 The Kannaviou Formation

The Kannaviou Formation sediments are similar to those in Area 1, but outcrops are more limited in extent. The exposures of the Kannaviou Formation in Area 2 are limited to two main regions: in the vicinity of Lapithiou village in the western part of the study area, and south of Vrecha village in the northeast. Extensive Kannaviou clays are exposed east of the Xeros river outside the study area. On the Asproyia-Panayia road, minor outcrops of Kannaviou clays are found directly below disturbed chalk and chalk talus. However, it is not clear whether these bentonitic clays are in-situ or represent reworked landslipped material. Pockets of bentonitic clays were observed elsewhere in highly disturbed chalky material involved in landslides.

The argillaceous sequences consist of greyish-green bentonitic clays and silty mudstones, and darker greenish-grey laminated shales which, near the surface, are generally highly weathered and appear as a greenish grey clayey soil forming a characteristic hummocky terrain. In relatively fresher outcrops, however, the mudstones and shales can be recognised as alternating bands within the Kannaviou succession.

The volcaniclastic sandstones form fewer exposures than in Area 1. They form lenticular bodies, forming shallow ridges and scarps within the overall degrading terrain of the bentonitic clays. The most significant volcaniclastic sandstones are found near Lapithiou village where they dip gently to the E or NE. Less extensive sandstones are also found in the Palaeomylos river north of Lapithiou village and in tectonic contact with the serpentinite/lava ridge west of Statos.

The lower contact of the Kannaviou Formation with the Pillow Lavas is exposed in the western part óf the study area in the Paleomylos river valley. This is the type locality described by Lapierre (1972-1975) and comprises a sequence of greenish-grey and unusual reddish-brown non-calcareous bentonitic clays resting on lava breccias and overlain by volcaniclastic sandstones. Unfortunately, the type section is obscured by recent landslide debris. The contact with the underlying Troodos lavas is also observed near Asproyia village, where thick bentonitic clays directly overlie the Troodos Pillow Lavas.

The limited Kannaviou Formation outcrop in the eastern part of Area 2 is represented by greenish-grey bentonitic clays overlain by Melange. No distinct, mappable sandstones were found although their presence is indicated by relatively harder bands of silty, sandy material and by minor exposures in small stream sections.

6.3.2.3 The Mamonia Complex

The stratigraphic unit of Petra tou Romiou Formation (Lapierre 1975) or Dhiarizos Group (Swarbrick and Robertson 1980) incorporate igneous (lavas) and sedimentary (limestones) rocks in close contact. During the field mapping, no effort was made to distinguish between the lavas and limestones, although in some places (for example on the western slope of the Xeros river) limestones could be found within the broad igneous rock outcrops.

Outcrops of the igneous rocks (broadly representing the Dhiarizos Group as defined by Swarbrick & Robertson, 1980) are concentrated in two broad areas. The first extends westwards from Statos village forming a continuous outcropping ridge about 3km long and 400m wide. Much smaller scattered outcrops occur south and west of this ridge. The second area of outcropping igneous Mamonia (1km long and 0.5km wide) is located on the lower parts of the ESE-facing slope below Pendalia and Galataria, close to the Xeros river. Smaller igneous outcrops are found across this slope exposed in the Melange cover.

The sedimentary Mamonia rocks outcrop extensively in the area. They comprise an assemblage of highly disturbed, tectonised rocks of mainly thinly-bedded shales and cherts, sandstones, and limestones belonging to the the Ayios Pghotios Group (Swarbrick and Robertson, op cit.). The limestones are generally massive recrystallised hard rocks forming huge isolated blocks. The other sedimentary sequences are generally bedded and in places faulted, sheared and folded (e.g. Photo. 7.10). At some outcrops, these rocks are relatively undisturbed with subhorizontal bedding preserved for at least 10m thick sections. For example, on the Ayios Photios - Khoulou road 3km south of Ayios Photios village (Photo. 7.11), thinly-bedded reddish shales and cherts, with virtually no structural disturbance, form a near-vertical cliff face c. 10m high. The outcrop is used as a source of road-base material. Throughout most of the study area, however, the structural and lithological character of these rocks changes within several metres. In places, weathering and decomposition is so severe that only remnant rock structure remains, picked out by intermittent harder and more resistant bands.

The sedimentary (stratified) Mamonia rocks crop out extensively in the west-central and southwest part of the study area on the W-facing slope below Statos, Ayios Photios and the Pendalia plateau (Photo. 6.11), and on the E-facing slope below Pendalia (Photo. 6.5). In these two broad areas, the lower contact with the Troodos and/or Kannaviou is not exposed. The Mamonia rocks are discontinuously overlain by Melange or Mamonia-derived colluvium. As shown on the engineering geology maps, isolated smaller outcrops of Mamonia rocks are found higher in the slopes protruding through the Melange/colluvium cover.

6.3.2.4 The Melange

The Melange is extensively developed in Area 2. In addition to the Melange 'proper' (i.e. the Melange found also in Area 1), a melange-like superficial deposit forming a mantle of variable thickness over the Mamonia slopes was also recognized. This is shown on the 1:10 000 maps as 'Superficial Melange'. The boundaries between the Melange and Superficial Melange are gradational, due largeley due to widespread shallow slope movements involving both materials.

The Melange 'proper', as in Area 1, consists of a reddish brown, to purplish clayey silty matrix in which angular to subrounded clasts and fragments of mainly Mamonia origin are found in chaotic arrangement (Photo. 6.8). The outcrops do not show evidence of strong sedimentary structures, however, at some localities clast-bedding (Photo. 7.6) and colour banding (Photo. 7.5 and 7.7) are clearly seen. In a few outcrops, bands of thin (c. 10cm), often sheared, pelagic chalk are present separating Melange sequences sometimes contrasting in matrix colour and/or clast type and size (e.g. Photo.6.9). According to Swarbrick & Naylor (1980), these calcareous bands indicate pauses in Melange (debris flow) sedimentation.

The Superficial Melange is a generally structureless deposit comprising a matrix with fragments and clasts of Mamonia Complex rocks. However, it differs from the 'proper' Melange by exhibiting more granular soil characteristics. The matrix is generally more silty and sandy, and lighter in colour (usually brownish with the characteristic purple-reddish colour characteristic of the Melange 'proper' not so common). The fragments are more angular and irregular both in size and distribution, and the clast lithologies at any one locality are usually limited to the types of Mamonia Complex rocks found in the close vicinity. The thickness of the Superficial Melange is considered generally not to exeed much more than c. 5 metres and, at outcrop, is not characterized by the distinctive gulley erosion features so typical on the steeper slopes of Melange 'proper' (Photo. 6.7). These materials, which differ markedly from the Melange 'proper', with regards to particle size distribution, sedimentological character, and thickness, were therefore mapped as a separate deposit.

The Superficial Melange is closely associated with the Mamonia Complex rocks and is believed to be a weathering product of the latter. In several places, they rest on top of more competent Mamonia strata forming a c. 2-4m thick cover, the colour of the matrix, and the greater part of the included clasts being related to the underlying 'intact' Mamonia rocks (Photo. 7.9). In other places, a distinct difference in the colour and lithological character between the underlying Mamonia rocks and the Superficial Melange occurs (e.g. Photo.6.12). Here, the Superficial Melange is usually thin (c.1m) and has invariably undergone shallow slope movement.

The erosion of the Mamonia rocks to produce the Superficial Melange probably occurred after their tectonic emplacement following exposure to weathering and erosion. The present day erosion of the highly weathered Mamonia Complex rocks produce superficial slope deposits very simlar to the Superficial Melange, but they are thinner and often retain remnant bedding features (Photo. 6.13) indicating that they have not undergone intermixing to the same degree. Reworking of superficial materials derived by weathering of highly sheared weathered Mamonia Complex rocks is accomplished by shallow mass movements and/or landslides (e.g. Photo. 7.8), and this may be an important process in the intermixing of the weathered slope mantle to form Superficial Melange.

Around Pendalia village, a distinctive type of Superficial Melange occurs which locally reaches c. 8m in thickness (Photo. 6.14). This deposit is clast-dominant with virtually no matrix, and contains a relatively high proportion of calcareous rock fragments. It is not, however, distinguished as a separate deposit on the engineering geology map sheets.

6.3.2.5 The chalks and other calcareous rocks

The main 'chalk' outcrop comprises the central Panayia Plateau area. The basal chalk sequence commences with bedded chalks, chalk and cherts, marly chalks and subordinate marls, present in the form of thin interbeds, belonging to the Lefkara Formation. This is overlain by a horizon of Terra Formation limestone which is capped, on the plateau surface, by thinnly-bedded chalks and marly chalk probably belong to the Pakhna Formation.

Overall bedding dips are generally shallow to sub-horizontal but locally may change dramatically due to extensive faulting and landslide disturbance.

The uppermost margins of the plateau are bounded by vertical cliffs up to 30m high which suffer considerable rock fall and other slope failures (see Chapter 8). These failures are largely controlled by well-defined faults and joints trending, dominantly, NW-SE and NE-SW. The flattish plateau top is characterized by intersecting fissure, fault and joint lines, and extensive deep gullies, indicating the alignments along which further potential failures may occur.

The flanks of the plateau comprise a cliff and step-like topography which continues downslope to near the main Statos-Pano Panayia road on the western slope, and above Galataria and Kilinia villages on the eastern slope. Moving downslope, there is a tendency for the successive steps to get wider and cliffs to become more gentle. On the lowermost flanks, the chalk strata degrades into masses of highly broken chalk and chalk talus, some of which extends for more than 2kms. across the underlying Melange slopes. For example, west of Pano Panayia in the northern part of the area and below Vrecha village in the east, extensive continuous accumulations of highly disturbed chalk debris occur as a result of large scale mass movements.

The northeastern slope of the Panayia plateau is steep and less disrupted by large-scale landslides. Here, the chalks directly overlie Troodos lavas.

Away from the central Panayia Plateau, a smaller plateau surface occurs near Pendalia village, with chalk strata forming a 50m thick cap above Melange and Superficial Melange deposits. Chalks are also found in the western part of the Statos area opposite Melamiou village overlying Melange and, locally, Mamonia Complex rocks.

South of Vrecha village, a band of chalk is found to rest on, and is overlain by, Melange (Photo. 6.15). Although inconclusive, the unusual position of this outcrop is probably related to a combination of downfaulting and landsliding (see Chapter 8).

6.3.2.6 The Alluvium

Alluvium deposits consisting of gravels, boulders, sands silts and clays are found in the main river valleys. This heterogenous material includes rock types from all lithologies encountered in the study area.

Some well preserved river terraces were observed in the western part of the area but are not distinguished on the 1:10 000 scale maps. River terraces are believed to have been relatively widespread, particularly in the Ezousas and the Xeros river valleys, but have been largely destroyed by recent landslides and, for the most part, only isolated or discontinuous remnants remain.

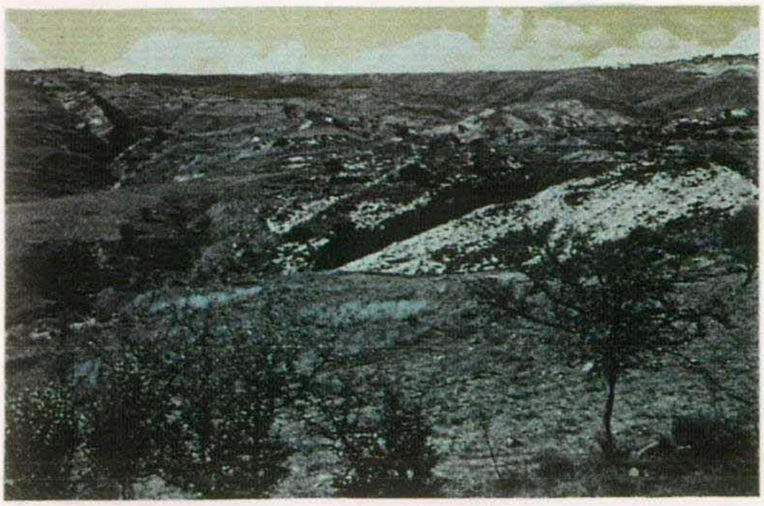
6.3.3 Geological Structure

Major lineaments indicative of possible fault lines were determined by interpretation of existing 1:10 000 and 1:25 000 aerial photographs. Of these alignments, the most significant ones, supported by field evidence, are shown on the maps. In addition to these inferred faults, others were selected mainly from the published 1:50 000 scale goelogical map of Lapierre (1971) or determined on the basis of field evidence. The thrusts, as interpreted by Lapierre, are not shown on the maps in order to avoid confusion in map presentation.

From the aerial photographic analysis and field mapping, it was clear that both study areas (and particularly Area 2) were extensively faulted. Many more faults are therefore present than are indicated on the 1:10 000 engineering geology map sheets. The reasons for this are twofold. Firstly, the map scale did not allow all lineaments to be shown without obscuring the topographical, geological and landslide details. Secondly, the interpretation of many of the lineaments in terms of existing faults is in doubt; the elucidation of which was beyond the scope of the present study.

6.1 View towards Anadhiou looking toward ENE, (Area 1)

6.2 View of slopes between Ay. Dhimitrianos and Kritou Marottou, looking NW towards Phiti, (Area 1)



6.3 Ridge of Kannaviou sandstone to west of Kannaviou village, looking westward, (Area 1)

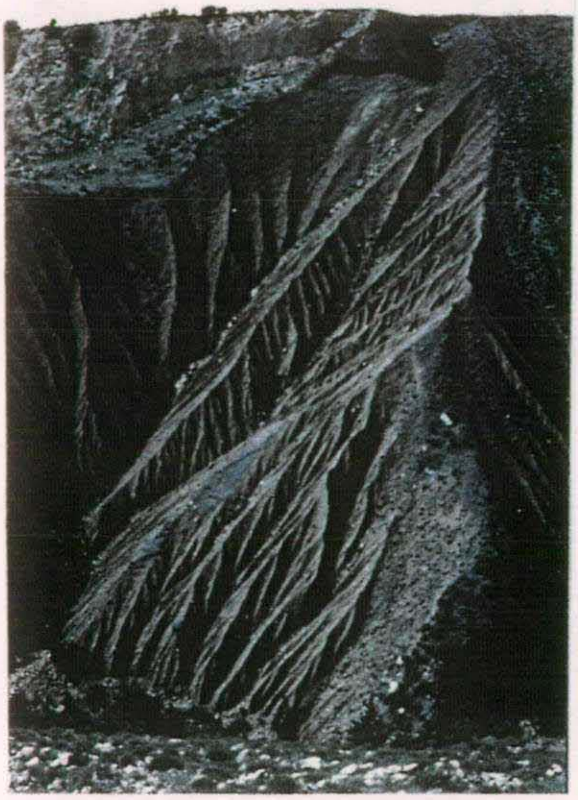
6.4 Ridges of Kannaviou sandstone to N & NE of Lasa, looking towards WSW, (Area 1)

6.5 View of slopes below Galataria looking towards NW, (Area 2)

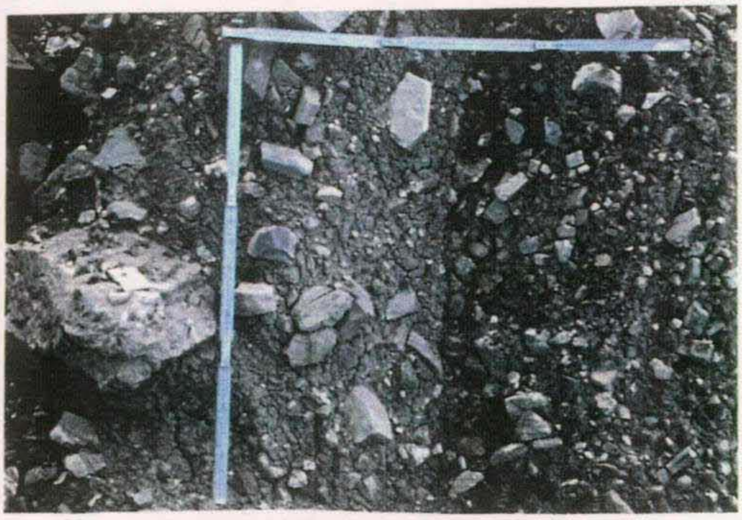
Photos 6.3 to 6.5

6.6 View of slopes between Pano Panayia and Statos (Area 2), with Kritou Marottou in foreground; looking towards SE.

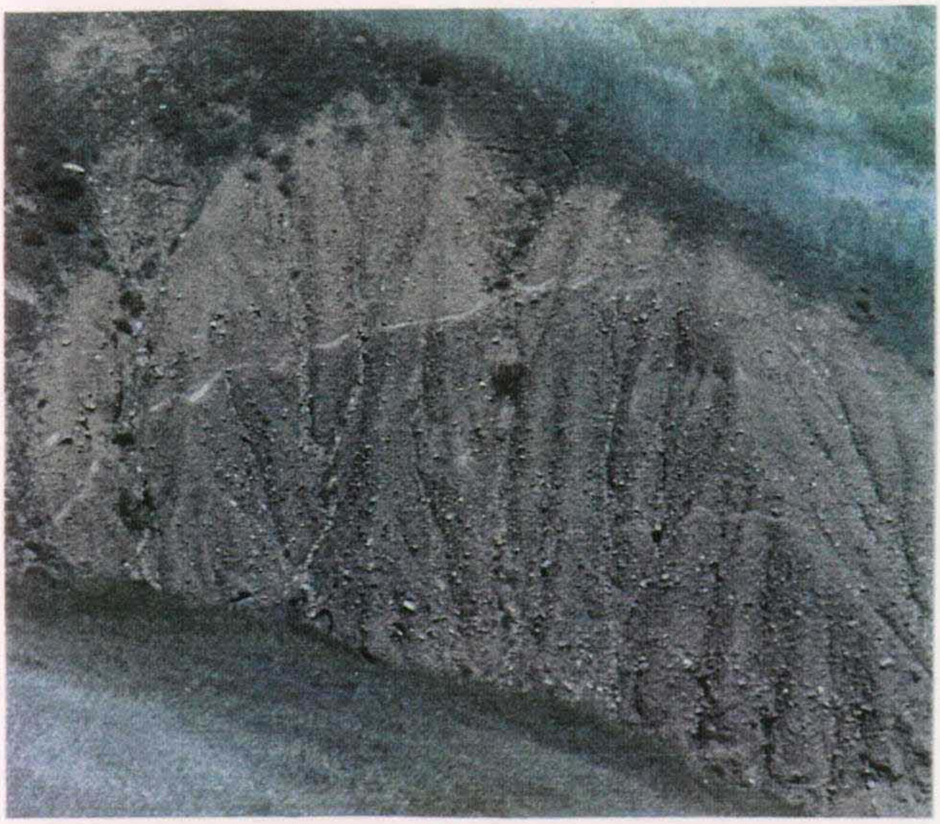
Photo 6.6



6.7 Slope of melange overlain by chalk to W of Kathikas (outside study area, GR 44665 386255)

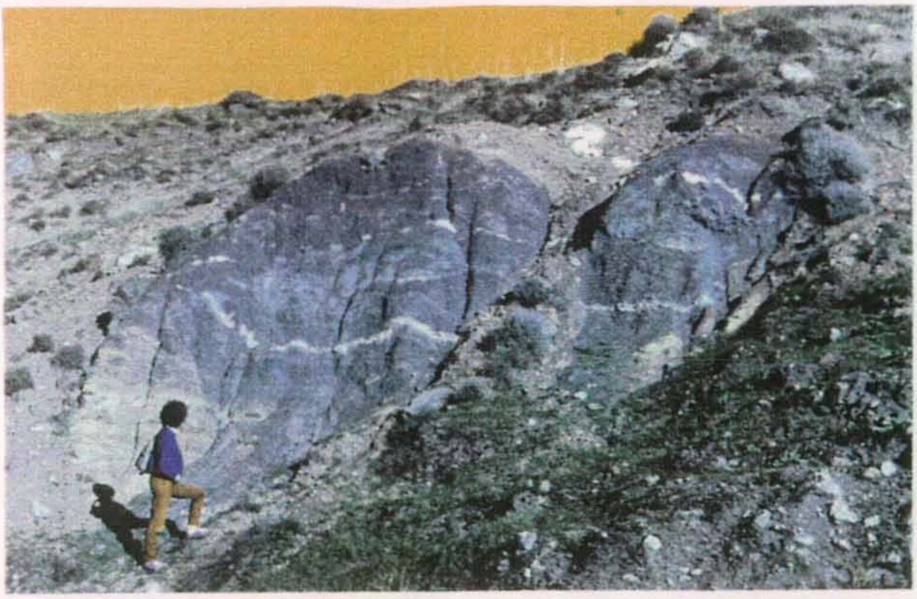


6.8 Melange in road cut to S of Galataria, (Area 2, GR 46630 385905)



6.9 Gully in melange at Galataria (Area 2, GR 46660 386000)

Photos 6.7 to 6.9

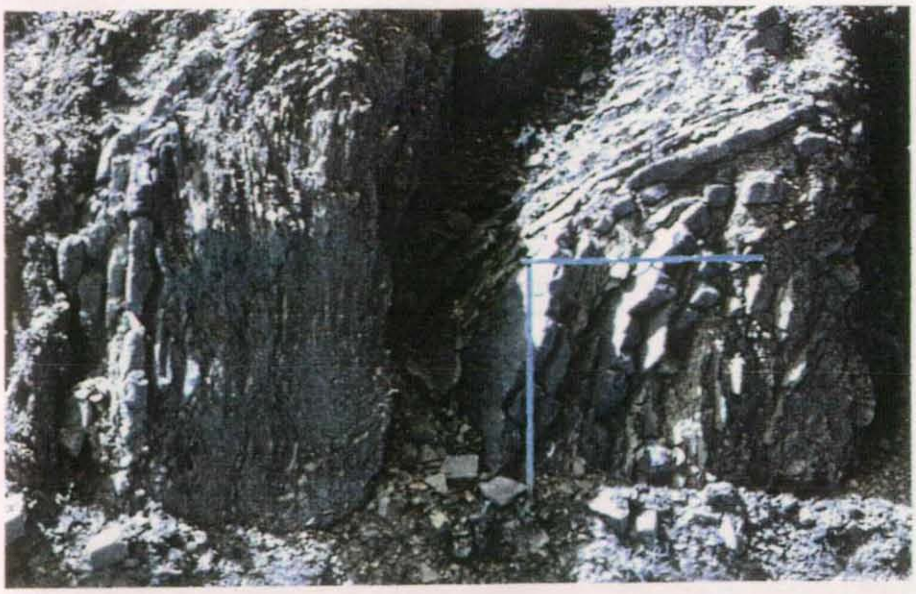


6.10 Stratified Mamonia mudstones with Melange in slip scarp at Dhrinia (Area 1, GR 45720 386400).

6.11 View of stratified Mamonia slopes below Ayios Photios - (Ayios Photios - Phalia road in middle distance), looking towards NW (Area 2).

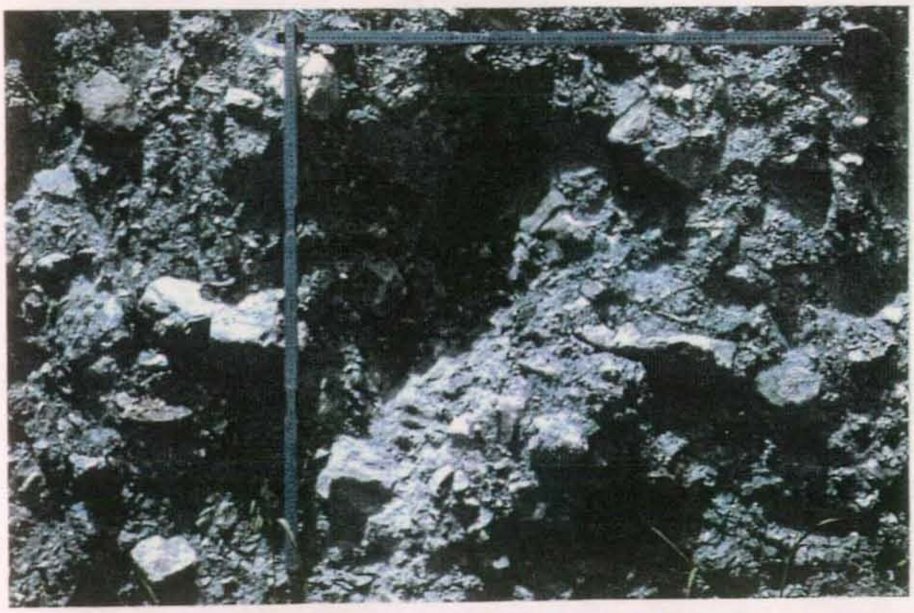
6.12 Superficial melange overlying folded and sheared stratified Mamonia shales and cherts to WSW of Ayios Photios (Area 2, GR 46375 385875).

Photos 6.10 to 6.12



6.13

Folded & sheared stratified Mamonia shales/ siltstones/cherts, weathering to immature superficial melange; Dhiarizos valley (outside study area, GR 46400 384500); Scale: 1 x 1 metre.



6.14

Clast-dominant superficial melange.Pendalia village, (Area 2, GR 46515 385705); Scale: 1 x 1 metre.

6.15

View of Kannaviou/ melange/chalk ridge to SW of Vrecha, looking towards WNW, (Area 2).

Photos 6.13 to 6.15

7. GEOTECHNICAL CHARACTERISTICS OF THE MELANGE, KANNAVIOU, WEATHERED STRATIFIED MAMONIA AND SUPERFICIAL MELANGE IN STUDY AREAS 1 AND 2

7.1 Introduction

Laboratory testing of samples from the two study areas was carried out both at the Geological Survey Department Nicosia, and at the British Geological Survey. A wide range of tests was undertaken, some of which were standard and others specialized. Samples for testing were obtained in the following forms:

a) Borehole core - mainly 100mm diam.(U100)
b) Bulk samples from pits
c) Surface bulk samples

The test programme may be broadly divided into two parts:

a) geotechnical tests carried out by the soil mechanics laboratories at GSD and BGS

b) mineralogical tests carried out by the BGS and GSD geochemistry laboratories

Those abbreviations used in some tables and graphs are shown below in square brackets.

7.2. Test Methods

7.2.1. Geotechnics

A detailed account is not given here of standard test methods which are described in British Standards BS1377 (1975). A summary of the geotechnical test programme is as follows:

	BS1377 test	No of tests	Lab
Natural moisture content [MC]	1A	87	GSD&BGS
Liquid limit (Casagrande apparatus) [LL]	2B	267	GSD&BGS
Plastic limit [PL]	3	265	GSD&BGS
Particle size distribution [%SAND] [SILT] [%CLAY]	7A & 7D	250	GSD&BGS
Linear shrinkage [LS]	5	12	BGS
Specific gravity [SG]	6A	6	BGS

Other tests are as follows:

Consolidated-undrained Triaxial (CIU Triax) giving total and effective shear strength [c,ϕ; c'ϕ'] (refs: Head, 1986; Vickers, 1983). Normal stresses applied: 76, 150, 248 & 497kPa. A 50kN load frame with 100mm triaxial cell was used.

Drained Ring-shear giving effective residual shear strength [ϕ_r, ϕ_r'](Ref: Lupini et al, 1981; Bromhead, 1979) A Bromhead-type apparatus was used.

Swelling pressure test giving maximum swelling of undisturbed core sample on wetting with zero volume change [Psw]. (Ref: Hobbs et al, 1983).

7.2.2. Mineralogy

The mineralogical test programme may be divided into a) tests carried out by GSD Geochemistry laboratory and b) tests carried out by BGS Mineral Sciences and Isotope Geology Research Group (refs: Mineralogy and Petrology Reports No. 85/8 and 85/27 by Bloodworth & Bernard; 1985). All tests were carried out on air-dried samples ground to pass 100 mesh sieve.

a) Tests carried out at GSD were:

Total carbonate content [$CaCO_3$] using a quantitative method; HCI digestion to dryness followed by titration with EDTA. The assumption is made that all calcium is in the form of $CaCo_3$. (Ref: Chaney et al., 1982)

Montmorillonite content [MONT or MONTMOR] using a quantitative method; methyl blue dye adsorption method. A 0.01N solution of methylene blue dye in 2ml increments is added to a suspension of the clay until the dye ceases to be adsorbed. This point is determined by spot testing the clay suspension on filter paper. The volume of dye added is then used to calculate the cation exchange capacity (c.e.c.), (see also Section 7.2.2).

b) Tests carried out at B.G.S. were:

	No. of tests
Qualitative X-ray diffraction analysis (XRD), full mineralogy	137
Quantitative XRD analysis:	137
1. Surface Area (EGME method ref: Carter et al 1965) giving calcium montmorillonite content [MONT or MONTMOR] based on a surface area for pure montmorillonite of 800 m^2/g.	(122)
2. Thermogravimetric analysis using weight loss due to CO_2 release between 800°c and 900°c. giving calcite content [$CaCO_3$].	(78)
3. XRD peak intensities for quartz were compared with those for artificially prepared mixtures, giving quartz content [QTZ or QUARTZ]	(102)

(Twenty-one quantitative XRD tests were duplicated at B.G.S. and G.S.D.).

7.3. Lithology, fabric & structure

7.3.1. Kannaviou Formation

The Kannaviou Formation in the study areas consists of a sedimentary sequence of bentonitic clays/shales and sandstones/siltstones of Lower Campanian to Mid-Maestrichtian age. These are folded along a dominantly NW-SE axis and are overlain in part by the Melange. The Formation is particularly well exposed in Study Area 1. The overall dip of the beds is to the south and the thicker beds of massive, hard sandstone form distinctive ridges and cliffs (see Photos 6.3, 6.4, 8.3 and 8.4), whereas the beds of mudstone and clay are easily eroded and subject to widespread landslipping particularly when exposed in synclinal troughs between sandstone ridges.

The sandstones and siltstones of the Kannaviou Formation are volcaniclastic, and for the most part calcareous, rocks (Robertson 1977c).

In broad engineering-geological terms, the following lithological types have been recognised in the study area:

a) A virtually structureless massive medium-grained volcaniclastic sandstone which forms the mid slope scarps up to 15m in height in the Phiti Study Area (see Photo 7.2). Joints are generally widely spaced and bedding is difficult to discern. A feature of these sandstones is the presence of sub-spherical clasts of hard intensely fractured dark greenish-grey claystone up to 1m in diameter described as "slump balls" (Ealey & Knox, 1975) or "clay balls" (Robertson 1977b). In some exposures these have fallen away entirely leaving hemi-spherical cavities in the sandstone (see Photo 7.4). Occasionally, current bedding and slump structures are seen in the sandstones. Taken together these structures are indicative of very rapid deposition on a steeply sloping seafloor (Robertson, 1977b). These massive sandstones are clearly seen at, and to the west of, Kannaviou village (GR's 613 643 and 600 638) and to NNW of Lasa (GR 565 661). The dominant joint sets are subvertical and trend to the

WNW-SSE and WSW-ENE. The lowermost part of this sandstone is often less well cemented and hence relatively soft, and a characteristic feature is the abundance of biotite phenocrysts.

b) Above and below the massive sandstones, are more variable very thin- to thickly-bedded, fine- to medium-grained micaceous sandstones (see photo 7.3) which contain bands (0.01 - 0.5m thick) and lenses of: 1) iron-rich and occasionally turbulent or convolute laminated sandstone; 2) very coarse and porous sandstone which has possibly undergone the leaching-out of its carbonate cement; 3) slightly shaley sandstones; 4) poorly bedded white poorly calciferous siltstones; 5) a fine to medium grained, highly porous sandstone of very low density resembling pumice.

In the vicinity of the serpentinite to the SW and SE of Kannaviou the sandstone beds are disrupted and veined with quartz. Highly-veined bands of hard erosion-resistant sandstone in this area form unusual subvertical sheets which, where exposed, resemble tilted walls (e.g. GR's 605 633 and 6225 6375).

On the standard Munsell Soil and Rock Color Charts (Munsell, 1975), the most common (dry) colours for Kannaviou sandstones and siltstones are:- 5Y 8/1 (white) and 5Y7/2 (light grey) or 5GY 8/1 (light greenish grey); with the siltstones/ fine-grained sandstones tending to white (the lighter colour not necessarily due to a higher carbonate content). Weathered medium-grained sandstones tend towards 2.5Y7/4 (pale yellow).

The <u>mudstones and clays</u> of the Kannaviou Formation are found interbedded with the sandstones and siltstones described above. They range from hard fissured clays to shaly mudstones and usually contain both calcium montmorillonite and calcium carbonate in varying proportions. Robertson (1978b) describes these clays as 'bentonitic'. They tend to occupy the shallower hummocky slopes or 'troughs' between unslipped sandstone bands (e.g. at GR 604 655). The shaly mudstones disintegrate readily to a gravel-sized scree in dry conditions or a soft clay in wet conditions. The clays/mudstones often contain thin laminae of poorly cemented tuffaceous sand and silt. Close to the contact with the overlying Melange, the clays were seen to be strongly slickensided (B.H. EG 10/84, depth 128m). It is possible that these slickensides are related to the deposition of the olistostrome Melange. Undisturbed borehole core revealed that the upper part of the Kannaviou Formation, at least, contains hard, fissured overconsolidated clays of high plasticity. On the Munsell Color Chart (Munsell, 1975) the clay/mudstone colours range from 5Y4/2 (olive grey) to 5Y4/4 (olive) on wet samples and from 5Y6/2 (light olive grey) to 5Y8/1 (white) when dry. In undisturbed, fresh core a dusky blue-green colour (5BG 3/2 on the rock colour chart) is seen which rapidly oxidises in air to a dusky yellow-green (5GY5/2). Deep reddish-brown coloured clay was found in the Palaeomylos river valley (GR 6280 6445); this clay (sample 85/9) was found to be lacking in calcium carbonate but rich in montmorillonite.

Fissuring may be severe enough to produce a flaky or friable texture and, in some instances, a sheared 'scaly'structure is seen (see photo 7.1); this is probably equivalent to the "lenticular bodies" or "rhombahedral scales" of the Argille Varicolori (variegated shale) of Southern Italy (D'Elia, 1977; Evangelista et al, 1977) and possibly the "thrust shear joints" of the Siwalik clay of Pakistan (Binnie et al 1967; Fookes, 1965). Fissure surfaces are frequently coated in various oxides and in some cases fine sand or coarse silt. Those clays rich in montmorillonite tend to have a soapy texture. Extensive, apparently sinuous shears often coalesce to form zones of lenticular peds which may have an unweathered core. Within landslipped deposits the Kannaviou clay is generally soft to firm and may contain small clasts of harder clay or mudstone often with multidirectional listric surfaces. These represent material not yet broken down to matrix size.

7.3.2. Melange

The Melange, i.e. Kathikas Formation, is a distinctive debris deposit broadly consisting of two clearly defined components:

1) a relatively uniform, micro-fissured silty clay matrix usually reddish-brown in colour (but occasionally grey) and,

2) a clast component comprising a wide variety of exotic rock types of all sizes 'suspended' chaotically within the matrix. Clast sizes range predominantly from gravel- through to boulder-grade. In some areas of SW Cyprus blocks of up to 1km in length have been recorded. The most common clast lithologies are: a) reddish mudstones of the Episkopi Formation which tend to occur as angular gravel-sized fragments and represent the dominant source material of the reddish-brown clay matrix; b) grey quartzose sandstones of the Vlambouros Formation which are found as angular boulders and cobbles, notably within the grey Melange; c) various other sedimentary rocks, cherts, shales, siltstones, sandstones and limestones; d) various igneous rocks (notably basalt, serpentinite, dolerite, gabbro, and metamorphic rocks, such as amphibolite and mica schist.

The incorporated clasts exhibited a wide range of particle shape ranging from rounded to angular depending on lithology; clasts frequently showed slickensided surfaces. The matrix of in-situ Melange (i.e. Melange unaffected by post-depositional landslipping) showed an abundance of randomly-oriented micro-shears, usually immediately adjacent to clasts. Micro-shears or fissures within the in-situ Melange matrix away from included clasts were difficult to identify. Where present, they were usually only a few millimetres in length and possessed no obvious orientation. In Melange that had undergone post-depositional landslipping, however, a more persistent, pervasive shear fabric was seen. This fabric results in a somewhat 'scaly' structure which is easily separated in hand specimens. Rudimentary 'bedding' within the larger Melange exposures was indicated by colour banding, discontinuous bands of boulders, and thin laminations of chalk separating 'beds', or successive debris flows, of Melange which may differ both in colour and clast composition, abundance and size (see also

Swarbrick and Naylor, 1980). Examples of these features are illustrated in Photos 7.5 to 7.7 and Photo 6.9.

A scanning electron micrograph of a sample from a thin chalk band showed it to consist of a marly, dolomitic chalk with broken coccoliths and slickensided surfaces. Clast size and shape is strongly dependent on lithology. The weaker, thinly bedded source rocks (e.g. Episkopi mudstones and shales) tend to produce the gravel size angular fragments and, the thickly-bedded rocks (e.g. Vlambouros sandstones) tend to produce the angular boulders; the igneous rocks invariably comprise the more rounded clasts.

Examples of typical Melange exposures are shown in Photos. 7.4 and 7.8, and Fig. 7.17. At some localities large blocks of incorporated, bedded sandstone, breaking up in-place, were found (see Fig. 7.25). The clasts generally show no preferred orientation, although large elongate clasts tend to be sub-horizontally aligned, as do smaller clasts, close to slip planes and chalk bands.

All the clast types could have been derived locally from within S.W. Cyprus; the majority being derived from the Mamonia Complex and the remainder from the Troodos Complex (Swarbrick & Naylor, 1980). Little Kannaviou Formation material was found incorporated within the Melange except at certain localities close to the Melange/Kannaviou contact and within recent landslip deposits.

The Melange tends to infill depressions in the underlying bedrock, for example borehole EG 13/84 penetrated 61 m of Melange within a 350 m wide outcrop. Also, recent cuttings on the Ayios Dhimitrianos-Kannaviou road in Study Area 1, revealed Melange 'feathering out' rapidly against Kannaviou sediments. Smaller-scale channel or trough deposition is seen in fresh scarps within a bowl of active slipping mid-way between Phiti and Ayios Dhimitrianos. Movement of groundwater into these troughs may influence local slope stability (see Chapter 8).

The Melange frequently forms steep (30° - 35°) slopes up to 50m in height, e.g. below Galataria (see Photo 6.5). These slopes usually exhibit distinctive gully erosion features. A notable feature of the river eroded, near-vertical lowermost slopes, is the way in which boulders provide a protective 'cap' for their supporting column of matrix. Ultimately these columns are eroded and undermined, and the boulder falls. This process is also seen in some boulder clays (e.g. at Bolzano, N Italy). Occasionally, on very steep slopes where gulley and sheet erosion are severe, the matrix (including small clasts) is 'plucked' out leaving the boulders projecting from the slope (see Photos 7.6 & 6.8). On the shallower slopes however, landslip debris and colluvium mantle much of the surface, obscuring the boulders and providing protection from surface erosion (see Photo 8.23).

Areas of outcropping Melange often bear the local Greek name 'melanos', meaning red. In fact, typical Munsell colours for the Melange matrix are either a) 2.5 YR4/2, weak red - 5YR 4/3, reddish brown in the moist condition and 2.5 YR5/2-5YR 6/3 dry, or b) 10YR 5/1, grey - 10YR 5/2, greyish brown in the moist condition and 5Y 7/2 dry. Locally, reddish-brown to grey mottling may occur. In general however, one overall colour is usually persistent within a single Melange sequence. Colour banding on a small scale is occasionally present as seen in Photo 7.7. In field examination of the Melange exposures, care must be taken not to confuse in-situ colour-banding and clast-bedding with similar features produced by recent landslipping.

7.3.3. Superficial Melange

The type of melange here referred to as the 'Superficial Melange' is essentially equivalent to Swarbrick & Naylor's (1980) "immature melange". It represents an intermediate stage between severely broken rock masses with very little or no clay matrix, and Melange 'proper' described in Section 7.3.2, above. The Superficial Melange is a locally-occurring weathered mantle overlying the sedimentary (stratified) Mamonia Complex rocks, containing large boulders and blocks within a variable, often poorly developed clay matrix. It is usually clast-dominant and may show evidence of remnant bedding depending on the degree of break-down and intermixing. Unlike the Melange 'proper', clasts tend to exhibit a preferred orientation parallel to the surface slope. Examples of Superficial Melange are shown in Photos 7.8, 7.9 and 6.12.

The Superficial Melange deposits generally occur up to 5m in thickness and in most localities have probably undergone slope movements of only limited extent, i.e. they remain close to their source rock. Superficial Melange derived from the Vlambouros sandstone is a particularly common deposit in Study Area 2. The Superficial Melange derived predominantly from the shales and cherts of the Episkopi Formation is extremely susceptible to breakdown by weathering processes, and is usually readily eroded before deposits of any appreciable thickness are allowed to build up. Variations in the deposits of Superficial Melange are clearly controlled by the variability of the underlying stratified Mamonia source rocks. As such the Superficial Melange exhibits neither the wide variety of clast lithology nor the uniformity of matrix seen in the Melange 'proper'. The approximate extent of Superficial Melange is shown on the 1:10,000 scale engineering geology maps which accompany this report.

An unusual type of Superficial Melange, of limited extent, occurs in Study Area 2 near Pendalia village close to the overlying chalks. It is clast-dominant and distinguished by a poorly-developed, cemented matrix but having varied clast lithologies more akin to the Melange 'proper'(see Photo 6.14). The matrix is stiff, pale buff in colour, and is carbonate-rich.

7.3.4. Mamonia Complex rocks

The sedimentary deposits of the Mamonia Complex (i.e. the Ayios Photios Group; Robertson & Woodcock, 1979), referred to in this report as the stratified Mamonia, outcrop mainly in the Statos Study Area (Area 2). They consist mainly of thinly-bedded (0.02 to 0.2 metre) reddish-brownish-grey and greenish-grey mudstones /shales and cherts of the Episkopi Formation (Robertson & Woodcock, 1979) or "Cherts" (Lapierre, 1975), (see Photos 7.10, 7.11 & 6.13), and thickly-bedded and cross-bedded white and yellowish-white sandstones of the Vlambouros Formation (Robertson & Woodcock, 1979) or Grès a végétaux (Lapierre, 1975).

The mudstones/cherts are volumetrically dominant in the study area and form what is probably the greatest thickness of the Episkopi Formation in S.W. Cyprus (Robertson & Woodcock, op cit.).

The Ayios Photios Group is, in general, heavily folded and faulted and is frequently mantled by either a thin weathering mantle or a thicker Superficial Melange (see Section 7.3.3). The mudstones weather readily and are often subject to shallow landslipping (e.g. GR 667 573). The sandstones, are hard and, if thickly-bedded, form weather-resistant 'whaleback' ridges or, if thinly bedded and disrupted, very narrow sawtooth ridges (eg GR 623 600) of vertically-bedded sandstones (these features are sometimes mistaken for walls on topographic maps). These erosion-resistant outcrops usually comprise bands of hard grey quartzitic sandstones (Akamas sandstone, Robertson & Woodcock, op cit.). Fossil plant remains and ripple marks are seen along separated bedding planes of flaggy sandstones.

Tectonic deformation at its most severe is seen as tight folding, fractures, joints, and faults. Bedding slip, overthrusts, and shear zones have also been observed (see Photos 6.13 & 7.10). At the same locality, almost completely undisturbed exposures of near horizontally-bedded rock may be found (see Photo 7.11). It is clear that tectonic disturbance, and consequent in-place disintegration of the rock mass, favour the agencies of weathering and slope movement, which may lead to the development of Superficial Melange. Breakdown of the thinly-bedded rocks is facilitated by closely-spaced joints/fissures and bedding separations, which enhances infiltration of water. The mudstones readily breakdown further in the presence of water and the rock mass loses its competence. The chert or sandstone beds are reduced to cobble-sized rectangular prisms which constitute a large proportion of the clasts within Superficial Melange.

When moist, the dominant Munsell colours of the mudstones, shales and clays of the weathered Episkopi Formation are: weak red (10R 4/4) with bands of pale olive (5Y 6/4) to olive yellow (5Y 6/6). The equivalent dry colours are: pinkish grey (5YR 7/2) to reddish-brown (2.5 YR 5/4) and light olive grey (5Y 6/2). Red is the most dominant colour in the study area and is similar to the red colouration of the Melange matrix (see section 7.3.2). The sandstones, siltstones and quartzites of the Vlambouros Formation are variably grey to yellowish grey depending on lithology and degree of weathering.

7.4. Test Results - Kannaviou Formation

7.4.1. Index Tests

7.4.1.1. Moisture content/density/porosity

Due to the difficulty in obtaining undisturbed samples, only 49 moisture content and 26 density determinations were made for clays, and 9 density and porosity determinations for sandstones. The 'natural' moisture contents (m) for the Kannaviou clays range from 17% to 62% (mean = 33.6, S.D. = 9.9); bulk densities (γ_b) ranging from 1.53 to 2.18 Mg/m^3 (mean = 1.78, S.D. = 0.16) and dry densities (γ_d) from 1.05 to 1.76 Mg/m^3 (mean = 1.32, S.D. = 0.19). Mean specific gravity was found to be 2.59.

Dry densities for the Kannaviou sandstones and siltstones range from 1.33 to 2.12 Mg/m^3 and porosities from 17% to a maximum of 44%, the latter, higher, result representing a highly porous tuffaceous sandstone or pumice (see Table 7.1). Density and

TABLE 7.1 Laboratory determination of density, porosity and slaking for Kannaviou sandstones and siltstones from Area 1

SAMPLE NO.	DESCRIPTION	BULK DENSITY ρ (Mg/m^3)	DRY DENSITY ρ_d (Mg/m^3)	GRAIN DENSITY ρ_g (Mg/m^3)	POROSITY n (%)	SLAKING (sample standing in distilled water for 3 days)
84/4A	fine-grained silty SANDSTONE	1.75	1.48	2.25	34.25	very slight
84/7	thinly bedded silty SANDSTONE	2.25	2.12	2.57	17.58	-
84/11	strongly jointed fine-grained SANDSTONE	1.71	1.36	2.42	43.80	none
84/13	thinly-bedded soft/ friable fine-grained silty SANDSTONE	1.83	1.54	2.46	37.21	-
84/15	poorly-bedded moder- ately hard fine- grained silty SANDSTONE	2.00	1.76	2.54	30.98	-
84/23	massive fine-medium grained SANDSTONE	1.94	1.72	2.40	28.29	very slight
84/26	massive fine-medium grained SANDSTONE	1.94	1.69	2.47	31.79	none
84/30	current bedded fine- grained clayey, silty SANDSTONE	2.24	2.08	2.64	21.26	moderate
84/33	medium to course- grained SILTSTONE (No Hcl reaction)	1.66	1.33	2.28	41.87	very slight
BH145	fine-grained clayey silty SANDSTONE	-	-	-	-	total (completely slaked in 10 mins)

Densities were determined using paraffin saturation under vacuum and submerged weighing. (Density of paraffin at 20°C taken as 0.787 Mg/m^3)

porosity of montmorillonite-rich sandstones and siltstones were measured using a paraffin saturation or paraffin wax coating technique (I.S.R.M., 1980) due to slaking of these rocks in water. The relationship between natural moisture content and dry density for clays is shown in Fig.7.2. A clear inverse correlation is seen (r = 0.63). Dry density, bulk density and moisture content are related by the following equation:

$$\gamma_d = 100\ \gamma_b/(100+m)$$

From the above, the following equation may be derived with the assumption that the soil is fully saturated:

$$1/\gamma_b = 1 - (1 - 1/Gs)(100/m+100)$$

A graph of $1/\gamma_b$ v 100/(m+100) is shown in Fig.7.2), the slope being represented by -(1-1/Gs). Units of 'm' and γ_d are '%' and 'Mg/m^3', respectively.

The wide scatter of points is notable (r = 0.29). This is due almost entirely to the non-saturated condition of most of the samples at the time of testing, and accounts for the good correlation between dry density and moisture content (Fig.7.1).

The overall relationship between moisture content and depth below ground level shown in Fig.7.3, is not clearly demonstrated (no moisture contents were measured below 17m). The graph suggests a narrowing of the range of moisture contents below 5m. The log for BH DA1 (see Appendix 1A) shows a steady decrease in moisture content from about 40% near the surface to 20% at 16m. This pattern is not necessarily followed in the case of landslipped material (e.g. BH A10). In most instances, seasonal drying of the uppermost 3 metres occurs with a desiccated crust developing within the top metre; the exception being active landslip deposits which may remain saturated throughout the year.

There is a general <u>decrease</u> of moisture content with increasing calcium carbonate content but an <u>increase</u> in moisture

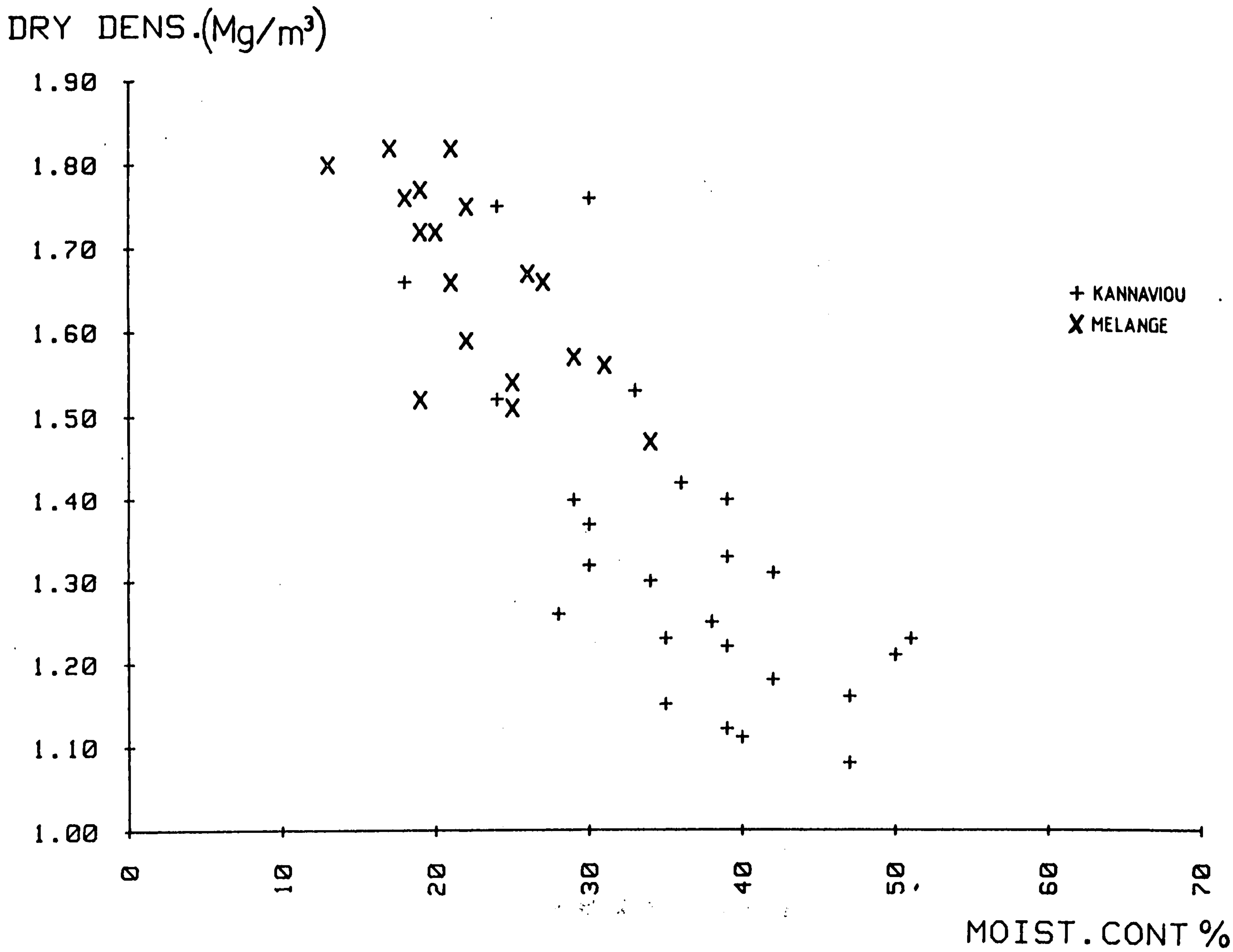
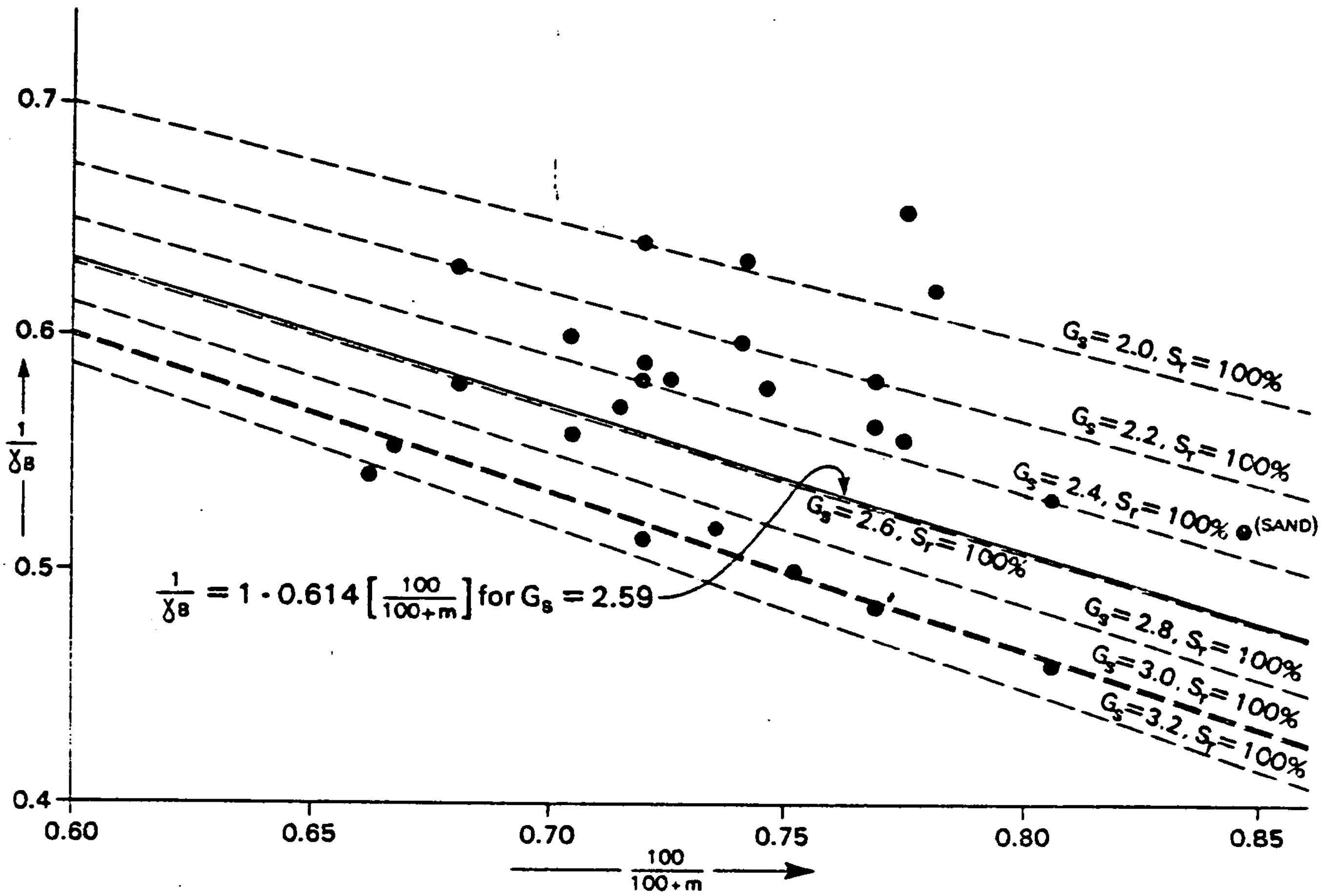


Fig. 7.1 Dry density v moisture content - Kannaviou & melange



Best fit linear regr.:-

$$y = 0.89 - 0.27\,X$$

$$\frac{1}{\gamma_B} = 0.89 - 0.27\left[\frac{100}{100+m}\right]$$

G_s = Specific Gravity

S_r = Degree of Saturation %

m = Moisture Content (natural) %

Fig. 7.2 1/γb v 100/(m+100) - Kannaviou clays

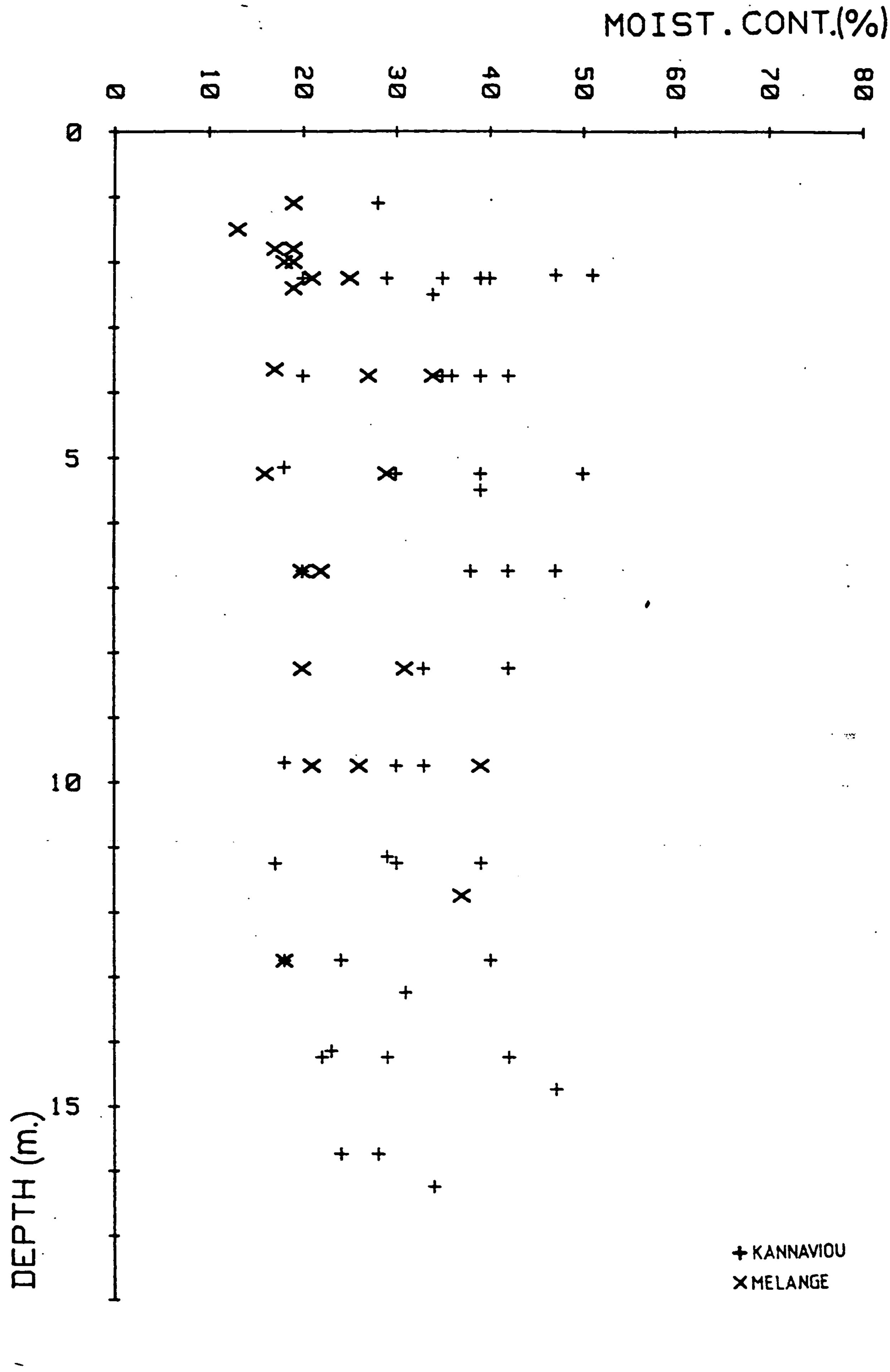


Fig. 7.3 Moisture content v depth - Kannaviou clays & Melange

content with increasing montmorillonite content. It is, however, difficult to generalise about the natural moisture content or bulk density values of the Kannaviou samples owing to the limited number of tests carried out, the lithological variability of the Formation, and seasonal moisture changes. Figures 7.2 & 7.3 may however act as a general guide.

7.4.1.2. Plasticity

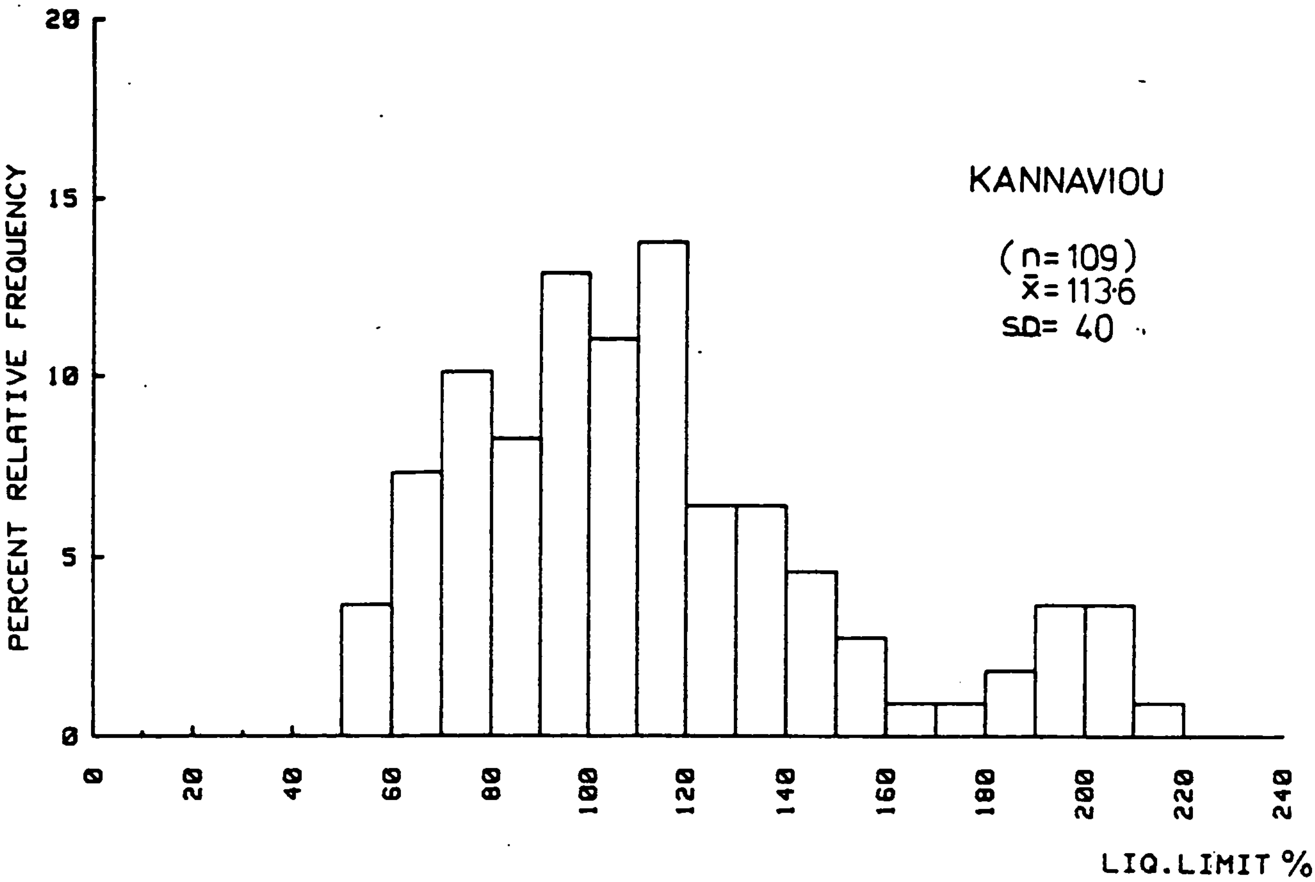
A total of 109 liquid and plastic limit tests were carried out on Kannaviou samples. Liquid limits (LL) exhibited a wide range from 56% to 237% (mean = 113.6, S.D. = 40) and plastic limits (PL) from 5% to 57% (mean = 38.9, S.D. = 9.8). Histogram plots are shown in Fig. 7.4. The distribution of liquid limit is seen to be bi-modal with a secondary mode at LL = 200%. This secondary mode is due to a group of highly montmorillonitic sheared clays possibly associated with the Kannaviou-Melange contact as shown in BH's EG 10/84 and EG 13/84 and pits 10A and 14. There is a possibility of drilling-mud contamination in the case of these two boreholes. Tests carried out by GSD specifically to investigate this possibility have, however, indicated that such contamination is insignificant.

Plasticity index (PI) and liquidity index (LI) are defined as:

$$PI = LL - PL$$
$$LI = (m - PL)/PI$$

where 'm' is natural moisture content; all parameters expressed as percentages.

The relationship between plasticity index and liquid limit is shown on the standard 'Casagrande' graph (Fig.7.5). It can be seen that the British Standard Classification System (B.S.C.S.) is inadequate to describe the range of plasticity of the Kannaviou clay. The B.S.C.S. merely describes the Kannaviou as being of high to extremely high plasticity. Most samples lie above and close to the A-line, the equation of which is:



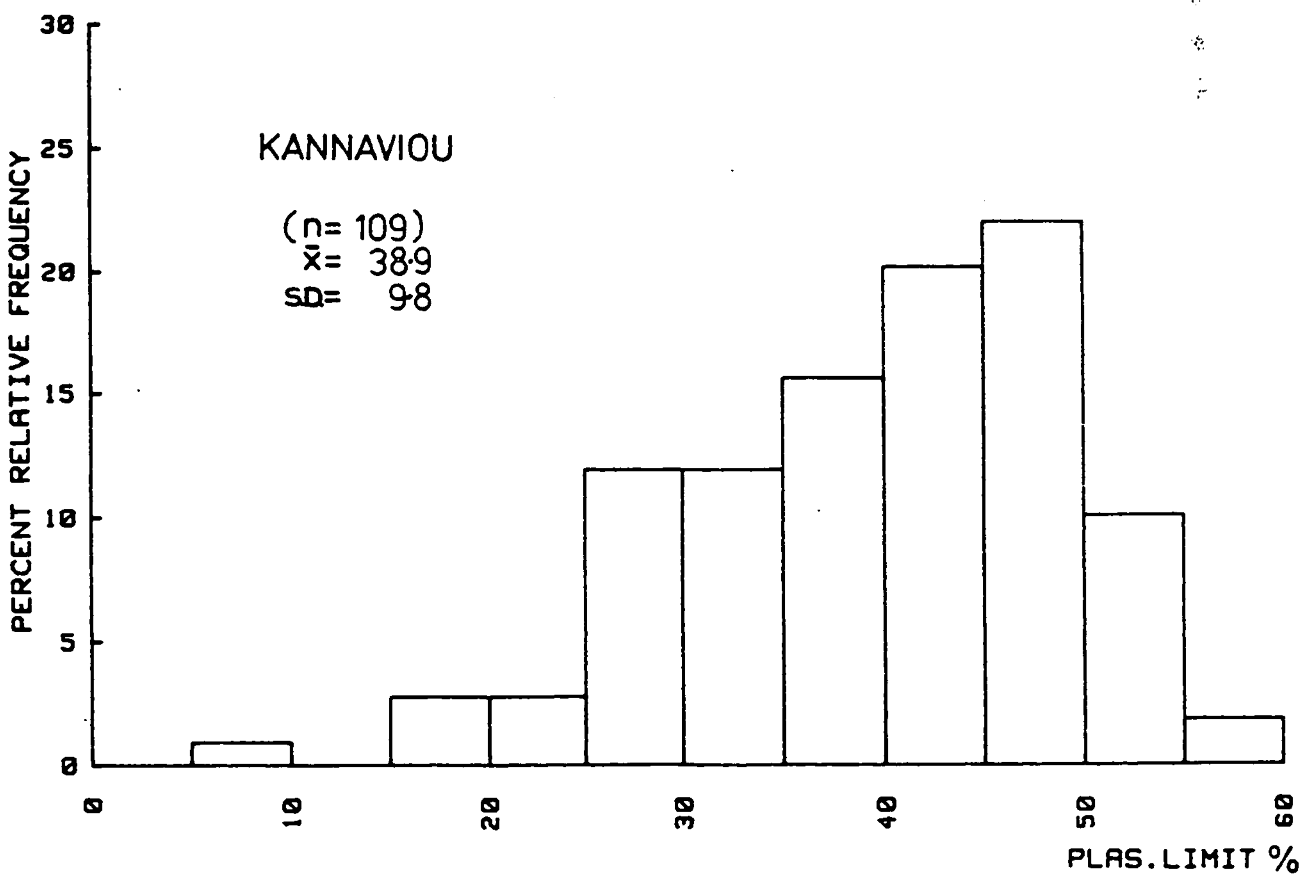


Fig. 7.4 Histograms of Liquid Limit & Plastic Limit - Kannaviou

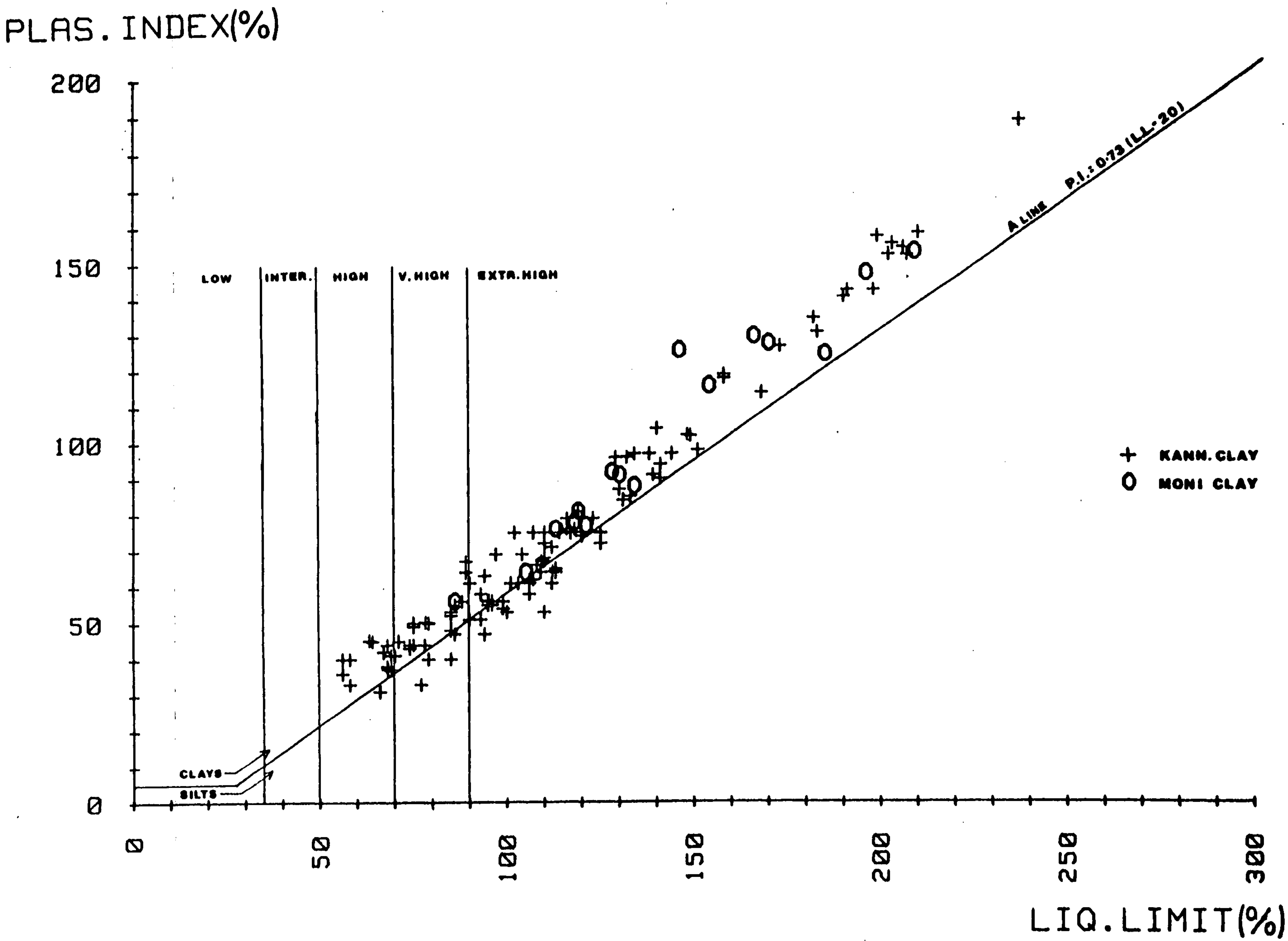


Fig. 7.5 Casagrande plot; Liquid Limit v Plasticity Index - Kannaviou & Moni clays

PI = 0.73 (LL-20)

It is notable that for liquid limits above 150%, the 'best-fit' line appears to diverge from the A-line. This trend is also found to occur for pure ca-montmorillonites (Grim, 1962).

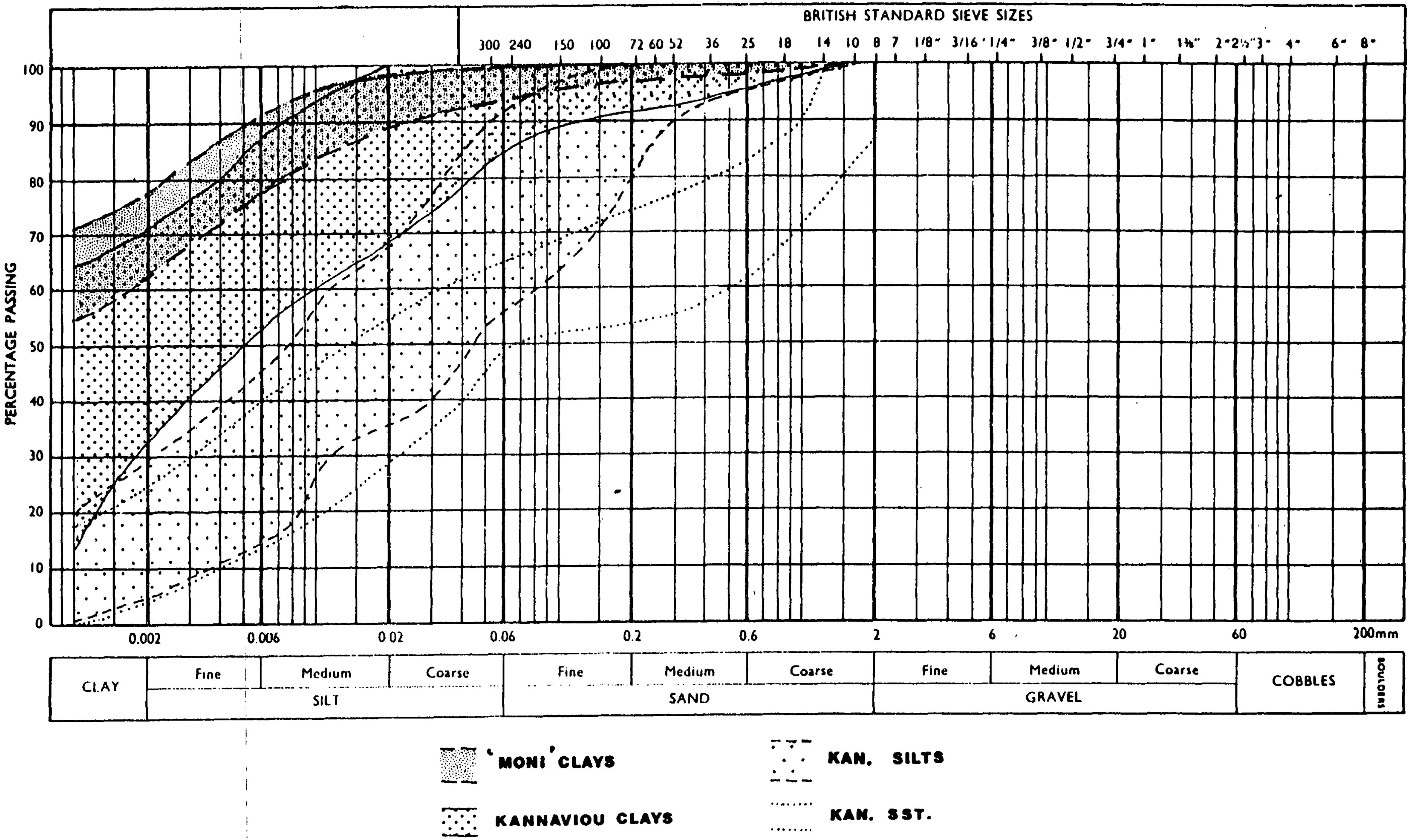
On the borehole logs presented in Appendix IA, moisture contents are plotted on the same scale as liquid limit and plastic limit data. This gives a visual indication of liquidity index (LI) which ranges from -0.32 to +0.18 (mean = -0.06, SD = 0.13, n = 34). In most cases, the moisture content is less than the plastic limit giving a negative value for LI, indicating a state of overconsolidation. No overall trend of liquidity index with depth (to 16 metres) is indicated by the plotted data. This is to be expected given the highly variable lithologies encountered. Unfortunately, no moisture content values were obtained for the Kannaviou sampled in deep boreholes EG 10/84 and EG 13/84, and no inference of liquidity indices was possible.

Thixotropy, defined as a reversible sol-gel transformation without moisture content change (Perloff & Baron, 1976), has been observed in highly montmorillonitic Kannaviou clay samples. For a soil in its natural condition this is analogous to a recoverable sensitivity at constant moisture content (see section 7.7.2). The thixotropic effect is demonstrated by vigorously stirring a sample of clay which has been remoulded at a moisture content in excess of the liquid limit. The vigorous agitation results in the remoulded sample forming a 'slurry' which then becomes liquid enough to be poured. On ceasing agitation, the remoulded strength is regained fairly rapidly, with no change in moisture content.

7.4.1.3. Particle size analysis

Ninety-six Kannaviou samples were tested for particle size analysis. Results are given in the form of cumulative frequency-distribution or grading curves (see Fig.7.6), and as

Fig. 7.6 Particle size distribution envelopes - Kannaviou & Moni clays



%SAND: %SILT: %CLAY in Appendix IIA. The sand content (0.06 mm to 2 mm grain size) ranges from 0% to 50% (mean = 12.8%, SD = 15.3); the silt content (0.002 mm to 0.06 mm grain size) ranges from 16% to 77% (mean = 44%, SD = 12.4); and the clay content (<0.002 mm grain size) from 5% to 84% (mean = 43.1%, SD = 18.9). It is notable that the silt content is normally distributed.

The particle size envelopes for those Kannaviou sediments described as 'siltstones' and 'clays' are reasonably distinct (see Fig.7.6) whilst the 'sandstones' have variable clay contents ranging from 5 - 25% (an important factor affecting their engineering behaviour, see Section 7.7.2). It is, perhaps, worth noting that difficulties may be experienced in the measurement of particle size where grains of mica are present. Conventional sieving techniques do not lend themselves to the analysis of platy grains nor of grains which vary greatly in density (Suthren, 1985).

Activity, A_c, defined by Skempton (1953) as PI / %CLAY, gives an indication of the colloidal 'potency' of the clay size fraction (ie <0.002 mm). Values of Activity range from 0.62 to 5.71 (mean = 1.94, S.D. = 0.86, n = 92). The highest value of A_c attained by a clay/mudstone sample was 3.5; the higher values belonging to 'sandstones' and 'siltstones' probably have little significance. These results are plotted on a graph of PI v %CLAY (Fig. 7.7). Some of the higher values of A_c reached may be due to aggregation of clay particles (Barden, 1972). This possibility is further suggested by the wide scatter of points on the graph showing %Montmorillonite v %Clay fraction (see Fig.7.8) where some samples actually show a %Montmorillonite to %Clay ratio greater than unity. Clays with an Activity greater than 1.25 are termed 'active' (Perloff & Baron, 1976); this places 80% of the Kannaviou samples tested in the 'active' category.

A reasonably good correlation (20 samples, r = 0.79) exists between Activity and dry density. Work on artificial soils (Seed et al., 1964a & 1964b) has shown that Activity can be accurately used to classify soils regardless of clay mineral

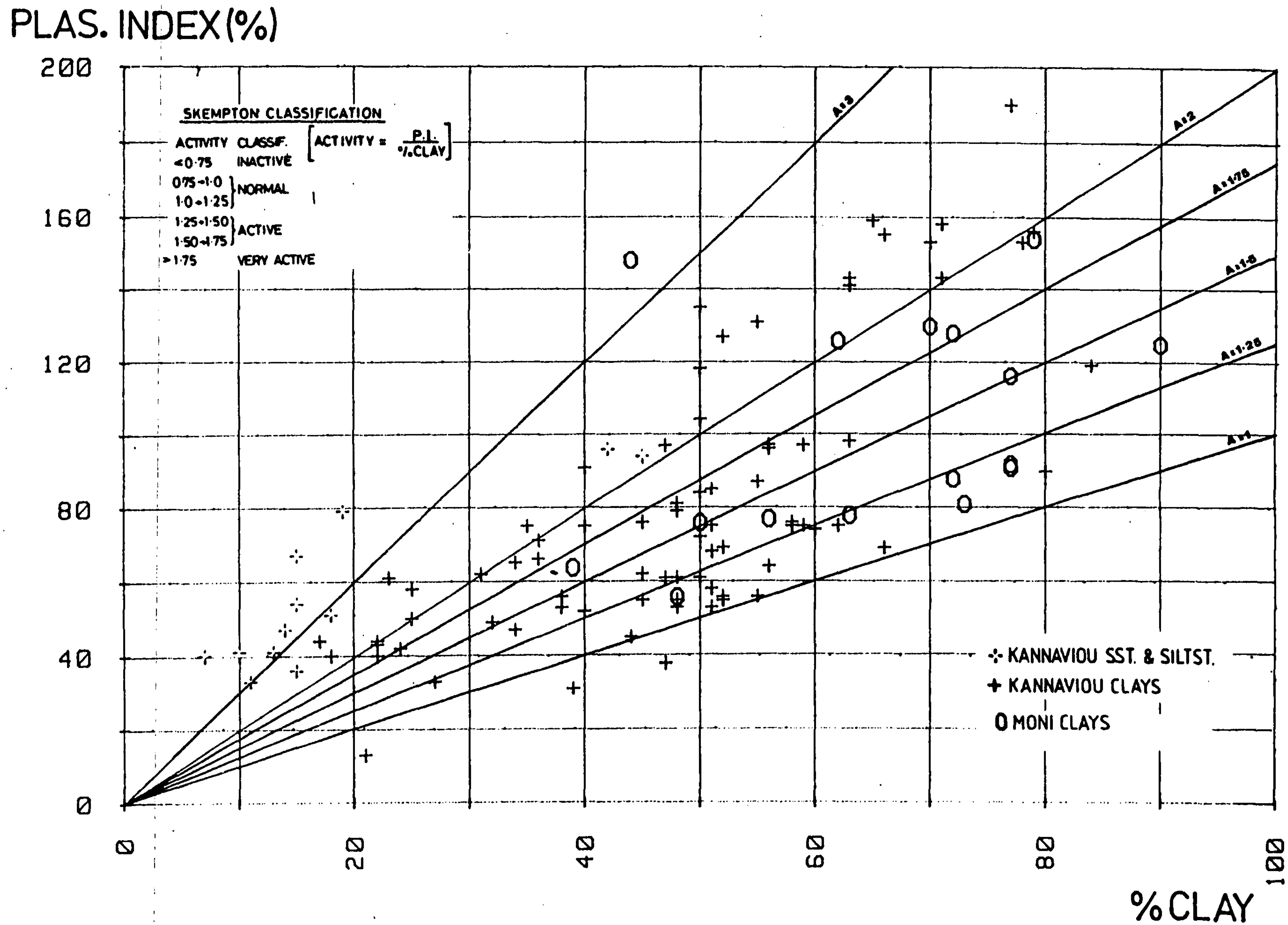


Fig. 7.7 Plasticity Index v %clay - Kannaviou & Moni clay

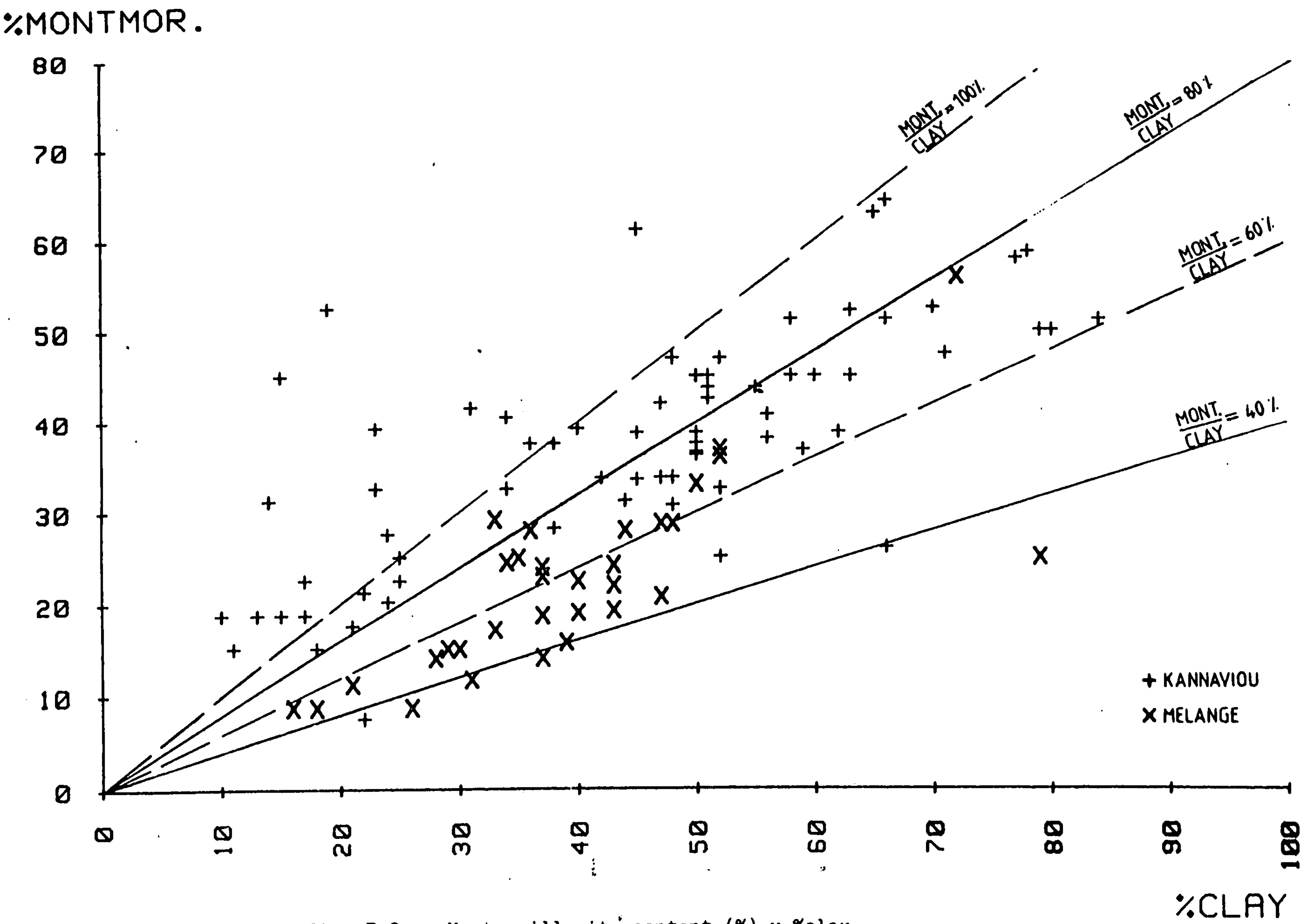


Fig. 7.8 Montmorillonite content (%) v %clay
Kannaviou, Melange,

composition. The fact that this is not the case with the Kannaviou samples highlights the difficulties presented in the geotechnical analysis of natural soils.

7.4.2. Mineralogy

7.4.2.1. General

All the tested samples of the Kannaviou Formation were found to contain calcium montmorillonite (sometimes known as fuller's earth, and a member of the smectite group of clay minerals often referred to, loosely, as 'bentonites') and quartz in varying proportions (see Appendix IIB). In addition, qualitative XRD analyses identified the following minerals:

calcite (86% of samples tested), feldspar (58%), mica (48%), chlorite (35%), zeolite and clinoptilolite (19%), cristobalite (16%), dolomite (16%), amphibole (13%), and kaolinite (13%).
Appendix 2B lists the above minerals in order of abundance.

The mica is probably in the form of muscovite (and possibly as biotite in some sandstone samples) and is, in most cases, associated with chlorite . The muscovite may exist, in part, as mixed layers with the montmorillonite (Deer et al, 1962). Chlorite a mixed layer mineral (consisting of layers of talc and brucite) and may itself form mixed layer aggregations with montmorillonite. Chlorite is a common weathering product, as well as a product of the low-grade metamorphism, of basic igneous rocks and tuffs, and occurs in many common argillaceous sediments. Chlorite is also found as a coating on joints and fissures particularly in basalts. A chlorite-like substance called 'swelling chlorite' may also be produced from montmorillonite by the action of $Mg(OH)_2$ & $Fe(OH)_2$.

Clinoptilolite, a member of the zeolite group of minerals was detected in small amounts in samples of mudstone and siltstone from boreholes D1 and D2. Clinoptilolite is found in fuller's earth (California), associated with devitrified glass (N.S.W., Australia), in highly weathered basalts (Wyoming, U.S.A.), and generally in altered vitreous tuffs (Roberts et al, 1976; Suthren, 1985). Cristobalite, detected in some silty clays and mudstones of the Kannaviou, may occur as a high-temperature alteration product of montmorillonites, sepiolites attapulgites and kaolinites (Grim, 1962) and commonly occurs in rhyolitic lavas, and less commonly in basaltic lavas and on fracture surfaces in olivine-basalt. Amphibole was detected in sandstones from boreholes D1 (50-58 metres) and D2 (47 metres). Dolomite is found in Kannaviou mudstones associated with high proportions of calcite.

A typical x-ray diffractometry log for a Kannaviou clay sample is shown in Fig.7.9.

7.4.2.2. Montmorillonite

The clay mineral montmorillonite found extensively in the Kannaviou samples is of the calcium variety, otherwise known as fuller's earth. It is a sheeted silicate which is notable for its ability to take up water between its structural layers and to readily exchange cations. Montmorillonite is the product of the very rapid weathering and diagenesis characteristic of volcaniclastic sediments in particular of volcanic glass and plagioclase (Suthren, 1985). Robertson (1977b) describes the presence of sodium montmorillonite in the Palaeomylos River area where the basal members of the Kannaviou Formation are exposed. No such Na-Montmorillonite was detected in the present study. Montmorillonite may be interlayered with other clay minerals including chlorite to form 'mixed layer' clays.

The Ca-montmorillonite content of those Kannaviou samples tested, ranged from 7.5 to 64.3 (mean = 37.8, S.D. = 12.8, n = 95). Good positive correlations exist (see Fig 7.10) between montmorillonite content and liquid limit (r = 0.83), and between montmorillonite content and plasticity index (r = 0.75),(see Fig.7.11a). The relationship between montmorillonite and

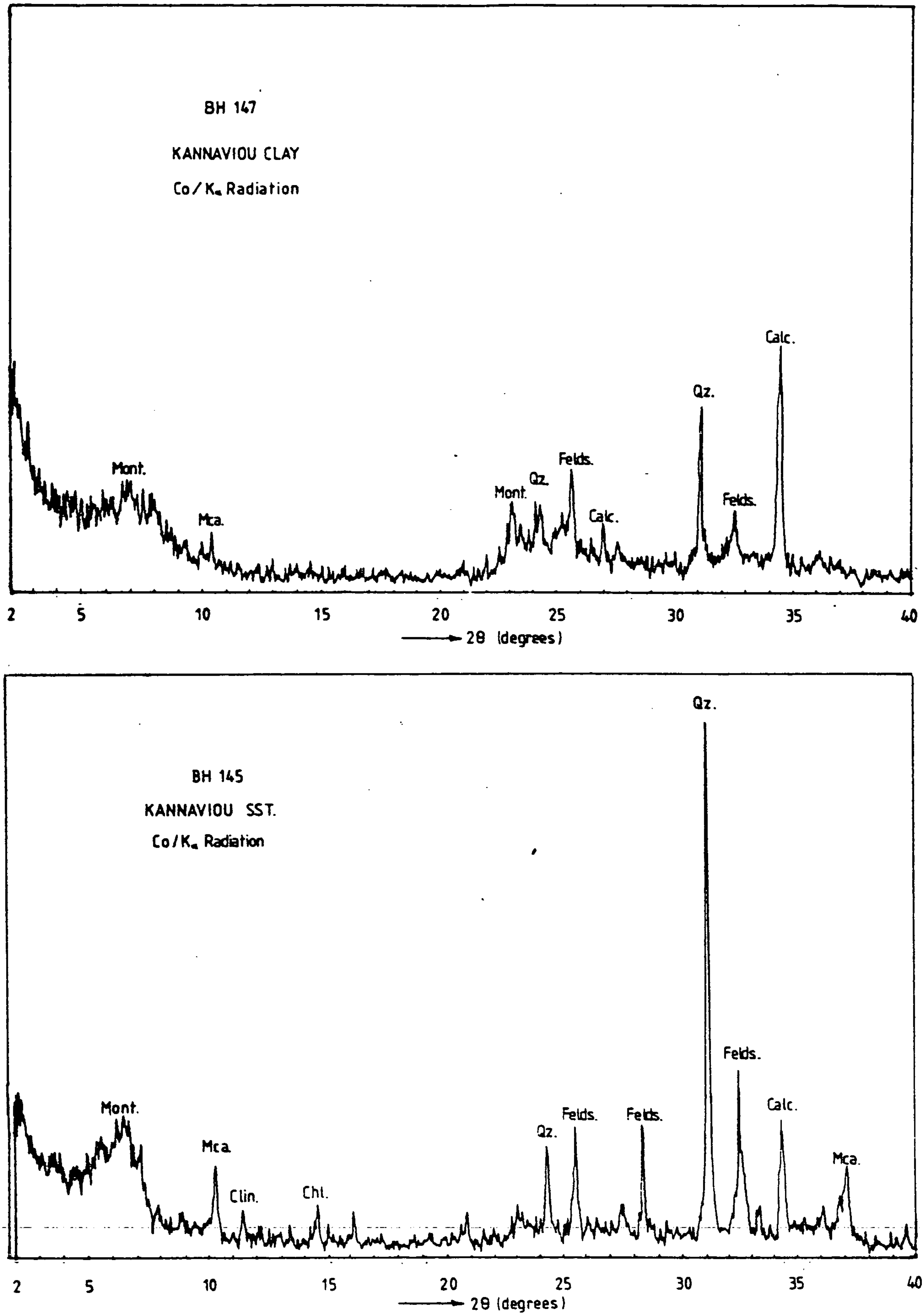


Fig. 7.9 X-ray diffraction traces - Kannaviou

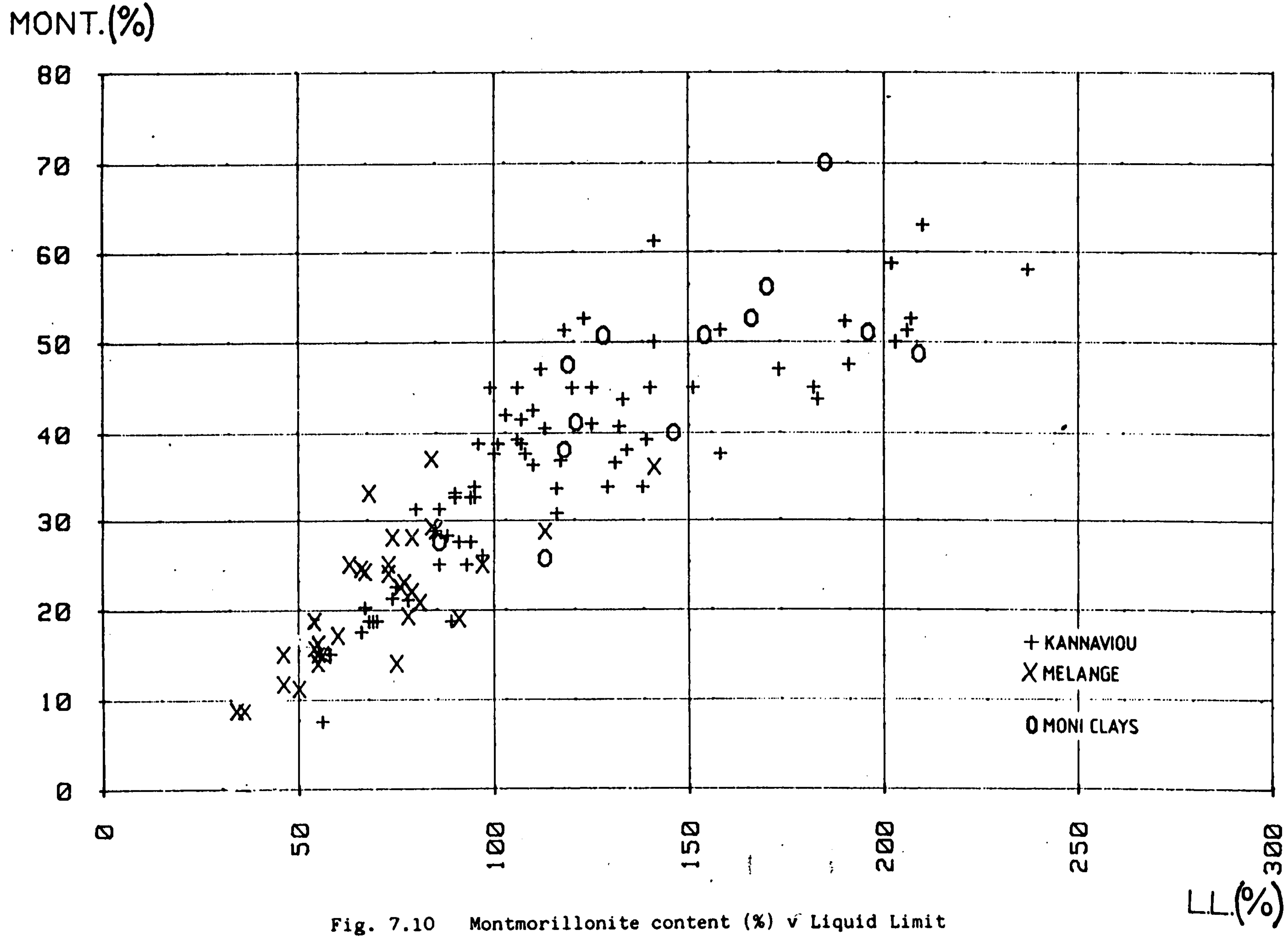


Fig. 7.10 Montmorillonite content (%) v Liquid Limit
Kannaviou clays & Melange

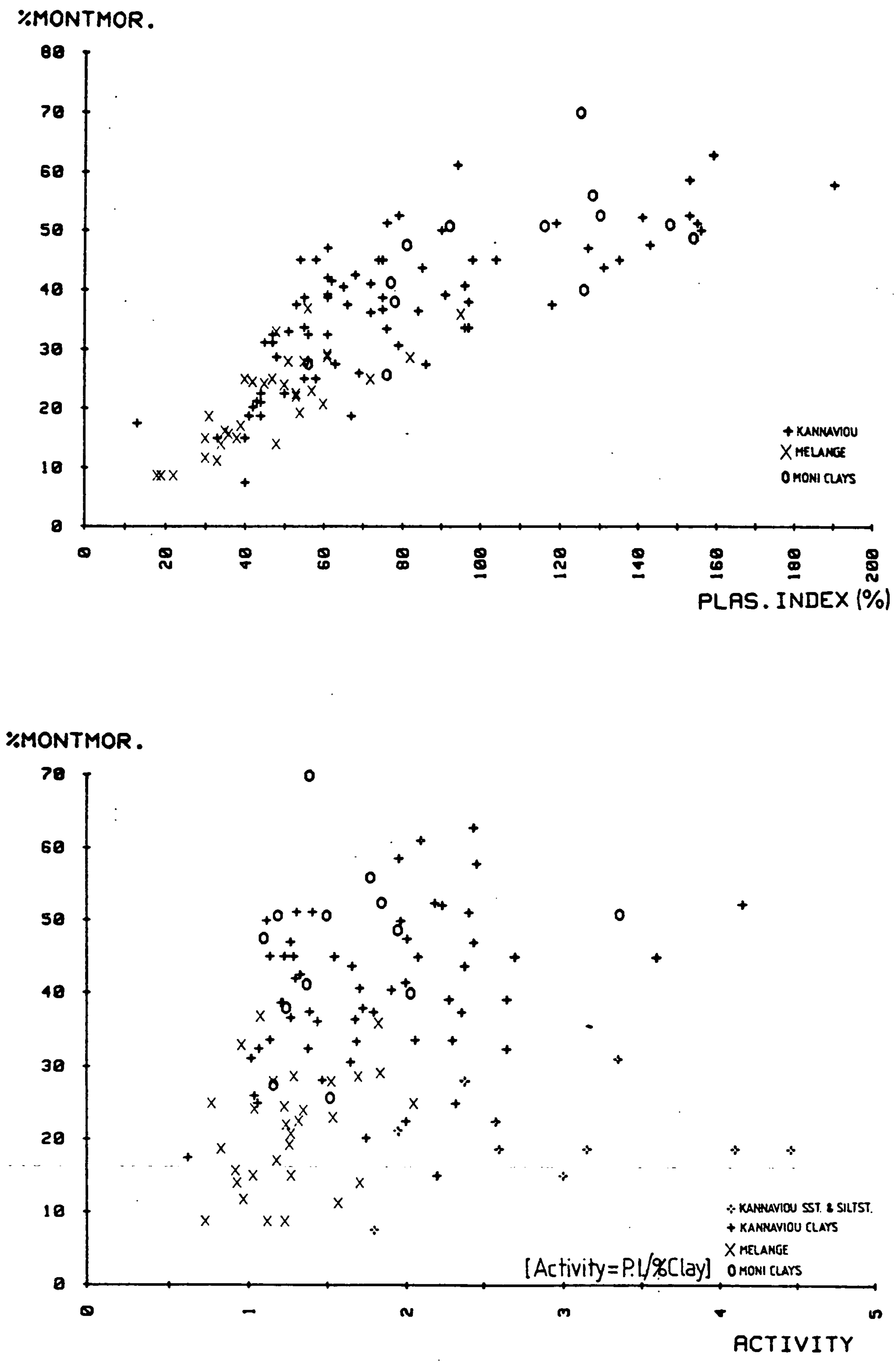


Fig. 7.11 (a) Montmorillonite content (%) v Plasticity index
(b) Montmorillonite content (%) v Activity (= P.I./% CLAY)

Activity (see Fig.7.11b) is less well defined. The high liquid limit values are due to the ability of montmorillonite to disperse into extremely small particles with a very large potent adsorbing surface. The presence of montmorillonite when interlayered with other clay minerals or aggregated with other minerals facilitates the dispersion of these micro structures, and forms planes of weakness when subjected to stress (Grim, 1962).

The plot of %montmorillonite v Activity (see Fig.7.11b) shows a rather poor positive correlation. If, however, the sandstones and siltstones are isolated the correlation is improved. The general carbonate/montmorillonite/other composition of the Kannaviou is shown in Fig.7.12b.

The variation of montmorillonite content with depth is shown for boreholes EG 10/84 (Phiti) and EG 13./84 (Ayios Dhimitrianos) in Appendix IA . Little variation of montmorillonite content with depth is seen, with the marked exception of the cored samples at the Melange/Kannaviou contact where montmorillonite contents exceed 40%. This anomaly may be partly due to contamination of the core by bentonite drilling mud, but this has not been proved.

There are indications that clays of the lower facies of the Kannaviou formation, close to the contact with the lavas, contain higher than average montmorillonite contents and lower than average carbonate contents, Robertson (1977b).

In the Palaeomylos river valley, between Asproyia and Kannaviou (GR 6280 6445) two bands of red clay are seen. These are non-calcareous but rich in montmorillonite, and are interbedded with sandstones. They are probably equivalent to the brown, pure montmorillonite clays described by Lapierre & Afrodisis (1979).

7.4.2.3 Carbonate

Carbonates form a significant proportion of Kannaviou

Formation sediments, and are found throughout the clays and mudstones as well as in the sandstones and siltstones. The carbonate detected is almost entirely calcite (calcium carbonate). Calcite is a common product of the alteration of basic igneous rocks (notably the more basic plagioclases). A small number of samples with high calcite contents were found to contain dolomite (calcium-magnesium carbonate) in small amounts. Some of the dolomite may have undergone de-dolomitization whereby the dolomite reacts with clay minerals to produce calcite.

Carbonate contents range from 0% to 28.7% (mean = 8.6, S.D. = 7.4, n = 90). An overall inverse correlation (r = -0.6) exists between montmorillonite content and carbonate content; and also between moisture content and carbonate content (r = -0.63).

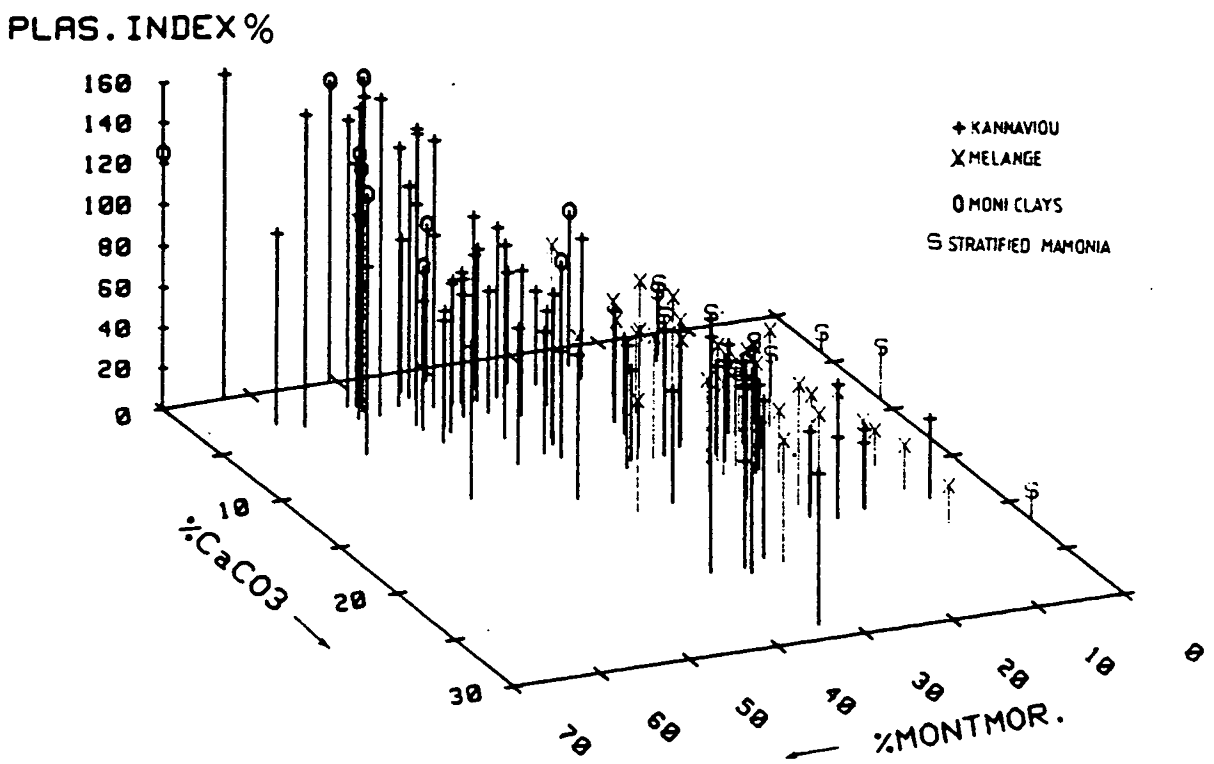
An XYZ graph (Fig.7.12a) of plasticity index v montmorillonite v carbonate shows that the liquid limit and also the plasticity index are dependent on the relative proportions of montmorillonite and carbonate.

The variation of carbonate content, over the maximum borehole depths investigated in the present survey, does not appear to follow a pattern. Data from deep boreholes EG 10/84 and EG 13/84, for example (see Appendix IA) suggest a constant carbonate content throughout the Formation sampled.

7.4.3. Volume Change

7.4.3.1. Consolidation and permeability

A single high-pressure consolidation test was carried out on a 100mm diameter disc cut from sample BH124, a stiff silty clay, in a specially adapted 15-ton capacity Denison oedometer at BGS. The results (see Appendix IIIb) indicate the most-likely value of Overconsolidation Ratio (OCR) to be approximately 15; with minimum and maximum probable values of 9



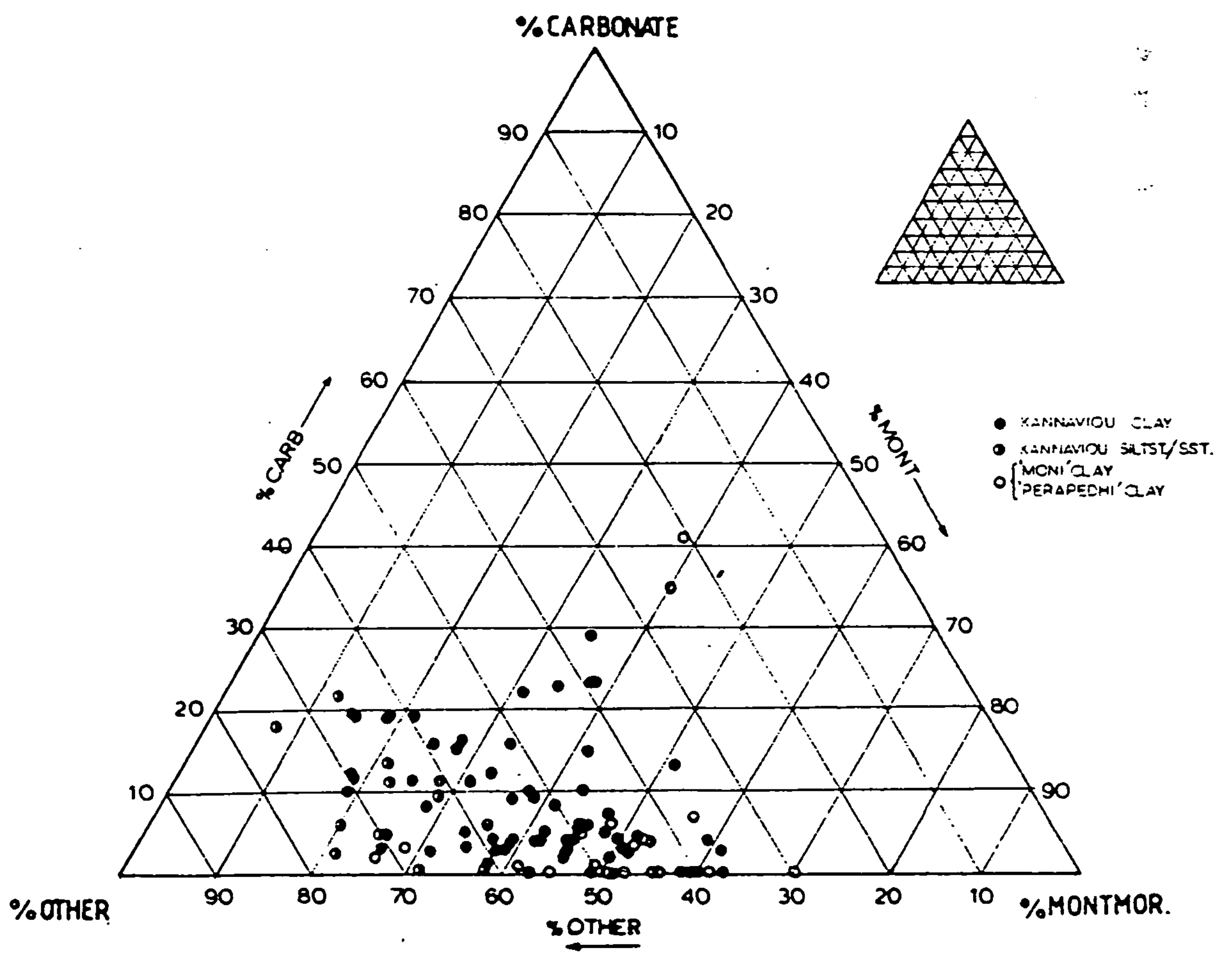


Fig. 7.12 (a) XYZ plot Plasticity index/%$CaCO_3$/%Montmorillonite - Kannaviou Melange, Moni clay & stratified Mamonia

(b) Triangular plot %Carbonate/%Montmorillonite/%Other - Kannaviou clays, Kannaviou siltst./sst. and Moni & Perapedhi clays and 25 respectively, (taking present effective overburden as 0.1MPa). The coefficient of Volume Compressibility (Mv), ranges from .001 to .05 m^2/MN (classified by Head,1982, as 'very low') and the coefficient of Consolidation (Cv), ranges from 0 to 4 $m^2/yr.$; these giving a derived permeability (k_v) of between $6x10^{-11}$ and $6x10^{-14}$ m/sec. over the full range of applied pressures (i.e. 0.3 to 18.6 MPa), using the formula:

$$k_v = Mv.Cvx0.31x10^{-9} \quad m/sec.$$

The coefficient of Secondary Compression ($C\alpha$) ranges from 0 to .001 with values mainly <.001 for pressures below the estimated OCR; this being indicative of overconsolidation (Lambe & Whitman, 1979). Indeed the upward curve of the $C\alpha$ - log p' plot lends support to the estimate of OCR described earlier.

As a result of difficulties in preparing oedometer-type consolidation specimens of both Kannaviou and Melange, the standard CIU triaxial (consolidation-stage) data has also been used to derive approximations of coefficient of consolidation (c_v), coefficient of volume compressibility (m_v), and hence permeability (k). The results are given in Table 7.2. It is emphasised that these results are only approximations for the following reasons:

a) The standard CIU triaxial test features both drainage at one end and side or radial drainage. The formulae for calculating cv do not cater for this complex drainage regime but are given in the following form (Head, 1986):

<u>for ideal vertical drainage to one end only</u>:

$$c_{vi} = \frac{0.197 \times 0.526 H^2}{t_{50}} \qquad \text{(i)}$$

$$= \frac{0.1036 H^2}{t_{50}}$$

$$= \frac{4145}{t_{50}} m^2/yr \text{ (for 200mm long sample)}$$

(where c_{vi} is the isotropic vertical coefficient of consolidation, H is the drainage path length in mm and t_{50} is the time for 50% pore pressure dissipation in mins.)

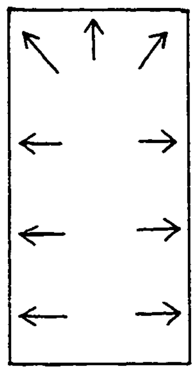
for ideal radial drainage only:

$$c_{hi} = \frac{0.087 \times 0.131D^2}{t_{50}} \qquad \text{(ii)}$$

$$= \frac{114}{t_{50}} \text{ m}^2/\text{yr (for 100mm diameter sample)}$$

(where c_{hi} is the isotropic horizontal coefficient of consolidation, D is the specimen diameter [in mm])

Thus, it can be seen that the resulting coefficient of consolidation obtained for a given value of t_{50}, using one formula, is 36 times greater than that obtained using the other. However, the first case given above (eqn.i) is probably much further from the true situation than is the second case (eqn. ii). Bearing in mind the most likely drainage regime for an 'ideal' material, (see sketch below)



the following formula has been employed to derive the data in Table 7.2:

$$c_{hi} = \frac{260}{t_{50}} \quad \text{(for sample 100m diameter and 200mm long)}$$

b) Neither the Kannaviou clay nor the Melange can be described as 'ideal' materials in the context of consolidation theory. Clearly consolidation drainage paths are strongly influenced by fissures and shears as well as lithological variations along the specimen, and pore pressure dissipation is not governed purely by Darcy's Law.

c) The coefficient of consolidation and modulus of volume

TEST NO.	SAMPLE NO. (STRATIG)	BH. NO. DEPTH (m)	EFF. CELL PR. (kPa)	c_{hi} (m^2/Yr)	m_{vi} (m^2/MN)	k_h (m/s)
100/1	BH47	DAI	50	SAMPLE SWELLING		
	(KAN)	5.0-5.5	150	21.1	0.06-0.16	$3.7x10^{-10}-1.0x10^{-9}$
			300	12.8	0.08-0.2	$3.0x10^{-10}-7.9x10^{-10}$
100/2	BH109	A7	50	SAMPLE SWELLING		
	(MEL+KAN)	8.0-8.5	150	-	0.08-0.14	-
			400	-	0.14	-
100/3	BH65	A2	50	25.4	0.37-0.51	$2.9x10^{-9}-4.0x10^{-9}$
	(MEL)	5.0-5.5	150	11.7	0.25-0.29	$9.1x10^{-10}-1.1x10^{-9}$
			400	11.7	0.13	4.7×10^{-10}
100/4	BH59A	A1	50	SAMPLE SWELLING		
	(KAN)	5.0-5.5	150	28.8	0.13-0.20	$1.2x10^{-9}-1.8x10^{-9}$
			400	12.2	0.06-0.12	$2.3x10^{-10}-4.5x10^{-10}$
100/5	BH121	A6	50	SAMPLE SWELLING		
	(KAN)	5.0-5.5	200	1.2	-	-
			400	0.2	-	-
100/6	BH80	A4	50	14.7	0.62-0.84	$2.8x10^{-9}-3.8x10^{-9}$
	(KAN)	5.0-5.5	50	19.9	0.29-0.38	$1.8x10^{-9}-2.3x10^{-9}$
			150	5.3	0.37-0.38	6.2×10^{-10}
			400	3.2	0.19-0.20	$1.9x10^{-10}-2.0x10^{-10}$
35/1	P85/5B	PIT 5	100	-	-	-
	(MEL)	1.6	200	-	-	-
			400	16.3	0.18-0.26	$9.1x10^{-10}-1.3x10^{-9}$
GSD/1	BH57	A1	50	-	-	-
	(KAN)	2.0-2.5	150	4.7	-	-
			300	4.2	-	-
GSD/2	BH78	A4	100	-	-	-
	(KAN)	2.0-2.5	200	33.0	-	-
			400	20.0	-	-

Table 7.2 Table of consolidation parameters (Chi,Mvi & Kh) derived from Triaxial tests - Kannaviou clay, Melange

compressibility derived from the isotropic consolidation stages of the triaxial test are not equal to those obtained from the oedometer one-dimensional consolidation test, and neither groups are necessarily equal to those prevailing in the field. Head (1986) suggests the following relationships:

$$m_v = 0.67 m_{vi} \quad \text{(approx.)}$$
and
$$c_v = 1.25 c_{vi} \quad \text{(approx.)}$$

(no indication is given of the relationship between c_v and c_{hi})

Values of permeability are derived from the relationship:

$$k = c_v m_v . 0{\cdot}31$$

Little information exists on the consolidation behaviour of structurally complex formations such as the Kannaviou. Japelli et al (1977) quote values of m_v ranging from 0.1 to 0.3 m^2/MN for sheared clays from Sicily (Numidian Flysh Formation), compared with values of 0.1 to 0.4 for the Kannaviou.

The compressibility of the Kannaviou may be defined as 'medium' (Head, 1986) and comparable to weathered London Clay. These values bear little relation, however, to those obtained from the high-pressure oedometer test described earlier. Values of m_v are generally lower for 'undisturbed' unweathered soil.

The determination of the coefficient of consolidation, c_v, is difficult, particularly in the case of complex sheared or fissured soils. The values of c_v obtained for the Kannaviou are unusually high (2 to 35m^2/yr), even when disturbance is taken into account, when compared with the high-pressure oedometer values. Lambe and Whitman (1979) suggest values for c_v of between 0.1 and 1 m^2/yr for high plasticity montmorillonitic clays. Loosening of the sheared and fissured structure due to coring and specimen preparation may be a contributory factor. All the triaxial samples are from shallow depth and have undergone natural disturbance either of a tectonic or a superficial (slope instability) nature. One severely disturbed sample, BH 109, was unable to provide any c_v values.

Values of permeability (k), derived from consolidation tests, must be considered to be speculative as they rely for their accuracy largely on the coefficients of consolidation. As described earlier, the calculation of c_v (or c_{hi}) assumed a dominantly horizontal flow path for the pore fluid draining out during consolidation, therefore the permeabilities quoted are strictly horizontal permeabilities (k_h). Values range from approximately 1×10^{-10} to 4×10^{-9} m/sec across the range of pressures used in the triaxial tests. These values may be considered to be at the lower end of the expected range for fissured and weathered clays generally (Carter, 1983), but are notably higher than those obtained from the high- pressure oedometer test. Clearly, differences in test technique and sample size have an important effect on the determination of permeability (derived), consolidation and compressibility. Highly sheared clays and clay shales of the Argille Varicolori Formation of Southern Italy are reported as having permeabilities of the order of 10^{-11}m/sec (D'Elia, 1977). It is pointed out, however, that unloading of these clays results in a significant increase in mass permeability. Field values of permeability are probably greater than the laboratory values described here owing to the frequently loose, open and strongly fissured and sheared nature of the Kannaviou formation both within the zone of surface disturbance (e.g. triaxial specimens) and at considerable depth (e.g. BH EG 10/84).

Though not available to the authors during the testing programme, a 'Ko' triaxial cell may be used for a type of consolidation test which duplicates the boundary conditions of the oedometer test, (Head,1985). This test would be ideally suited to soils such as the Kannaviou clay and the Melange from which it is extremely difficult to prepare the thin disc-shaped samples required by the oedometer test.

7.4.3.2. Swelling and slaking

Six swelling pressure tests were carried out on Kannaviou samples from Study Area 1 using special equipment developed at the British Geological Survey (Hobbs et al, 1982). The results are given in Appendix IIIc. The samples showed maximum swelling pressures of between 45 and 180kPa; initial moisture contents ranging from 24% to 51%. There are insufficient data to form reliable correlations with other geotechnical parameters. The rates of swelling pressure development, however, can be used as a guide to the permeability of the test specimens. Swelling pressure in the case of the Kannaviou specimens (sample nos P6/4, P13/1, BH57, BH78b, BH109, BH118) was observed to develop quite rapidly (<1hr) when compared with the Gault Clay and Oxford Clay of the UK (Hobbs et al, 1982), and the Nicosia marl of Cyprus (see Rep. No. EGARP KW/86/1 -this series). This is probably due, in part, to the presence of discontinuities within the test specimen and is almost certainly reflected in the field mass behaviour. This would, however, need to be confirmed by field pumping tests. Swelling was also observed during initial consolidation of triaxial test specimens at an effective cell pressure of 50 kPa. Although good correlations between swelling pressures and Atterberg limits are reported in the literature (see Report EGARP KW/86/1), experience has shown that these correlations do not necessarily translate directly to other materials.

It is likely, however, that a broad positive correlation between swelling behaviour and plasticity exists, though there are insufficient data to confirm this in the case of the Kannaviou formation. A potential source of error is introduced by the degree of saturation of a particular specimen at the time the swelling test is carried out. The size of the test specimen is also a source of error, e.g. small specimens may lack the discontinuities, lenses or bands characteristic of the soil mass. Quality of test specimens is a major factor, e.g. disturbed specimens may have lost much of their swelling potential.

Slaking, i.e. the process of mechanical and chemical breakdown of a rock immersed in water, is closely related to swelling where clay minerals are present. The rate and ultimate extent of the breakdown of coherent pieces of Kannaviou sandstone when immersed in water, were observed to be directly related to the montmorillonite content of the specimens. Seven slaking tests were carried out on a variety of coarse-grained Kannaviou sediments (see table 7.1); of these, two showed rapid slaking (samples BH145 & 84/30). Sample BH145, in particular, 'erupted' when immersed in water and was 50% disintegrated within 5 minutes (The montmorillonite content of sample BH145 was 21%).

7.4.3.3. Shrinkage

Shrinkage was measured on six Kannaviou clay specimens using the linear shrinkage test (B.S. 1377, 1975 test No. 5). Five samples were from BH D1/DA1. Values of linear shrinkage (i.e. the % decrease in length upon drying from the liquid limit state) ranged from 12% to 24%; there being a good positive correlation between linear shrinkage,(LS) and liquid limit,(LL). The best-fit line (Fig. 7.13) has the equation:

$$LS = 0.8 \times LL^{0.88} \qquad (r= 0.96)$$

The relationship between linear shrinkage and plasticity index (PI) is found to have the equation :

$$LS = 2.3 \times PI^{0.48} \qquad (r= 0.97)$$

This compares with a linear relationship for clays generally of: $PI = 2.13 \times LS$ given by Vickers (1981). The linear shrinkage test should be taken as an index indicating the potential for shrinkage rather than the actual amount one might expect in the field, as the specimen has been completely remoulded at high moisture content and its only parallel in the field is probably the material constituting active mudflows. Hexagonal shrinkage crack patterns were observed, for example, in the dried beds of head-ponds within active landslips (e.g. at GR 588 642). Elsewhere, the amount of shrinkage may be expected to be less than that measured in the laboratory, but generally proportional to plasticity, and hence percentage of active clay minerals. The effects of shrinkage may be disguised by the presence of pre-existing discontinuities which may widen and become filled with debris.

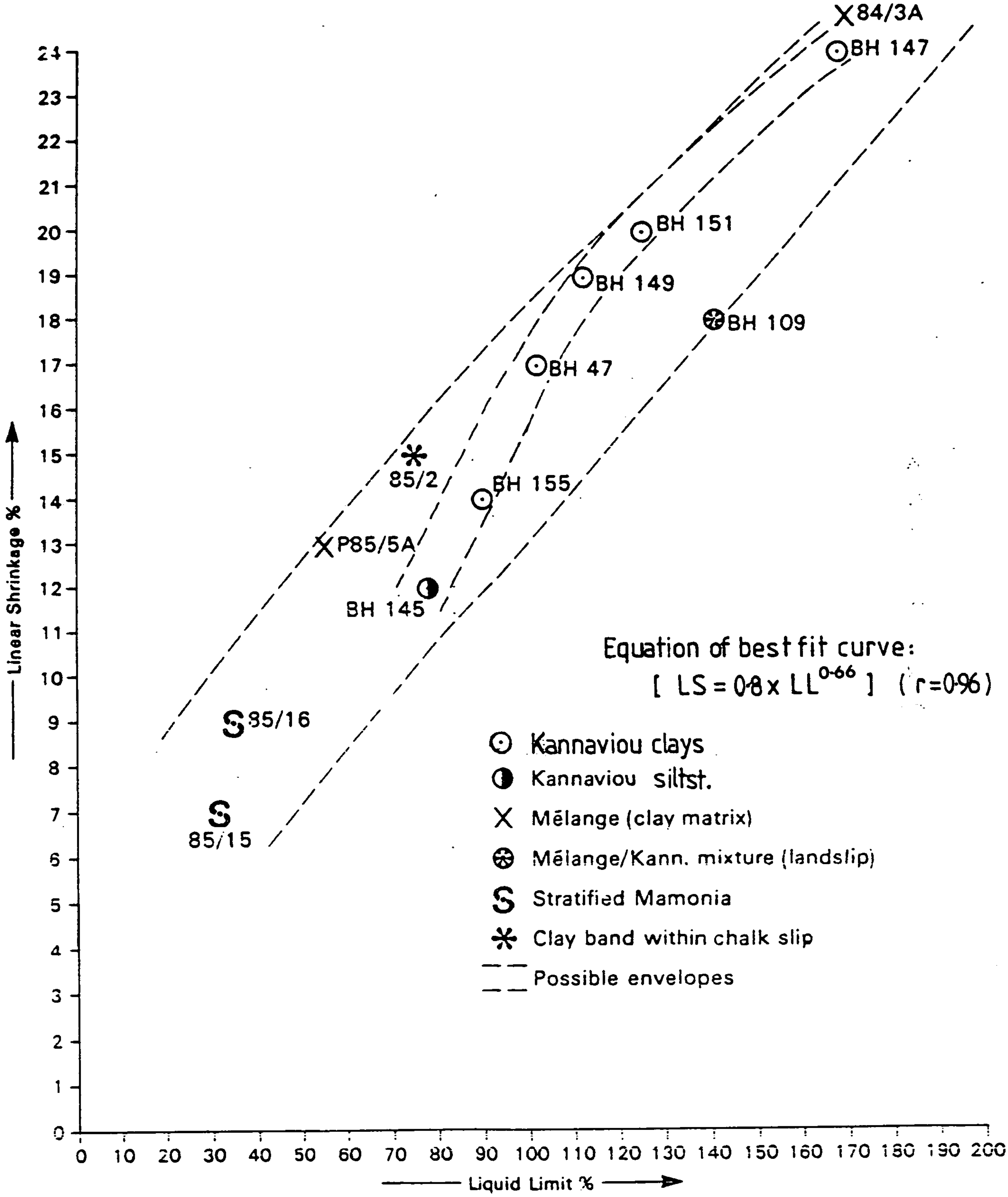


Fig. 7.13 Linear shrinkage v Liquid limit - Kannaviou, Melange & stratified Mamonia

7.4.4. Strength

7.4.4.1. Triaxial tests

Six multi-stage, isotropically-consolidated, undrained (CIU) triaxial tests were carried out on Kannaviou clay specimens. These specimens were 100mm diameter (U100) and obtained from boreholes DA1, A1, A4 and A6 at depths ranging from 2.0m to 5.5m. A seventh specimen was tested, sample No. BH 109, which contained disturbed Melange and Kannaviou clay. Results of these tests are given in Table 7.3, and Appendices II & III.

The specimens were generally in a broken or disturbed condition due to natural fissures and proved difficult to trim; (one specimen, sample BH59A, contained a sharply defined natural shear plane at an angle of 30° to 40° to horiz. (see Table 7.3). Some specimens had to be capped at both ends by casting plaster of paris (using a split former device) in order to form flat and parallel ends. This method did not appear to adversely affect the behaviour of the sample.

Values of effective cohesion (c') and effective friction angle (ϕ') range from 13 to 50kPa[1] and 18.3° to 29.7°, respectively. Values of total cohesion (c_u) and 'total' friction angle (ϕ_u) ranged from 10 to 40 kPa[1] and 13.5° to 25.6°, respectively.

As might be expected in such a complex formation as the Kannaviou, the triaxial data are widely scattered. Test samples with similar index and mineralogical properties have different strengths under the same undrained stress conditions. An interesting case, however, is that of sample BH59A. Here, a very sharply defined, pre-existing, apparently natural, shear plane has acted as the triaxial failure plane with no other significant deformation. The result has been an effective cohesion (c') of zero and an effective friction angle (ϕ') of 29.7°. This may be considered to represent the residual

[1]With the exception of sample BH59A

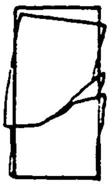
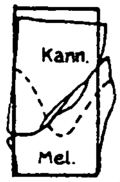
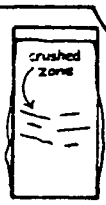
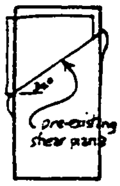
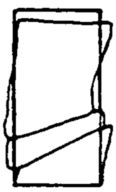
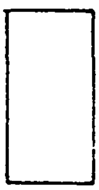
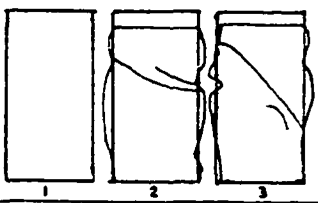
TYPE	TEST No	TRIAXIAL POST-TEST DESCRIPTION			STRENGTH
CU ×3 Multi-stage	100/1 BH47 5.5m		**KANNAVIOU CLAY** - Olive grey highly fissured, partly disturbed, partly shaley mudstone, thin laminae of silt/fine sand. - Fissures dipping 45° to horiz. but curved in part. - Orange/brown staining. - Softening & high m/c in area of shear failure plane.	Plaster ends	$C_u = 20$ $\phi_u = 14.6$ $C' = 15$ $\phi' = 16.7$
CU ×3 Multi-stage	100/2 BH109 8.25m		**MELANGE + KANNAVIOU CLAY** - Mixture of Mel. & Kann. with some chalk debris between. Both Kann. & Mel. have fragments of Kann. mudstone in them. Kann. clay is not fissured but plastic (remoulded). - Triax. failure plane clearly slickensided probably parallel to natural shears. - Some staining on clasts & shears, within Kann. - Mel. is without fissures/shears.		$C_u = 15$ $\phi_u = 13.5$ $C' = 9$ $\phi' = 18.3$
CU ×3 Multi-stage	100/3 BH 65 5.25m		**MELANGE** - Loose, soft, highly disturbed 'debris' of sand/sst. and chalk in matrix of soft melange. - Slip zone clay band cuts specimen at high angle. - Specimen compacted considerably during Triax. test.		$C_u = 15$ $\phi_u = 19.8$ $C' = 7.5$ $\phi' = 20.5$
CU ×3 Multi-stage	100/4 BH59A 5.25m		**KANNAVIOU CLAY** - Pre-existing sharply defined 'polished' shear plane at 30° to 40° to horizontal. - Highly fissured unweathered but softened in part (gener.wet). - Dk. blue-green colour oxidising rapidly in air to olive-green. - Black and brown staining on some fissures. - Clay on slip plane itself, plane is dry and hard.	Plaster ends	$C_u = 0$ $\phi_u = 25.6$ $C' = 0$ $\phi' = 29.7$
CU ×3 Multi-stage	100/5 BH121 5.25m		**KANNAVIOU CLAY** - Friable, partly broken, clayey slightly sandy SILT & clayey silty fine SAND (with some marl/chalk). - Brown & black staining and fissures. - Dominantly vertical joints/fissures. - 2.5cm thick shear zone of olive & brown clays dipping 12° → 13° at top of specimen.		$C_u = 30$ $\phi_u = 14.3$ $C' = 18.4$ $\phi' = 25$
CU ×3 Multi-stage	100/6 BH80 5.25m		**KANNAVIOU CLAY** - Disturbed (landslipped) fissured clay/mudstone, generally plastic. - Clasts of hard mudstone. - Brown/black staining on fissures.		$C_u = 18$ $\phi_u = 16.2$ $C' = 13$ $\phi' = 23$
CU ×3	35/1 P85/5B 1.6m.		**MELANGE** - Highly matrix dominant probably remoulded 'red' Melange with some gravel -size clasts. - Horizontally-oriented samples. - Relatively homogeneous.	U 35 samples	$C_u = 35$ $\phi_u = 11.3$ $C' = 35$ $\phi' = 13$
CU ×3 Multi-stage	100/7 BH57 2.25m		**KANNAVIOU CLAY** - Stiff dk. olive grey highly fissured, friable. - Considerable sampling disturbance. - Some melange clasts. - Probably slipped material.	No Vol. change data recorded	$C_u = 10$ $\phi_u = 14$ $C' = 18$ $\phi' = 19$
CU ×3 Multi-stage	100/8 BH78 2.25m		**KANNAVIOU CLAY** - Stiff dk. grey, highly fissured, 'flakey' friable clay/mudstone with some chalk debris. - Reddish & black staining on fissures. - Slip debris material.		$C_u = 40$ $\phi_u = 16$ $C' = 50$ $\phi' = 21$

Table 7.3 Table of Triaxial sample data.

friction angle (ϕ_r') (Skempton, 1985) , but differs from most values obtained from the ring-shear test (see Appendix II) for the following reasons:

a) the moisture content on the shear plane is lower in the case of the triaxial test, b) the shear displacement experienced in the triaxial test is smaller (15mm compared with 1m for the ring shear test), and c) membrane restraint is operating in the triaxial test.

A comparison of the ring shear and triaxial data for Kannaviou sample No. BH80 shows that, whilst values of c' and c_r'are similar, the value of ϕ'is almost double that of ϕ_r'. A similar result is seen for sample No. BH109. Both of these samples were taken from within large slip masses. Of all the Kannaviou triaxial samples, only sample No. BH47 can be positively said to be unaffected by recent slope movements. It is unfortunate that it was not possible to obtain deep intact core of unslipped Kannaviou clay due to limitations in the drilling techniques available.

In the case of fissured or sheared clays, specimen size influences the shear strength results, and it is recommended that a representative test sample should be of a diameter not less than 20 times the minimum spacing between fissures (McKinley et al, 1975). This recommendation is difficult to implement in the case of some Kannaviou samples which feature lenticular or scaly shear-derived peds. Here, shear planes form what might be described as a 'braided' or 'scaly' structure (see also Rep. No. EGARP KW/86/2). In practical terms 100mm diameter was the largest triaxial sample size which could be accommodated. Problems exist in the interpretation of triaxial tests on fissured and partially-saturated materials, the use of multi-stage tests (i.e. one specimen is consolidated and loaded more than once), and the use of combined top and side drains in undrained tests (see 7.4.3.1). Atkinson et al (1985) describe how triaxial consolidation with side drains may result in unequal moisture content and hence stress distribution within the sample. Anderson (1974) recommends the use of multi-stage tests for highly variable materials, but only for samples which do not reach a peak value of compressive stress. Test values for undrained friction angle, ϕ_u, greater than zero are largely a result of fissuring and partial saturation. Strictly speaking values for c_u and q_u should only be quoted for specific ranges of normal stress. In general, values of cohesion and friction angle obtained from the triaxial test, whether total or effective, are unreliable at very low values of normal stress.

Small scale hand-held vane tests carried out in trial pits (see Appendix IB) give a mean equivalent undrained shear strength of 116 kPa (n = 16); thus placing those Kannaviou clays tested in the 'stiff' clay category (CP 2004).

7.4.4.2. Ring shear tests

Fourteen ring shear tests were carried out on Kannaviou clay samples, one on sandstone and three on natural mixtures of Kannaviou clay and Melange. The test involves the preparation of a reworked paste of clay mixed thoroughly at a moisture content close to the liquid limit (the test is usually carried out at the same time as the liquid limit test). The paste is worked into an annular mould, the top part of which is then subject to a normal load followed by a torsional load. The resistance of the soil paste to this torsional load is measured for different values of normal load. The essence of the test is that torsional strain is unlimited. In practice, the strains during a test may reach 1 metre. It is this factor which enables the residual, or minimum, shear strength to be determined (unlike test conditions in the triaxial test where shear displacement is restricted by the geometry of the sample and the restraining effect of the rubber membrane).

The apparatus used was the Bromhead ring shear device (Bromhead, 1979). Effective normal stresses (σ_n') of between 75 & 500 kPa were used. Results of the tests are given in Appendix II in the form of effective residual cohesion, c_r' and effective residual friction angle, ϕ_r'. These values are derived from the best-fit line on the shear stress v normal stress (σ_n') plot, and are unreliable at low values of σ_n'.The intercept of the best-fit line with the shear stress axis defines c_r', but the 'true' value of c_r' may be lower (or even zero). Figure 7.14 is a plot of ϕ_r' v normal stress(σ_n'). The key feature of this plot is the rapid drop in residual friction angle(ϕ_r') with increasing normal stress, which is most pronounced at low effective stresses; i.e. at σ_n'<100kPa (this behaviour is in contrast to that exhibited by the marls and silts where the drop in ϕ_r' with increasing σ_n' is much less marked). Above normal stresses of about 150kPa values of ϕ_r' remain virtually constant, or show a very gradual decrease with increasing normal stress.

Clearly, the Kannaviou Formation exhibits a wide range of residual strengths which are largely dependent on the montmorillonite content and the proportion of granular material in the test specimen. As would be expected, fissured/sheared bentonitic clays give the lowest, and siltstones/sandstones the highest values. Two examples of sheared shaly mudstone, BH155 (58m depth) and BH164 (56m depth), however, gave higher residual strengths than the weak sheared clays. A plot of plasticity index (PI) v ϕ_r' is shown in Fig 7.15a; comparison is made with artificial bentonite/sand mixes (Lupini et al,1981), with natural clays of medium Activity (Vaughan et al, 1978), and with a worldwide selection of natural cohesive soils (Voight,1973). The main feature to be expected from this plot is a marked fall in ϕ_r' above a plasticity index of approximately 27%. In fact the minimum value of PI for the Kannaviou clays tested is 47%. Nevertheless, the trend is, as expected, for those samples with a high proportion of 'platy' clay minerals to have a significantly lower value of ϕ_r' than those samples with a high proportion of rounded or angular particles, such as the siltstones or sandstones. Lupini (1981) explains this difference of behaviour in terms of 'sliding shear' and 'turbulent shear'. Vaughan et al (1976) indicate that samples of aggregated clays may exhibit both characteristics if disaggregation and subsequent orientation of clay minerals takes place along the shear plane. A plot of residual friction angle v %clay is given in Fig. 7.15b ; where comparison is made with sheared/fissured clay-shales from Pakistan (Binnie et al, 1967)

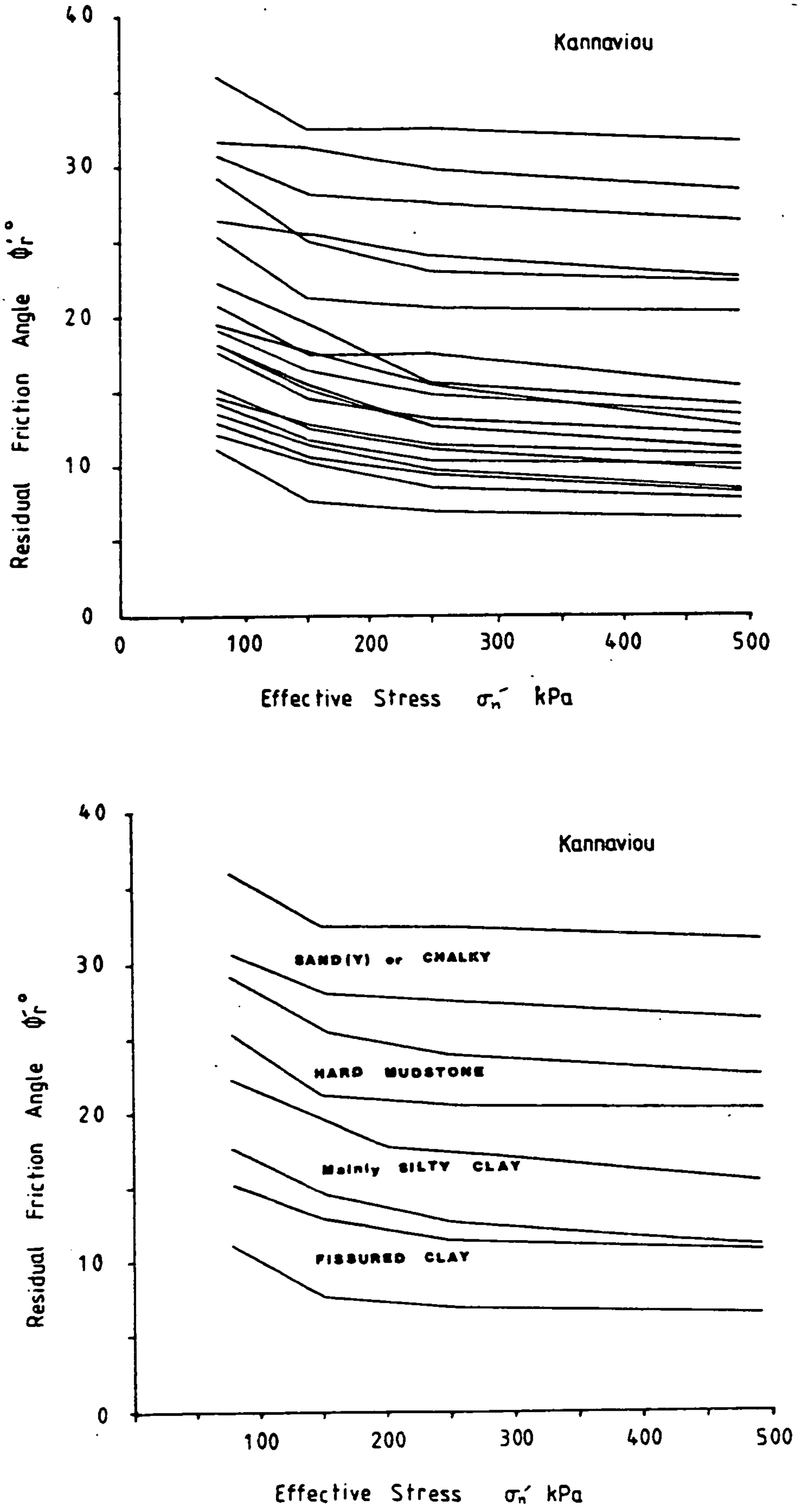
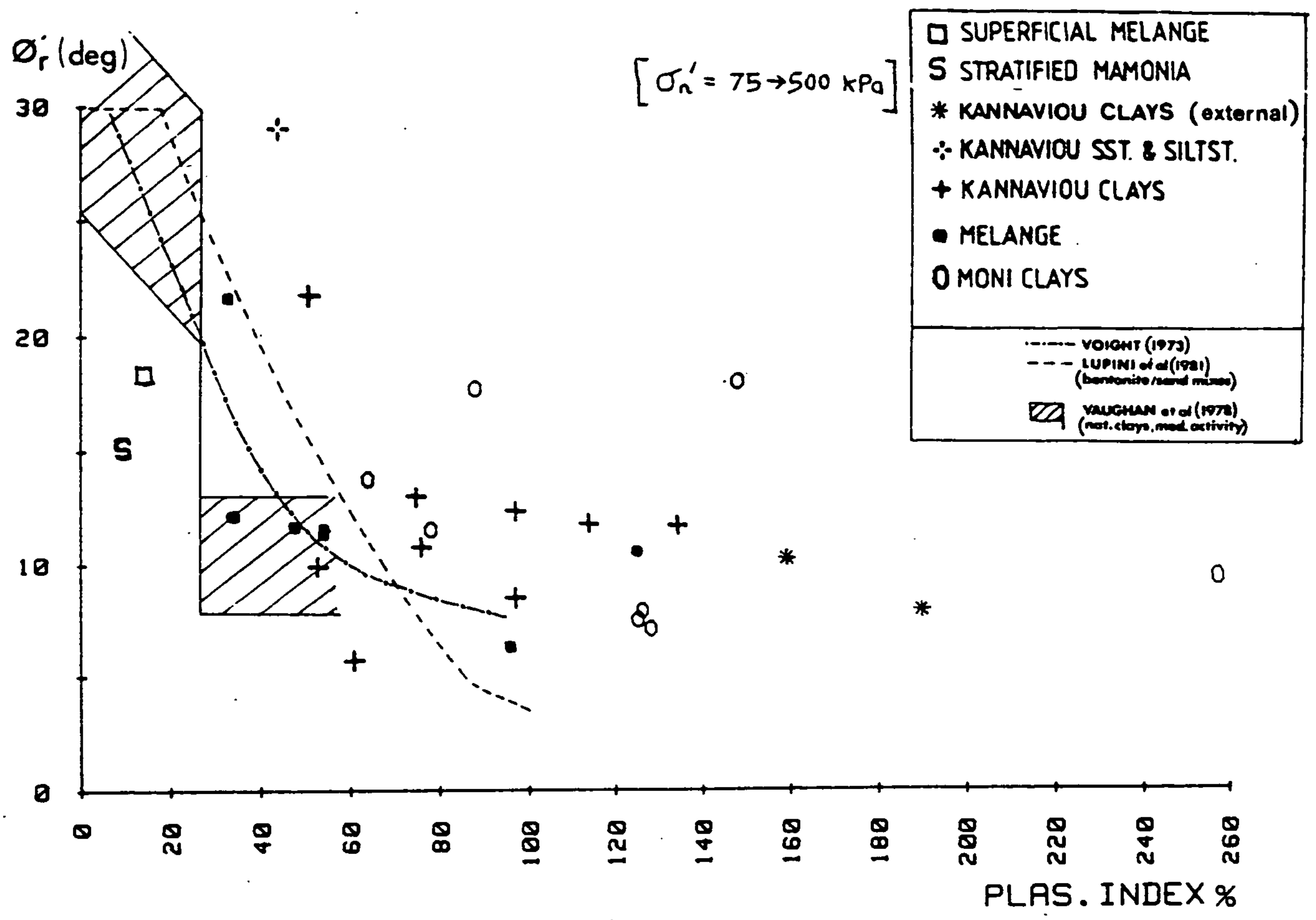


Fig. 7.14 Effective normal stress v Effective residual friction angle - Kannaviou



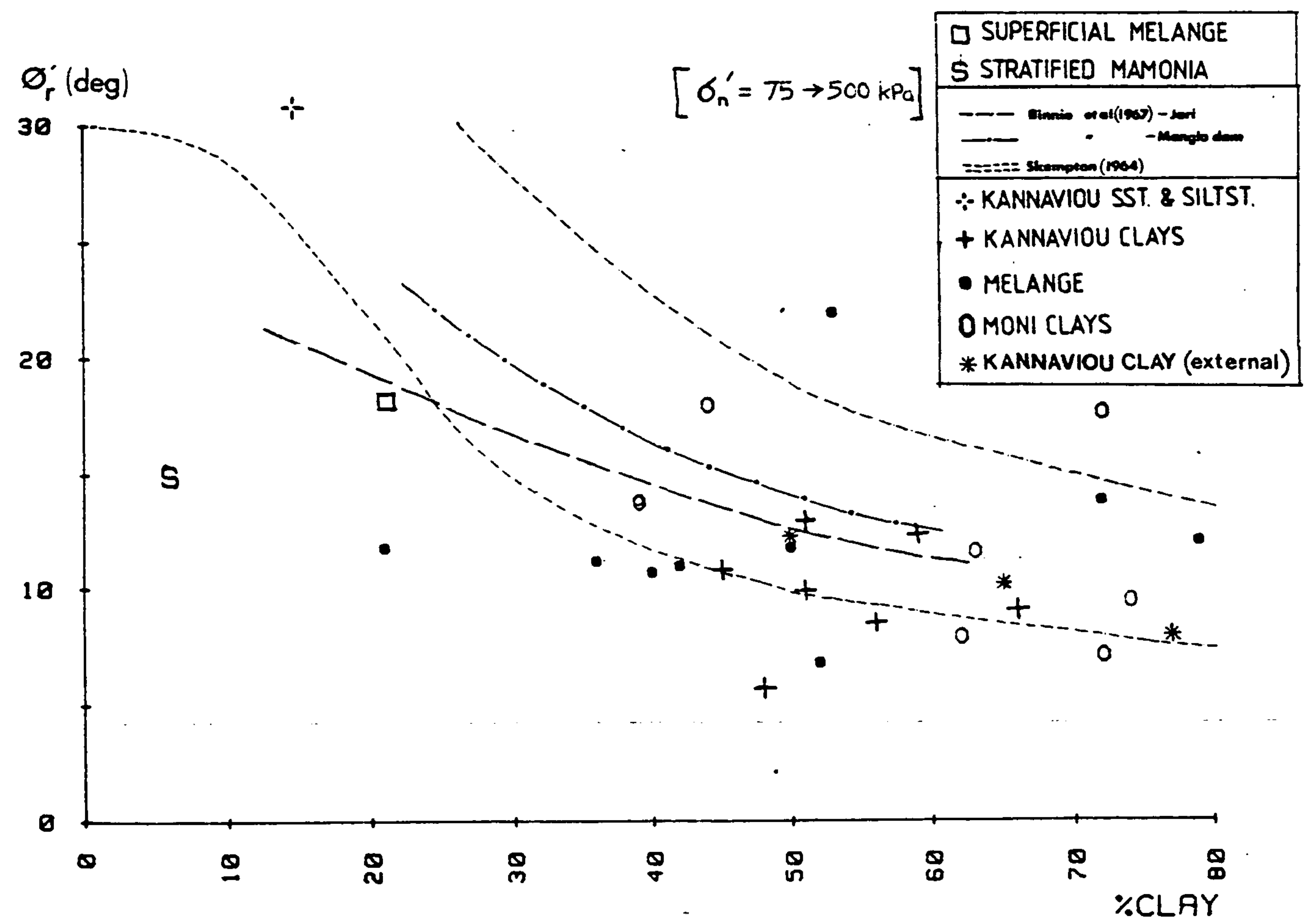


Fig. 7.15 (a) Residual friction angle v Plasticity index - Kannaviou, Melange & Moni clays
(b) Residual friction angle v %clay — Kannaviou, Melange & Moni clays

and with London clay (Skempton,1964). Test data plot mainly within the lower part of Skempton's (1964) envelope.

7.4.4.3. S.P.T.

A total of 40 Standard Penetration Tests (S.P.T.) were carried out in the augered boreholes (see Appendix IA). S.P.T. results for the Kannaviou Formation are seen in boreholes A1, A4, A6, A7, A8 and A10. Results of the S.P.T.'s test are given as 'N' values, i.e. the number of blows required to penetrate 1 ft (305mm) using a standard Raymond sampler. No corrections for overburden or water table have been made. The range of 'N' values for the Kannaviou formation is from 23 to 115 with some tests (particularly in B.H. A10) resulting in refusal. Clearly, the disturbed near surface argillaceous material tends to give lower 'N' values, whilst the deeper material undisturbed by superficial processes gives the higher 'N' values. Most instances of refusal were in sandstones and siltstones (borehole A10 in particular). It is notable however, that an inverse correlation between 'N' value and plasticity of clays and mudstones, is not borne out by the results. For example, clays with liquid limit greater than 120% give 'N' values in excess of 80. 'N' values are taken to be directly proportional to undrained shear strength for saturated insensitive clays (de Mello, 1971) and a relationship between mass shear strength and 'N' value is given by Stroud (1974), as:

$$c = f_1 \times N$$

where f_1 is a constant independent of depth and discontinuity spacing.

Stroud (1974) gives a value for f_1 of between 4 and 4.5 kPa for a variety of British clays, whereas Sowers (1954) gives values as low as 2.4 kPa for "clays with failure planes". In the case of sensitive clays, however, a drastic decrease in 'N' value is suggested (de Mello, 1971). This does not appear to be the case for the Kannaviou clays tested. The reason for this is probably due to the partial saturation of the Kannaviou clays tested.

The ability of the SPT test results to predict the compressibility of clays is unclear. Fletcher (1965) maintains that "the most important limitation of the SPT in cohesive soils is that it does not reflect preconsolidation". De Mello (1971), and Stroud (1974), however, contradict this in the light of experience in Brazil and England. Experience in the use of the SPT in stiff/hard fissured clays is very limited. Stroud (1974) reports that, in the case of London Clay, SPT results agreed well with 100mm diameter triaxial test results in the uppermost 15 to 20 metres where the clay is weathered and discontinuity spacing is small. The SPT and triaxial results for the Kannaviou are not in agreement, probably as a result of the much more severe fissuring and additional shearing present within the Kannaviou when compared with the London Clay.

7.4.4.4 Overconsolidation

Overconsolidation is suggested by the triaxial stress-paths, the liquidity indices, and the single high-pressure oedometer test data; the latter suggesting an OCR of at least 9 for sample BH124, a very stiff fissured silty clay from a depth of 8m (see Section 7.4.3.1). In contrast, the triaxial test stress-paths for samples BH121 and BH47, both from 5m depth and lithologically similar to sample BH124, suggest OCR's of between 2 and 3. The degree of overconsolidation is difficult to determine given that no high quality samples of unslipped, undisturbed Kannaviou clay were obtained.

7.4.5. Geophysical Properties

An electrical resistivity survey was carried out at two locations in Area 1 (Kramvis,1984) by the geophysics department of G.S.D. The purpose of the survey was to study the continuity of two thick sandstone bands beneath the Kannaviou clays near Kannaviou and Phiti, as an aid in the assessment of possible slope movement. The survey consisted of eleven resistivity soundings (see Chapters 5 and 8). Two of these soundings were made on outcrops of the Kannaviou sandstone to determine their 'true' resistivity and thus characterize the various electrical layers identified beyond the outcrop.

A fairly large contrast was found between the Kannaviou sandstones and clays, although the resistivity of the sandstones was found to be very low when compared with other sandstones (no doubt due to the high clay content of the Kannaviou sandstones). The resistivities of the sandstone and clay were found to be 17 ohm m and 2 to 10 ohm m respectively. The lowest values for the clay were found at depth, presumably due to the higher moisture content. Resistivities in excess of 10 ohm m were found in the dry surface clays. (Although not specifically investigated, the resistivity of the near surface Melange at one location was found to range from 12 to 37 ohm m . Kramvis (1984), in comparing the Kannaviou sandstone with other sandstones, states that: "the Kannaviou sandstone .....has very low resistivities most probably as a result of the inclusion of a large proportion of bentonitic clay".

7.5. Test Results - Melange

7.5.1. Index Tests

7.5.1.1. Moisture content/density

Twenty-five moisture content and 18 density determinations were made on the Melange matrix. Moisture content ranged from 16% to 39% (mean = 22.7, S.D. = 5.9); i.e. lower than the Kannaviou clays. The reason for this is partly mineralogical but is also a function of the markedly higher dry density of the Melange, 1.47 to 1.82 Mg/m^3 (mean = 1.66, S.D. = 0.11), due to the incorporated exotic sand- and gravel-sized clasts. The density of the exotic clasts varies between approximately 2.5 and 3.0 Mg/m^3. Although no density determinations were made on the 'grey' Melange it seems likely that its density is slightly less than that of the 'red' Melange due to the fact that the former contains fewer clasts of igneous origin. Also, it appears that Melange which has suffered shallow, post- depositional landslipping has a lower density than its un-slipped counterpart due to preferential mobilization of fines within flow-type slips. A clear relationship between moisture content and depth has not been shown for the Melange samples tested.

Figure 7.1 shows the relationship between dry density, γ_d, and moisture content. It is noted that the Melange results are clustered in comparison to the wider spread of γ_d values obtained for the Kannaviou samples.

7.5.1.2. Plasticity

Sixty-two liquid and plastic limit tests were carried out on Melange samples. Liquid limits (LL) range from 34% to 200% (mean = 73.3, S.D. = 31.2) and plastic limits (PL) from 14% to 47% (mean = 23.6, S.D. = 7.6). The histogram of liquid limit (Fig.7.19) shows that the higher values of liquid limit (>110) are due to natural mixtures of Melange and Kannaviou clays. These are found either close to the surface within landslip deposits or close to the contact between the Melange olistostrome and the underlying Kannaviou bedrock (e.g. BH EG 10/84 at Phiti). The relationship between liquid limit and plasticity index, PI (defined as PI = LL-PL) is shown in the Casagrande graph (Fig 7.18), which shows that the Melange samples cluster in the 'intermediate' to 'very high' plasticity groups (B.S.C.S. classification). The borehole logs for deep boreholes EG 10/84 and EG 13/84 (see Appendix IA), record the values of clay content, montmorillonite content, and plasticity. It is notable that a higher overall clay fraction and hence plasticity was obtained in borehole EG 10/84 compared with borehole EG 13/84. As shown on the augered borehole logs (Appendix IA), moisture contents for the Melange samples generally plot at values lower than the plastic limit, indicating mean liquidity indices slightly below zero. Although there is no discernible trend with depth, the results are indicative of a state of overconsolidation; but to what extent the Melange is overconsolidated is difficult to say from the current test data.

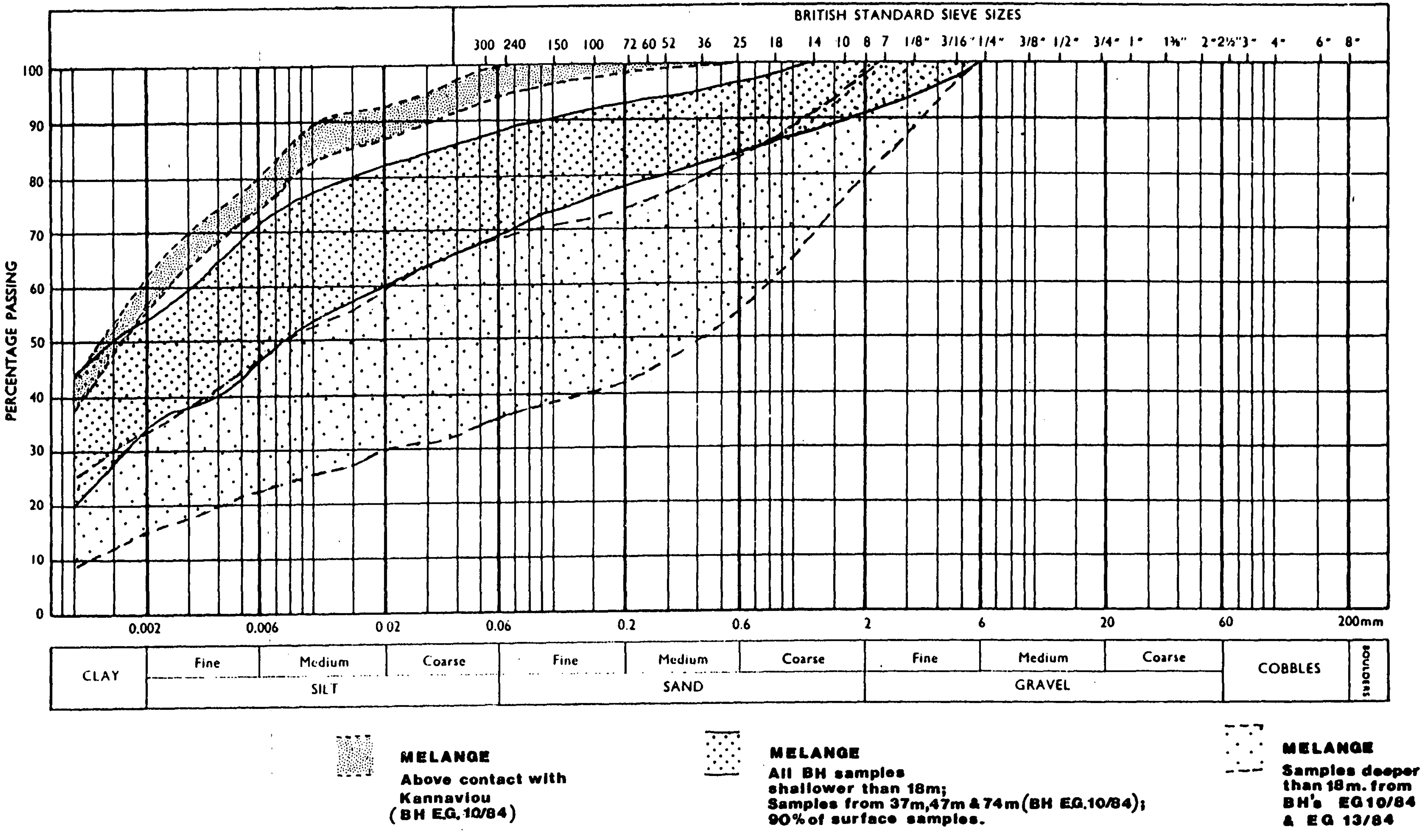
7.5.1.3. Particle size analysis

Determination of the mass particle size distribution of the Melange poses considerable problems (see Photos 7.6, 7.7 & 6.8). Grading curves have been produced for the matrix (see Fig.7.16). The Melange, in common with stoney boulder clay (Lewis & Rowlands, 1985), contains cobbles, boulders and blocks of widely varying size, shape and specific gravity. It is reported (Swarbrick & Robertson, 1979) that in the Akamas peninsula, blocks exist in the Melange which are up to 1km in length. These may be of similar origin to submarine 'glide blocks' discussed by Ineson (1985). Statistical methods of estimating boulder size from borehole core (for example, Tang & Quek, 1986) assume that all boulders are spherical. However, in the case of the Melange more readily observed evidence of boulder size is found in the many exposed faces undergoing very active erosion (e.g. Photo 6.8). Here, the matrix is eroded more rapidly than the boulders and the latter are exposed in partial relief so that an impression of their overall size and shape may be gained. Using a series of calibrated photographs of such exposed faces, a numerical estimate of boulder size can be made. On the basis of the four exposures represented in Fig. 7.17, an estimate of the cross-sectional areas as a percentage of the total exposure area has been made for four ranges of clast size. The results are:

For	max.	dimension	> 0.3	metres,	c.s.	area	= 0 to 5.2 %
"	"	"	0.2-0.3	"		"	= 0 to 3.4 %
"	"	"	0.1-0.2	"		"	= 1.6 to 12.9%
"	"	"	0.05-0.1	"		"	= 2.1 to 10.4%

Thus, if we take 0.05 metres as the boundary between 'gravel' grade, and 'cobble' grade, we find that the most clast -dominant of the 4 exposures in Fig.7.17 is composed of 25 to 30% (approx) of particles of 'cobble' size and larger, whilst the most matrix-dominant is composed of 5 to 10% (approx.) of particles of 'cobble' size and larger. If 'gravel'size and smaller is taken to be the 'matrix', we obtain, from the exposures in

Fig. 7.16   Particle-size distribution envelopes - Melange



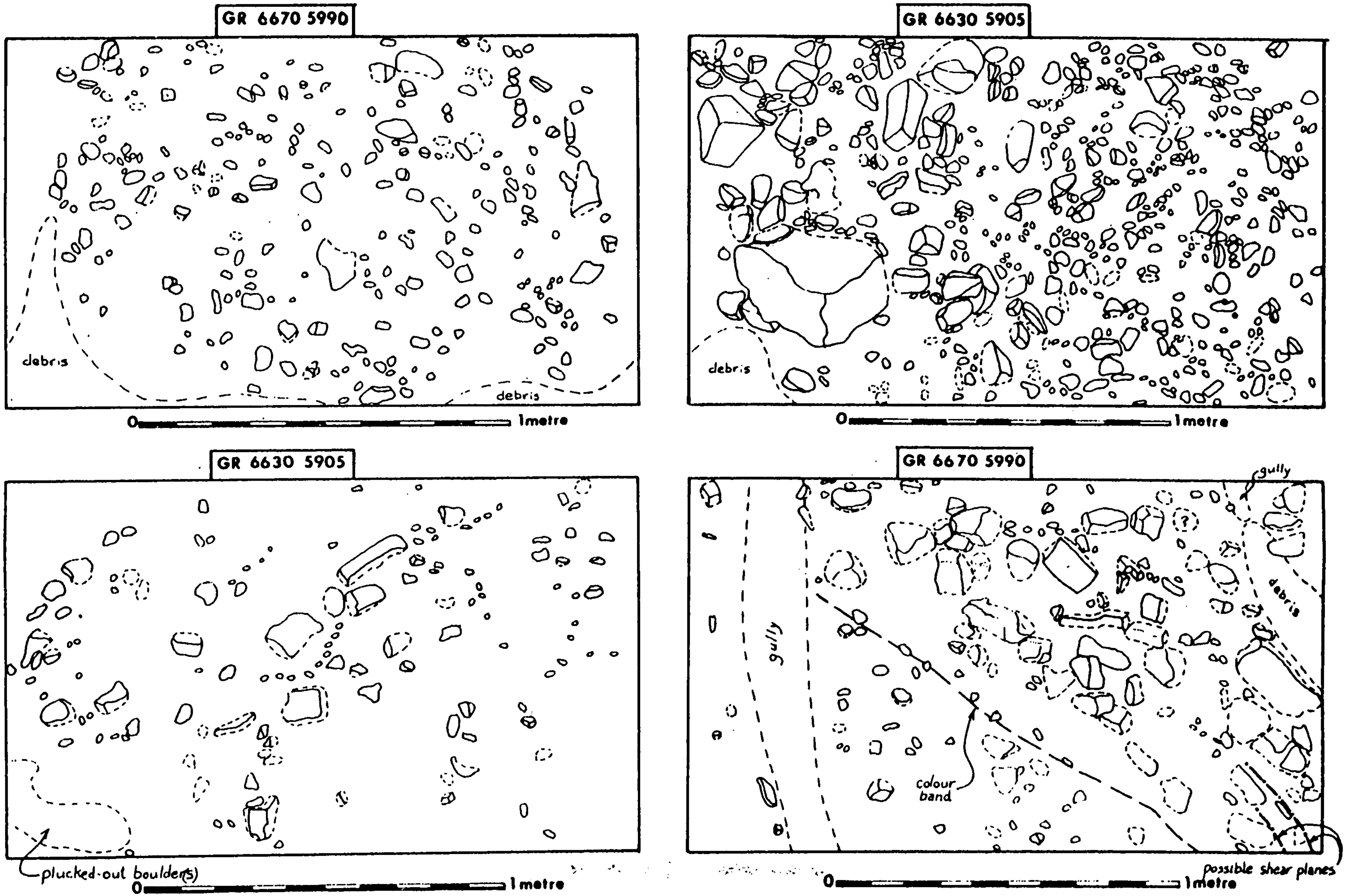


Fig. 7.17 Examples of exotic clast distribution within the Melange

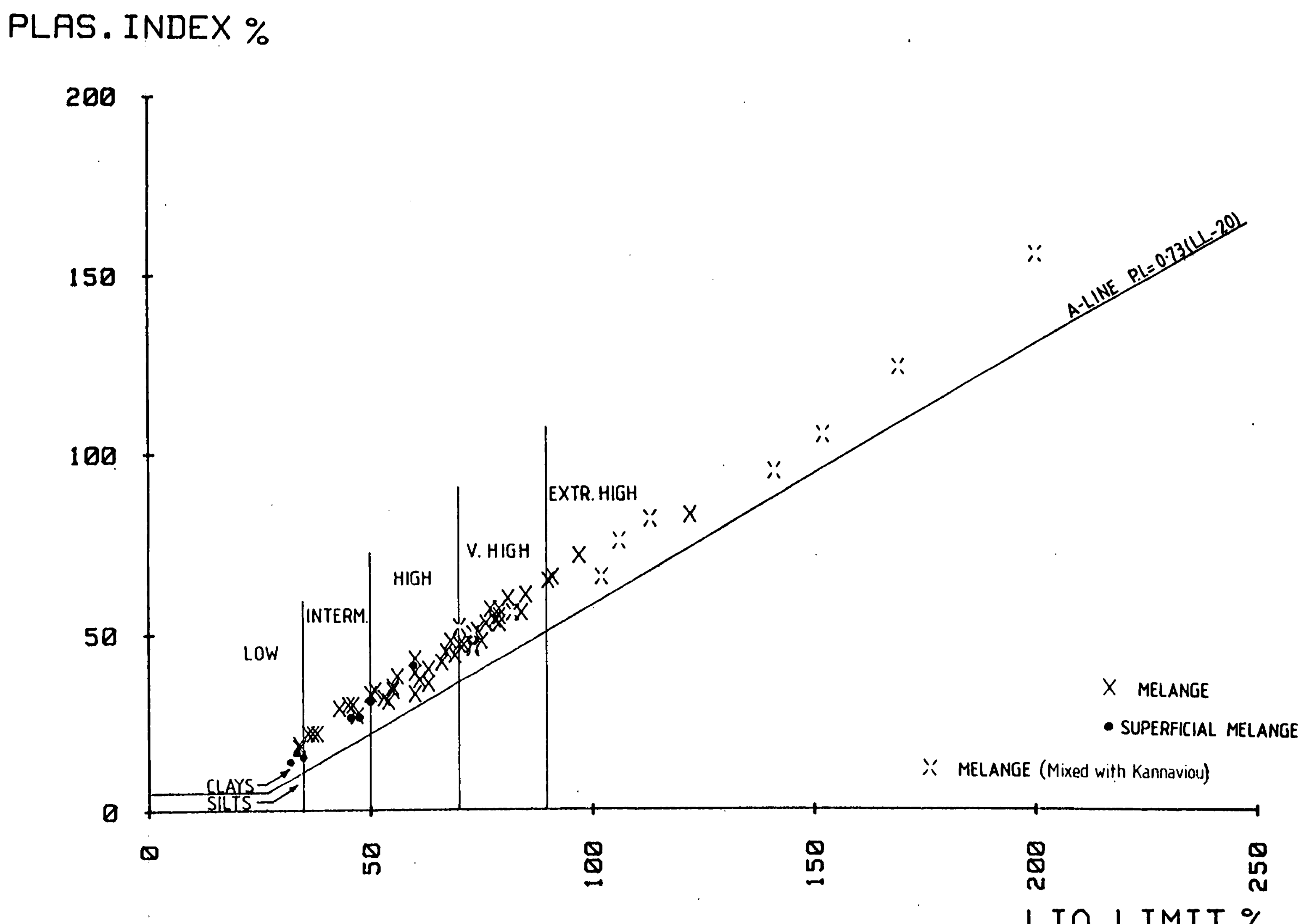
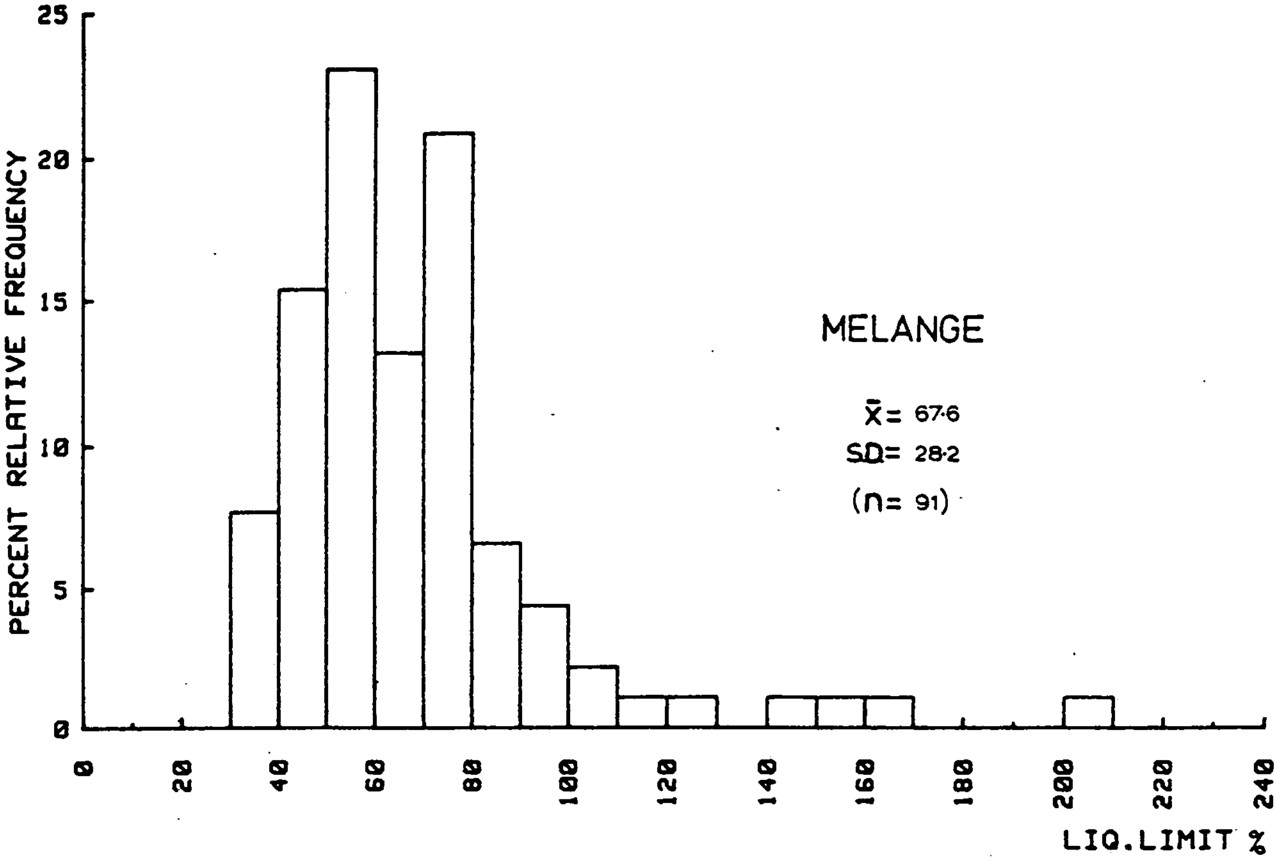


Fig. 7.18 Casagrande plot:- Liquid Limit v Plasticity index - Melange, superficial Melange



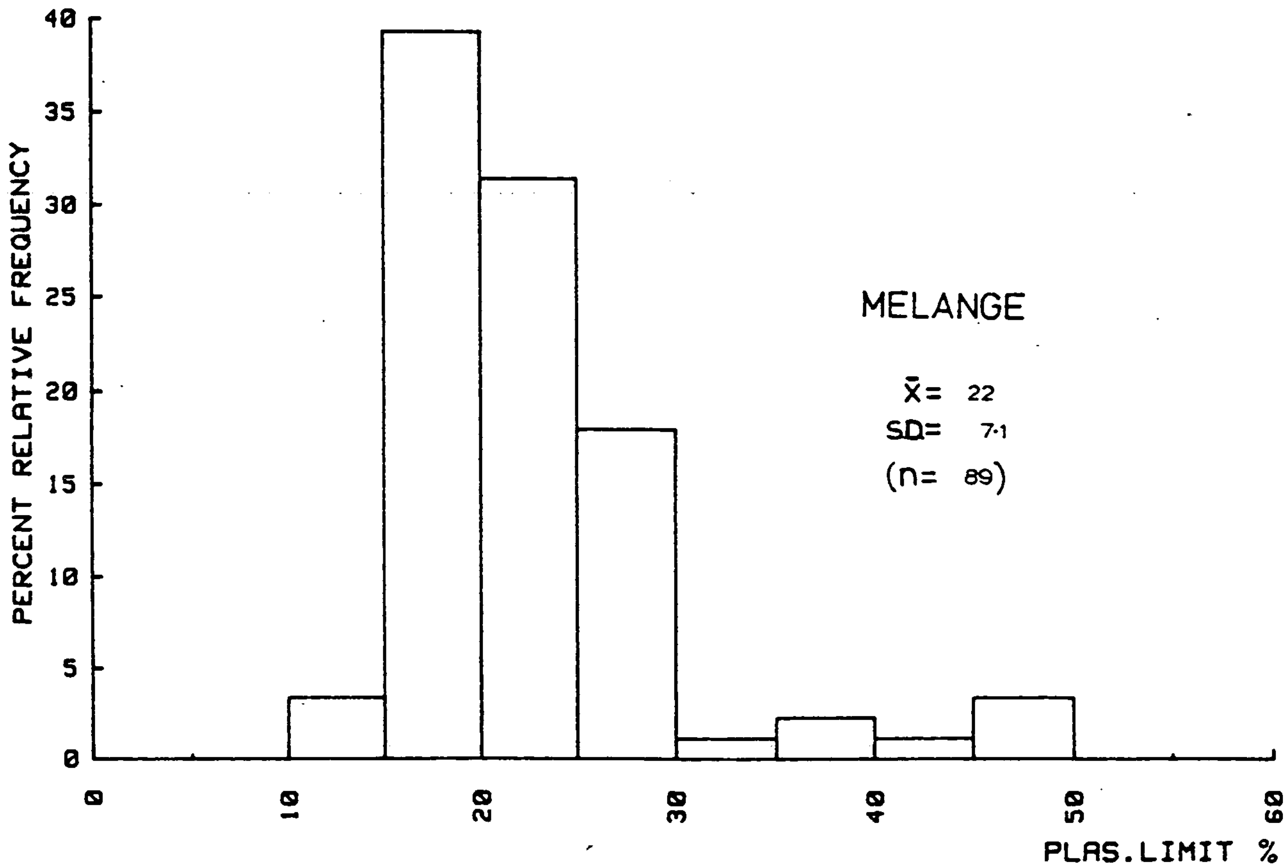


Fig. 7.19 Histograms of Liquid limit and Plastic limit - Melange

Fig.7.17, a matrix content for the Melange of between 70% and 95% by volume. From field observation it would appear to be the case that very large boulders and blocks constitute only a small proportion of the Melange mass whereas cobbles and small to medium size boulders constitute a more significant proportion. The typical Melange may thus be described as matrix-dominant. The matrix-dominance is often exaggerated in shallow landslips of the flow type.

Particle size envelopes for the matrix component of the Melange are given in Fig.7.16. This plot reveals that, in general, the Melange becomes coarser with depth and that, barring drilling mud contamination, a particle size decrease occurs at the Melange-Kannaviou contact. Small peaks of clay content are seen in B.H. EG 10/84 at 37m, 47m and 74m. These may indicate the presence of three distinct Melange olistostromes having downward-coarsening particle size profiles (see Swarbrick & Naylor, 1980). In addition, boulder-rich beds are indicated at approximately 90, 110 and 125 metres below surface (B.H. EG 10/84). Such peaks are not seen in the log of BH EG 13/84 (except perhaps at 52 metres); the Melange here (60 metres thick) may represent a single olistostrome sheet.

On the basis of the particle size envelopes (Fig.7.16) the Melange matrix can be said to range from a silty clay through a sandy, silty clay to a clayey sandy silt. Difficulty exists in accurately measuring the gravel size fraction because much of this fraction is made up of red Mamonia shales which may break down during the sieving process. An XYZ graph of %sand/%silt/%clay for Melange and stratified Mamonia is given in Fig.7.21a; the close grouping of the Melange data points is clearly seen in this diagram.

Activity values, Ac, (defined as PI / %clay) determined on Melange samples is shown in Fig.7.20. Samples are grouped within the range 0.6 to 2.2, i.e. 'normal' to 'active'. The relationship between montmorillonite content and clay fraction is shown in Fig.7.8 . The Melange data show a Mont./clay ratio of between 40% and 80%; scatter of data is, as elsewhere, less

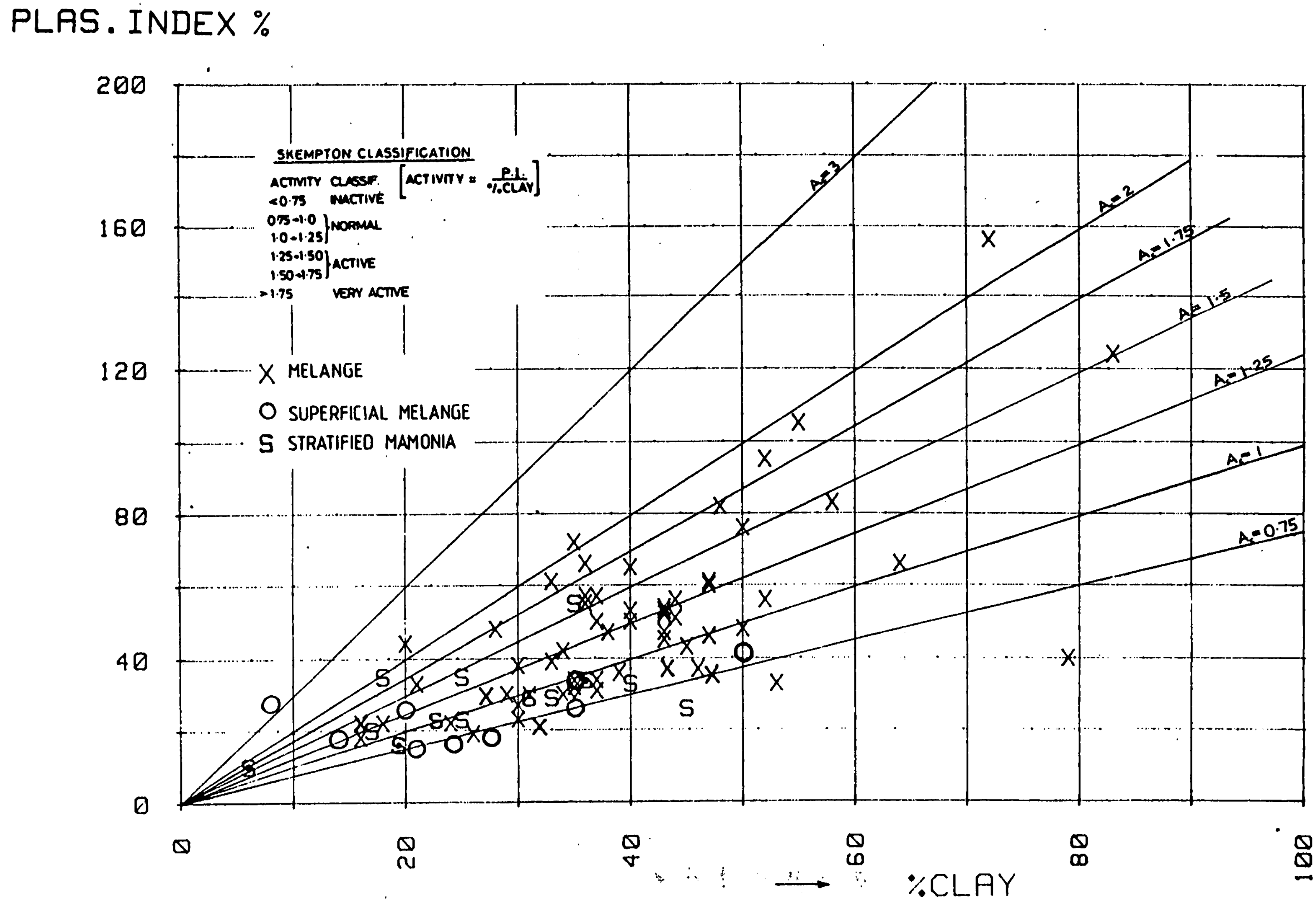
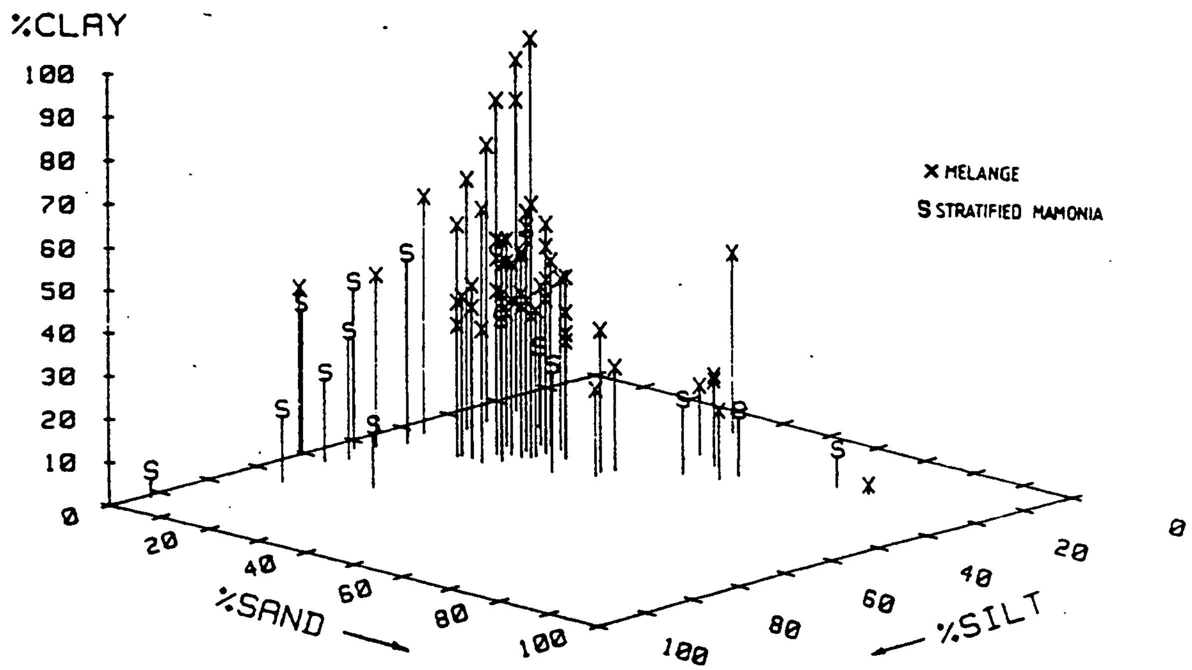


Fig. 7.20 Plasticity index v %clay ———— Melange, stratified Mamonia & superficial Melange



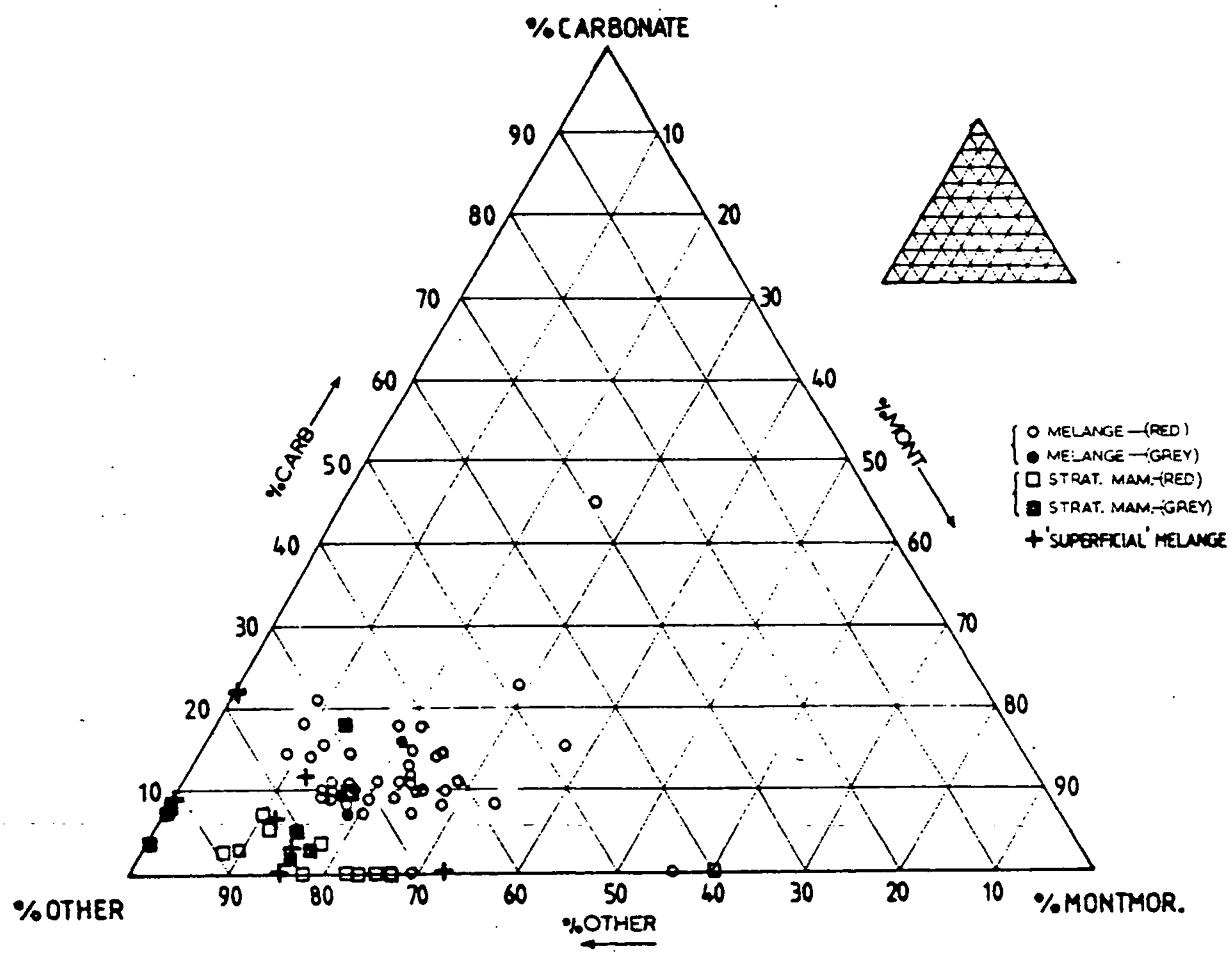


Fig. 7.21 (a) XYZ plot - %Sand/%Silt/%Clay - Melange, stratified Mamonia

(b) Triangular plot - %Carbonate/%Montmorillonite/%Other - Melange, stratified Mamonia & superficial melange marked than is the case for the Kannaviou data.

Boulder and cobble shape differs from the 'red' Melange to the 'grey' Melange. The latter tends to comprise more angular and elongated boulders (sandstones, quartzites) whilst the former has a predominance of rounded boulders (igneous). Sand size particles in both Melange types tend to be angular consisting mainly of broken-down red shales. In general a random orientation of clasts is seen, (see Fig.7.17). However, not infrequently, ill-defined banding resulting from either a preferred orientation of boulders (see photo 7.6) or colour changes in the matrix (see photo 7.7) may be seen. It is also possible to discern, in one of the exposures represented in Fig.7.17, a convolute or spiral 'bedding' structure, probably resulting from turbulence during deposition of the olistostrome. The features described above usually bear no obvious relationship to the present topography and are probably associated with syndepositional substructures within the original olistostrome.

7.5.2. Mineralogy

7.5.2.1. General

The mineralogical analyses of 48 Melange samples are listed in Appendix IIB. Examples of XRD traces are given in Fig. 7.24, and a triangular plot of %carbonate: %montmorillonite: %other is given in Fig.7.21b. All samples contained calcium montmorillonite (sometimes known as 'fuller's earth', or, more loosely, 'bentonite'), quartz and calcite (calcium carbonate). Other minerals were detected in the following percentage of samples:-

mica (in 85% of samples tested), chlorite (80%), feldspar (25%), gypsum (15%), dolomite (15%) and kaolinite (5%).

Samples of 'grey' Melange from Pit 7 show no appreciable difference in mineralogy from the 'red' Melange. Swarbrick and

Naylor (1980) report the presence of haematite and geothite in XRD analyses of Melange. These minerals were not positively identified in this study. It does seem likely, however, that the red colour of the Melange is due to iron compounds derived from the red shales of the stratified Mamonia.

Pit sections revealed the presence of totally weathered in-situ rock products within the Melange. Near-spherical homogeneous boulder-size clasts of white, pinkish-white or greenish-white, very fine, powder were occasionally noted in pit sections. It is thought that these may be sepiolite (or possibly talc) and represent the final weathering stage of serpentinite boulders. These were possibly incorporated into the Melange matrix as partially- weathered boulders and suffered further alteration and breakdown following deposition of the olistostrome.

7.5.2.2. Montmorillonite

High calcium-montmorillonite contents were recorded for the Melange close to the contacts with the Kannaviou Formation in boreholes EG 10/84 and EG 13/84. It has not been clearly established whether these had a natural cause or were the result of drilling mud (bentonite) contamination during coring operations. Recent mineralogical tests, however, tend to discount contamination (G. Petrides, pers comm.). In general, Ca-montmorillonite content ranges from 8.7% to 33%; values higher than 33% were recorded for mixtures of Melange with Kannaviou clay found in landslips; and a montmorillonite content of 56% was recorded for a thin layer of greenish clay forming a slip plane within a mass of otherwise 'normal' Melange (Pit 16, sample 2). The mean value of calcium montmorillonite content for 'uncontaminated' Melange matrix was found to be 22% (S.D. = 8.5, n = 48). For all Melange samples tested the montmorillonite content was found to be less than the clay fraction (%) which was not the case for many Kannaviou samples. Good positive correlations (Fig.7.22) exist between montmorillonite content and liquid limit (r = 0.78) and between montmorillonite content and plasticity index (r = 0.79); see

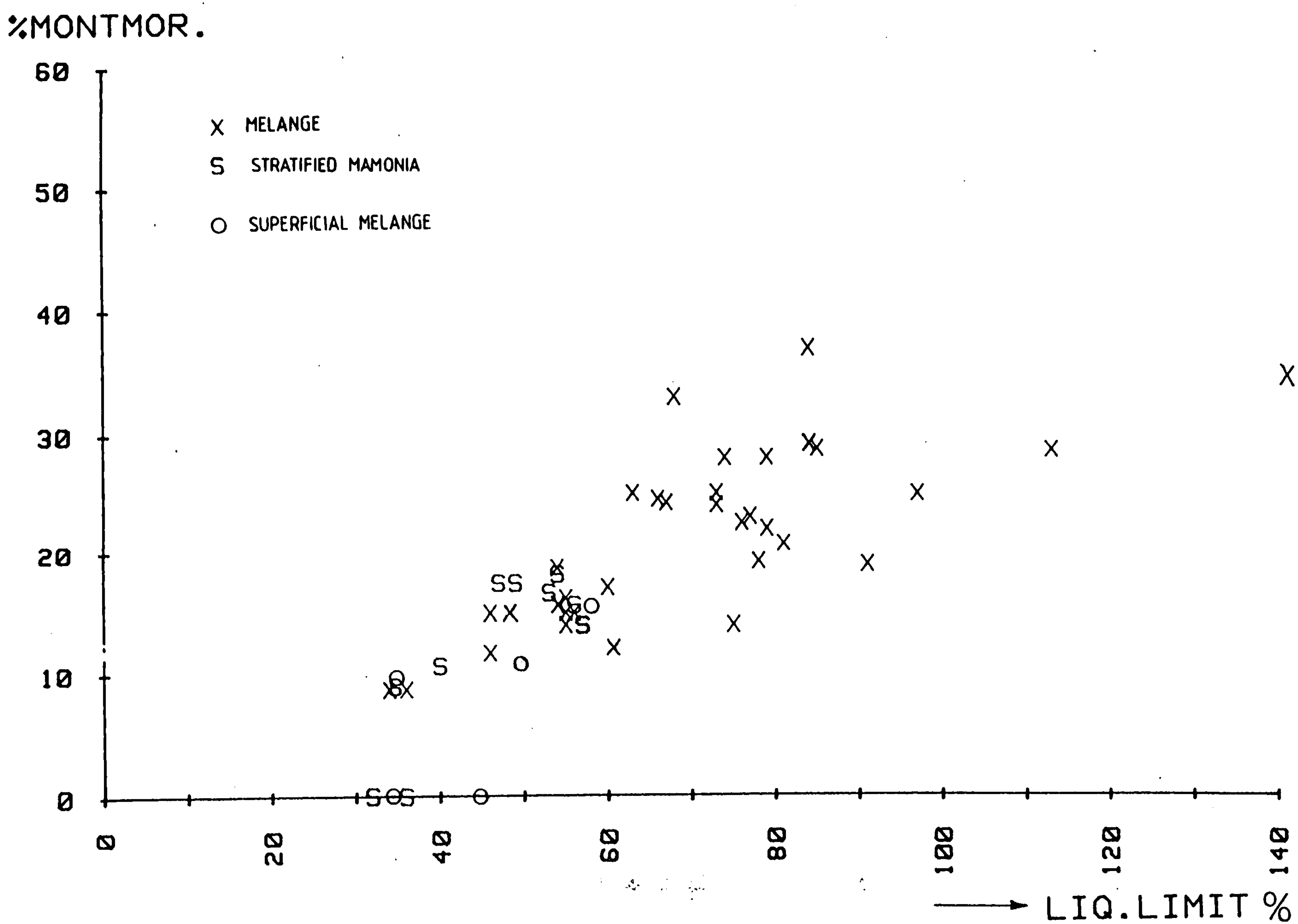


Fig. 7.22 Montmorillonite content v Liquid limit - Melange, stratified Mamonia & 'superficial' melange

Fig.7.23a. The correlation between montmorillonite content and Activity (see Fig.7.23b) is very poor (r = 0.32) and similar to that for the Kannaviou Formation if sandstones and siltstones are ignored. Variation of montmorillonite content with depth is, in general, very slight (see logs for B.H.s 10/84 and 13/84, Appendix IA).

7.5.2.3. Carbonate

Calcium carbonate contents for the Melange were found to range from 0% to 22% (mean = 12%, SD = 6.6). Values of 33% and 46% were, however, recorded for samples BH65 and BH84 respectively, both of which were taken from within recent landslips. Variation of carbonate content with depth (B.H.s 10/84 and 13/84) is only slight. The variation of plastic limit with both montmorillonite and carbonate contents is shown in Fig 7.12a .

7.5.3. <u>Volume Change</u>

7.5.3.1. Consolidation and permeability

As a result of the considerable problems involved in preparing disc-shaped specimens of Melange for the oedometer consolidation test, no such tests were attempted. Two triaxial tests, on samples BH65 and P85/5B, were carried out. Consolidation and permeability parameters derived from the isotropic consolidation stages of these tests are given in Table 7.2. In addition, a series of conventional falling-head permeability tests on one specimen, using a 100x150mm cell (Head, 1981) apparatus with capillary tube were carried out (sample no. P85/2B). Readings were taken over a period of 15 weeks to allow for complete removal of air from the system and for establishment of dynamic equilibrium. Results were calculated using the relationship:

$$k_t = 3.84(aL/At)\log_{10}(h_1/h_2)\times10^{-5} \quad \text{m/sec}$$

where, a = capillary tube diam. (mm)
L = length of sample in cell (mm)
A = area of sample in cell (mm^2)
t = time elapsed to travel from h_1 to h_2 (mins)
$h_1 h_2$ = initial and final height of capillary water column above datum (mm)

Results from 10 tests ranged from $k_T = 8x10^{-11}$ to $3.0x10^{-10}$ with a mean of 2.0×10^{-10} m/sec. This result is approximately an order of magnitude less than the values for k_h obtained indirectly from the consolidation stages of the triaxial tests. Some of the variation in the falling-head test results may be due to fluctuating laboratory temperatures. The mean value for k_T of $2.0x10^{-10}$ m/sec compares with that obtained for some U.K. lodgement tills (McGown, 1985; Lewis & Rowlands, 1985). No information has been found in the literature on the permeability of olistostrome melanges. Analogy with stoney boulder clay does not seem unreasonable in general terms, though compressibility values appear greater for the Melange. With the possible exception of clast-bedded zones (e.g. Fig. 7.17), the mass permeability of the Melange is determined by the matrix. The mass permeability is probably lower than that measured in the falling-head test because of the small size of the test sample relative to mean clast size. It is recommended that determinations of consolidation and permeability parameters for Melange be carried out using Ko-consolidation stages in triaxial tests (Head,1985), and constant flow-rate permeability tests on a triaxial specimen (Olsen,1985). These tests are best carried out on large specimens, e.g. 100mm.

7.5.3.2. Swelling

Six swelling pressure tests were carried out on Melange samples, and an additional one on a (natural) mixture of Melange and Kannaviou clay. The results are given in Appendix IIIc. The apparatus used was that described in Hobbs et al (1982). The test specimens were representative of the Melange matrix in that they contained no large clasts. Maximum swelling pressures range from 56 kPa to 630 kPa (moisture contents of these samples ranged from 17% to 29%, respectively).

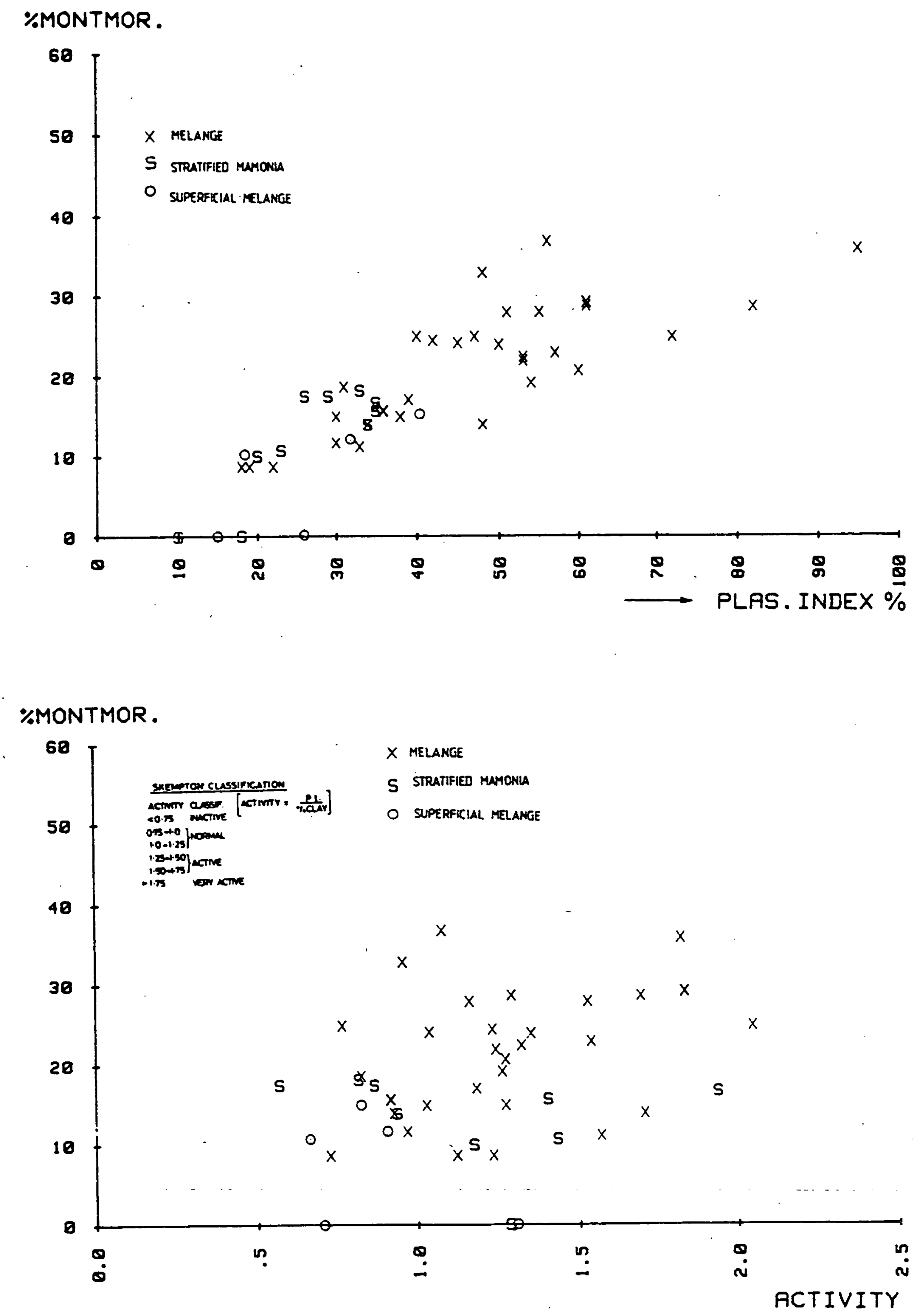


Fig. 7.23 (a) Montmorillonite content v Plasticity index - Melange, stratified Mamonia & 'superficial melange.
(b) Montmorillonite content v Activity - Melange, stratified Mamonia & 'superficial' melange

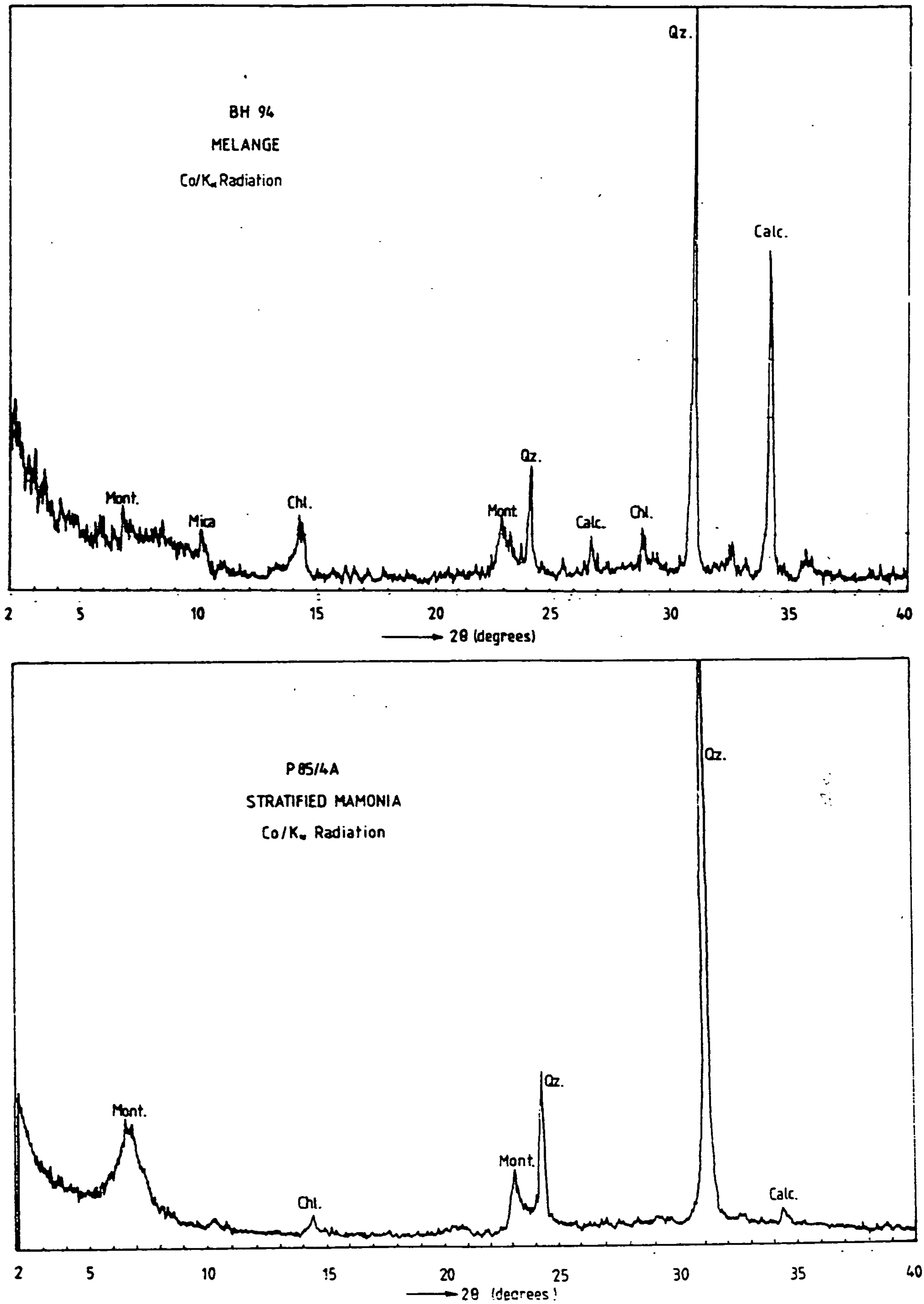


Fig. 7.24 X-ray diffraction traces - Melange & stratified Mamonia

The correlations of maximum swelling pressure with plasticity index and moisture content are poor. It is likely, however, that a positive correlation does exist between maximum swelling pressure and plasticity index, and between maximum swelling pressure and the inverse of moisture content (see also report No. EGARP KW/86/1); although too few samples were tested to investigate these relationships satisfactorily. Swelling of the Melange sample was also noted during the initial stages of the falling-head permeability test (see Section 7.5.3.1.).

7.5.3.3. Shrinkage

The linear shrinkage test (B.S. 1377, 1975; Test No. 5) was performed on three samples of Melange matrix. The results are listed in Appendix IIA and the relationship between linear shrinkage and liquid limit is given in Fig. 7.13 . Values for linear shrinkage range from 13% to 25%. Too few results are available to make a representative assessment, although a good correlation is indicated between linear shrinkage and both montmorillonite content and liquid and plastic limits.

7.5.4. Strength

7.5.4.1. Triaxial tests

Only two tests were successfully carried out on Melange (samples BH65 and P85/5B) and one test on a natural mixture of Melange and Kannaviou clay (sample No. BH 109). Neither sample BH65 nor sample P85/5B could be said to be representative of the typical Melange as the former contained considerable chalk and some sand contamination as a result of landslipping, and the latter was relatively clast-free clay matrix; as such the results are probably of little significance. Severe difficulties were encountered in producing cylindrical specimens of typical 'stoney' Melange for the triaxial test. Many potential test specimens were found to contain large pebbles which could neither be cut to shape nor removed. Ideally, representative triaxial specimens of Melange would have to be of the order of 200mm - 300mm in diameter to overcome preparation problems. Unfortunately, suitable large scale test equipment was not available. Sample P85/5B was probably weaker than average and represents a remoulded softened material. Values of ϕ' and c' are, in fact, comparable with residual strengths obtained for other Melange specimens in the ring shear test. The most suitable test method for measuring the strength of the Melange is probably to use 300mm samples in a 10-ton shear box. The 'portable' rock shear box device may also prove suitable where it is not possible to form a conventionally shaped shearbox sample.

Small-scale hand-held vane tests carried out in trial pits (see Appendix IB) give a mean equivalent undrained shear strength for the Melange matrix of 158 kPa (n = 12); this result places the Melange at the boundary between 'stiff' and 'very stiff' clay (CP2004).

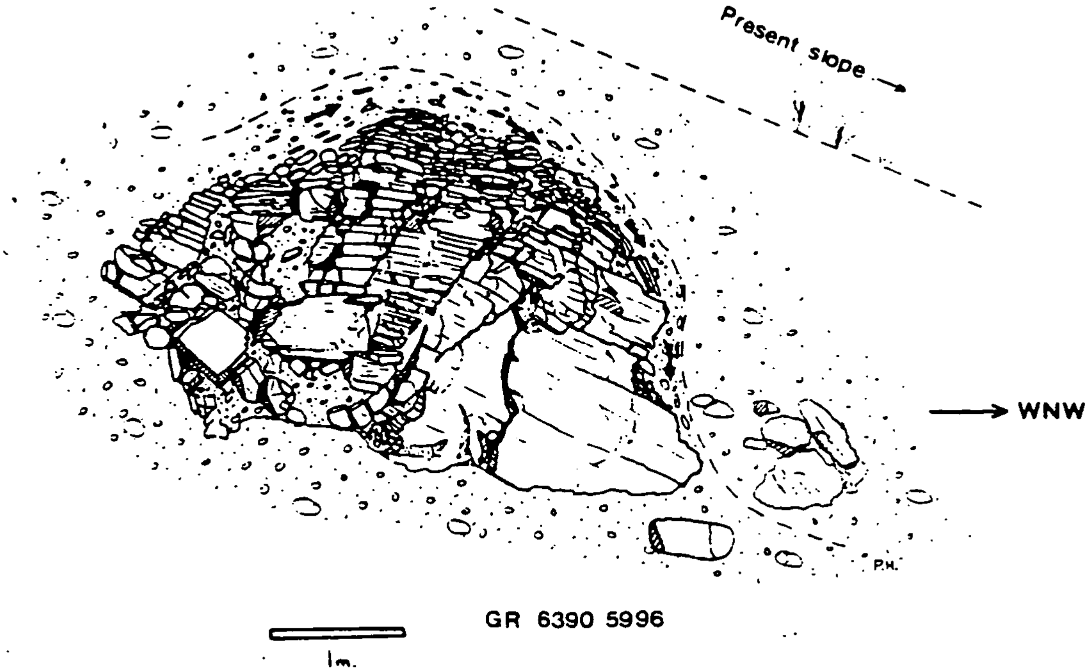
Strength anisotropy is probably very small or non-existent for in-situ Melange (with the possible exception of Melange that has undergone post-depositional landslipping), as little oriented structure has been observed either in the field or in test specimens. With few exceptions, the clasts are more often than not randomly oriented, (see Fig. 7.17). The striking angularity of a large proportion of the gravel to boulder sized sedimentary rock (see Photo 7.6) points to a debris flow (olistostrome) mode of deposition for the Melange, whereby large clasts are supported by a viscous matrix which limits inter-clast abrasion and the consequent rounding familiar in other forms of deposition (Johnson, 1970).

The development of excess syndepositional pore pressures resulting in passive shear failure as reported for the Moni Formation melange in Report No. EGARP KW/86/2 (this series) is not likely to apply to the Melange in the study area. The location of a selected test sample within the olistostrome may, however, affect the shear strength values inasmuch as the edges of the debris flow may exhibit a dominantly shearing or laminar flow action against the country rocks whereas the centre or 'plug' of the flow may be dominated by a turbulent 'mixing' action (Johnson, 1970). This condition may be broadly analogous with the 'residual' and 'remoulded' conditions respectively. No distinct shear surface has been observed at outcrop between the base of the Melange olistostrome and the underlying Kannaviou formation in the study area. Inclined shear surfaces found in Pit 10 (see Appendix IB) may, however, represent the characteristic steep flank of the subsidiary olistostrome lobe probed by borehole EG 13/84.

Swarbrick and Naylor (1980) suggest a maximum 'likely debris strength' for the olistostrome at time of formation as 3.5kPa, and Johnson (1970) suggests 0.1 to 5 kPa for various terrestrial debris flows in California. Clearly, if these figures are correct, the Melange has gained strength approximately tenfold since deposition; this is probably due largely to over-consolidation. The likely key factors discussed in Johnson (op cit.), relating to the emplacement mobility of debris flows are: a) the relative densities of matrix and clasts, as well as the submerged density of the whole; b) dispersive forces which tend to move boulders to a position of minimum shear stress (i.e. inward from the flanks and upward from the base); c)lift generated by movement within a 'viscous fluid' of suitably shaped boulders.

If the above factors are in a state of balance it appears that boulders can remain in suspension without moving to the top or the bottom. The movements are generally 'non-violent' and collisions of boulders are few. Thus, it is possible for relatively incompetent boulders to be transported without breaking-up (Johnson, 1970). Two examples of the initial stages of boulder break up due to shear forces within the olistostrome were however, observed in the Statos Study Area (Area 2). (See Fig 7.25).

Recent terrestrial debris flows of the type described by Johnson (1970) incorporating Melange deposits, have been observed in both study areas (for example at G.R. 6390 6365, Area 2). These exhibit the convex snout and flanks, and the



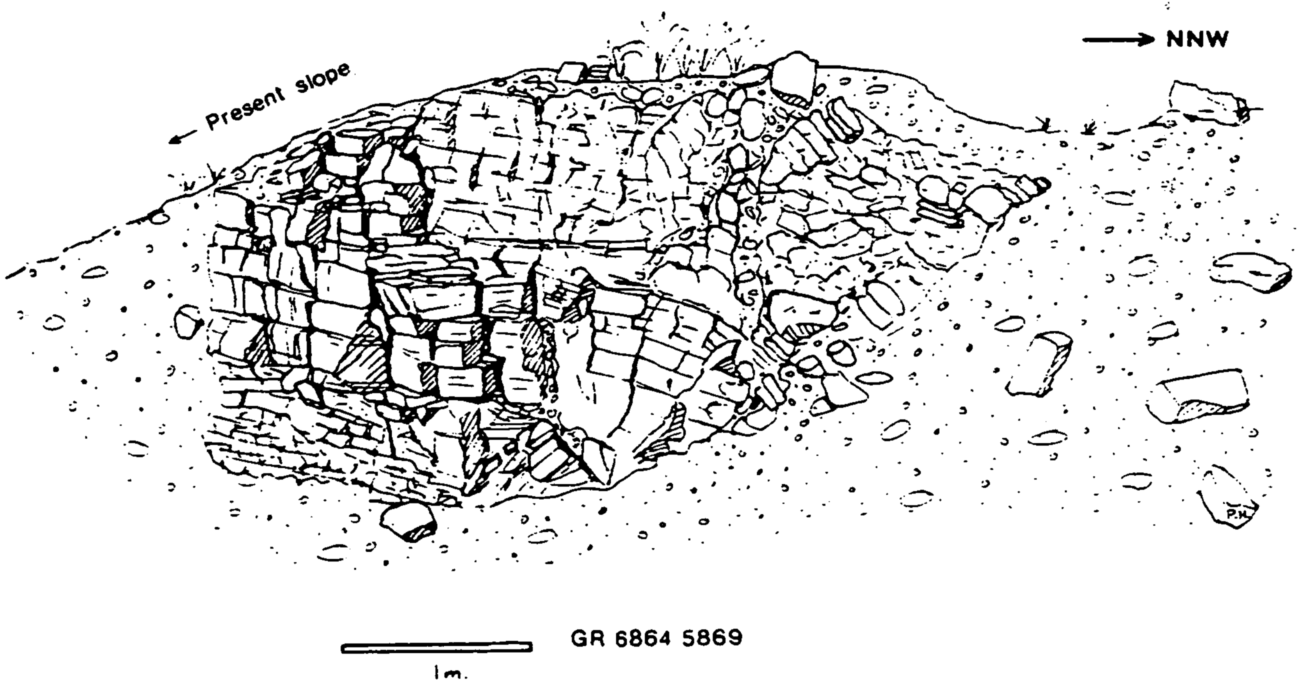


Fig. 7.25 Examples of the deformation of sandstone blocks within the Melange

distribution of cobbles and boulders characteristic of debris flows (see Chapter 8).

7.5.4.2. Ring shear tests

Ten ring shear tests on Melange matrix and a further 4 on natural mixtures of Melange and Kannaviou clays from landslip deposits were carried out (see Section 7.4.4.2 for test procedures) under effective normal stresses(σ_n') of between 75 & 500 kPa. Values of effective residual cohesion (c_r') and effective residual friction angle (ϕ_r) for the Melange matrix range from 3.3 to 19.3 kPa and 10.8° to 22.3°, respectively (see Appendix IIB); these values are obtained from the best-fit line on the shear stress v normal stress plot, and may be unreliable at low effective normal stresses (σ_n'<100kPa). The relationship between effective normal stress (σ_n') and ϕ_r' is shown in Fig.7.26 . Also, plots of plasticity index (PI) v ϕ_r'and %clay v ϕ_r'are given in Fig. 7.15. Results are similar to those obtained for the silty clays of the Kannaviou Formation. The results for samples BH65 and BH 36/1 show surprisingly high values for ϕ_r' of 22.1° and 22.3°, respectively, and reflect the high sand-grade content in the sub-samples.

7.5.4.3. S.P.T.

A total of 17 Standard Penetration tests were carried out on the Melange in shallow boreholes A2, A3, A7 and A8. The range of uncorrected 'N' values for the Melange is from 10 to 45 blows per foot (mean = 21, n = 16) with one refusal, probably due to a boulder. Stroud and Butler (1975) recommend the use of the SPT in boulder clay and give detailed correlations between both 'N' value and undrained strength and 'N' value and compressibility. These correlations are heavily dependent on plasticity index. Using the c_u/N v PI correlation given in Stroud and Butler (op cit.) the c_u/N value for the Melange (if comparable to boulder clays and tills in the sense that both deposits comprise a distinct matrix and clast component) would be in the region of 4-5 kPa; thus giving a mean mass c_u in the region of 80-110 kPa. Stroud & Butler describe the results of a

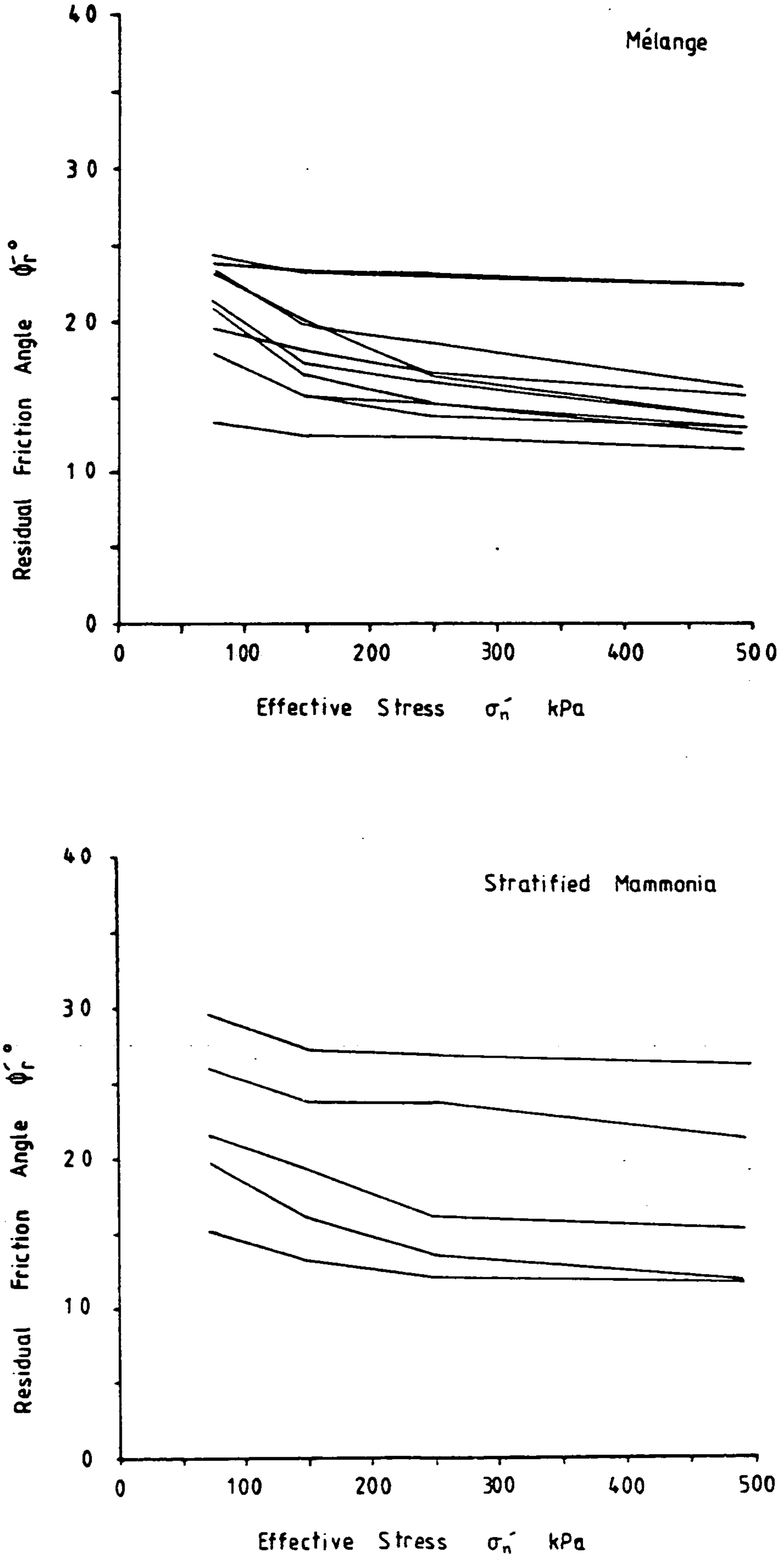


Fig. 7.26 Effective normal stress v Effective residual friction angle - Melange, stratified Mamonia

large number of SPT's on stoney till from South Wales and quote a mean 'N' value of 48 (n = 256). An account of interpretative techniques is given in Whyte (1985).

7.5.4.4 Overconsolidation

Vane test and liquidity index data suggest that the Melange is overconsolidated but to what extent, based on current data, is difficult to say. The triaxial test data are not considered to reflect the undisturbed Melange and no oedometer consolidation test data are available.

7.5.5. Geophysical properties

An electrical resistivity survey was carried out at two locations in area 1 - Phiti, (Kramvis,1984) for the purpose of studying Kannaviou strata (see section 7.4.5.). The survey did, however, indicate, a value of resistivity for Melange, albeit disturbed Melange, of the order of 12 - 37 ohm metres. A comprehensive geophysical investigation of the Melange may provide useful information in future work.

7.6 Test Results - Stratified Mamonia and Superficial Melange

7.6.1. Index Tests

Three samples of weathered stratified Mamonia and six samples of Superficial Melange (colluvium derived from the weathering, breakdown and partial intermixing of stratified Mamonia rocks; see Section 7.3.3.) were tested for liquid limit, plastic limit and particle size grading. These 'disturbed' samples were taken from surface exposures in Study Area 2. Of these, one sample each of stratified Mamonia and Superficial Melange (85/15 and 85/16) were tested for linear shrinkage (see Section 7.7.3) and one sample of Superficial Melange (85/29) for specific gravity (found to be 2.70).

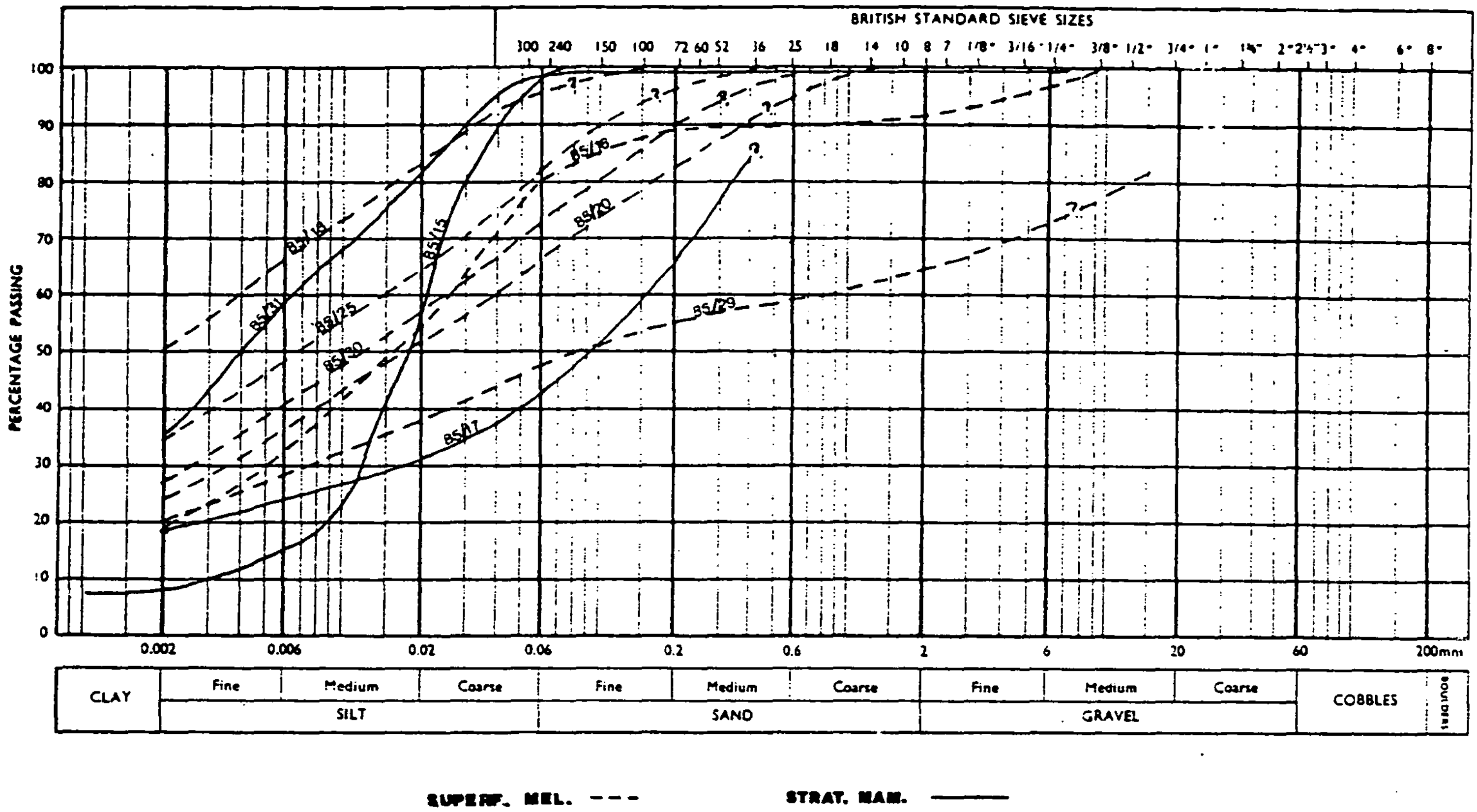
On the standard Casagrande diagram (Fig.7.28) the samples of weathered stratified Mamonia and Superficial Melange plot slightly above A-line within the 'low' and 'intermediate plasticity' ranges, with the exception of samples 85/31 and 85/13 which fall within the 'high plasticity' range.

Particle size distribution envelopes are shown in Fig.7.27 ; with the exception of sample No. 85/29, the samples of Superficial Melange are grouped in the sand/silt/clay areas with occasional gravel (<10%), and may be described as relatively well-graded. The three weathered stratified Mamonia Samples show a variety of curves, with sample 85/15 (a relatively thin mudstone band) standing out as being uniformly graded (mainly medium to coarse silt). A distinction is made, based on further samples external to the study area (see report EGARP KW/86/5), between the particle size envelopes for 'grey' and 'red' stratified Mamonia; the 'grey' being generally coarser than the 'red'. Too few samples from the study area were tested to propose particle size envelopes.

The correlation between clay fraction and plasticity index (PI) is shown in Fig.7.20. Values of Activity, Ac (=PI / %CLAY) for the study area samples only, range from 0.9 to 1.7 (i.e. 'normal' to 'active') for the stratified Mamonia samples, and 0.7 to 1.3 (inactive to active) for the Superficial Melange. Again, too few results were obtained for them to be considered representative enough for regional assessments to be made.

7.6.2. Mineralogy

Six samples of weathered stratified Mamonia and five samples of Superficial Melange, were tested for mineralogical content. Carbonate contents ranged from 0 to 18% for stratified Mamonia and 3% to 22% for Superficial Melange. Calcium montmorillonite contents range from 0% to 27% for the stratified Mamonia and 0% to 15% for the Superficial Melange. Quartz contents ranged from 25% to 30% and 27% to 31% for the



ENVELOPES

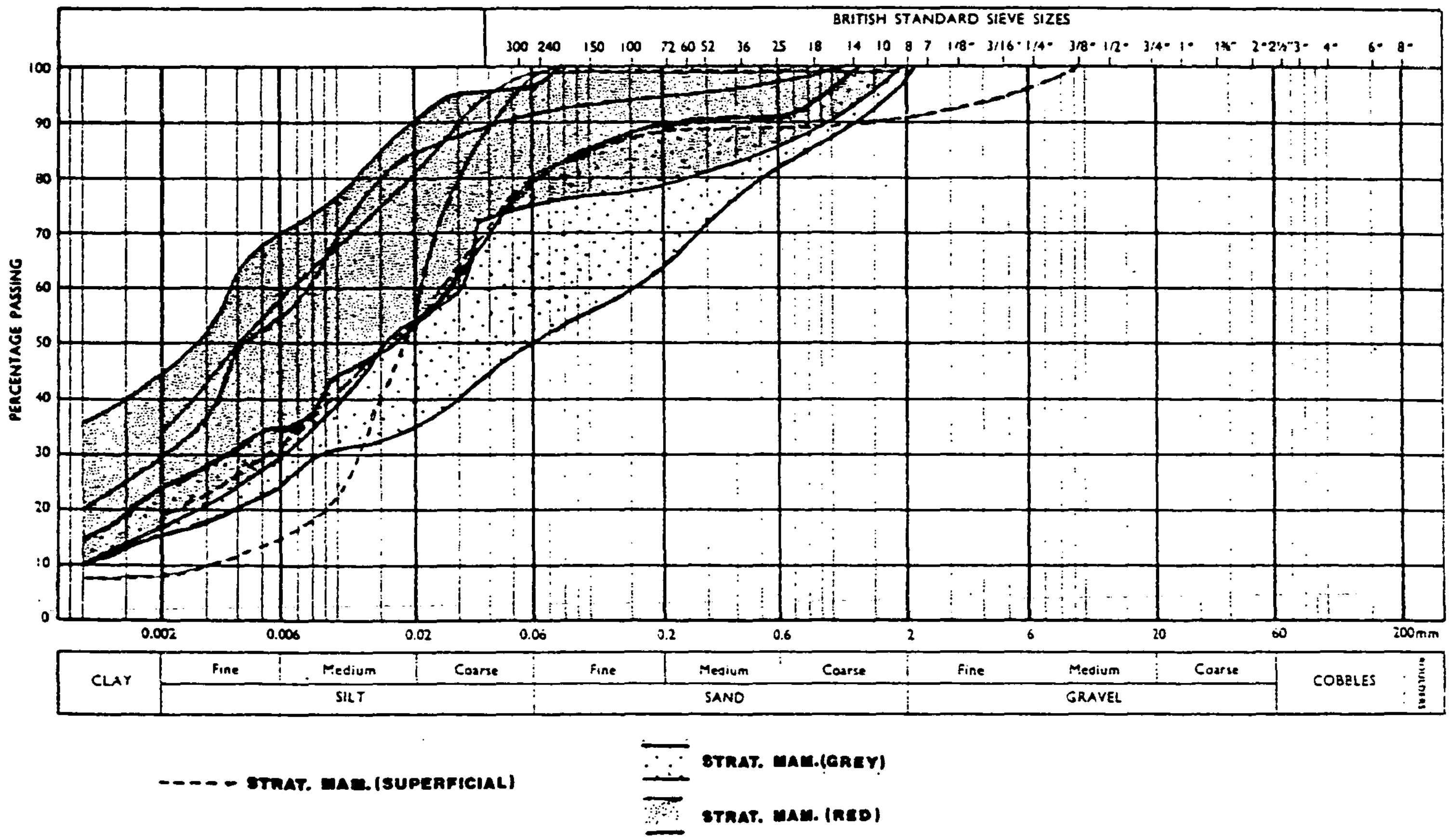


Fig. 7.27 Particle size distribution plots - stratified Mamonia, 'superficial' Melange

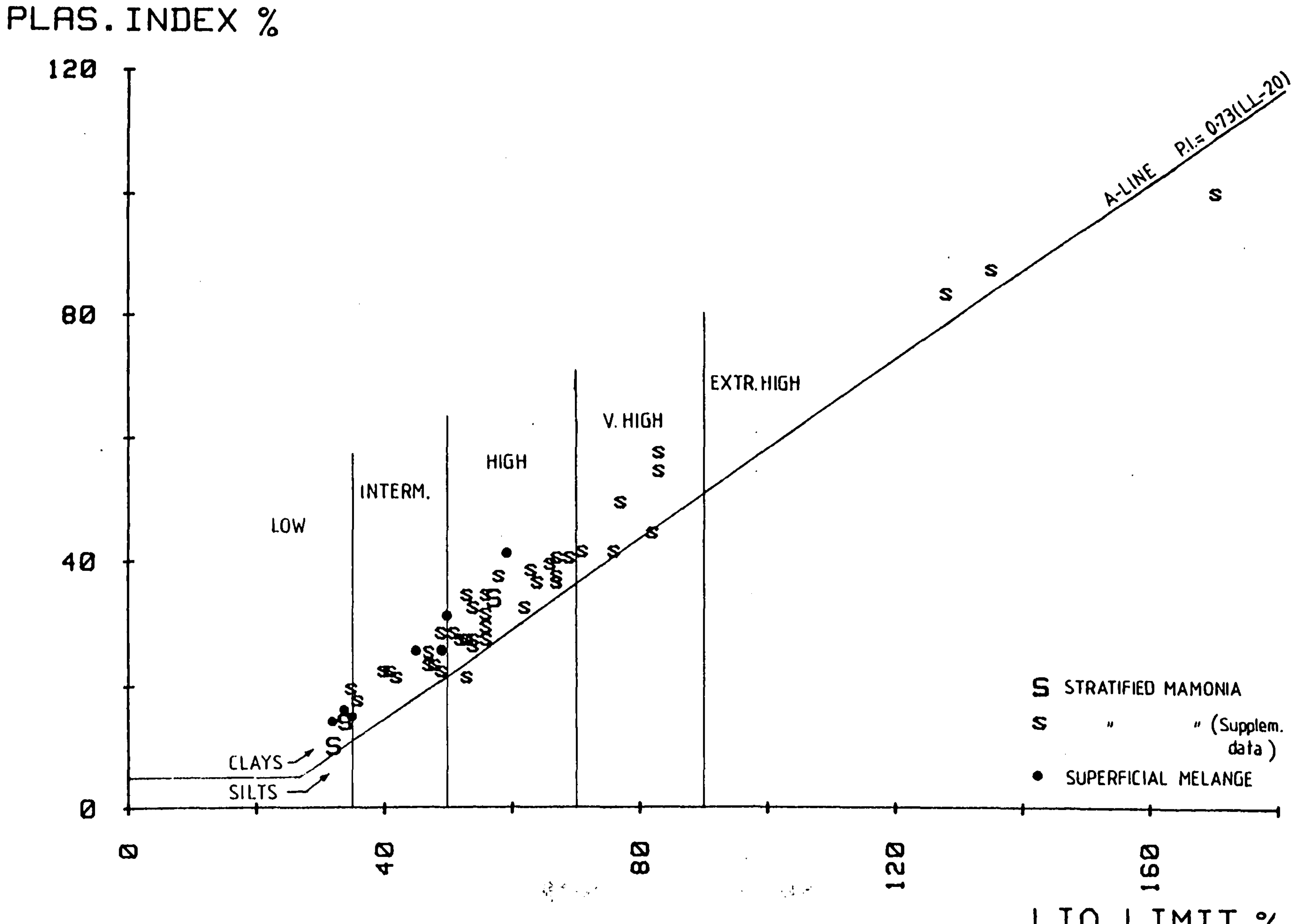
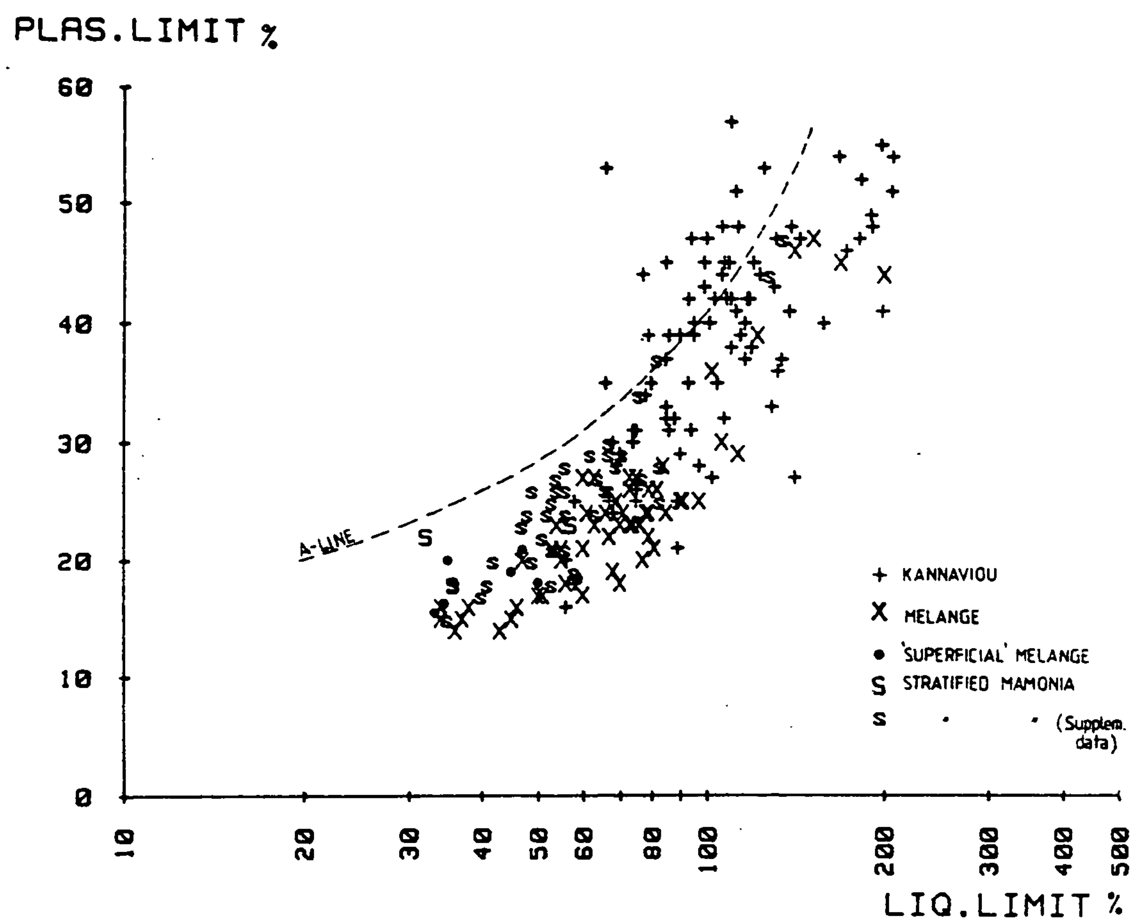


Fig. 7.28 Casagrande plot: Liquid limit v Plasticity index - stratified Mamonia, 'superficial' Melange



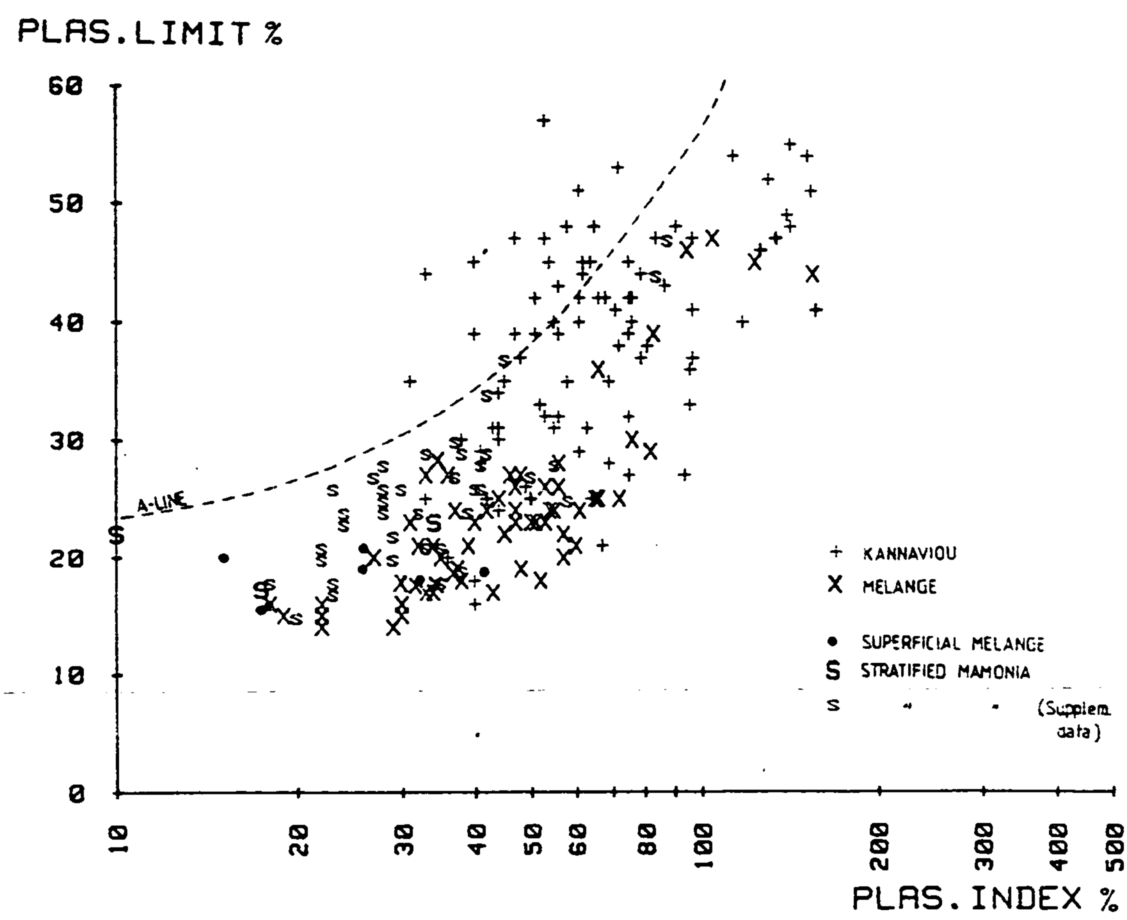


Fig. 7.29 (a) Plastic limit v (log) Liquid limit - Kannaviou, Melange, stratified Mamonia & 'superficial' Melange
(b) Plastic limit v (log) Plasticity index - Kannaviou, Melange, stratified Mamonia, 'superficial' Melange

stratified Mamonia Superficial Melange, respectively. These results are shown in the form of a triangular diagram in Fig.7.21b .

Subsidiary minerals detected by X-ray diffraction methods are chlorite, mica, feldspar and gypsum. These minerals are present in both the Superficial Melange and stratified Mamonia. An example of an X-ray diffraction trace of stratified Mamonia (sample P85/4A) is shown in Fig.7.24. The 'red' stratified Mamonia reportedly contains haematite and goethite (Swarbrick and Naylor, 1980) in quantities which are small yet sufficient to give rise to the red colouration. Correlations of montmorillonite content with liquid limit, plasticity index and Activity are shown in Figs. 7.22 & 7.23.

7.6.3. Volume change

Two linear shrinkage (LS) tests (British Standard BS 1377, 1975, Test No. 5) were carried out on sample 85/15 (stratified Mamonia) and sample 85/16 (Superficial Melange); the results were LS=7% and LS=9%, respectively. The relationship between LS and moisture content and between LS and liquid limit are shown in Fig.7.13. Taking all lithologies into account, the correlation between shrinkage and plasticity is well defined. Unfortunately, no swelling pressure or consolidation tests were carried out on samples of either stratified Mamonia or Superficial Melange.

7.6.4. Strength

No Triaxial strength tests were carried out on stratified Mamonia or Superficial Melange samples. However, ring shear tests (to measure residual shear strength) were carried out on sample 85/15 (stratified Mamonia) and on sample 85/16 (Superficial Melange). Values of effective residual cohesion, c_r' and residual shear angle, ϕ_r', were $c_r' = 6.0$ kPa, $\phi_r' = 15.0^\circ$ for sample 85/15 and $c_r' = 18.0$ kPa, $\phi_r' = 8.2^\circ$ for sample

85/16. Plots of Effective normal stress ($\sigma n'$) v $\phi r'$ are given in Fig.7.26, and a plot of $\phi r'$ v plasticity index (PI) is given in Fig.7.15. The values of $\phi r'$ for samples 85/15 and 85/16 are seen to be unusually low, despite high silt contents. No Standard Penetration Test (S.P.T.) data were recorded for stratified Mamonia or Superficial Melange.

The reader is referred to report No. EGARP KW/86/5, of this series, in which further test data, for samples from outside Study Areas 1 (Phiti) and 2 (Statos), are described. The lithology and structure of the stratified Mamonia and Superficial Melange are described in Sections 6.3.2.3, 7.3.3 and 7.3.4 of this report.

7.7 Engineering Behaviour

7.7.1 General

The geological setting, lithology, structure, mineralogy and geotechnical properties of the constituents of the Kannaviou formation in the study area have all been dealt with in previous Sections of the report. The purpose of this Section is to summarize engineering problems which have either been reported elsewhere or which may be considered likely in the future. One particular engineering problem which is of great significance, i.e. landslipping, is discussed in detail in Chapter 8. Instability will, however, be looked at here in more general terms as this relates to engineering works. In considering engineering behaviour, the laboratory and field test results, discussed earlier, are taken into account.

In discussing the geotechnical properties and hence the engineering behaviour of the various formations it should be borne in mind that the disturbed and/or weathered materials exposed at the surface and at shallow depths, or within landslips, may differ significantly from their undisturbed or fresh counterparts at depth; this is particularly the case for the mudstones and clays of the Kannaviou where stress relief, fissuring and weathering have a profound influence on mass properties. The geotechnical test data described earlier in the Chapter, deal with disturbed or weathered materials with the exceptions of deep boreholes EG 10/84, EG 13/84 and D1. Additionally, all geotechnical test data introduce the further element of sample disturbance to a greater or lesser degree, depending on sampling method and its suitability to the material being sampled. For example, a block sample of Melange obtained from a pit is probably of better quality than a cored sample of bentonitic Kannaviou clay. However, once in the laboratory, the sample of Melange is probably even more difficult to test satisfactorily than the Kannaviou clay and further disturbance may be incurred in preparing a final test specimen from the block. One must, therefore, judge the extent to which variability within any data set is a function of true variability within the material or of differences in sampling and test methods. This is particularly the case where only small numbers of tests were carried out; as for example for the stratified Mamonia and Superficial Melange.

7.7.2 Kannaviou Formation

The various lithological components of the Formation have been described in Section 7.3.1. The Kannaviou in the study areas may be considered, in general terms, to comprise a distorted multi-layer sequence of 'strong' sandstones and 'weak' clays, with interbedded 'weak' sandstones.

On a macro-scale, distinct lithological zones in the order of 5-15m in thickness may be recognised, which, particularly in the dominantly argillaceous materials, may comprise individual units ranging from c.1cm-1m in thickness. The thicker, harder sandstones form prominent cliffs and ridges, whereas the argillaceous components tend to be poorly cemented, and/or bentonitic, softer, and more prone to erosion and slaking. One particular variety of volcaniclastic sandstone seen in the study area is a low density, porous rock approaching pumice. This material may be of minor economic importance, but lacks persistence in the study area. An interesting feature of the typical massive sandstone is the presence of 'balls' of bentonitic clay up to 1 metre in diameter situated randomly within the deposit. At depth these are probably in a partially or fully saturated state whereas at exposures they are either dry and fissured or have eroded away leaving hollows in the sandstone (see Fig. 7.4). For the purposes of rock engineering, these can be considered as voids and their presence is difficult to detect.

Few geotechnical data are available for the Kannaviou sandstones and siltstones, these being confined to simple slaking tests, porosity/density and particle size and mineralogical determinations. No strength or permeability data were obtained. Dobereiner and de Freitas (1986) tested a variety of 'weak' sandstones from around the world and suggested a saturated unconfined compressive strength of 0.5 MPa as the dividing line between sandstones which disintegrate with immersion and those that don't; this boundary also coincides with that commonly taken as separating 'rocks' from 'soils'. An upper boundary for 'weak' sandstones is suggested to be at an unconfined saturated compressive strength of 20 MPa. An important factor related to the shear strength of sandstones, was found by Dobereiner and de Freitas (op cit.) to be grain contact and moisture content. As smectite (and to a lesser extent amorphous silica) were found (in the S.E.M. study) coating sand-sized grains (see also Suthren, 1985), the montmorillonite content, (often as high as 25%), may be a general guide to the likely extent of grain contact and hence the strength of the Kannaviou sandstones. Dobereiner and de Freitas found a generally poor correlation between porosity and permeability as measured in the laboratory. The influence of moisture content on the strength of bentonitic sandstones is probably considerable. Small percentage increases in saturation may cause the strength to fall dramatically.

The Kannaviou clays are characterized by high bentonite content, overconsolidation and zones of intense tectonic shearing. These tectonic shear planes differ from the less pervasive shear planes associated with recent landslipping. The former tend to be tightly closed with virtually no foreign material within them, whereas the latter are more varied, may be drier <u>or</u> wetter than the surrounding material (depending on age and landslide activity) and often contain a smear of foreign material or material altered by the passage of water through the shear plane. There is no reason, however, why tectonic shear zones should not be re-activated by engineering activity. Overconsolidation of the Kannaviou clays is suggested by triaxial stress-path data, the single high pressure oedometer test, and the liquidity indices; though the relative contributions of complex tectonic forces and vertical overburden forces is difficult to assess. It is possible that the principle and minor stress directions were the reverse of those normally associated with the over-consolidation process (i.e. sedimentation followed by erosion). The effect of the high montmorillonite content of the clays on their engineering behaviour is highly significant. Liquid and plastic limits are normally very high. Swelling and shrinkage potentials, and Activity (PI/%Clay) are similarly high and residual strengths low. Thixotropy (or recoverable sensitivity at constant moisture content) has been observed in the more smectite-rich clays. The possible influence of thixotropic hardening on slope stability is discussed in d'Onfro & Bombolakis (1979).

The argillaceous Kannaviou deposits are particularly prone to slope instability and are a major contributory factor in the development of extensive landsliding within the Study Areas (see Chapter 8). The ready passage of water through the sandstone and siltstone bands and the fissures within the Kannaviou clay/mudstone sequences aggravates this potential instability. An illustration of this fact is that no unsupported sub-vertical cuts in Kannaviou clay in excess of c. 1m are seen in the field (see report No. EGARP KW/86/2) and that virtually all natural slopes at the foot of Kannaviou sandstone outcrops have suffered instability.

The behaviour of the Kannaviou formation as a foundation material is difficult to assess. Few examples of the performance of foundations in the field are available, except those generally affected either by landslipping and/or earthquake shocks or by poor construction. It has been suggested from model tests by Knox and Zacas (1983) that when alternating weak and strong bands form the foundation medium, the following points may be observed:

- The weak strata absorb most of the settlement.
- The nearer to the surface the weak strata occur, then the greater the settlement and the lower the overall bearing capacity.
- The relative strengths of the weak and strong strata affect both the bearing capacity and the deformability.

The above comments apply in general terms to the Kannaviou Formation and may affect foundation conditions locally. The extent and variety of natural slope instability within the area is, however, likely to be the most significant influence on the design of foundations.

The choice of a representative value for the strength of Kannaviou clay for design purposes is particularly difficult. Triaxial tests on relatively large (100mm diam.) samples, all of which have undergone natural disturbance in one form or another, in addition to any sampling disturbance, have revealed very low total peak strengths ($s_u < 60$ kPa). Small-scale vane tests give total peak strengths approximately 5 times higher. This discrepancy is due to the discontinuities present within the triaxial samples. The shear strength along these discontinuities is much lower than that of the intact clay; a factor which does not figure in the small vane test. The large strains developed in the ring-shear sample provide an additional, residual, value of shear strength. Thus a selection of laboratory-derived shear strength values are available from which to choose. In the case of fissured/sheared clays, the mobilised strength is largely the undrained strength of the discontinuities, and strength variations at any cell pressure reflect the different orientations within the specimen (Report No EGARP KW/86/2-this series). Skempton and Petley (1967) suggest that a conservative residual strength should be used for engineering design in materials with "minor shears".

Discontinuities within the argillaceous Kannaviou strata range from micro-fissures, through joints, to randomly or partially-oriented shears and large scale shear surfaces or zones. These discontinuities give rise to two important factors which affect the engineering behaviour of the soil mass. The first concerns degree of orientation or randomness of the discontinuities which influences the anisotropy of the mass shear strength and the development of continuous failure surfaces beneath a foundation or slope. The second is the shear strength mobilised along the discontinuities themselves, which determines the stresses at which failure will be initiated, and hence the selection of safety factors. Thorne (1984) points out that drained shear strength, in particular, is stress dependent and varies with the relative magnitude of matrix strength, discontinuity strength, and orientation of the discontinuities.

It has been observed that in the case of the highly sheared clays a minor disturbance may result in the partial disintegration of the soil structure into a mass of loose lenticular pieces, each bounded by slickensided surfaces. This phenomenon has been reported for sheared clays in Sicily and Central and Southern Italy (Evangelista et al, 1977; Jappelli et al,1977; D'Elia, 1977). The behaviour of this material then approaches that of a coarse granular soil, the size of the 'grains' being a function of the spacing of the shears. Whilst it is true that these scaly 'grains' interlock in the undisturbed condition, the friction between them is less than for normal granular non-cohesive soils and the frictional properties are anisotropic.

Care is needed when core drilling in the Kannaviou Formation to prevent both contamination of the core by bentonitic drilling mud, and swelling of the core due to the addition of water, either during drilling or during removal of the core from the barrel. It is recommended that plastic liners are used as part of a triple barrel system, so that the core is preserved from mechanical damage, moisture loss, and contamination both during drilling and subsequent removal to the laboratory.

7.7.3 Melange

The Kathikas Melange is, by any account, an unusual material, combining a remarkable heterogeneity of clast size and type and notable uniformity of matrix. Comparisons with the more stoney varieties of boulder clay or till of northern latitudes (Weltman & Healy, 1978; Fookes et al, 1975) are tempting when considering local engineering behaviour. The Melange is, however, noteable for the high proportion of clasts, and the high plasticity of the silt-clay matrix, which usually contains randomly-oriented micro-fissures or shears. There is an intimate mixing or suspension of the clasts (not unlike that of currents in a cake mix) within the silt-clay matrix, which, with relatively few exceptions, appears to be completely random. Swarbrick & Naylor (1980), however, describe examples of olistostromal bedding within the Melange, and suggest a range of thickness for individual debris flow 'beds' or sequences of between 0.2 and 15.0 metres. Samples from deep boreholes EG 10/84 and EG 13/84 have revealed the presence of clast-rich bands. Indications here, are that the thickness of individual olistostrome sheets is in excess of 15 metres.

Although the genesis and qualitative descriptions of melanges worldwide are frequently found in the literature, very few accounts include reference to any geotechnical assessment of the material. The Kathikas Melange of S.W. Cyprus appears to differ from other documented melanges, for example the Franciscan melange of N. California (Bedrossian, 1980; Hsu,1971; Savina et al,1978), particularly in respect of the matrix, and probably has more in common with recent submarine debris flows on modern continental shelves (Jacobi, 1976; Embley,1976). Attempts to classify melanges are found in Hsu (1972), Gansser (1974), and Raymond (1984).

The generally good stability of the Melange at many locations in the Study Area is indicated by numerous high and oversteepened natural slopes which remain stable at angles of up to 35°. These are usually associated with rapid river erosion and surface run-off and, in some cases, have a thin chalk capping. The silt/clay/fine-gravel matrix exhibits a notable uniformity of particle size, plasticity and mineralogy when compared with the Kannaviou Formation and thus, bearing in mind that the matrix forms as much as 70% or more by volume of the Melange, one might expect the engineering behaviour to be reasonably predictable. The clasts exhibit a wide variety of lithology, size, and shape. Large blocks cause difficulties for excavation work, and may have to be exposed and blasted. Detection of large individual blocks during site investigation is difficult using drilling and pitting. It is virtually impossible, with conventional drilling equipment, to obtain continuous undisturbed core in the Melange, and hence to estimate block size. Geophysical methods may be applicable here, bearing in mind the relative uniformity of the Melange matrix, and the likely contrast between the geophysical properties of the essentially clayey matrix and the blocks, particularly those of igneous and metamorphic origin.

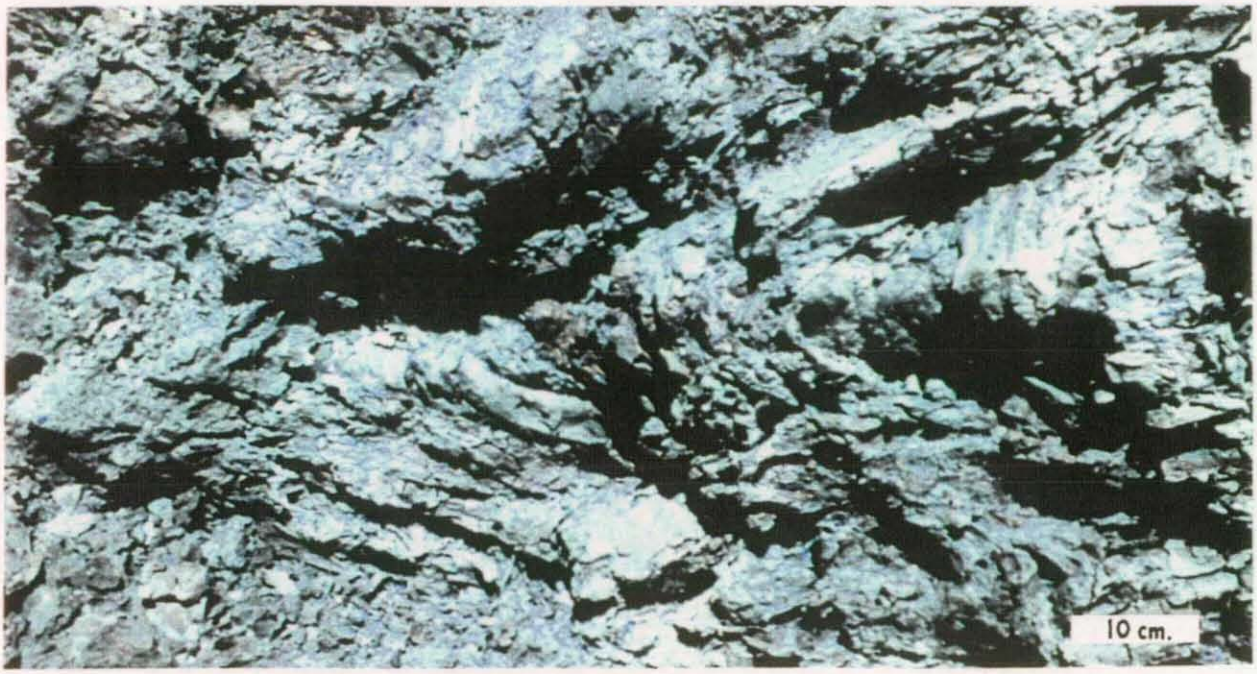
The engineering behaviour of the Melange at most localities is likely to be determined primarily by the properties of the matrix. To date geotechnical studies of the Melange are confined to small-scale laboratory samples of the matrix and further research involving large-scale field tests, such as instrumented embankment loading, and back-analysis of landslides, is recommended.

Due to the clast component, particular problems are encountered in obtaining cored samples from boreholes in a sufficiently undisturbed condition to allow meaningful geotechnical testing, other than index testing, to be carried out. The current field investigation has shown that block sampling from pits or trenches is the most cost-effective method for obtaining good-quality undisturbed samples. Sampling depth is, however, limited and the problems of preparing suitable test specimens remain.

It is interesesting to note that particularly large exposed exotic blocks (olistoliths) of limestone have attracted small-scale quarrying operations on the slopes below Galataria (Area 2).

7.7.4 Stratified Mamonia

The sedimentary, or stratified, deposits of the Mamonia Complex (the Ayios Photios Group of Robertson & Woodcock, 1979), consist of alternating variable sequences of thinly-bedded mudstones, shales, and cherts, and thicker-bedded sandstones. Occassionally, thin bands of clay are present which may, at some localities, represent mylonites or shear zones of tectonic origin. The two principal features affecting the engineering behaviour of the materials are weathering and tectonic disturbance. The severity of tectonic disturbance may vary greatly, even within a small area. This fact makes prediction of the mass properties very difficult indeed. Intense deformation, seen as tight folding, and closely-spaced faulting and jointing, results in the break-up of the Mamonia Complex Formations into a loose association of blocks, the size of which is largely a function of bedding thickness and discontinuity spacing. Whilst the overall structure of the deformed mass is normally retained, the discontinuities promote weathering, breakdown, and intermixing to form slope colluvium or thicker deposits of Superficial Melange. The 'softer' components of the formation, i.e. the shales and mudstones, particularly of the Episkopi Formation, breakdown readily and only limited intermixing, generally as a result of slope movement, is then required to produce the Superficial Melange. At some localities, less severely disrupted Mamonia rock units have only a thin superficial weathered mantle, and bedrock is often exposed or within c. 1m of the ground surface. In these localities the Mamonia rocks may present problems to engineering works, mainly with regard to discontinuities, but in general terms constitute a competent foundation medium. The chert/mudstone sections of the stratified Mamonia are quarried locally on a small scale for road stone. They are easily

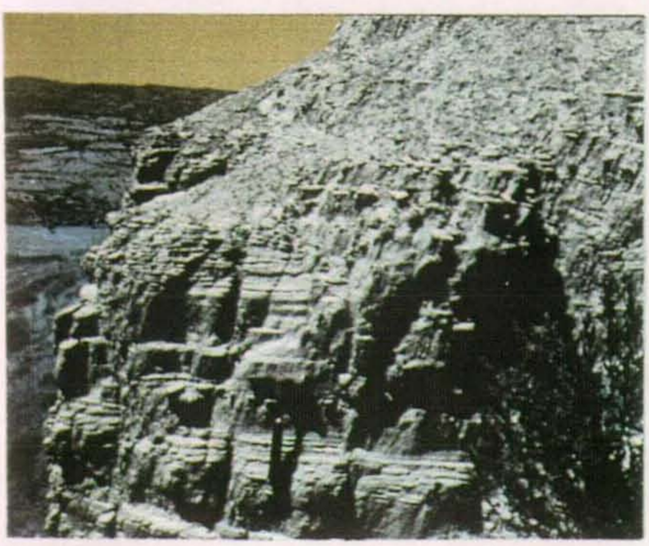


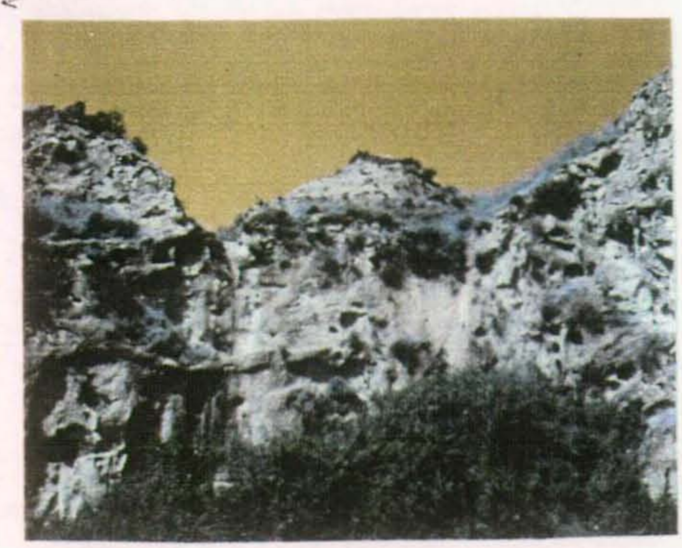
7.1 Kannaviou clay -- road cut Ayios Dhimitrianos (Area 1, GR 46020 386320).

7.2 Kannaviou sandstone -road cut, Kannaviou village (Area 1, GR 46130 386430).

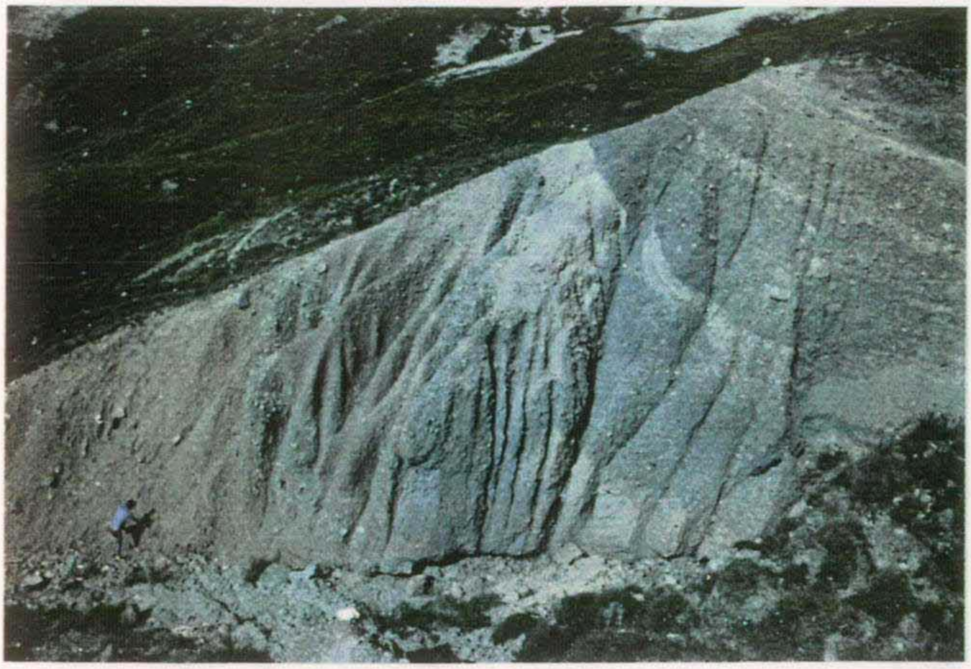
7.3 Kannaviou sandstone - ridge between Lasa & Simou (Area 1, GR 45680 386698).

7.4 Kannaviou sandstone & silt -stone -- to NW of Phiti (Area 1, GR 45770 386652).

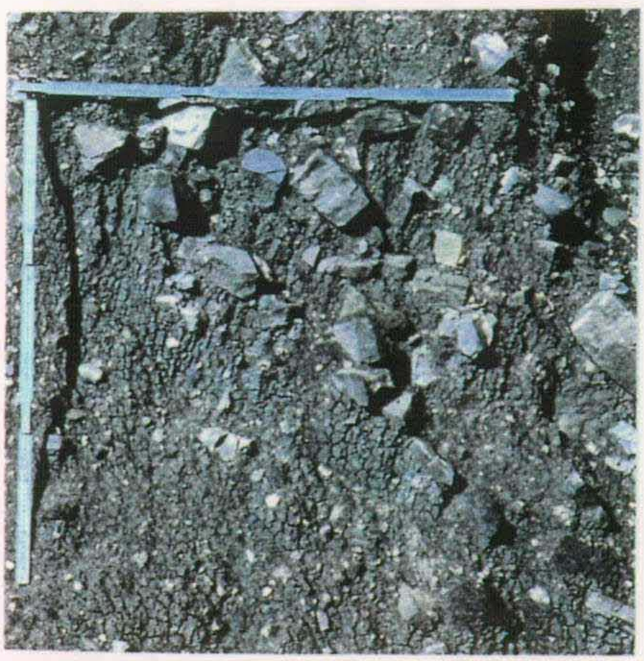




PHOTOS 7.1 to 7.4

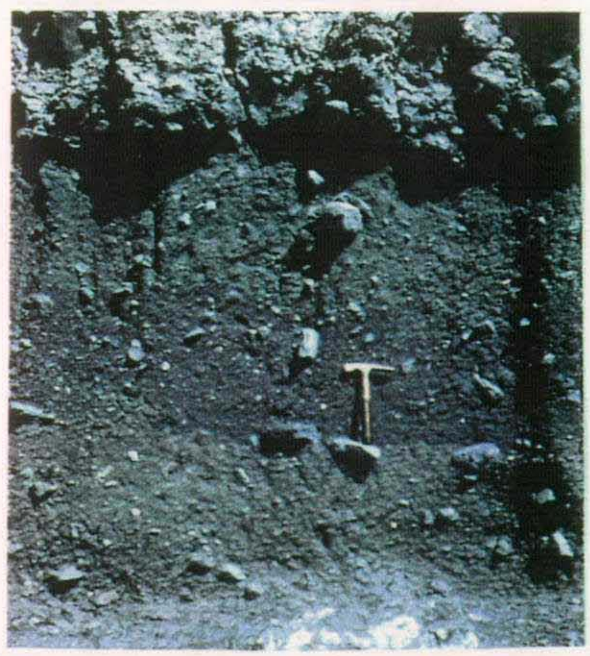


7.5 **Kathikas melange** -gully to NE of Lapithiou, (Area 2, GR 46390 386305).



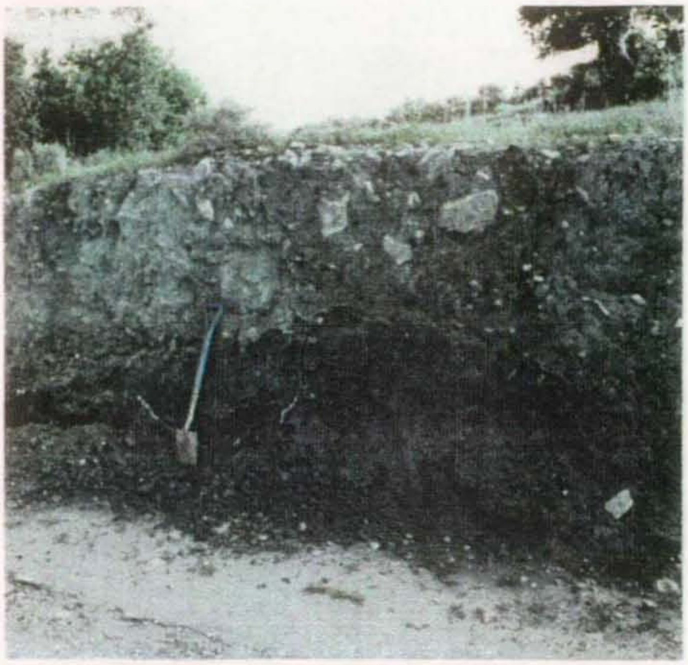
7.6 **Kathikas melange** - eroded road cut, (Area 2, GR 46670 385990). 1x1m. scale.

Galataria,

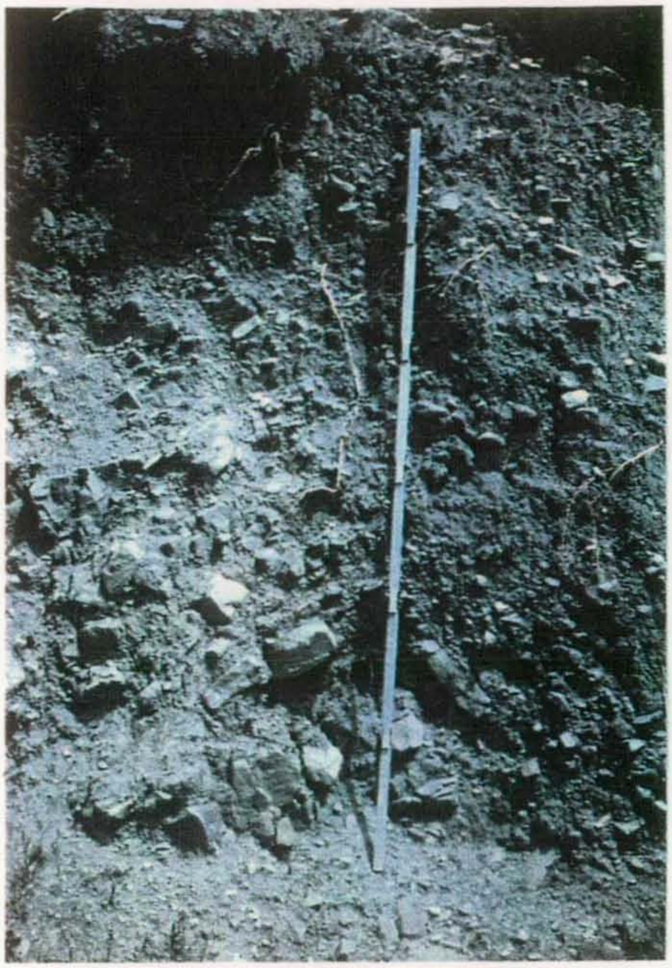


7.7 **Kathikas melange** - to SW of Kathikas (outside study area, GR 44660 386250).

PHOTOS 7.5 to 7.7

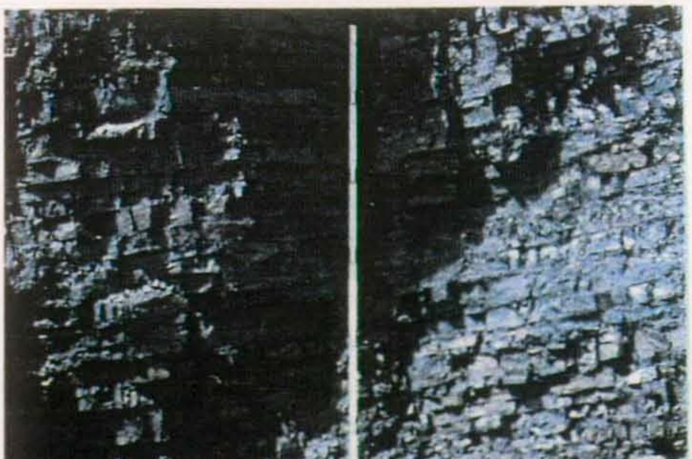


7.8 Stratified Mamonia - weathered mudstones overlain by superficial melange, road cut to E of Pendalia (Area 2, GR 46790 385690).



7.9 Superficial melange - road cut to W of Ayios Photios, (Area 2, GR 46325 385980). 2m. scale

7.10 Stratified Mamonia - mudstones & cherts, road cut between Ay. Photios & Phalia, (Area 2, GR 46435 385900, 2m.scale



7.11 Stratified Mamonia - cherts & mud-stones, road cut between Ay. Photios & Khoulou, (Area 2, GR 46180 385935). 2m. scale.

PHOTOS 7.8 to 7.11

excavated with a bulldozer. Undisturbed core sampling for laboratory testing is likely to be difficult owing to rapid lithological and structural variations.

The Superficial Melange is an intermittent, lithologically variable deposit, and unpredictable in general engineering terms. In this respect it resembles periglacial 'head' deposits of northern Europe. It represents the intermediate stage of mechanical breakdown, of the Mamonia rocks, somewhere between the deformed stratified Mamonia and the Kathikas Melange,(see also Swarbrick & Naylor, 1980). The 'matrix' and 'clast' phases are clearly seen, with the matrix comprising a non-homogeneous, generally silty, gravelly material (see Photo 7.9). The fundamental differences between the Superficial Melange and the Melange 'proper', as far as engineering behaviour is concerned, are: a) the clast dominance and lithological anisotropy of the Superficial Melange and, b) the more granular soil characteristics of the matrix as compared with the more cohesive silt-clay matrix of the Melange 'proper'.

8. <u>ASSESSMENT OF SLOPE INSTABILITIES IN THE PHITI AND STATOS STUDY AREAS.</u>

8.1 Introduction.

In the Paphos region the geological, topographic and climatic environment is such that the occurrence of landslides as natural phenomena is facilitated. The highest incidence of mass movements occurs in the region's highlands where a high relief in conjunction with steep slopes underlain by sheared and fissured bentonitic clays and weak rocks, and high winter rainfalls combine to form an area particularly susceptible to slope instabilities. In addition, the region lies in one of the most seismically active areas of Cyprus (Chapter 3, Fig. 3.3) and the landslide problem is compounded by the effects of earthquake shocks which are known to have triggered widespread and often catastrophic landslides in the historic and recent past (c.f. 1953).

In SW Cyprus, remnant landslide features probably date from the Late Pleistocene times, when the drainage pattern and relief were much the same as at present but precipitation was higher, erosion more intense, and the slopes steeper. In geomorphological terms, slope instability in the region is clearly an important mechanism of landform development by which material constituting the valley slopes adjusts its surface angle and height to changes in the hydro-climatic and geomorphological conditions. Thus, even without the exacerbating effects of earthquake shocks, landsliding is a common degradational process which plays an important role in the evolution of the landscape.

In the social context, as outlined in Chapter 4, mass movements present significant problems to human activity in the region and are of pronounced importance in influencing future land use decisions and planning.

To date, no systematic studies of mass movements in the Paphos region have been carried out. The most significant published account of landslides in the region (and elsewhere in Cyprus) is that of Pantazis (1969) who documents, from contemporary records, villages affected or destroyed by mass movements and distinguishes between a) "landslides caused by the 1953 earthquake" and b) "landslides caused by rain after 1953". A further useful, though unpublished, account of landslides in the region was prepared by Afrodisis (1971) which describes the occurrence of landslides with respect to the various geological formations and discusses in more detail the possible causal factors giving rise to movement. Both accounts recognise the importance of the Kannaviou and Melange clays to the widespread occurrence of slope instabilities in the region.

The Phiti (Area 1) and Statos (Area 2) study areas, selected for the investigation of the 'problem' cohesive soil formations in the current survey, probably encompass the most landslide-prone terrain in Cyprus. For the Paphos District as a whole, Pantazis (1969) lists some 20 villages seriously affected by landslides since 1953, 14 of which were damaged by movements related to the Kannaviou and Melange Clays or sediments derived from the rocks of the Mamonia Complex. Of this total, 7 villages are located within the two study areas, all of which have been either partly or wholly resited due to recurrent slope movements. Roads and services suffer repeated damage from minor slope movements resulting in considerable expenditure on remedial measures and route realignment costs, and yearly harassment and disruption of valuable arable land severely restricts agricultural development.

In assessing the slope instability problem in the two study areas, particular attention was paid to the field recognition and classification of the various types of mass movements and to the identification of the causative conditions and processes leading to their initiation or re-activation. Systematic engineering geological (landslide) mapping was undertaken in order to both (i) assess the distribution and extent of the mass movements with respect to particular geological/lithological formations, topography and hydrological features and (ii) to present mass movement information in a form readily acceptable to engineers and planners concerned with urban and regional development in the area. The methodology and techniques employed in the present study may be used as a basis for further regional assessments of mass movements in Cyprus and elsewhere in the world where complex geological formations associated with 'ophiolite terrains' give rise to extensive slope stability problems.

8.2 Recognition and Identification of Mass Movements

The survey of slope instabilities in Study Areas 1 and 2 was primarily concerned with the field recognition and identification of those relatively rapid mass movements generally referred to as 'landslides', as distinct from slow, long-term slope movements such as surface creep and phenomena more akin to mass transport by surface water such as hillwash or sheet erosion. Within the continuous spectrum of mass movements, however, both surface creep and erosion processes can, and do, influence 'landslide' instability and, with regards to their effects in the two study areas, are discussed in Section 8.6, below.

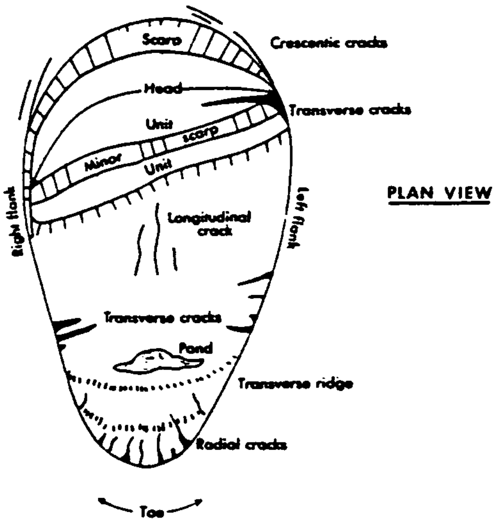
Three main methods were employed in the recognition of slope instabilities, namely:

- (i) Aerial reconnaisance
- (ii) Field reconnaissance, and
- (iii) Subsurface investigation.

The procedures adopted for the complementary use of these methods in the Phiti and Statos Area surveys are described in Chapter 5, Section 5.2.

8.2.1 Aerial and Field Reconnaissance

The aerial and field reconnaissance methods relied on the recognition of anomalous landform 'patterns' which involved the identification of characteristic morphological features indicative of existing mass movements (e.g. Fig. 8.1). During field reconnaissance, the recognition of marked lithological unconformities and/or shear zones exposed in stream and man-made cuttings provided supplementary evidence indicative of landslide movement (Photos 8.1 and 8.2).



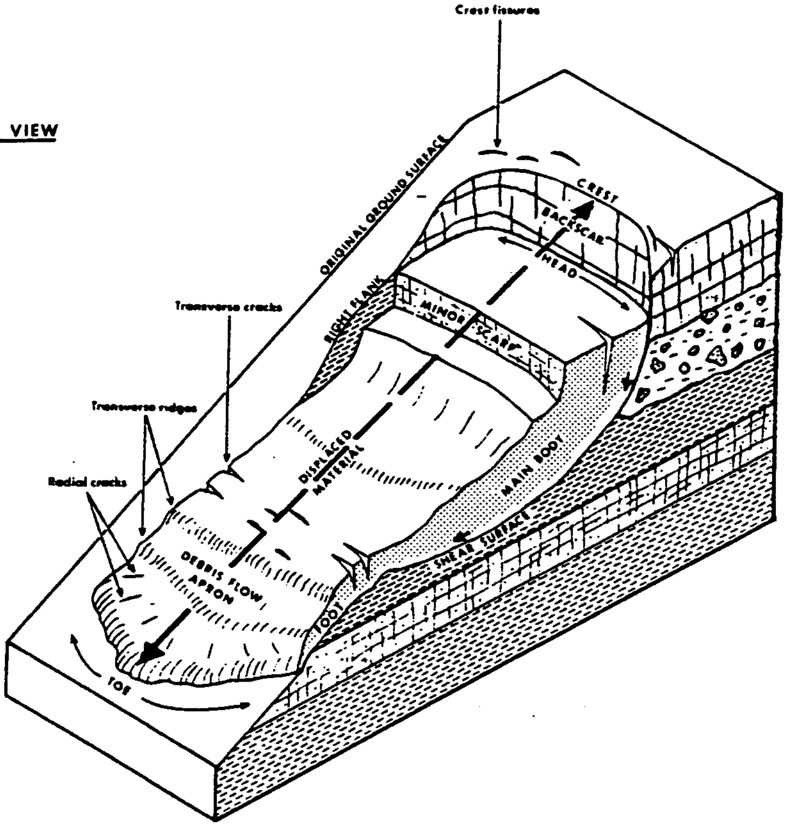


Fig. 8.1

Example of characteristic landslide morphology. (based on Brunsden, 1973 and Varnes, 1978)

The technique of ground evaluation by pattern recognition analysis is based on the premise that landforms developed by the same geological processes in the same environmental setting will have similar and distinctive 'patterns'. It is imperative, therefore, that for accurate recognition and analysis of anomalous ground patterns suggestive of mass movements, the geological and geomorphological processes that have contributed to the present day physiography of the region under study are adequately understood and their influence on the development of characteristic landform patterns appreciated. This premise is particularly applicable to regional ground assessments conducted in 'ophiolite terrains' such as that encountered in SW Cyprus where complex geological and tectonic histories have resulted in allochthonous 'broken' formations (the Mamonia Complex), folded and 'tectonized' sediments (the Kannaviou Formation), and olistostromal deposits (the Melange) occurring in juxtaposition on valley side slopes. Natural erosion of these formations has at many localities resulted in 'in-situ' landforms showing many characteristics of old landslides (e.g. tectonically disrupted rock masses that resemble apparent backtilted or translated landslide blocks displaced by sub-aerial gravity sliding, as shown, for example, in Photo 8.3).

In relatively recent or re-activated older slope failures the characteristic features indicative of displaced ground were readily identifiable on all rock types. Similarly, few problems of landslide recognition were encountered with respect to old, dormant mass movements in the weak Kannaviou and Melange clay formations where failure had also incorporated the harder, more resistant chalk caprock. Even when highly disrupted, old chalk slide blocks or masses of chalk debris, indicative of past mass movement could be identified in exposures or by irregularities in topography, vegetation or ground tone, often at anomalous stratigraphic positions within the Kannaviou and Melange clay terrains more than a kilometre from the slope crests.

Landslides within the weak bentonitic clays of the Kannaviou and Melange formations rapidly become degraded by both normal erosion processes and/or agriculture. On the Kannaviou clay slopes in particular, shallow minor slips and flows become markedly degraded over a period of only one or two winter/summer cycles. Where exposures are rare or non-existent, and appreciable amounts of incorporated chalk debris are absent, field recognition of old dormant and degraded landslides in these deposits can be unclear. In the present study, re-assessment of the aerial photograph cover following a walk-over field survey usually enabled recognition and, in most cases classification, of old 'clay' landslides with respect to extent and failure type. At some localities in both the Phiti and Statos study areas, however, the existence of old, highly degraded landslides, without recourse to subsurface investigation, remains uncertain and has been indicated as such on the 1:10 000 scale engineering geology (landslide) maps accompanying this report.

8.2.2 Subsurface Investigation

Within the overall context of the 'Cohesive Soil Study', the main aims of the subsurface investigations in the two study areas (detailed in Chapter 5, Section 5.2.3) were to determine the characteristic litho-stratigraphic successions in the hillside slopes, to describe these deposits in engineering terms, and to obtain disturbed and undisturbed samples for mineralogical and geotechnical classification in the laboratory. The location of boreholes and trial pits (Chapter 5, Figure 5.1) was not, therefore, specifically directed towards detailed assessment and stability analysis of individual landslides. The extensive areal distribution of mass movements did, however, result in eight of the twelve Area 1 boreholes being sited on landslipped ground, four of which were located primarily to ascertain the depth of sliding and type of material involved at selected landslip sites.

Of the thirty-one trial pits excavated in the two study areas, all but nine were located in landslipped ground.

The subsurface investigations were of particular use in:

a) the identification of landslipped ground by examination of material type and fabric, particularly in areas where erosion and degradation made landslide recognition by aerial and field reconnaissance uncertain, and

b) ascertaining the thickness of the slip mass (i.e. the depth of movement).

8.2.2.1 Trial Pit Excavations.

Trial pit excavations proved the most successful method for the assessment of near-surface lithological and structural features diagnostic of landslips in the cohesive soil formations. These excavations constituted a rapid and cost-effective method for the subsurface examination of landslipped ground and should form an essential part of any engineering site investigation in areas of known or suspected mass movements.

The most diagnostic subsurface feature of landslide deposits is the contact between the displaced mass and the underlying surface. In nearly all cases this contact is marked by a distinct unconformity distinguished by an abrupt change in slipped/unslipped material fabric and/or lithology (e.g. Photo 8.1). Where ground displacement has occurred by shear failure, the unconformity may also be marked by one or more shear surfaces or a shear zone. The shear surfaces characteristically consist of a thin 2mm - 2cm thick band of virtually clast-free, remoulded soft plastic clay overlying a hard 'polished' and striated surface. When exposed in a pit face, the shear zone may also mark a line of seepage where downward percolation of groundwater through shears or fissures in the overlying slip mass is impeded by the virtually impermeable shear zone clay (e.g. Pit 22, Appendix 1B). In such cases, the slipped clay within and for approximately 10 - 20 cm above the shear zone has a measurably higher moisture content and a soft to firm consistency. This is shown, for example, in Pits 22 and 10B, Appendix 1B, by a decrease in undrained shear strength values across the shear zone (determined by hand-held shear-vane measurements at vertical intervals in the pit face).

Two pit sections in the Kannaviou and Melange clays revealed shear zones where no seepage or increase in moisture content could be detected and where the shear plane clay, resting on hard slickensided shear surfaces, was of very stiff to hard consistency (Pits 15 and 16, Appendix 1B). These shear zones appeared to be associated with old landslide movements and probably reflect subsequent desiccation of the slip mass due to changing local or regional groundwater conditions over a prolonged time period.

Particular problems may be encountered in the subsurface detection of landslides involving the Melange Formation when movement is not indicated by a clearly anomalous position of these deposits on the valley slopes. Due to its mode and environment of deposition as a submarine debris flow(s) in the Late Cretaceous (Chapters 3 and 6), the textural characteristics of the Melange are very similar to those found in recent sub-aerial debris flows (Swarbrick and Naylor, 1980; Johnson, 1970, 1984; Kelsey, 1978). The 'in-situ' Melange rests unconformably on either the allochthonous sedimentary rocks of the Mamonia Complex or on the Kannaviou sediments (Figure 5.1). Virtually everywhere the contact with the clast-free Kannaviou clays is sharp, with the Melange immediately above the contact often showing inverse grading and containing fewer and smaller clasts than average (Swarbrick and Naylor, op. cit.). Such features are also encountered in pit excavations and cutting exposures in landslipped Melange (clearly indicated by topographical evidence) that has been displaced over the Kannaviou clays. In these excavations and exposures, subsurface evidence of 'recent' landslide movement could be positively ascertained only by the identification of a distinct slickensided shear surface or shear zone either within the Melange itself or the immediately underlying Kannaviou clays (e.g. Pits 16 and 10B, Appendix 1B).

In their study of the depositional environment of the Kathikas Melange in SW Cyprus, Swarbrick and Naylor (op.cit.) state that the Melange matrix "only rarely has a polished slickensided fracture surface or scaly foliation" and that these features "only occur in recently landslipped masses of melange". Although the precise meaning of the term 'fracture surface' as used by Swarbrick and Naylor is rather unclear, the Melange pit sections in the current investigation showed that slickensided <u>shear</u> surfaces or zones, as described earlier, were found only in Melange that had undergone Recent landslipping. Examination of the pit sections and undisturbed block samples also revealed that the matrix of landslipped Melange was commonly characterised by small-scale, randomly-orientated, tight, slickensided, shear discontinuities giving these deposits a rather 'scaly' appearance. This 'penetrative' shear fabric (i.e. continuous throughout the mass, as opposed to shear surfaces concentrated in individual shear zones) was not positively identified in Melange deposits that were not involved in recent landslipping. Insufficient detailed examinations of intact Melange samples were carried out in the present study to confirm that these 'scaly' structures are confined only to 'recent' landslipped material, however, observations to date would tend to suggest that this may be the case. The recognition of these small-scale shear discontinuities in Melange excavations may therefore be a positive indicator of recent landslipping and/or ground potentially subject to future mass movement as a result of, for example, earthquake shocks or imposed engineering works.

Where the Melange overlies the sedimentary rocks of the Mamonia Complex, the basal contact may show a lateral and/or vertical gradation from broken Mamonia lithologies, through an 'immature' melange, into the Melange proper (Swarbrick and Naylor, op.cit.). In the Statos study area, a superficial melange-like deposit (the 'Superficial Melange') was identified, forming a superficial cover over large tracts of the sedimentary Mamonia Complex rocks from which it is derived (Chapters 6 and 7). This deposit is in part synonomous with and lithologically akin to the 'immature melange' described by Swarbrick and Naylor. This deposit, although possessing a dominantly argillaceous matrix has not undergone break-up and mixing to the extent of the Melange proper, and as a result, contains within the matrix many tabular or platy clasts of bedded chert, sandstone and weak fissile red mudstone or shale. Subsurface detection of landslipping within this deposit, with or without admixture of the Melange proper, may be ascertained by the identification of a continuous shear surface or shear zone often characterized by the preferential orientation of the platy or tabular clasts aligned sub-parallel to the direction of ground movement (e.g. Pits 5 (85), 6(85) and 7(85), Appendix 1B).

8.2.2.2 Boreholes.

Boreholes are the only way to examine materials at depths greater than about 3 metres without resorting to multi-stage pit and trench excavations. Homogeneous cohesive soils present few difficulties in the recovery of undisturbed core sample or samples obtained from hydraulically driven steel cylinders (e.g. U100 samples). However, few areas in the present study whether slipped or in-situ showed significant thicknesses of these materials. The Melange, for example is a heterogeneous polymict deposit with consistency and grain size varying from firm clay to hard boulders. Core drilling in such deposits is difficult and the recovery of full and undisturbed core-runs is virtually impossible. Core drilling in the Kannaviou Formation poses fewer problems but relatively rapid vertical facies changes and 'tectonized' shear zones, resulting in frequent sequences of highly sheared and structurally weak clays and mudstones, again inhibit full recovery of undisturbed core (e.g. Boreholes EG 28/84 (D1) and EG 29/84 (D2), Appendix 1A).

The conclusion to be drawn from drilling boreholes in heterogeneous deposits, particularly near-surface polymict ('melange-like') landslip deposits, is that it is usually unsuitable for the preservation and recovery in an undisturbed condition of small and subtle indications of structure. This often includes landslip shear surfaces which, as described earlier, may be represented by 5-20mm thick zones of soft plastic clay particularly susceptible to drilling disturbance or washing out by drill flush. In the present study, it was found that the use of boreholes for the subsurface recognition of mass movements was best reserved for the determination of major boundary positions, both within landslipped material and between landslipped and in-situ deposits, and for obtaining a general assessment of the nature of these materials. As described in Chapter 5, section 5.2.3.3, this was carried out primarily by continuously-sampled augered boreholes drilled to a maximum depth of 18 metres. Alternating bulk, undisturbed (U100) and standard penetration testing/sampling (SPT) in each borehole enabled a continuous record of lithological and approximate structural characteristics to be determined and major boundary positions to be identified. For example, Borehole Log EG 22/84 (A4), Appendix 1A, clearly indicates an inverted sequence of landslip deposits probably representative of three distinct phases of movement. Borehole Logs EG 24/84 (A8), EG 25/84 (A7) and EG 26/84 (A6), Appendix 1A, show the existence of landslipped Melange and Kannaviou deposits overlying 'in-situ' Kannaviou sediments.

The inability to detect landslip shear surfaces was a major limitation of these borehole investigations. Thus, although, in BH EG/24 (A8) for example, a major boundary between slipped Melange and Kannaviou sediments was identified, it is not certain if the landslip shear surface was located at this lithological interface or within the immediately underlying Kannaviou clay, or if secondary shear surfaces were present within the Melange slip mass itself. A further limitation was the inability to determine major landslip boundaries below 18 metres (the maximum depth of the augered boreholes). High quality core drilling using sophisticated hardware such as triple-tube core barrels may return sufficiently undisturbed Kannaviou core to enable the accurate identification and location of landslide shear planes. If the shear surface is at the Melange/Kannaviou interface, however, the inherent problems in recovering any sufficiently undisturbed core, regardless of hardware, through the Melange sequence would still make shear surface detection uncertain. For regional surveys in extensively landslipped areas such as those in SW Cyprus, the cost-effective use of sophisticated core drilling and specification of any borings to depths in excess of about 20 metres for sub-surface landslide recognition is questionable. Such investigations can perhaps only be justified for the detailed assessment and stability analysis of individual landslides in situations where potential movement poses a threat to human life and/or existing or proposed high-cost engineering structures.

8.2.2.3 Geophysical Methods.

Geophysical methods involving resistivity or seismic refraction techniques[1] may, in some situations, be used as a useful supplementary tool for the indirect subsurface detection of landslipped ground. At the present time these methods are rarely adopted as a routine and integral part of landslide surveys and should never, in any case, replace borings or pit excavations. A major disadvantage with both resistivity and seismic refraction techniques, is that data interpretation is difficult and largely conjectural where strata are not horizontal or uniform in thickness and where contrasts in the resistivities or seismic velocities of the materials are not sharp. The seismic refraction technique is also limited to strata that are successively more rigid with depth; it cannot differentiate softer strata below rigid ones. In relatively homogeneous material the failure surface of a landslide may sometimes be detected as a zone of low resistance due to the concentration of moisture; however, the lithological, and often structural and hydrological, complexity of most landslide deposits invariably precludes positive identification of any shear surface.

As noted in Chapter 5, limited geophysical resistivity surveys were carried out at two localities in study Area 1 near the villages of Kannaviou and Phiti (G.R. 597 638 and 577 660, respectively). The surveys were centred on two major sandstone outcrops occurring within a thick sequence of Kannaviou clays and mudstones. Near Kannaviou village (Fig. 8.2a), the sandstone crops out as an 800 metre long ridge, marked along most of its length by a 10-15m high upslope-facing scarp. Bedding features are difficult to distinguish, but the upper exposed surface shows a marked southerly (downslope) dip of c. 30°. Superficially, the feature shows characteristics similar to that of a large translated 'block', but geological field evidence indicates that the outcrop is part of an extensive in situ sandstone sequence with the upslope-facing scarp formed by

[1] A detailed description of these methods is beyond the scope of this report and is not, therefore, presented here. For further information the reader is referred to any standard geophysics text.

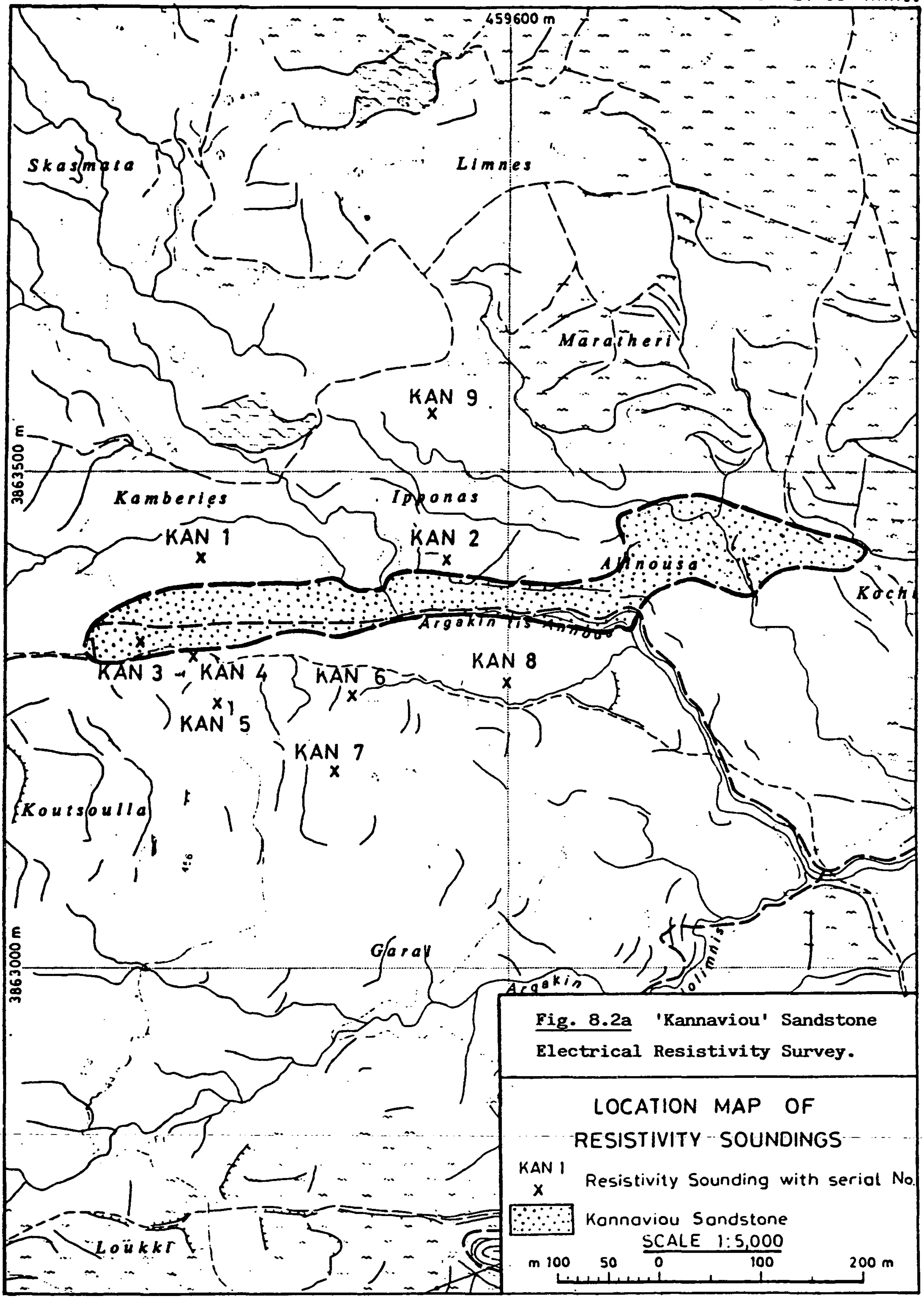


Fig. 8.2a 'Kannaviou' Sandstone Electrical Resistivity Survey.

(from GSD Report No. G/GP/5/84; Kramvis, 1984) fault displacement and\or stream erosion along an E-W striking fault zone (rather than representing the trailing scarp of a translated sandstone 'block'). Geophysical resistivity measurements were carried out to see if this technique could trace the steeply-dipping sandstone band below a sequence of Kannaviou clays and detect any downfaulted sandstone immediately upslope (northwards) of the main scarp. Despite uncertainties in the resistivity interpretations (incurred largely as a result of topographic irregularities) sufficient resistivity contrast between the clay and sandstone lithologies was obtained in six soundings on the 'dip-slope' side of the scarp (Fig. 8.2a, soundings KAN 3-8) to identify and trace the sandstone feature as a continuous, steeply-dipping, c.20 metre thick 'sheet' for some 200 metres downslope. Immediately to the north of the scarp, two soundings (Fig. 8.2a, soundings KAN 1 and 2) did not indicate the presence of sandstone to a depth of at least 30 metres, whilst sounding KAN 9, 200 metres further upslope, recorded decreasing resistivity values with depth which were interpreted as indicating the presence of clays to depths in excess of 69 metres.

The sandstone feature near Phiti village differed from that near Kannaviou village by having a pronounced into-slope dip of c. 15°. Superficially, this 15 metre thick outcrop resembled a back-tilted slump block characteristic of rotational landslide movement. The absence of a landslip backscarp or a significant thickness of sandstone cropping out upslope did not, however, suggest rotational landslipping. Also, similar 'into-slope' dipping sandstone outcrops were observed at a similar elevation across the Kannaviou clay slopes, indicating that the sandstone (as near Kannaviou village) formed part of a continuous, folded (and possibly lenticular), faulted 'sand-sheet'. The Phiti sandstone feature did, however, show evidence of displacement or distortion across a 10-12 metre high, 200 metre long scarp face which marked the downslope side of the outcrop. (Fig. 8.2b, Photos. 8.3 and 8.4). For a distance of 60 metres along the western side of the NE-SW trending outcrop, the scarp face was near-vertical and characterised by incipient toppling rockfall failures with mounds of fresh sandstone debris accumulated at

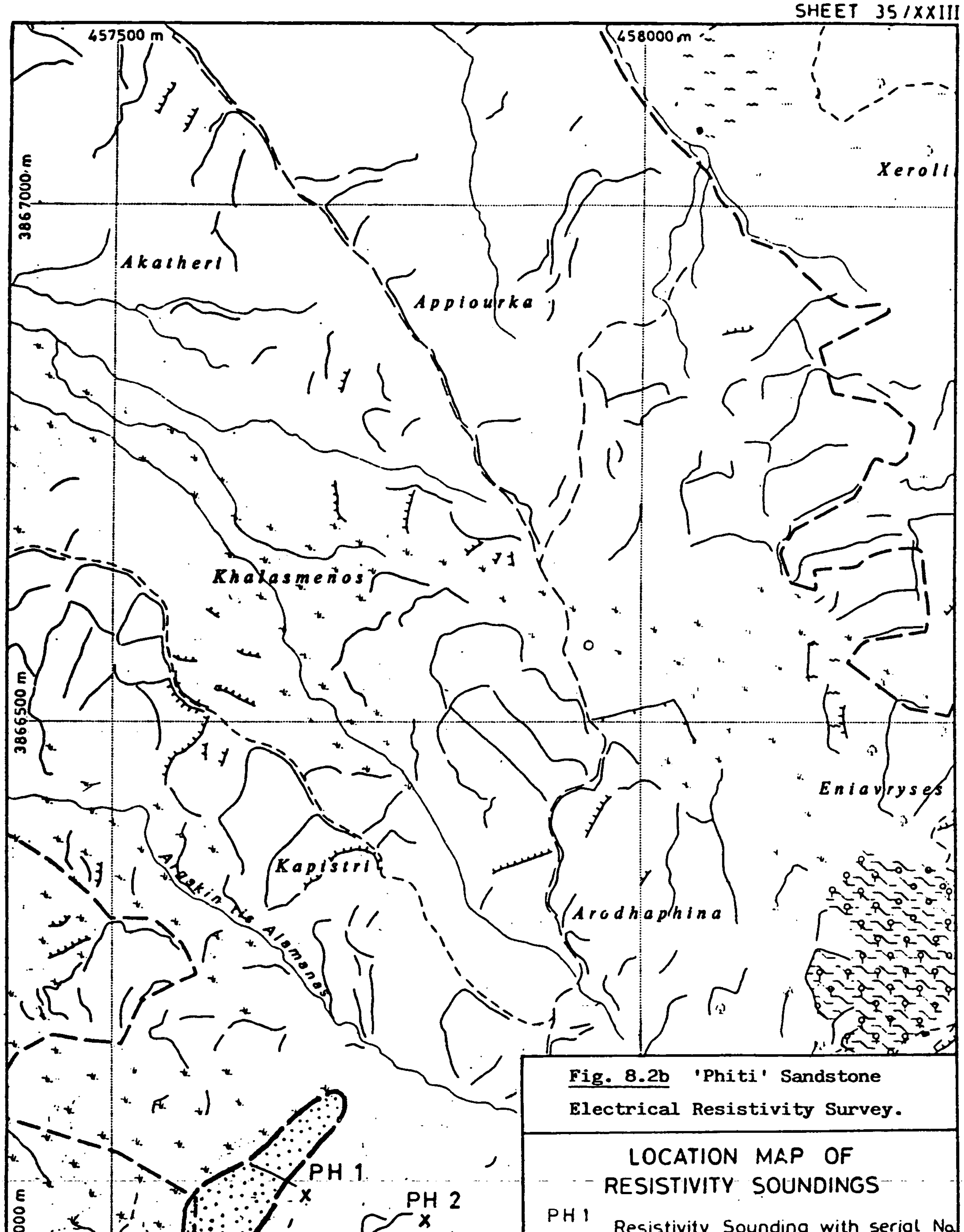


Fig. 8.2b 'Phiti' Sandstone Electrical Resistivity Survey.

(from GSD Report No. G/GP/5/84; Kramvis, 1984) the scarp foot. A 10-12 m wide zone of disturbed, broken rock separated this unstable section from the rest of the scarp face which stood at an angle of c. 65-70° and showed no evidence of rockfall instability apart from mounds of old vegetated debris at its foot. The possibility existed that distortion of the sandstone outcrop may have arisen as a result of detachment from the main sandstone band accompanied by limited displacement downslope as a translated block. Resistivity soundings (PH1 and PH2, Fig. 8.2b) were undertaken in an attempt to detect and trace the 'into-slope' continuity of the steeply-dipping sandstone body as was achieved at the locality near Kannaviou village. An irregular hummocky topography and steep ground slopes, however, incurred marked uncertainties in the interpretations of the two resistivity soundings and additional soundings were not considered worthwhile. At sounding PH1 sited over the sandstone band, an overburden of clay prevented determination of a 'true' measure of the resistivity and a unique solution for the thickness of the sandstone. Sufficient resistivity contrast was obtained, however, to detect the sandstone at a depth of between 5.3 and 7.2 metres. Sounding PH2, a further 120 metres upslope, failed to detect any sandstone to a depth in excess of at least 24 metres. This latter result, led to the tentative conclusion that the sandstone could indeed represent a detached slide block. This interpretation was subsequently tested by comparison with results obtained from a cored borehole (BH EG 29\84 - D2, Appendix 1A), drilled to determine the Kannaviou succession, at the site of sounding PH2. Field dip measurements at outcrop show that the sandstone was detected in the borehole as a c. 10 metre thick band 42 metres below ground surface. The boring also showed at least three siltstone/sandstone bands, 1-3 metres thick, occurring within the upper 28 metres; none of which could be detected by the resistivity soundings.

It was concluded from the field and borehole data that the 'Phiti sandstone' outcrop is in-situ, and that distortion of the sandstone mass is due to differential 'foundering' in-place, i.e. with no significant downslope displacement (translation). Foundering and tilting, giving rise to active rockfall instability as described above, was probably the result of softening and weakening of the underlying Kannaviou clay by groundwater concentration and seepage at the basal sandstone-clay contact. Old and partly re-activated debris flows comprising clay with incorporated blocks of sandstone rock debris extend for 250 metres downslope of the present scarp (Photo. 8.4), and these shallow slides and flows have almost certainly exacerbated foundering by the removal of underlying support at the sandstone base. The 10 metre wide zone of disturbed, broken rock which separates the 'tilted' active scarp from the more stable section probably represents a small NW-SE trending fault which in addition to weakening the rock mass, has probably concentrated, or influenced, groundwater flow and the occurrence of shallow landslides in the underlying clay, leading to differential distortion of the sandstone.

The findings of the geophysical surveys carried out near Phiti and Kannaviou have shown that resistivity soundings yielded only limited success in the detection of steeply-dipping sandstone strata within the variable clay-mudstone-siltstone and sandstone sequences of the Kannaviou Formation. Serious limitations in the interpretation of resistivity (and seismic refraction) records are incurred due to the geological complexity and steep, irregular topography encountered in the landslide-prone regions of SW Cyprus and in similar terrains elsewhere. In these areas, it is therefore unlikely that geophysical techniques can provide, as a routine integral part of <u>regional</u> landslide surveys, a useful supplementary method for the subsurface detection of displaced ground.

Full details of the methodology and results of the resistivity surveys described above are given in GSD Report No. G\GP\5\84 (Kramvis, S; 1984).

8.3 Classification of Slope Movements

Numerous schemes have been established for the classification of slope movements, each having some usefulness in emphasizing features pertinent to identification, avoidance, control or other purpose for which they were designed. Although demands for a standardization of terminology continue, a rigid classification is perhaps neither practical or desirable for slope stability assessments carried out in widely differing geological, topographical and climatic terrains and with different ultimate aims.

In the present study, the classification of slope movements in the Phiti and Statos areas was based largely on the schemes of Skempton and Hutchinson (1969) and Varnes (1978). This classification is constructed using readily observable surface morphological features in order to facilitate a relatively rapid regional investigation based on the study of topographical maps and aerial photographs in conjunction with a 'walk-over' field survey. The chief criteria used were:

(1) Type of movement (primarily)
and (2) type of material involved,
(3) estimated depth of movement,
(4) state of activity (secondarily.)

(1) Five types of movement have been recognised, namely: Falls, Rotational and Translational movements, Flows and Founders. Slope failures may be 'simple', comprising only one mode of movement, or 'complex', comprising a combination of the major modes of movement.

(2) The terms 'bedrock', 'cap-rock', 'debris', 'earth' and 'mud' have been used to describe the main material types involved in the slope movements. These divisions of material type are entirely gradational and are defined as follows:

<u>Bedrock</u> - Unaltered geological substrate underlying weathered/superficial materials and in outcrop.

<u>Cap-rock</u> - Rock strata forming (capping) the upper part or crest of a valley slope; usually comprising

chalks/marly chalks of the Lefkara Formation in study Area 1, and chalks/marly chalks/limestones of the Lefkara, Terra and Pakhna Formations in study Area 2.

Debris - Surface accumulation of weathered and fragmented rocks or argillaceous material that contains a relatively high percentage of cobble- to boulder-sized clasts and coarse fragments. Deposits of chalk talus form a common type of rock debris that in many areas covers the basal contact of the chalk cap-rock with the underlying clays. These deposits are particularly extensive in Area 2 where they are involved in widespread landslipping.

Earth/Mud - Surface accumulation of plastic, water-saturated, argillaceous debris that contains at least 50% sand-, silt-, and clay-sized particles with or without admixture of subordinate comminuted material of other rock types.

(3) An arbitrary distinction has been made between deep-seated and shallow slope failure movements, based on a visual assessment generally without recourse to subsurface information.

(a) A landslide has been designated as deep-seated if the failure has involved bedrock to a depth estimated as being in excess of approximately 5 metres. These failures invariably incorporate a significant part of the cap-rock forming the slope crest and, in the two study areas, include the larger Rotational and Translational slides, and Founder failures described in Section 8.4, below.

(b) Landslides designated as shallow typically involve near-surface weathered bed rock and/or superficial material. Depth of failure is usually governed by heterogeneities of structure and material and is generally less than about 5 metres.

(4) The activity state of the landslides has been described as either active or dormant. The distinction between these two states is not always clear and may be complicated by rejuvenation resulting from climatic or man-made causes.

(a) Landslides were classified as active if field evidence indicated that movement was occurring at the present time, or within the last cycle of seasons. In such landslides, the morphological features are fresh, usually easily recognizable and have not been significantly modified by weathering processes and erosion. Indications of active movement may include features such as: fresh tension cracks within or at the boundaries of a slip mass; fresh scarps; a wet, spalling or otherwise active toe; recently tilted or uprooted trees; fresh cracking accompanied by heaving or subsidence of road pavements and verges; broken and displaced water pipelines; and cracking and displacement of walls and other engineering structures. Photos. 8.5 to 8.10 show a number of the above features indicative of current or recent activity in the two study areas.

(b) Landslides which showed no field evidence of current or recently active movement within the last cycle of seasons, as indicated by the features described above, were considered to be dormant. The morphological features of these landslides have undergone various stages of degradation by normal weathering processes and a more-or-less continuous vegetation cover has developed over the slip mass.

The active or dormant state assigned to a landslide or landslide area, and illustrated on the 1:10 000 scale engineering geology (landslide) maps which accompany this report, is the state observed at the time of the field survey, i.e. summer 1984-1985. It should be realized that changes in the stress conditions of the landslide slope or shear strength of the slope materials, due to natural or man-made causes, may cause the activity state to change from dormant to active or from active to dormant.

8.4 Slope Movements and Characteristic Landslide Types

Characteristic types of landslide may be distinguished primarily on the basis of type of movement undergone by the displaced slope material. In categorizing the type of slope movements from aerial photography and walk-over field surveys, emphasis was placed on the landslip morphology and arrangement of debris and, hence, an assessment made of the shape of the moving mass at the time of failure. Fig. 8.3 illustrates the characteristic landslide types arising from these movements in the Phiti and Statos study Areas in SW Cyprus.

8.4.1 Types of slope movement

8.4.1.1 Falls

The term 'rockfall' is used to describe the free fall of rock debris and bedding plane- and joint-bounded rock masses under gravity. Movements are very rapid to extremely rapid and may or may not be preceded by minor movements leading to progressive separation of the mass from its source. In the two study areas, rockfalls are primarily associated with the jointed and fractured rocks of the chalk and limestone formations which cap the main valley crests, and with the major outcrops of volcaniclastic Kannaviou sandstones exposed in the clay/mudstone slopes. They occur most often along steep cliffs (>55°), fault scarps, landslide backscarps and steep road cuts, with the size of the individual blocks being governed largely by the discontinuities present in the parent mass. Various types of rockfall instability are illustrated in Fig. 8.4 and Photos. 8.11 to 8.13.

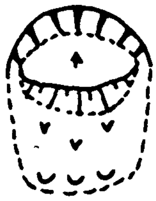
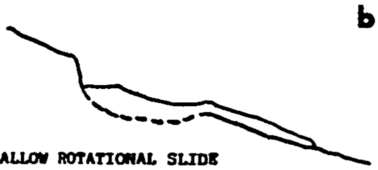
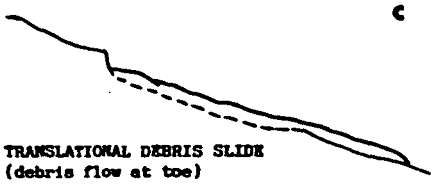
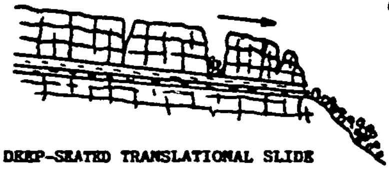
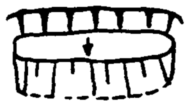
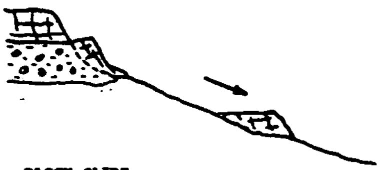
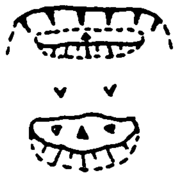
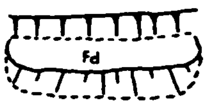
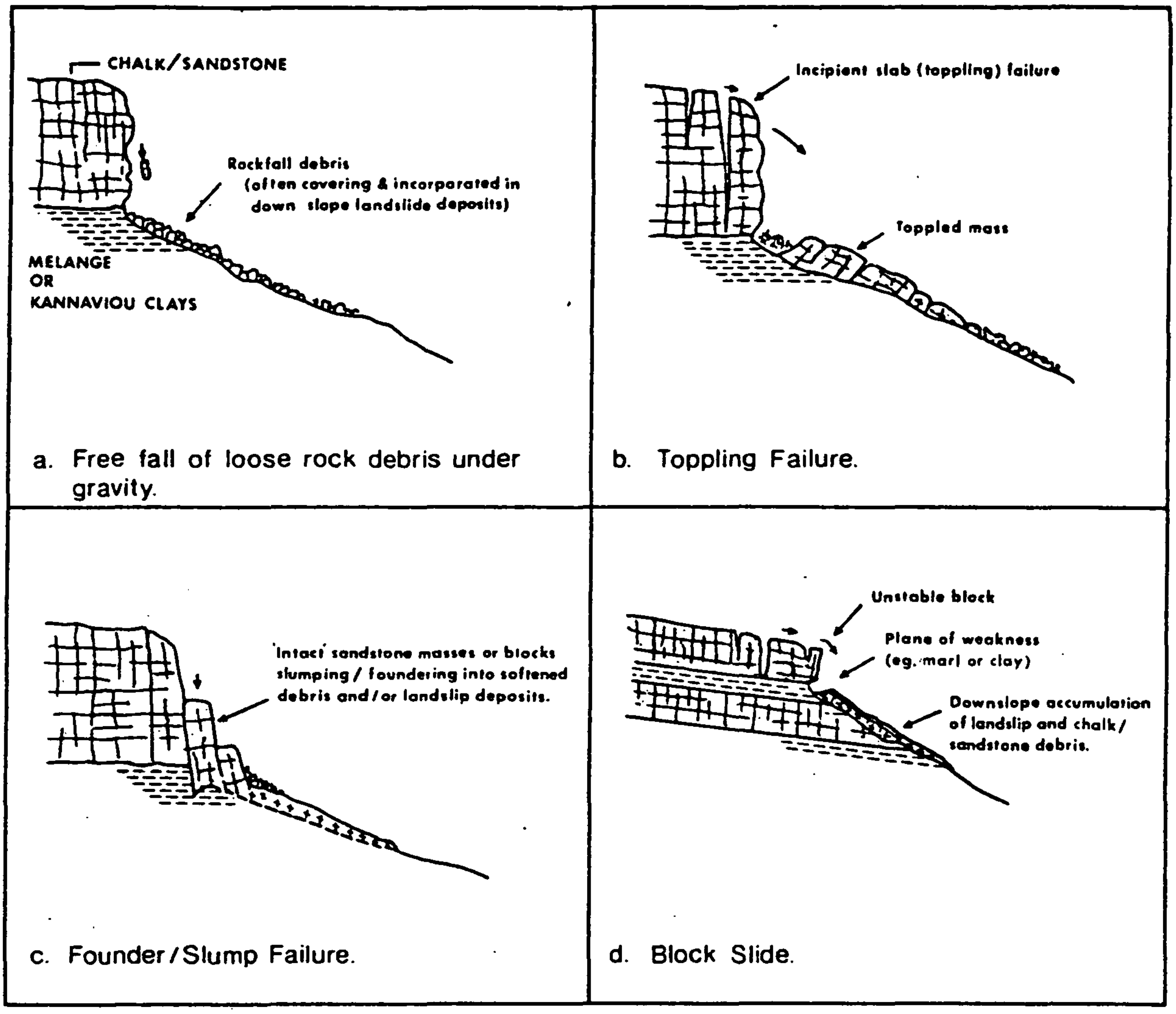
Diagrammatic Cross-sections of Main Slope Movement Types	Symbol on 1:10 000 Scale Engineering Geology Maps	Dominant Material Involved	Average Range of Slope Angles
a  DEEP-SEATED ROTATIONAL SLIDE (debris/earthflow at toe)		Chalk/limestone cap-rock, Kannaviou clays & mudstones, Melange.	$20^{\circ} - 22^{\circ}+$
b  SHALLOW ROTATIONAL SLIDE (debris/earthflow at toe)		Kannaviou clays, Melange, Chalk talus, argillaceous landslip materials.	$18^{\circ} - 20^{\circ}$
c  TRANSLATIONAL DEBRIS SLIDE (debris flow at toe)		Kannaviou clays/mudstones, Melange, Mamonia-derived colluvium, talus.	$10^{\circ} - 16^{\circ}$
d  DEEP-SEATED TRANSLATIONAL SLIDE		Chalk/limestone overlying interbedded marl and marly chalk.	out-of-slope bedding dips: c. 10°
e  BLOCK-GLIDE		Chalk masses/blocks, Kannaviou sandstones.	c. $15^{\circ}+$
f  DEBRIS FLOW		Softened, weathered argillaceous material (Kannaviou clays, Melange, Mamonia-derived colluvium), incorporated clasts of all rock types.	$18^{\circ} - 9^{\circ}$
g  FOUNDERED STRATA (fault-controlled)		Chalk/limestone formations overlying Melange.	—

Fig. 8.3 Characteristic types of slope movements in the Phiti and Statos Study Areas.



a. Free fall of loose rock debris under gravity.
b. Toppling Failure.
c. Founder/Slump Failure.
d. Block Slide.

Fig. 8.4 Rockfall failures associated with the Chalk and Kannaviou Sandstone outcrops.

'Soil' or argillaceous debris falls involving the Melange deposits also occur but are of relatively minor importance. They are associated with the undercutting of steep, gulley-eroded slopes of Melange (e.g. Photo. 6.7) along stream and river courses and from fresh, wet backscars of active or very recent Melange landslides (Photo. 8.6). Isolated falls of course fragments and clasts up to boulder-grade embedded in the silty clay Melange matrix, probably occur continuously on steep unvegetated slopes due to removal of the fine-grained argillaceous material by erosion resulting from high-intensity rainstorms. Matrix erosion is compounded by swelling, shrinking and cracking of the upper few centimetres of the deposit during alternating cycles of wetting and drying.

In general, rockfall failures constitute secondary movements at major landslide and fault scarps formed by initial larger-scale slope displacements. At some of these localities, however, rockfalls have contributed large amounts of rock debris to the slide areas which becomes incorporated in, and forms a major component of, subsequent landslide movements. For example, extensive rockfall detritus is incorporated in debris slides below two major cliff scarps of Kannaviou sandstone in study Area 1 near Phiti (GR 577 660; Photos. 8.4 and 8.12) and Lasa (GR 565 661; Photo. 6.4) villages, respectively. The most extensive rockfall failures occur along the northwest and southeast flanks of the 'Panayia Plateau', extending NE-SW between Panayia (GR 665 643) and Ambelitis (GR 655 605) villages in study Area 2. Here, widespread deposits of chalk and limestone rock debris, derived from large fault and slip scarps (e.g. Photo. 8.13), are strewn over large areas of irregular, stepped terrain formed by deep-seated landsliding. The rockfall deposits combine with numerous broken and disrupted slip masses to form extensive areas of chalk talus which blanket the peripheral slopes of the chalk plateau. At the contact of the plateau chalks and the underlying Melange clay, this rock debris is incorporated in debris slides and debris flows which at some localities extend 1-3 km downslope over the melange outcrop (e.g. near Kilinia and Vrecha villages, GR 663 604 and 687 612, respectively).

8.4.1.2 Rotational slides

Rotational slides occur typically along curved, concave-upwards, failure surfaces that impart a back-tilt or into-slope dip to the slipped mass which thus sinks at the rear and heaves at the toe. At the head area, movement may be almost wholly downward and have little apparent rotation, however, the top surface of the slipped mass commonly tilts backward into the slope. Such slides may be either deep-seated (Fig. 8.3-a) or shallow (Fig. 8.3-b).

Deep-seated rotational movements show a tendency to occur on the steeper slopes (generally >20°) and involve bedrock to a depth in excess of 5 metres. In both study areas, the largest rotational failures, often tens of metres in depth, involve significant masses of chalk caprock that have failed along shear surfaces passing through the underlying Melange and/or Kannaviou clays (Photos. 8.14 to 8.17) In virtually all cases, erosion and subsequent shallow slides and flows have degraded the initial slide features (such as toe heave, en-echelon cracks,etc.) in the clay strata to leave back-tilted chalk masses and prominent chalk backscarps as remaining evidence of deep-seated rotational landsliding.

The backscarps of these deep failures are invariably steep and often spectacular. At many localities the scarps are of 'classic' arcuate shape as shown, for example, at the Old Anadhiou landslide in Area 1 (Photo. 8.14) and the massive landslides near Ayia Moni monastery in Area 2 (Photo. 8.15), but this is not always the case. Often, e,g. near Simou (GR 554 666) and along the north-facing chalk escarpment between Lasa and Phiti villages (GR 572 651; Photo.8.16) in Area 1, and above Pendalia village (GR 651 574) in Area 2, the steep backscarps, although curved at their lateral extremities, are typically linear across their breadth, reflecting dominant fissure, joint and fault trends running sub-parallel to the slope crests (see the 1:10 000 scale engineering geology maps which accompany this report). The most pronounced linear scarps occur along the northwest- and southeast- facing flanks of the 'Panayia Plateau' in Area 2 (an area of widespread rockfall failures, as described above). Here, steep 15-20+m high, irregular but essentially linear scarps extend for up to 1km in breadth at the rear of rotational and complex slides of massive chalk, limestone and rock debris. The scarps clearly follow a major NE-SW trending set of joints and faults which play an important role in controlling the type and extent of the failure movements. It is also evident that a number of the deep-seated rotational slumps, particularly at the higher elevations around the periphery of this plateau, occur entirely within the chalk strata, i.e. the curved failure surfaces do not pass into the underlying Melange clays. These slip masses are invariably joint and/or fault controlled and the main shear surface is probably located in the weaker alternating marly chalk and marl layers within the chalk cap-rock sequence.

In addition to chalk bedrock, relatively deep (>5m) rotational debris slides also occur within the thicker and more extensive deposits of chalk talus, both as secondary failures in the accumulated debris of older slides and as movements initiated by the excavation of road cuts. Although such slides may be in excess of 5m depth, they are not, by definition, true deep-seated failures as the shear surface is contained entirely within the talus material and does not pass into underlying chalk bedrock. Photos. 8.7 and 8.8, for example, show a rotational failure in a c. 20° slope of relatively fine-grained chalk talus that occurred in 1985 during realignment of the road between Panayia village and Chrysorroyiatissa Monastary (GR 6610 6365) in Area 2. During excavation, a steep, 10-12m high road cut in the talus material failed, effectively removing support from the slope and resulting in a rotational landslide. The slide was marked by an arcuate scarp some 80m upslope of the initial road cut and a 20m wide slump mass which disrupted a vineyard, minor road and water pipe. The total width of disturbed ground was approximately 60m and the depth of failure estimated to be in excess of 10-12 metres.

Deep-seated rotational failure movements involving Melange and the underlying Kannaviou clays, but with no chalk caprock, are of relatively frequent occurrence on steeper slopes near the outcropping Melange-Kannaviou contact, particularly in Area 1. In many instances erosion and degradation have obscured much of the characteristic landslip features, but a Melange 'bench' or 'flat' with a reverse surface slope below a steep arcuate backscarp can nearly always be distinguished. These failures tend to grade to debris or mud flows at the toe and, as such, tend to form complex landslide areas. A large and well-defined complex landslide with a deep-seated rotational failure involving Melange and underlying Kannaviou clay at the head is shown in Photo. 8.17, located on the south-facing slope 1km S of

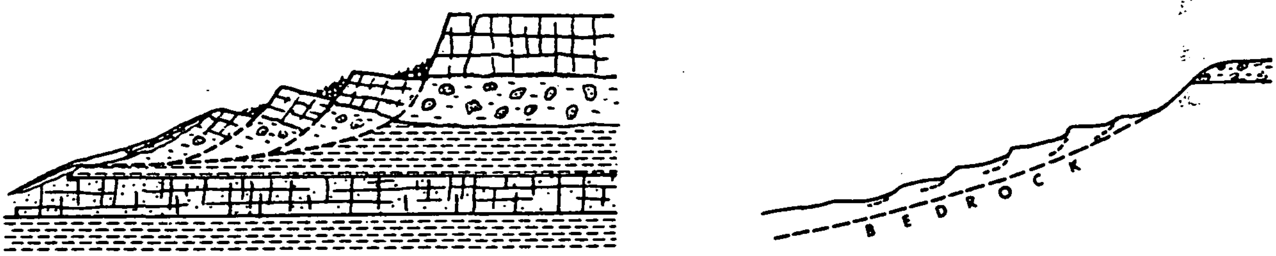
Phiti village in Area 1 (GR 586 643).

Relatively deep-seated rotational movements, on a much smaller scale than those involving the chalk cap-rock and Melange, also occur within the Kannaviou slopes in association with the larger sandstone outcrops exposed within the clay-mudstone sequences (e.g. Photo. 6.4), and, less frequently, within the clay-mudstone sequences with no exposed 'capping' sandstones. In the former case, 'true' rotational slides are often difficult to define owing to degradation of the clay slopes and a cover of rock debris. In many instances, it is likely that sandstone masses have slumped from the cliff scarps as a result of removal of support due to earlier shallow failures of the underlying clays. The slumped sandstone, on becoming embedded or incorporated within the shallow slip debris, may remain adjacent to the back scarp or, with renewed movement, translate downslope as a block-glide, still maintaining a rotational-like backtilt (e.g. below the large sandstone outcrops on the N-facing slopes of Area 1 below Simou and Lasa villages at GRs 557 669 and 566 661, respectively). Rotational slides in excess of c. 5m depth entirely within the Kannaviou clay-mudstone sequences are relatively few and appear to be associated with river or stream erosion at the foot of the affected slope. They are often difficult to identify owing to rapid erosion and degradation, however, a recent and seasonally active example which regularly disrupts an access track is located 2km NW of Phiti village at GR 571 668.

<u>Shallow</u> rotational movements generally less than c. 5m in depth (e.g. Photos 8.18 and 8.19) are of common occurrence throughout both study areas within the near-surface weathered layers of the argillaceous Kannaviou and Melange deposits and the finer-grained deposits of chalk talus. In Area 2 they are also present in the dominantly argillaceous, weathered superficial deposits (e.g. 'Superficial Melange') derived from the sedimentary (or stratified) rocks of the Mamonia Complex. They occur as primary failures in natural slopes, river banks and steep road cuts, but are particularly prevalent as secondary failures in the accumulated debris of existing slides and flows.

Within the clay formations, the rotational element of these slides often tends to break up and grade to debris or mud flows at the foot and in many instances, erosion and degradation have resulted in the slide remnants being represented by vegetated bench-like features below steep arcuate breaks-of-slope indicating degraded backscarps.

Where the main mass of a rotational slide, whether deep-seated or shallow, moves downwards and outwards, the steep backscarp remains unsupported and a new failure similar to the original slump may occur. Also, water ponded or trapped by the backward tilting of the sliding mass may be an additional factor leading to the triggering of additional movements as the stability of the slope is decreased. This repetition of movement gives rise to 'multiple retrogressive' and/or 'successive' rotational landslides as illustrated in Fig. 8.5.



a. Multiple Retrogressive Rotational Slide

b. Successive Rotational Slips

Fig. 8.5 Rotational slides showing repetition of movement. (based on Skempton and Hutchinson, 1969)

Multiple rotational slides, generally deep-seated, are thought to develop from single rotational movements by the occurrence of further retrogressive failures which interact to form a common basal slip surface. Such failures tend to occur within the Melange and/or Kannaviou clay-mudstone sequences overlain by a thick layer of competent chalk. An example of one

FIG. 8.6

Diagrammatic section of the Ayios Photios landslide.

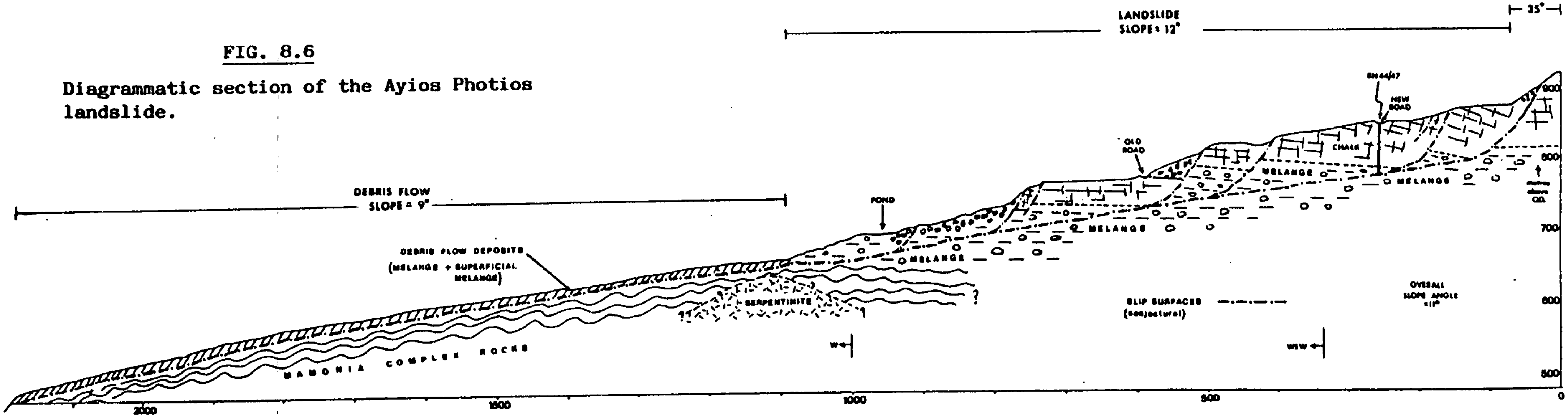
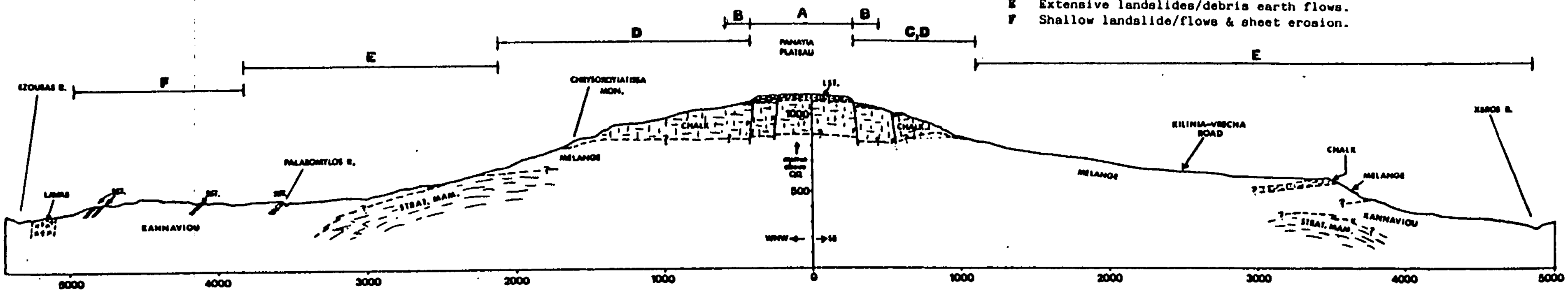


FIG. 8.7 **Diagrammatic section across the 'Panayia Plateau'.**



such landslide which forms part of an extensive area of complex slope movements between Ayios Photios and Statos villages in Area 2 (GR 643 601), is shown in Photo 8.21 and illustrated in diagrammatic cross-section in Fig. 8.6. This type of failure clearly becomes more translational in character as the number of component slip units increases, although, in failing, each block itself rotates backwards. In the absence of a competent chalk caprock, the scarp formed at the rear of the initial rotational slide tends to be rapidly degraded by shallow failures; this degradation inhibits the retrogressive development of further deep-seated movements.

Successive rotational slides consist of an assemblage of shallow rotational movements thought to spread upslope following initial failure at the slope foot. They occur most frequently in slopes of Kannaviou clay that are undergoing river or stream erosion at the slope foot. Both regular and irregular varieties may develop; the former producing 'step'-like features across the slope, the latter, a 'mosaic' pattern. A pattern of shallow slips forming regular, vegetated steps or ridges of successive rotational failures across a c. 15° slope of Kannaviou clay is shown in Photo. 8.20, adjacent to the Paleomylos River (GR 638 638) in Area 2.

8.4.1.3. Translational slides

Translational slides generally result from the presence of a plane of weakness beneath, and running more-or-less parallel to, the slope surface (Photo. 8.22). They typically show no rotation or backward-tilting characteristic of rotational slumps and the surface of failure is relatively planar. Both shallow and deep-seated translational movements may occur (Fig. 8.3-c and 8.3-d).

Shallow translational slides are extremely common in both study areas and involve near-surface, weathered Kannaviou clays/mudstones/sandstone debris, Melange, chalk talus debris and, in Area 2, also occur in weathered superficial material derived from the sedimentary Mamonia Complex rocks. They range in size from a few square metres (Photos. 8.23) to complex translated debris accumulations of chalk talus and Melange which may be measured in square kilometres (see the 1:10 000 scale landslide maps which accompany this report). As with shallow rotational slides, translational movements may occur as primary slope failures or as secondary failures involving existing slip material.

Primary shallow translational slides on low-angle slopes may move with little distortion of the sliding mass (Photo. 8.23); on steeper slopes the sliding mass tends to break up and become a debris slide. Such slides involving dominantly argillaceous material often grade into debris flows. The depth of these slides is generally controlled by a plane of weakness or heterogeneity below the slope surface. In the Mamonia Complex terrain in Area 2, for example, the form and depth of the slip masses tends to be controlled by the thickness of the weathered superficial deposits which slide along the weathered/unweathered bedrock interface running roughly parallel to the ground surface. In the Kannaviou and Melange terrains the depth of failure is probably also influenced by the depth of seasonal desiccation. During the summer months the upper parts of these deposits dry, and shrinkage, due to the presence of montmorillonite clay minerals, gives rise to cracking of the surface layers. In the Kannaviou clays, in particular, these shrinkage cracks may extend to c. 2m below the ground surface. Translational failures on sufficiently steep slopes may be triggered by heavy rainstorms which, abetted by the open fissures and drying cracks, rapidly wet these dry surface layers causing swelling, weakening and increasing pore pressures in the clays above the zone of permanent saturation.

The most extensive translational slides involve huge accumulations of broken chalk blocks and 'talus' debris derived from the distortion and breaking up of deeper (largely rotational) failures from the steeper slopes at or near the Melange/chalk contact. Following these initial failures, the chalk and incorporated melange debris has extended by further (largely translational) slide movements across the Melange, Kannaviou, and Mamonia Complex slopes. These slides are particularly well-developed around the periphery of the 'Panayia Plateau' in Area 2 at and below the villages of Mamoundali, Statos, Galataria, Kilinia and Vrecha (see accompanying 1:10 000 scale landslide map). Although dominantly translational in character, the largest slides (e.g below Vrecha village) tend to be somewhat complex in that they are accompanied by secondary rotational and flow failures and are probably the result of successive phases of movement leading to debris accumulations, in places, tens of metres in thickness. In both Areas 1 and 2, extensive isolated deposits or 'patches' of Melange with subordinate chalk and incorporated Kannaviou-derived debris occur on the Kannaviou slopes up to 2km below the in situ Melange outcrop. These would appear to represent the translated remnants of larger, possibly rotational, failures that were initiated upslope at or near the Kannaviou/Melange contact. Boreholes EG 24/84(A8) and EG 25/84(A7), drilled in two of these remnant Melange slips located on the lower, north-facing Kannaviou clay slopes below Phiti and Simou villages in Area 2, recorded Melange thicknesses (i.e. depth to the slipped Melange/Kannaviou clay contact) of 11m and 12.5m, respectively.

Deep-seated translational slides occur typically in the well-jointed and faulted chalk/limestone cap-rock. In primary failures (e.g. Fig. 8.3-d), the slip block separates from its parent mass along steeply-inclined joints, fissures or faults, and slides as a 'unit' on a well-defined plane of failure, usually a bedding plane. They are, therefore, generally confined to massive bedded chalk and limestone strata where the bedding dips towards the slope, with the dimensions of the slide block controlled by the spacing of bounding discontinuities. These deep-seated movements occur in Area 2 on the NW and SE flanks of the 'Panayia Plateau' between the villages of Panayia and Ambelitis (Fig. 8.7). On the middle and lower flanks of the plateau, primary deep-seated translational slide blocks are difficult, if not impossible, to identify owing to the complexity of the area in terms of extensive slope failures and broken masses of chalk covered in rock debris of all sizes. In these areas, on both the NW and SW slopes, the disturbed chalk blocks and masses show a preponderance of reverse dips or back-tilts, tending to indicate that the majority of primary, or initial, failure movements are rotational rather than planar. On the higher elevations of the plateau, particularly above c. 1000m AMSL within the Terra limestone and capping Pakhna chalks, large block slides can be seen at various locations round the main scarp. Photo. 8.24 shows the rear of a typical failure some 150m in breadth, with the displaced chalk/limestone mass separated from the in situ scarp by a chasm 30-40m wide. Bedding dips varying from sub-horizontal to c. 10° downslope in the intact chalk are reflected in the slip block which shows no evidence of back-tilting. Rockfall debris has accumulated below the foot of the slip block, grading downslope to rock debris slides above large slumped benches of displaced chalk.

It is probable that these slide blocks at the upper levels of the plateau are failing along a plane, or planes, of weakness provided by marl or chalky marl bands within the Lefkara chalk sequence which underlies the Terra limestones. Such failures are often initiated by removal of support from steep slopes or cliffs by earlier landslides or fault movements and occur when the inclination of the slope exceeds the angle of internal friction of the rock mass along the failure plane. If failure is occurring along a marl layer, the shear strength along this surface will also be reduced by increased pore-water and swelling pressures as a result of water permeating through the overlying fissured and jointed chalk and limestone. Within this area, however, the majority of these failures are probably triggered by earthquake shocks.

The flattish top of the Panayia Plateau is characterized by extensive, intersecting open joints and deep, talus-filled linear depressions or gullies, possibly reflecting fault lines, trending NE-SW and NW-SE (see accompanying 1:10 000 scale engineering geology map). These discontinuity lines indicate alignments along which further movements may occur. Indeed, the extent of these lines of weakness when seen on the air photographs, would tend to indicate that the 1.5km long limestone-capped plateau is undergoing massive tensional failure. Exacerbated by softening and swelling of the underlying Melange clays and removal of support by slope failures on the middle and lower plateau slopes, further large-scale failures of the massive chalks seem inevitable, particularly given the occurrence of periodic earthquake shocks. Immediately to the SW of the plateau surface, between the lower and apparently more stable chalk plateau surface on which Ambelitis village (GR 654 605) is sited, landslides initiated on the SE- and NW-facing chalk/limestone slopes have coalesced, and for a distance of some 500 metres no intact plateau surface remains (approx. GR 658 618).

The majority of translational block-glides involving large masses of chalk, probably occur as secondary (but still significant) movements following initial large-scale rotational failures of capping chalk and underlying Melange and Kannaviou clays (Fig.8.3-d). At many localities around the chalk plateaux in both Study Areas, backtilted blocks of chalk have translated downslope across the Melange and Kannaviou clays to rest, in places, more than a kilometre below the in situ chalk scarps. In some cases, e.g. at the upslope limit of the now abandoned village of Statos (Area 2, Gr 645 612), the upper surfaces of these chalk glide blocks are covered by subsequent deposits of slipped Melange debris. These displaced blocks (or their broken, degraded remnants) are clearly indicated on the 1:10 000 scale map sheets, and one such block below the Lasa-Phiti scarp in Area 1, is shown in Photo. 8.25. A particularly large 'intact' mass of displaced bedded chalk with a pronounced 10-15° backtilt resting on, and overlain by, Melange occurs 1km south of Vrecha village (Area 2, at GR 685 598) and is shown in Photo. 6.15. This chalk mass shows a minimum outcrop thickness of c. 10-15m and appears to have reached its present position on the Melange slope as a large block slide, following detachment from in-situ chalk upslope by possible earthquake shocks, down-faulting and/or rotational slumping. The glide block was then subsequently covered by slipped Melange debris. It is difficult to explain why such a large mass, some 2.5km below the present chalk-Melange contact, has remained apparently intact, and pending detailed subsurface investigations, its interpretation as a massive translated block remains conjectural.

GSD hold many records which describe ground movements affecting villages around the chalk outcrops following the severe 1953 earthquake. It is interesting to note that a number of these documents report that following the first catastrophic (dominantly rotational?) landslides, many of the subsequent slips were of villages sitting on blocks of chalk, limestone or talus that were moving en-masse (i.e. as translational block-slides) downslope on the underlying Melange clays. The occurrence of these secondary translational displacements as an important slope movement type in the two Study Areas, is borne out by the present landslide investigation.

8.4.1.4 Flows

The characteristic feature of flow failures (Fig. 8.3-f) is that the material involved breaks up as it moves downslope and flows as a viscous fluid, generally elongate or lobate in form. In the literature, the terms debris flow, earthflow, mudflow, mudslide, mudspate, and others, have been used to identify these and closely related slope movement processes. In the present study, the term 'debris flow' is preferred as it more accurately describes the nature of the Kannaviou-, Melange-, chalk-, and Mamonia-derived material involved in the majority of these slope movements in the two Study Areas; implying slipped material comprising a mixture of earth, mud, water, boulders, other granular solids, and incorporated vegetation similar to that described by Johnson (1970) and Johnson and Rodine (1984). Dominantly argillaceous flows, with little or no incorporated granular clasts of cobble- and boulder-size, occur within the Kannaviou clay outcrops on a relatively small scale. These flows are a particular type of debris flow, and are referred to here as 'earth flows' in order to differentiate them from the larger and lithologically more heterogeneous debris flows which comprise the majority of these movements.

The most common conditions noted in the literature that favour the development of debris flows are abundant water; unconsolidated source material; slopes steep enough to induce flowage in the material; and in most, but not all, cases, insufficient protection of the ground by forest cover. The availability of sufficient water for mobilization has long been recognised as a necessary condition for debris flow, and in the Phiti and Statos study areas this is provided by torrential rainstorms and by springs discharging within the debris (particularly from those issuing at the contact of the fissured chalk aquifers and the underlying Melange clays, but also from springs and seeps at various levels within the hillside slopes).

The size of the debris flows found in the Study Areas ranges from relatively small earthflows composed almost entirely of Kannaviou clay, formed at the foot of shallow rotational slides (Photo. 8.26), to massive debris flows incorporating argillaceous and granular material from virtually all rock types (Photos. 8.27 and 8.28). These large debris flows, with narrow elongated mid-portions that terminate in bulbous toes at river sections, are topographically similar to the 'earthflows' in the Fransiscan Melange of California described by Kelsey (1978). They occur as characteristic features on the slopes of Melange and Mamonia Complex rocks in Study Area 2. The debris flow shown in Photo. 8.27, for example, heads at the currently active lower scarp of the multi-rotational Ayios Photios landslide (see Photo. 8.21), ending in a river section 1.5km downslope of the landslide headscarp. The flow material incorporates chalk, Melange and weathered Mamonia debris which extends across a 9-10° slope underlain by rocks of the Mamonia Complex.

The large debris flows are nearly all confined to 'channels' or valley-like depressions, and this seems to be a necessary condition for the extensive downslope development of these features. The Ayios Photios debris flow and the debris flow shown in Photo. 8.28 (located 1.5km N of Phiti, GR 576 667) involving Melange, Kannaviou and subordinate chalk deposits, are 'channelized' in valley-like depressions in the Mamonia and

Kannaviou rocks, respectively.

Within the Study Areas, virtually all the debris flow failures initiate as parts of landslide masses within the Kannaviou, Melange, and weathered Mamonia rocks, which may or may not involve overlying chalk. There is a complete gradation from debris slides to debris flows depending on water content, mobility, and character of movement. This may be shown diagrammatically as:

Water content increasing

Rate of movement increasing

ROTATIONAL SLIDES / TRANSLATIONAL SLIDES

(softened, remoulded debris with usually a high percentage of coarse fragments and clasts to boulder-grade incorporated in a finer-grained matrix)

↓

DEBRIS FLOWS (& EARTH FLOWS)

(>50% sand-, silt-, clay-size material with little or no admixture of granular clasts of cobble- to boulder-grade)

↓

MUDFLOWS

The essential role of the sliding is to jostle and dilate the slide mass so that its water content is increased, and to remould the material so that its strength is reduced towards minimum values. The changes in apparent (undrained) strength properties during the transformation of a landslide mass into debris flow appear to be critical in the process of initiation of most debris flows (Johnson and Rodine, op cit). Only such remoulding can explain the ability of landslide masses that fail on chalk/Melange slopes of 25-35°, to transform into flowing debris that can move over slopes of 9° or less.

Although 'flow' is a dominant movement mechanism by which these slope failures progress down the valley slopes, the overall movements of the larger debris flows are clearly quite complex, involving translational sliding and rotational slumping as well as viscous flow. These complex movements are largely related to varying water contents and densities of the debris flow mass and topographical irregularities of the underlying slope. The flatter, less disrupted debris flow segments tend to move downslope by translational sliding on basal shear surfaces (e.g. Photo. 8.22). In contrast, 'extending' flow over the slope convexities results in tension cracks and shallow slumps that are common over the steeper debris flow slopes. The surface expression of 'compressional' flow over concave portions of the slope (indicated by pressure ridges and furrows developed parallel to the slope contours) were difficult to see by field inspection owing to erosion and vegetation cover, however they were identified from aerial photographs in some of the more recent Melange/Kannaviou debris flows in Area 1 (e.g. at GR 577 675). The lobate form of the toes and the piling up of debris flow colluvium behind large incorporated blocks, are evidence of flow within the debris flow mass above any sliding planes. Small debris (earth) flows are generally less complex but are commonly bounded by discrete basal, and often lateral, shear surfaces and the flow debris is often marked by secondary slumps and flows.

In a detailed study of the 'earthflows' in the Californian Franciscan Melange, Kelsey (1978) found that seasonal ground wetting of the earthflow slopes, which increases pore water pressures and reduces intergranular friction, is a major factor contributing to movement of these flows. Monitoring studies showed that after initial wetting during the first two or three rains, major episodes of movement coincided with periods of heavy rainfall. Seasonal movements of the active debris flows in the Phiti and Statos study areas also probably coincide with periods of intense winter rainfalls. Although detailed rainfall/debris flow movement correlations were not carried out in the present study, analysis of the 1963 aerial photography cover of the study area revealed widespread active debris flow movements that could be related with periods of heavy rainfalls recorded for the period Oct. - Dec. 1962.

A further major factor contributing to debris flow movement appears to be the removal of lateral support by erosion of the debris flow toes. For example, the toe of the seasonally active Ayios Photios debris flow is undergoing active river erosion and suffers additional removal of support by shallow rotational slumps from the over-steepened toe snout (Photo. 8.27). Indeed, as concluded by Kelsey (op. cit.) for the Franciscian 'earth flows', lateral support appears to exert a significant control on the movement of the large debris flows in the study areas, as indicated on the 1:10 000 scale engineering geology map sheets by the coincidence of actively eroding river/stream channels and 'active' debris flow movements.

Detailed analysis of individual debris flows in Study Areas 1 and 2 was beyond the scope of the present study. However, for an extensive review of debris flow movement processes the reader is referred to the excellent account given by Johnson and Rodine (1984) detailed in Section 10, 'Bibliography', of this report.

8.4.1.5 Founders

The term 'Founders' is used here to describe movements involving the foundering en-masse of large sections or blocks of strata along planes of weakness provided by near-vertical faults or joints (Fig. 8.3-g). In the Study Areas, these failure movements are restricted to the chalk/limestone cap-rock, with the failed (foundered) mass showing no appreciable rotational or horizontal displacement. On the 1:10 000 scale engineering geology maps which accompany this report, founder failures are indicated by the symbol 'Fd' on the displaced mass.

Vertical foundering of large blocks of chalk may occur from the backscarps of the larger, usually deep-seated landslides, such as those found 1.5km W of Lapithiou (GR 615 628 in Area 2, or immediately E of Ayios Dhimitrianos (GR 593 628) and along the Lasa-Phiti backscarp (GR 572 651) in Area 1. At some localities it is possible that these blocks may reflect the headward expression of deep-seated rotational failures showing little or no back-tilting. The field evidence, however, indicates that in most cases, these foundered blocks rest on the top of earlier, often back-tilted, slide masses, suggesting that secondary (but still significant) founder failures have occurred following initial rotational failure movements. Removal of lateral support from the rear scarp by the initial slide movement and subsequent earthquake shocks are probably the main contributing factors in promoting these secondary founders along major structural discontinuities.

At two locations (on the northern outskirts of Simou in Area 1, GR 548 670, and on the SE flank of the 'Panayia Plateau' in Area 2), foundering of large sections of chalk strata appears to have occurred along fault planes. At both localities, landsliding has taken place on the steep front faces of the displaced strata. On the 'Panayia Plateau' the foundered limestone/chalk forms a marked bench-like feature 1km long and 100-150m in width (GR 670 623) and shows no indication of rotational back-tilting. Again, the possibility exists that the displaced bench represents the downward headscarp movement of a massive rotational failure, but the extent of the elongate bench-like shape and intact nature of the strata would tend to indicate a less disruptive downward (foundering) movement along a plane of weakness provided by a sub-linear fault plane, probably triggered by earthquake shocks, rather than rotational failure. Although some uncertainty remains as to the actual failure mechanism of these large blocks of hillside strata, the 'Fd' symbols on the accompanying 1:10 000 scale maps indicate that, at the surface, the dominant displacement is a downward, essentially vertical founder with virtually no outward downslope component.

8.4.1.6 Complex landslides

With very few exceptions, nearly all landslides in the study areas can be described as complex, i.e. they show evidence of a combination of two or more of the main movement types described above. Of the variety of complex landslide movements possible on the study area slopes, the most common have been described in the preceding sections. These include multiple rotational movements; the developement of debris or earth flows at the foot of rotational and translational failures due to breaking up and softening of the slide mass; secondary rockfall failures from steep landslide backscarps; and the combination of rotational slumping and translational sliding as well as viscous flow within large debris flows.

Landslide complexity, particularly on the Kannaviou and Melange clay slopes, also results from numerous individual landslides varying in type, size, and degree of activity which encroach, over-ride, and coalesce with one another to form extensive areal zones of complex landsliding, separated by stable ridges of Kannaviou sandstone, Melange or Mamonia Complex rocks. In addition, massive older landslides host several orders of smaller landslides which, in turn, are dissected by erosional features such as rilling and gulleying. On the basis of the complexity of the geological formations in juxtaposition on the steep valley slopes and the known earthquake events which have affected the region in the historic past, similar landslide complexity would, perhaps, be expected to exist not only within the present study areas, but in similar terrains in both SW Cyprus and other areas of comparable geological, climatic and erosional histories.

8.5 Engineering Geology (Landslide) Maps

The main objective of the two 1:10 000 scale map sheets was to show landslide distribution and details in terms of type of movement, whether shallow or deep-seated, and whether active or dormant, in the Phiti (Area 1) and Statos (Area 2) study areas. Superimposed on a geological and contoured topographical base annotated with the marked positions of major springs, the landslide details are presented in relation to the geological formations/materials involved, relief, human settlement and communication routes, and hydrological elements. Areas of active sheet, gulley and stream erosion are also shown to further illustrate additional geodynamic processes acting within the surveyed areas.

As noted in Chapter 5, the presentation of the mapped landslide details followed, as closely as possible, recommendations by the Geological Society Engineering Group Working Party Report (Anon, 1972) and the IAEG Commission on Engineering Mapping (IAEG, 1976 and Matula, 1981). The field mapping techniques employed in the present study are also outlined in this earlier chapter and are not detailed further here. Mention should be made, however, of the limitations in the presentation of the landslide information on the prepared maps.

The presentation of landslide information on the map sheets is similar in a number of respects to the presentation employed on the 1:25 000 scale landslide map of Lattarico, Italy published by Carrara and Merenda (1974) and to the analytic map of engineering geological conditions at 1:10 000 scale in the Handlova area of Czechoslovakia (Malgot et al., 1973). The Phiti and Statos area maps differ, however, in that they attempt to show details of individual slope movements and landslide debris within extensive areas of complex coalescing areal landslide zones. In showing such detail at 1:10 000 scale, care had to be taken to ensure that the maps were not too 'cluttered' with detail to make them confusing and impractical to use. To overcome this problem compromises in the presentation of the landslide information were necessary.

Firstly, at some localities it was impossible to map individual coalescing slides due to their sheer complexity or lack of recognizable features resulting from degradation, vegetation, and/or erosion. Such areas are presented as 'areal landslide zones' with the estimated dominant type of movement indicated by single 'slide' or 'flow' symbols aligned in the direction of movement. This technique is also used to show areas of accumulated remnant slide debris at anomalous positions on the valley slopes (e.g. the patches of Melange slip debris at the foot of the Kannaviou clay slopes in Area 1). In both cases the estimated depth of sliding, or thickness of slip debris, in these zones is indicated by 'solid' (deep-seated) or 'dashed' (shallow) cross-hatching.

Secondly, within the 'mappable' landslide terrain, deep-seated failure movements are inferred from the size of the slide backscarp and the size of the displaced block or mass shown at the scarp foot. In most cases slide blocks or masses greater than c. 50m breadth as measured at the map scale, and occurring below large scarps, represent deep-seated failures in accordance with the definition in Section 8.3. At some localities, however, displaced blocks or masses of resistant rock >50m breadth are shown displaced downslope below usually less prominant scarps. In most instances these do not represent failures along 'true' deep-seated shear surfaces, but rock masses that have become detached from steep cliff scarps by undermining of the resistant rock by shallow failure movements in underlying clays (this applies particularly to the displaced masses of sandstone on the Kannaviou clay slopes).

Thirdly, on the shallower slopes downslope of the capping chalks, the majority of slope movements comprise complex shallow landslides, debris and earth flows. Although the combination of slide and flow movements is shown on the maps, it was impossible in most areas to distinguish between shallow translational and rotational failure movements at the 1:10 000 map scale. Thus the orientated arrrow ('v') symbols indicative of sliding movement represent translational and/or rotational movements.

Finally, at some localities interpretation of the type and extent of landslipped ground as determined from observable morphological features is uncertain. Where such uncertainty exists it is indicated on the map sheets by a '?' symbol.

In constructing the final format for the map sheets, consideration was taken of their intended use to planning and development in SW Cyprus (particularly by the Engineering Geology Section of GSD), and of landslide maps prepared by other workers in other slide-prone areas. In the latter respect, the examples of landslide hazard maps given and reviewed by Varnes (1984) can be particularly recommended.

The maps prepared for the Study Areas 1 and 2 may be classed as multi-purpose, large-scale analytical maps (IAEG, 1976), giving, it is hoped, a thorough and detailed presentation of the landslides, of zones subject to landslides, and of localities subject to erosion, on a geological/topographical base. Although the distribution of the mapped landslides indicates areas most susceptible to further instability, the analytical map data in conjunction with geotechnical parameters of the formation lithologies (discussed in Chapter 7), could be synthesized further to derive a 'summary' map of landslide hazard zones. Although such derived maps may be constructed in a number of ways, they essentially comprise a simple graphical portrayal of zones subject to various degrees of landslide hazard; each representing a summarized assessment of the geological, geotechnical, morphological, and hydrogeological data pertinent to landslide susceptibility in that zone. Hazard zonation maps have been prepared largely for the benefit of planners and administrators who require a simple interpretive document on which to base decisions (e.g. for development of infrastructure). Engineering geologists, however, tend to favour analytical maps showing the details and spatial distribution of factors from which hazard zones may be derived. The answer to this two-fold demand is perhaps, as suggested by Varnes (1984), the production of both an analytical map and a simpler synthesized map for areas subject to future development. In the geologically complex and landslide-prone terrain investigated in the two study areas, the analytical engineering geology maps presented with this report may be considered, therefore, as the initial stage in the production of a fully comprehensive map coverage dealing with the problems of landslide hazard with respect to planning and development.

8.6 Landslide Distribution and Causes

8.6.1 Landslide distribution

The occurrence of the main types of slope movements in the Study Areas has been outlined in Section 8.4, above. The detailed distribution of landslides is shown on the two 1:10 000 scale engineering geology map sheets which accompany this report.

Although landslides occasionally occur in unique situations they usually take place under geological, topographical and climatic conditions common to large areas. This is reflected on the engineering geology map sheets, the most striking feature being the widespread development of areal landsliding in both the Phiti and Statos study areas. The maps clearly show the importance of the weak, sheared and fissured, bentonitic clays of the Kannaviou and Melange Formations to slope instability. On the steeper clay slopes (generally in excess of c. 20°) around the periphery of the fissured and well-jointed chalk/limestone plateaux, the propensity for the development of large, deep-seated rotational slides is clearly illustrated. Downslope of the plateaux scarps the middle and lower Kannaviou and Melange slopes are characterized by extensive, coalescing, shallow slides and flows. In Area 2, the outcropping sedimentary (stratified) rocks of the Mamonia Complex give rise to an irregular dissected topography of steep slopes separated by sharp ridges. Here, deep-seated slope movements are rare, with nearly all landslides occurring within the 'Superficial Melange' or colluvium deposits which blanket the Mamonia rocks. Although less widespread than in the Kannaviou and Melange terrains, extensive shallow landslides in Superficial Melange and colluvium have been identified and mapped on the steep eastern slopes below Pendalia village.

A striking difference between the two study areas is the extent and complexity of landslides which affect the capping chalk plateaux. In Area 1, slipped chalk masses occur around the plateau edges where movement has clearly entailed failure of the underlying Melange and/or Kannaviou clays (e.g. on the northern and eastern flanks between Simou, Lasa, Phiti, Old Anadhiou and Kritou Marottou). On the southern flank, near Dhrinia and Milia villages, the chalks overlie Melange which in this area forms a more rounded and less rugged topography. Instability of the capping chalk is almost non-existent and landslips of any significance occur only near the contact of the Melange and underlying Kannaviou clays well downslope of the capping chalks. In marked contrast, the plateau chalks and limestones in Area 2 form one of the most extensive and complex landslide zones in the region. With the exception of the north-eastern flank where they rest on the Troodos lavas, the chalks, as in Area 1, are underlain by Melange. Here, however, the flanking slopes are steeper and the fissured and jointed chalk aquifer is thicker and more extensive, resulting in more numerous and copious springs and seeps at the basal contact of the permeable chalk and underlying Melange clays. Deep-seated rotational slides incorporating large sections of chalk strata are well-developed around the periphery of the plateau and grade downslope to widespread chalk debris slides and debris flows extending across the flanking Melange and Kannaviou slopes (see Fig. 8.7). Of particular importance are a series of major NE-SW and NW-SE trending faults that have riven the chalk/limestone plateau and promoted deep-seated complex slope movements and extensive rockfall failures at high elevations. As noted in Section 8.4 above, the flattish top of the 'Panayia Plateau' is characterized by intersecting open fissures, joints and gulleys and appears to be undergoing massive tensional failure, whilst at its south-western edge above the lower plateau surface on which Ambelitis village is sited, landslides initiated on the SE- and NW-facing chalk slopes have coalesced and no intact plateau surface remains. Although extensive landslides have affected the peripheral flanks of the 'Ambelitis' plateau (some of which are at least partly fault-controlled) the flat upper surface is currently stable. This appears to be due largely to the absence of major faults dissecting this 'intact' block. West of Panayia village on the NE flank of the 'Panayia Plateau', steep chalk slopes (often in excess of 30°) are maintained where these strata rest on the Troodos lavas. In places, shallow slides of chalk talus extend over the lava outcrops but compared to the flanking slopes underlain by Melange clays, the area is in general relatively stable. One major deep-seated failure has been identified 2km SE of Panayia Village (G.R. 680 630) and, as elsewhere on the plateau, is associated with a major fault.

Within the study area boundaries, the Troodos lavas show no significant problems of slope instability, with only isolated minor shallow slides in weathered surficial debris being recorded. Similarly, the igneous formations of the Mamonia Complex and the associated serpentinites showed no significant instability problems despite maintaining steep precipitous slopes. It should be noted, however, that in other areas of SW Cyprus (e.g. the Dhiarizos Valley) slope failures have been identified within highly sheared serpentinite and brecciated Mamonia lavas. Similarly, although the majority of landslides in the Mamonia Complex terrain occur in the slope colluvium, some failures have taken place in highly sheared, folded and distorted Mamonia bedrock. Often, these movements have involved units of intercalated shales and cherts which, when intensely sheared, contain weak zones of stiff-hard, slickensided shear clays prone to slope failures.

8.6.1.1 Limiting slope angles

In both the Phiti and Statos study areas, slope movements on the shallower (c. 9°-16°) clay slopes mainly comprise a combination of shallow translational slides and debris/earth flows that have developed from rotational slumps. The Kannaviou clay-mudstones, in particular, degrade rapidly by extensive shallow landslips and flows to form hummocky slopes of low relief, interrupted by scarps and cliffs of more resistant volcaniclastic sandstone. These intercalated sandstones form 'benches' or 'flats' on the hillside slopes and result in an overall slope form comprising a series of concave slope facets between successive sandstone bands. This is seen, for example, on the north-facing Kannaviou slope below Simou-Lasa-Phiti-Old Anadhiou villages in Area 1 (e.g. Photo 6.4). The sandstone benches tend to arrest downslope movement of the shallow debris slides/flows initiated on the steeper, upslope sections of the concave slope profiles. The Melange terrain is characterised by steeper slopes and hummocky, irregular, elongate-downslope, grassy ridges dotted with protruding incorporated Mamonia blocks (e.g. south of Dhrinia in Area 1 and on the extensive Melange slope east of Galataria in Area 2). Shallow slides and flows occur on the ridge flanks, and where the backscarps coalesce the ridge-tops are relatively sharp (e.g. south of Vrecha in Area 2).

At a number of locations, particularly in Area 2, rapid river erosion has resulted in steep Melange slopes standing at relatively consistent angles of between 30°-35°. These slopes are invariably bare of any vegetation cover and are often well in excess of 10 metres in height. In the summer months the matrix dries to a 'granular' skin containing numerous small drying cracks and the slope faces are intensely rilled and gullied, providing a clear indication of intense erosion following intense rainstorms (e.g. Photos. 6.7 and 6.9). These steep slopes are remarkably stable with respect to shallow landslide movements. This stability is largely due to the reduced infiltration of rainwater on the steep slope face and increased run-off which constantly strips loose material from the slope surface, inhibiting the development of surface slides and maintaining a steep slope profile. Steep, river-eroded slope faces of any appreciable height (c. 10m+) almost always occur in in-situ Melange, and their development in response to river downcutting is possibly related to the absence of extensive fissure and shear discontinuities which may be a characteristic feature of Melange affected by Recent landsliding (Section 8.2.2.1). Other controlling factors relate to the Melange thickness, underlying slope lithology (e.g. steep, stable slopes of Melange rarely occur where underlain by outcropping weak Kannaviou clays), and the local proportion and size of granular clasts and blocks incorporated in the Melange matrix.

A number of authors have interpreted the occurrence of characteristic slope angles as limiting angles for various types of mass movement, and have recognised that in areas which have a long history of slope instability, the slopes comprise relic features of past slope movements. In the Phiti and Statos study areas, very few, if any, slopes underlain by the clays of the Kannaviou and Melange Formations have not been affected to some extent by landslides, and recent activity is related primarily to the reactivation of earlier slope movements. In such areas the presence of old landslides and relic slip surfaces, along which the shear strengths have been reduced towards minimum (residual) values, is a major factor in governing slope stability.

The prediction of the angle of ultimate stability (i.e. the minimum slope on which movement will occur) is difficult, as it depends on a detailed knowledge of piezometric conditions and soil properties at shallow depth. As a first approximation, however, the stability of natural hillslopes with regard to shallow, largely planar, mass movements may be assessed by the 'Infinite Slope' analysis (Skempton and De Lory, 1957; Skempton and Hutchinson, 1969). The slope stability model assumes that the downslope length of the slipping mass is great in comparison to its depth, the failure surface is essentially planar, and seepage in the debris layer is parallel to the surface slope. Where residual strengths are operating, and effective residual cohesion (c_r') is assumed to be zero, the stability equation may be expressed as:

$$F = \left(1 - \frac{m.\gamma_w}{\gamma}\right) \frac{\tan \phi_r'}{\tan \beta} \qquad \text{---------(1)}$$

where, F = the factor of safety

m = position of the phreatic surface with respect to the slip surface and ground level (i.e. m=1, phreatic surface/ground level coincident; m=0, phreatic surface at or below failure surface)

β = slope angle

ϕ_r' = effective residual angle of shearing resistance

γ_w = density of water

γ = saturated bulk density of sliding material

It can be seen from equation (1) that the factor of safety varies linearly with the depth to groundwater table, with maximum pore pressures occurring in the sliding mass when m=1, i.e. the phreatic surface is coincident with the ground surface. This condition need not imply that the regional groundwater flow extends to the slope surface; a perched water table may occur.

For a factor of safety equal to 1, the limiting slope angle (β_L) for long-term stability may be represented as:

$$\beta_L = \arc \tan \left(1 - \frac{m.\gamma_w}{\gamma}\right) \tan \phi_r' \quad \text{------(2)}$$

ϕ_r' values determined in the laboratory at the levels of effective normal stresses (c.75 kN/m^2) usually operating on the failure planes of shallow landslips, ranged from 18.0°-24.4° (mean = 20.73°) for samples of Melange matrix, and 11.2°-26.4° (mean = 18.46°) for samples of Kannaviou clay/mudstone. The wide range of values is largely due to the variation in montmorillonite content and the proportion of sand/silt-sized granular material in the tested samples (see Chapter 7). In-situ bulk densities for the Melange ranged from 1.81-2.21 Mg/m^3 (mean = 2.04 Mg/m^3) and 1.51-2.18 Mg/m^3 (mean = 1.78 Mg/m^3) for the Kannaviou samples. Assuming the saturated condition, where m=1, and using the mean values of ϕ_r' and γ, the calculated limiting stability angles for shallow landslips on the Melange and Kannaviou clay slopes are:

Melange: β_L = arc tan [0.51 tan 20.73°]
= 10.92° (i.e. <u>approx. 11°</u>)

Kannaviou: β_L = arc tan [0.44 tan 18.46°]
= 8.36° (i.e. <u>approx. 8.5°</u>)

These values compare closely with the slope angles determined by Abney levelling along eight selected slope profiles carried out during the field mapping surveys, across shallow slide-flow failures developed on the Melange and Kannaviou slopes. The lower parts of the shallow slip masses formed slope angles ranging between 10°-14° in the Melange terrain, and 8.5°-10° in the Kannaviou terrain, respectively. The inference from these results is that, in general terms, under the prevailing conditions controlling shallow stability on the hillside slopes, the limiting slope angles for shallow landslip movements in the Melange and Kannaviou clay slopes are approximately 11° and 8.5°, respectively. It is stressed, however, that these limiting angles are mean values and will undoubtedly vary with local variations in material and groundwater conditions. For example, using the maximum and minimum values of ϕ_r' and γ noted above, the calculated limiting angles range from β_L = 9.5°-13° for the Melange, and β_L = 5°-12° for the Kannaviou materials.

The results also imply that the majority of the Melange and Kannaviou slopes in the study areas are close to limiting equilibrium for shallow mass movements. This is borne out by the frequent signs of recent instability on these slopes as shown on the engineering geology map sheets.

8.6.2 Main factors and processes affecting landslide development

In general terms, the initiation of landsliding can be considered to result from the interaction of two main groups of factors:

(a) Factors that contribute to a reduction in shear strength of the slope forming materials (which are dependent primarily on rock or soil composition and structure).

(b) Factors that contribute to increased shear stresses being imposed on the slope-forming materials (eg. removal of lateral or underlying support, and increased loading).

In the Phiti and Statos study areas these main factors arise primarily from the following:

1. A high relief and steeply inclined slopes which in places (particularly in the Kannaviou outcrops) display a concave water-collecting topography.

2. The weak, dominantly argillaceous rocks of the Kannaviou and Melange Formations which are fissured and/or sheared and show marked shrink-swell behaviour due to high montmorillonite contents. The Kannaviou clays, in particular are highly plastic and characteristically highly fissured and sheared. These discontinuities severely reduce the 'field strength' of the rock mass and are likely to play a significant role in the concentration of shear stresses leading to the development of deep-seated landsliding on steep clay slopes maintained by the competent chalk cap-rock around the peripheries of the plateaux scarps.

3. The extensive development of weak unconsolidated colluvial and 'Superficial Melange' deposits derived by weathering and breakdown of the tectonically disrupted and sheared rock formations of the Mamonia Complex.

4. The development of perched water tables in the hillside slopes which, in places, play a significant role in the development of extensive zones of coalescing complex landslides. Of particular significance are those associated with the volcaniclastic sandstones intercalated with the clay-mudstone sequences of the Kannaviou Formation. In addition, where the Melange infills 'troughs' in the underlying Kannaviou clay, water appears to be concentrated at these depressions, resulting in seepage horizons which promote instability along the exposed Melange/Kannaviou contact.

5. Extensive capping plateaux of chalks and limestones which act as major jointed and fissured aquifers, transmitting vast quantities of water to the valley slopes via numerous springs and seeps at the basal chalk/Melange contact; slope

instability is further enhanced by the presence of bands of marl and marly chalk which, particularly when combined with unfavourable out-of-slope bedding dips, provide zones of weakness conducive to planar block-sliding of overlying strata.

6. A large number of faults and shear zones. Of particular importance are the NW-SE/NE-SW trending faults which cut the chalk plateaux. Particularly prominent in Area 2, these major discontinuities not only displace and severely weaken the rock mass, but also enhance secondary permeabilities of the chalk aquifer by disrupting the intact chalk mass and opening joints and fissures. Shear zones resulting from the tectonic emplacement of the allochthonous Mamonia Complex rocks are of particular importance in promoting weathering and breakdown of these strata to form superficial colluvial deposits and Superficial Melange.

7. High winter rainfalls which occur as intense rainstorms causing saturation of the slope materials, high groundwater levels and increased pore pressures, expansion of the bentonitic clays, and erosion.

8. The undercutting of steeply-inclined slopes by river and stream erosion.

8.6.2.1 Deep-seated instability

An overall regional assessment of the causal factors leading to deep-seated failures in the Study Areas is difficult since the acquisition of data relating to water pressures acting within the slopes, the precise shape and depth of the failure surfaces, and the average shear strengths mobilized along these surfaces, was beyond the scope of the present investigation. However, a few general observations may be made:

1. The majority of deep-seated slope failures involve rotational movements.

2. These rotational failures appear to have occured on initial slopes generally in excess of 20-22°.

3. The great majority of these failures involve a significant part of the chalk strata capping the slope crests and many are associated with faults.

4. The chalk cap-rock, as a major fissured aquifer, transmits large amounts of water to the underlying clay slopes via stratum springs aligned along its basal contact with the more impermeable Melange and Kannaviou Formations, and deeper into the argillaceous hillside successions by means of faults and fissures. Water concentrated at the major stratum springs may provide a piezometric head capable of initiating deep-seated movement, particularly after prolonged periods of heavy rain and where the dip of the beds is towards the valley.

5. Shallow landslides and flows in the clay strata below the stratum springs are probably an important precursor to deep-seated failure movements, resulting in steepening of the slopes below the chalk cap-rock and removal of downslope and underlying support.

6. The degree of displacement of the deep-seated failures around the periphery of the chalk plateaux, suggests that the curved shear surfaces pass through a considerable thickness of dominantly argillaceous Melange and/or Kannaviou strata (i.e. clay, mudstone, shale).

7. Although the precise shape of the failure surfaces could not be corroborated by borehole data, the morphology of these failures suggests that they are generally circular where the slip surface is confined to a significant thickness of Melange, and markedly non-circular where the failure surface is controlled by the presence of Mamonia Complex rocks underlying a reduced thickness of Melange, or by the presence of sandstone bands or weak,

pre-existing tectonic shear zones in the Kannaviou Formation.

8. Ground accelerations and movements along fault lines produced by earthquake shocks greatly increase the potential for deep-seated failures, and have undoubtedly played a significant role in triggering these movements in the past.

8.6.3 Rainfall and groundwater

The high winter rainfalls which occur in the highlands of the Paphos region have a profound effect on the initiation and/or reactivation of landslides. In addition to increasing surface erosion, water absorbed into the ground, particularly via drying cracks and fissures, increases the bulk density of the slope materials (effectively loading the slope); loosens intergranular bands by chemical solution; causes swelling of the bentonitic clays; and, under certain conditions, lubricates potential planes of failure. Water pressure within the soil or rock strata, as reflected by the piezometric level, has a major influence on the shear strength of the slope forming materials. A rise in piezometric surface following prolonged rainfall and enhanced groundwater flow results in increased pore pressures and a subsequent decrease in shear strengths. This is of particular importance in the vicinity of major springs and is a main factor in the initiation and reactivation of landslides in the clay slopes of the Study Areas. The major springs and seeps concentrated at the interface of the the chalk cap-rock aquifers and the underlying Melange clays are of particular importance in transmitting large quantities of water to the hillside slopes, saturating the slope material, increasing bulk density and raising pore pressures.

A multiplicity of piezometric levels may be present in the hillslopes of the Study Areas, and perched water tables appear to be particularly prevalent within the Kannaviou and Mamonia Complex terrains and in Melange slopes blanketed by chalk talus debris, (a perched water table being one that is sustained above an underlying independent body of water by an aquiclude). Perched water tables are particularly common where superficial deposits or shallow slip debris (e.g. chalk talus, granular colluvium) have a higher permeability than the underlying slope material (eg. mudstones and clays). Normal aquifers may also be converted locally to perched aquifers by the rotational or founder movements associated with the larger slope failures. These water tables may be temporary or permanent features of a particular slope and they vary markedly with rainfall, groundwater flow and landslide movements. The changing nature of perched water tables is one of their most important characteristics and they undoubtedly play a significant role in the development and reactivation of shallow landslides by causing saturation of the near-surface materials at various levels on the valley slopes.

It is clear that the high winter rainfalls in the Phiti and Statos areas are a major factor influencing both the short and long-term stability of the hillside slopes. Of particular interest is the high incidence of reported landslides following intensive rainstorms or periods of prolonged heavy rainfall. This can be appreciated when consideration is given to the importance of the major stratum springs at the chalk/Melange contact in the development of slope instabilities. Because of intense fracturing of the chalk strata, the response of these major springs following intense rainstorms is rapid; increased amounts of water are quickly transmitted to the underlying clay slopes, resulting in a correspondingly rapid increase in bulk density and pore pressures and decrease in shear strength of the slope materials. Fig. 8.8, for example, shows the monthly rainfall plot for the 20-year period between 1951 and 1970 recorded at Panayia village in Area 2; a line indicating the mean 'peak' winter rainfall determined from the 70-year mean rainfall curve is superimposed. Also indicated on the rainfall plot are periods of major landsliding reported by Pantazis (1969) and Afrodisis (1971), in their respective accounts of landslides in the Paphos region. Although the documented evidence of landslide incidence is incomplete, the plot

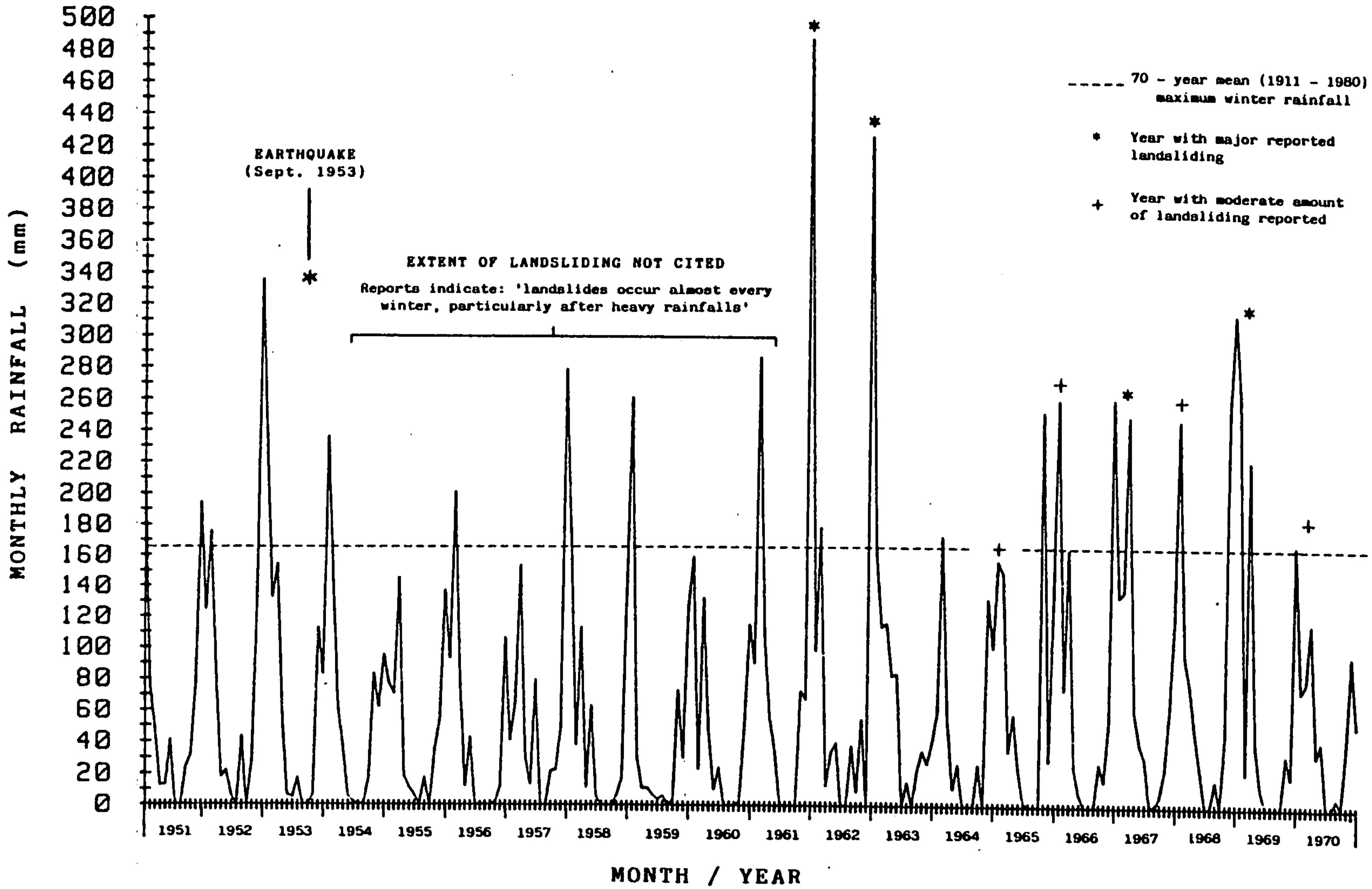


Fig. 8.8 Monthly rainfall plot for 20-year period 1951 - 1970, recorded at Rainfall Station No. 120, Pano Panayia, Study Area 2. Indicated periods of landsliding are based on the reports of Pantazis (1969) and Afrodisis (1971).

indicates that a relationship exists between heavy rainfall and landslide activity. The plot does not, however, give any indication of the time-lag which undoubtedly exists between rainfall events and the onset of many major slope movements. In planning terms, the measure of the frequency of occurrence of significant slope failures is a useful criterion in estimating the degree of risk involved for different land use activities. Frequency is most readily expressed in terms of probabilities of recurrence, based on frequency/magnitude theory. Unfortunately, the history of landslide activity is rarely sufficiently well-documented for the direct assessment of intervals of landslide recurrence. However, in the case of rainstorm-triggered events it is possible, by examination of the record, to establish the minimum rainfall intensity or depth required to produce landslides in certain terrains, and hence to establish indirectly from the meteorological record a recurrence interval for these conditions.

An indirect frequency assessment of this type would be of particular use in SW Cyprus and areas of similar geological and climatic environment, and further research is recommended. In order to determine minimum triggering parameters, analysis of landslide-producing rainstorms and periods of prolonged heavy rainfall in the region in conjunction with field analysis of resulting slope movements (in terms of type, slope angle and materials involved), and piezometric levels in the slopes would be necessary. Confirmation of results established by historical analysis (determined by detailed checking of meteorological data and documented records of landslide activity) could then be made.

8.6.4 Erosion

The intense erosion characteristic of so much of Cyprus is largely the result of past periods of uplift and rapid rejuvenation to which the island has been subject (Everard, 1963). That uplift is continuing at the present time is indicated by the many fresh erosional features, incised valleys, and stream terraces seen today. The 'driving force' for this uplift has been attributed to a northward-dipping subduction zone beneath Cyprus and obduction of Troodos onto the Afro-Arabian continental margin and/or hydration and serpentinization of deep-seated ultramafic rocks (Searle and Panayiotou,1979; Robertson, 1977c). Whatever the cause of this continued uplift, it clearly has important long-term implications with respect to erosion and slope stability in the highlands of SW Cyprus.

Within the Study Areas many erosion problems are associated with soft rocks of low permeability, moderate to steep slopes, areas of little or no vegetation, and short duration/high intensity rain storms. Areas undergoing active sheet and gulley erosion are indicated on the 1:10 000 map sheets.

The rocks most prone to erosion are: the weak, fissured Kannaviou mudstones/clays; the Melange; chalk talus debris; sheared, weathered sedimentary Mamonia Complex rock formations and associated colluvium deposits; and landslide debris.

Excessive erosion on steep slopes commonly produces steep-sided gullies, increases sediment load in streams, creates irregular surfaces, and removes lateral support from parts of the slopes, thus increasing the possibility of slope movement. The removal of lateral support by river and stream erosion at the toe of existing landslides and debris flows, is a major factor contributing to renewed movements of these failures.

Heavy rainfall after extended periods of dryness also causes the rapid dissection of fresh landslide scarps on the clay slopes, and sheet erosion and gulleying often conceals the recency of landslide movement. In many cases, deep gulleys are characteristic features on the steep sections of unmetalled access roads across the Kannaviou and Melange slopes. Where these gulleys have been enlarged and water has saturated the underlying materials, the roads have either started to slide or have been washed out. In the more remote agricultural areas these access roads are simply re-cut or scraped each summer by heavy plant (i.e. bulldozers). On the more important unmetalled access roads near to villages, low-cost remedial work such as the proper use of surface drains and gravel surfacing is advised in order to reduce these erosional problems and deter further damage that would eventually entail more costly repair. Erosion control measures along major metalled roads across all terrains in the Phiti and Statos areas is recommended.

8.6.5 Creep

All slopes are subject to creep although in most cases this is so small as to be virtually immeasurable. Seasonal or mantle creep is confined to the surface zone of fluctuating ground temperature and moisture content. It includes soil creep and talus creep and is highly seasonal. In the Phiti and Statos areas the only clear evidence of surface creep (indicated on the engineering geology map sheets) was seen on moderate, grassed slopes underlain by Melange and the Mamonia-derived colluvial deposits. It is however, extremely likely that creep in the extensive deposits of chalk talus is also an active slope process.

In the Mamonia Complex terrain, rock creep may be taking place at certain locations. This form of creep involves the plastic deformation (lateral and downslope) and fracturing of bedrock at a slow rate beneath the soil zone in response to gravity. Photo 7.10 possibly illustrates this deformation in highly disturbed and micro-folded intercalated shale and chert strata exposed in a road cut south of Ayios Photios village in Area 2.

In the creep described above there is believed to be a continuous gradation between the stationary and moving material and hence no definite shear surface is developed. In some instances, if the stability conditions of the slope change, mantle creep may develop into very shallow translational debris slides.

8.6.7 Earthquakes

The general seismicity of the Paphos region is discussed in Chapter 3, Section 3.4, and the effects of the most severe recent earthquake of September 1953 in the Phiti and Statos Study Areas are outlined in Chapter 6, Section 6.2. For a fuller account summarizing the effects of this earthquake the reader is referred to the report of Havouzari (1983).

In general terms, initiation of landslide movements, ground collapse, and reactivation of existing slides by earthquakes are due to seismic accelerations, changes of gradient angle on unstable planes, and possible thixotropic effects in clay strata (Solonenko, 1977).

Seismic accelerations trigger landslide movements, collapses, and other gravitational phenomena (e.g. rockfalls) on slopes by producing transitory changes in stress which may crack and fracture competent rock masses, damage intergranular bonds and result in an overall decrease in mass shear strength of the slope materials. Changes in gradient angle of selected slopes or planes of weakness may also trigger slope movements. Slopes that are at or close to limiting equilibrium are particularly susceptible to the initiation of slope failures or reactivation of existing landslides as only small changes in gradient angle may be required to trigger movement (often significantly less than half of one degree, according to Solonenko, 1977). Thixotropic effects (see Chapter 7) resulting from ground accelerations may also have played a significant role in triggering movements in existing highly remoulded argillaceous debris flow material, particularly those involving bentonitic Kannaviou, and possibly Melange, clays.

From records held at the Geological Survey Department of Cyprus, accounts of the effects of the 1953 earthquake in terms of slope instability (particularly movements relating to severe damage of villages and communication routes in the highlands of the region), indicate that these effects were most severe in areas previously affected by landslides and along, or in the proximity of, significant fault lines. Damage caused by a reduction of slope stability at a particular site would depend upon a number of variables such as the earthquake magnitude and duration, location of the epicentre, the stability of the slope materials, and the number and quality of man-made structures. Because it is impossible to prevent or control earthquakes, detailed engineering geological site investigations for any planned engineering structures should take into account the location of known or suspected faults in the area, their distances from the proposed site, and the potential scale and type of slope movements likely to be expected as a result of displacements along these lines of weakness should a maximum credible earthquake occur.

It is stressed here that the geological, topographical and climatic environment in the Paphos region is such that the occurrence of landslides as natural phenomona is facilitated. Seldom, if ever, can a landslide be attributed to a single cause and although earthquake shocks have undoubtedly triggered major slope movements in the past, they are often just one of a number of factors that have combined to set in motion an earth or rock mass that was already on the verge of, or had previously undergone, failure.

8.6.7 Human factors affecting landslide potential

As elsewhere in the world, human activities have caused drastic changes in the landscape of Cyprus. The effects of human settlement, construction and agriculture have undoubtedly affected local and regional slope stability either directly or indirectly, to a greater or lesser degree, by oversteepening and overloading slopes, removal of support, inhibiting drainage and increasing moisture levels in the slope materials.

The most pronounced effect of human activities on slope processes in Cyprus has been the removal of vegetation cover which, according to Everard (1963), has greatly accelerated slope erosion over the past few thousand years with all its consequential effects on slope stability. In addition to the decimation of trees for fuel and construction, free-range grazing by sheep and goats since at least 4000 B.C. has been particularly significant. Free-range grazing is practised on land too poor, rocky or steep for agriculture which, in the Study Areas, mainly comprises the Mamonia and steeper Melange slopes and the more hummocky, dissected areas occupied by debris slides. Aided by a climate of increasing desiccation since the Late Glacial (with temporary reversals of this trend at c.9000 and 5000 B.C.; Butzer, 1958), this has maintained a sparse vegetation cover of tufted grasses and dwarf scrub over large areas, resulting in slopes with virtually no vegetation mat (to protect the slope material from the direct impact of high-intensity rainfall and sheet erosion) or root network exerting a binding effect at ground level (to retard shallow slope movements).

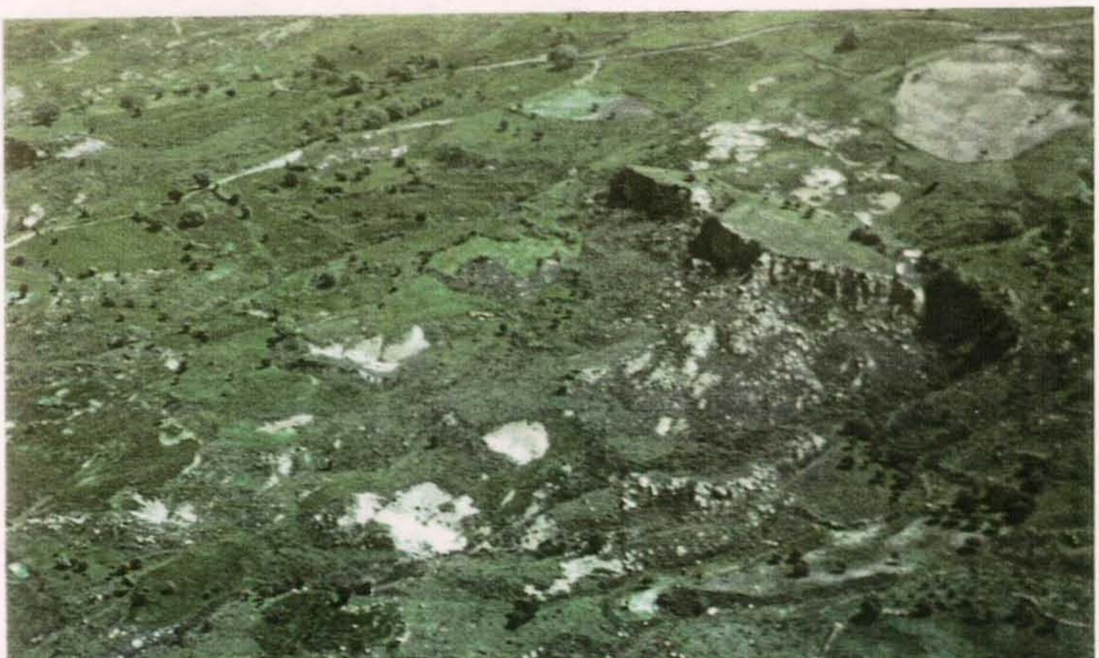
On the flatter agricultural land erosion is still rapid, and cultivation 'nicks' at the upper limit of ploughing or mechanical rotavation maintain steeper slope gradients than would otherwise be the case and increase the potential for shallow landslides. Unirrigated land is usually under a cereal/fallow rotation which further increases rapid erosion in a climate of torrential rainstorms. In recent years as the pressure of the population on agricultural resources has increased, cultivation on increasingly steeper slopes has taken place by means of terracing. Although this practice may enhance stability by effectively unloading the slope, ploughing and fallow rotation on the flat terrace surfaces reduces surface run-off, enhances infiltration of rainwater and increases saturation of the slope materials thus increasing the potential for slope failure. At some localities, irrigation is often successfully achieved by 'tapping' small springs developed at the base of aquifers formed by chalk glide-blocks that have come to rest at various locations on the lower-middle clay slopes. Pipe drains direct this water to cultivated terraces (usually excavated in landslipped ground), locally increasing groundwater levels and saturation of the slope materials.

8.1 Marked lithological/shear unconformity between slipped Melange with chalk debris overlying Kannaviou mudstones (Area 1, GR 4572 38662)

8.2 Striated, slickensided Melange shear surface at base of slipped chalk debris (Area 1, GR 4599 38665)

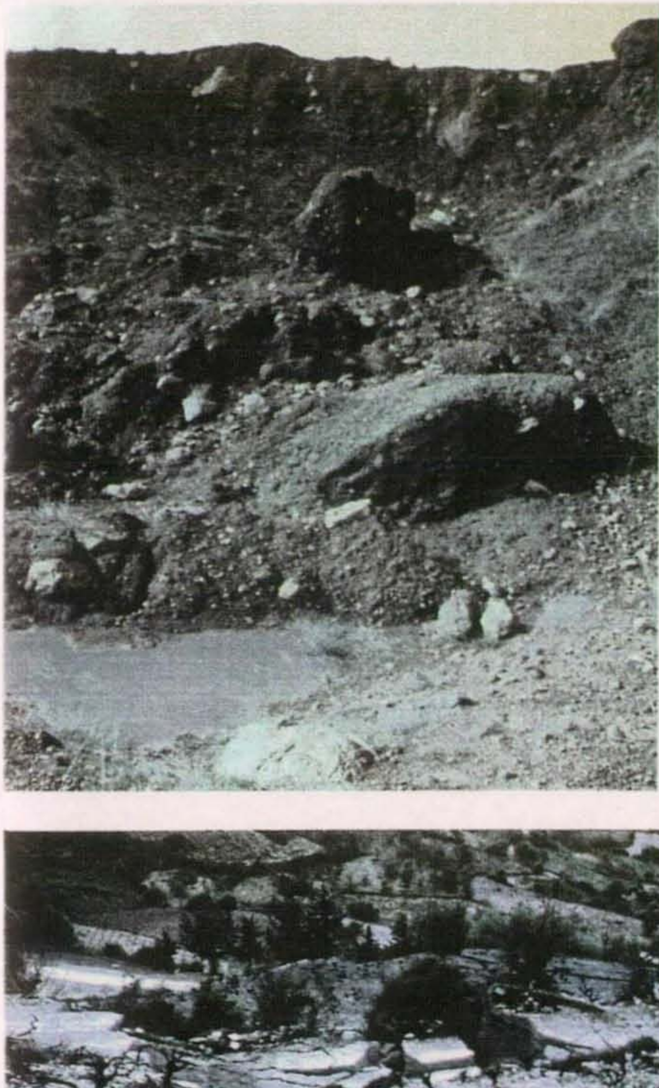
Photos 8.1 to 8.2

8.3 Distorted outcrop of Kannaviou sandstone showing active rockfalls from west scarp face, 1 km NW of Pniti village (Area 1, GR 4577 38660)



8.4 Distorted Kannaviou sandstone outcrop showing rockfall material incorporated in clay debris slides below scarp (GR 4577 38660)

8.5 Fresh scarps at head of active shallow slump in Kannaviou clay NW of Lapithiou (Area 2, GR 4639 386:



8.6 Fresh scarp, slip debris and standing water in recent Melange landslip SW of Kritou Marottou, (Area 1, GR 4587 38641)

8.7 Fresh ground crackin in chalk talus due t landslide movement S of Panayia (Area 2, GR 4661 38636)

Photos 8.5 to 8.7

8.8 Recent slump block in chalk talus displacing minor road (Area 2 GR 4661 38636)

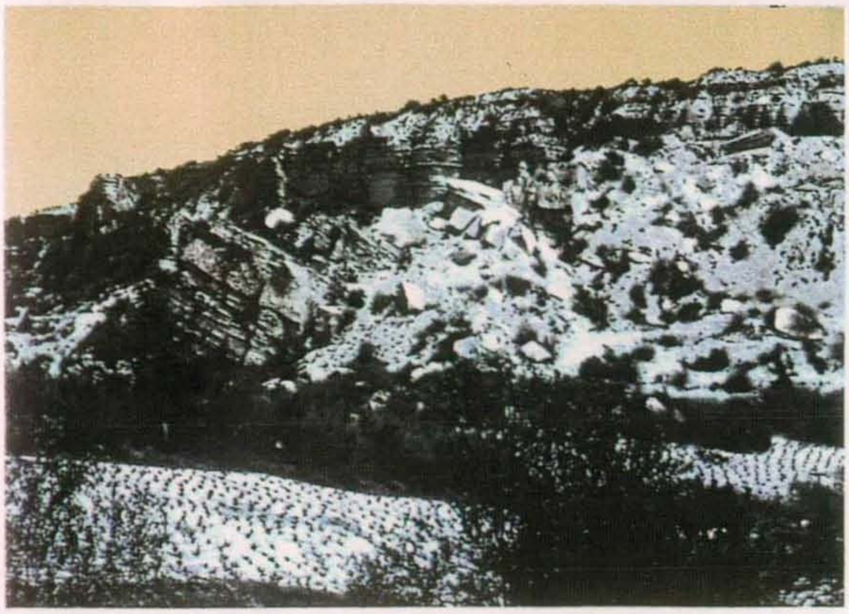
8.9 Cracking/displacement of Ayios Photios-Statos road pavement due to landslide movement (Area 1, GR 4645 38607)

8.10 Cracking/displacement of water tanks due to landslide movement S of Statos (Area 2, GR 4644 38603)

Photos 8.8 to 8.10

8.11 Massive incipient rockfall (toppling) failures in chalk/ limestone on NW flank of 'Panayia Plateau' (Area 2, GR 4666 38631)

8.12 Fresh rockfall debr from Kannaviou sandstone scarp, 1] NW of Phiti (Area 1 GR 4577 38660)

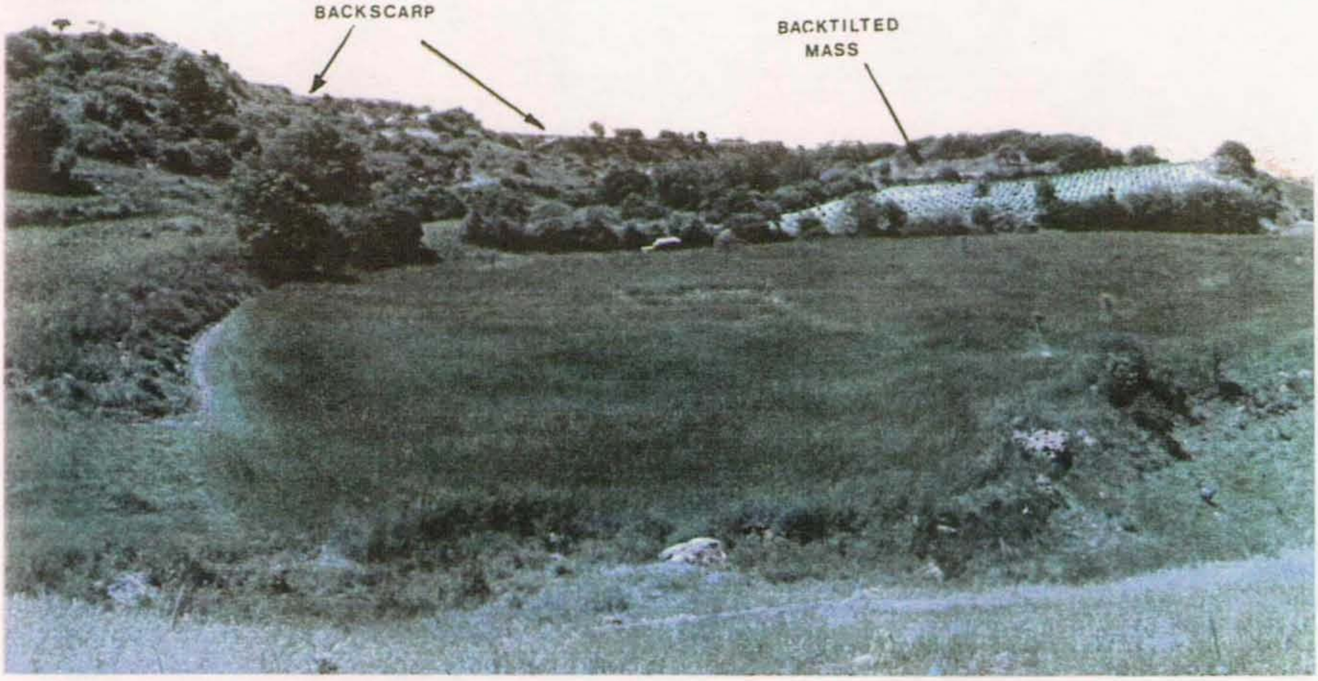


8.13 Large rockfall failures from chalk/limestone fault scarp, 'Panayia Plateau' (Area 2, GR 4665 38629)

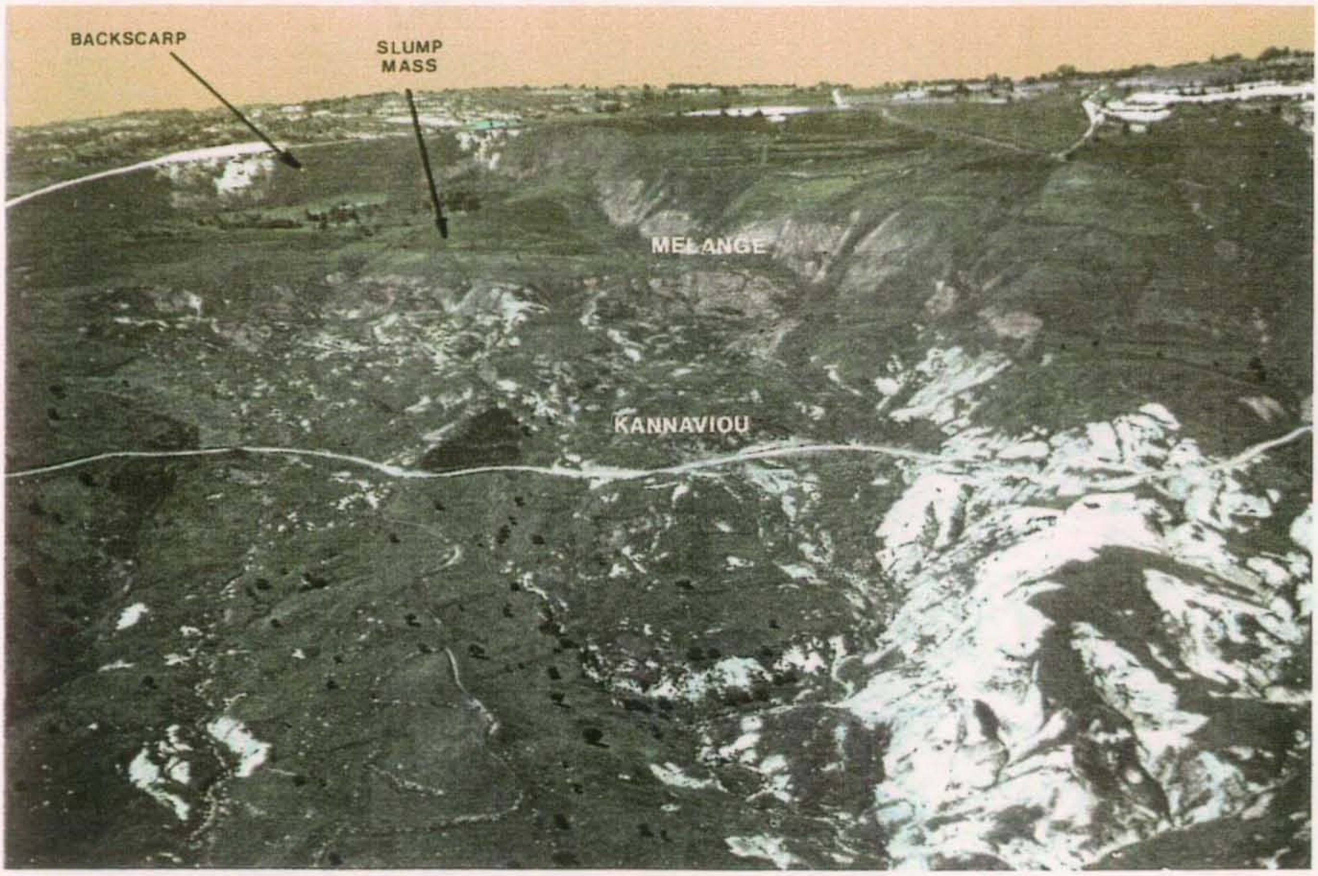
Photos 8.11 to 8.13

8.14 Vegetated, arcuate chalk backscarp of Old Anadhiou rotational landslide; failure is deep-seated involving underlying Melange and Kannaviou clays (Area 1, GR 4593 38665)

8.15 Massive deep-seated rotational landslide(s) in chalk and underlying Melange clays, Ayia Moni monastery, (Area 2 GR 4655 38622)



8.16 Back-tilted chalk strata resulting from deep-seated rotational failure involving underlying Kannaviou clays, N of Phiti-Lasa road, (Area 1, GR 4578 38655)



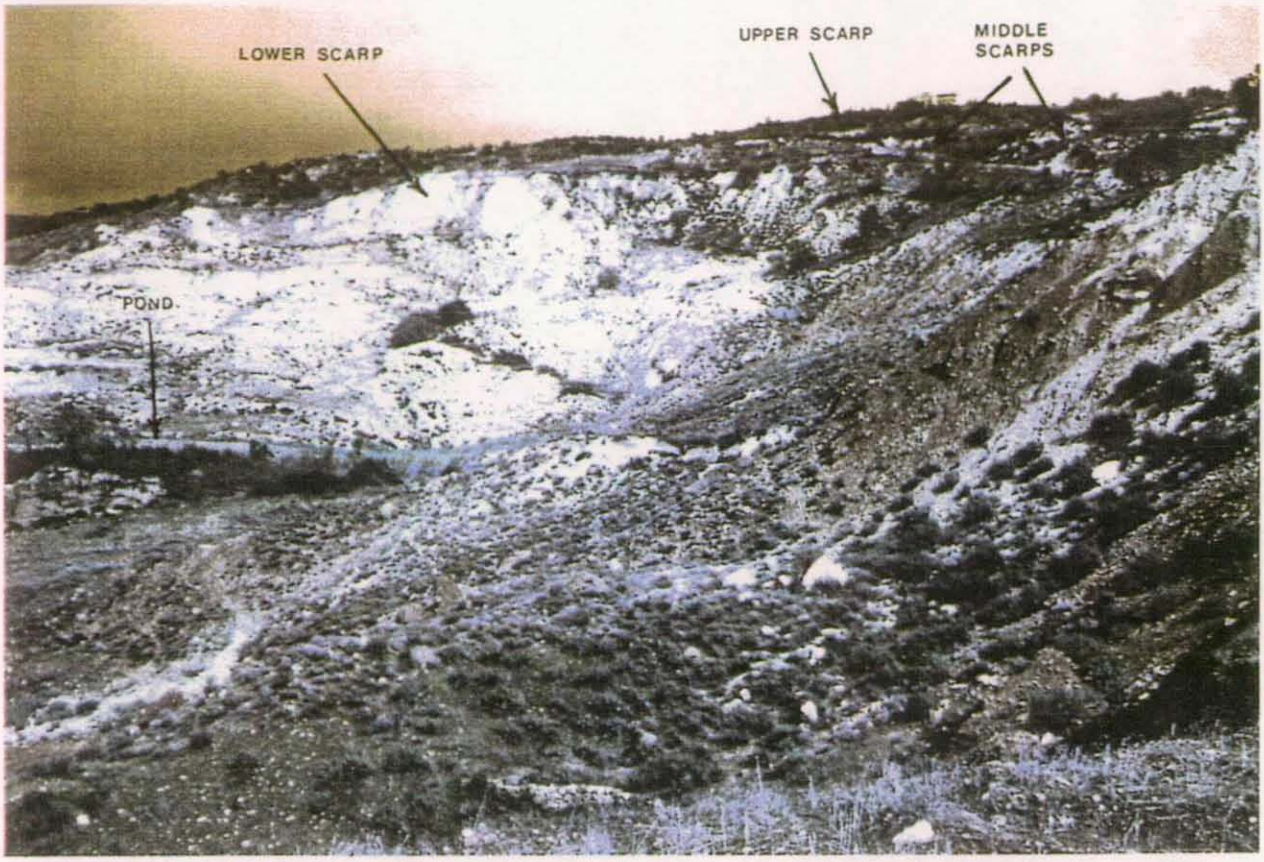
8.17 Complex landslide involving deep-seated rotational failure of Melange and underlying Kannaviou clays at head. Sheet erosion of Kannaviou clay-sandstone sequence in right foreground (Area 1, S of Phiti village, GR 4586 38643)

8.18 Recent shallow rotational slip in Kannaviou clay road cut

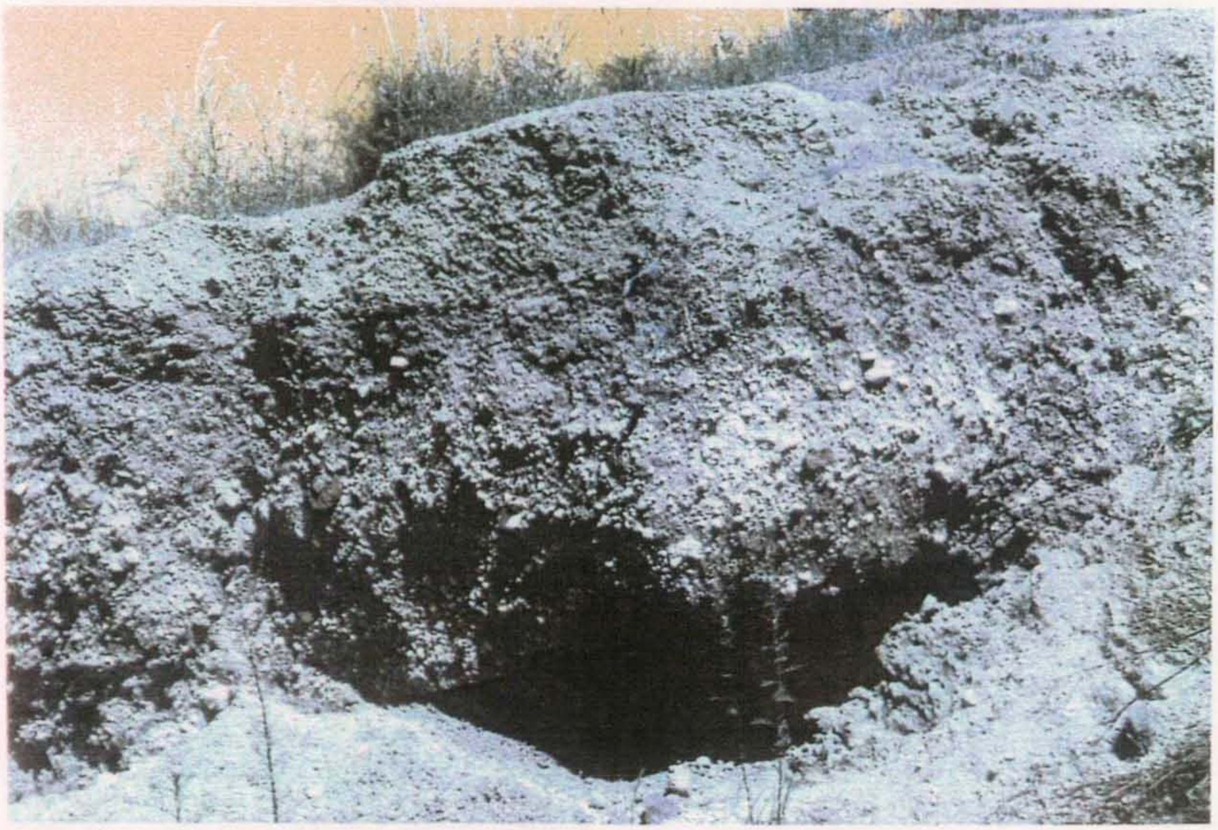
8.19 Shallow rotational landslip in Melange sidescarp of Ayios Photios landslide, (Area 2, GR 4641 38599)

8.20 Successive shallow rotational landslips in Kannaviou clay slope near Paleomylou River, (Area 2, GR 4638 38638)

Photos 8.18 to 8.20



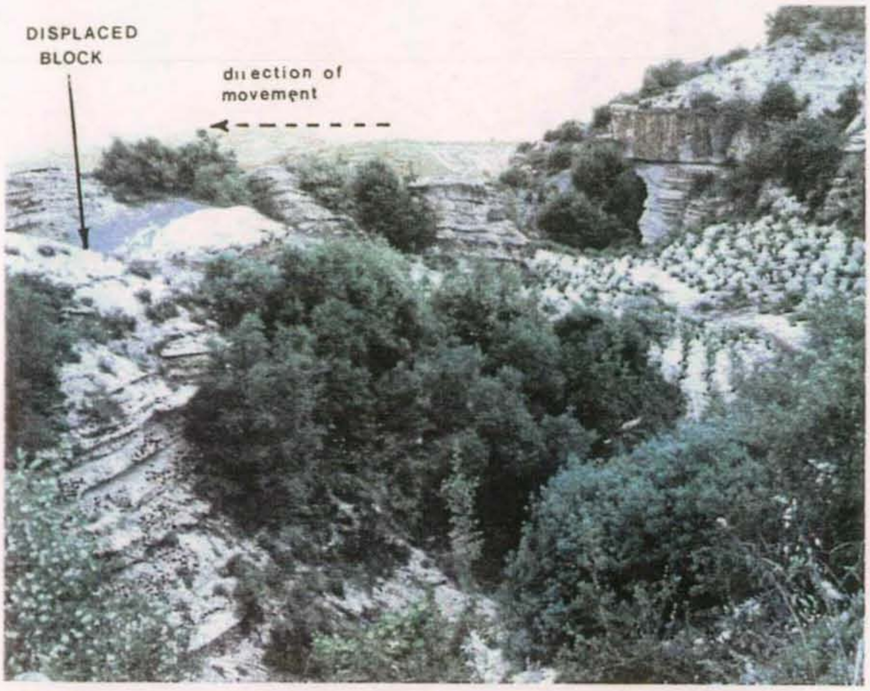
8.21 Headscarps of deep-seated multiple retrogressive rotational landslide near Ayios Photios village, (Area 2, GR 4643 38601)



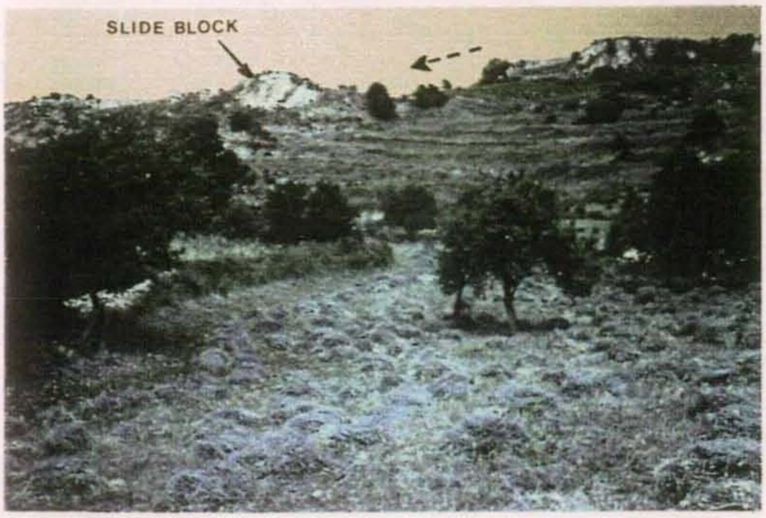
8.22 Planar shear surface at base of translational debris slide involving Melange and chalk debris sliding over Kannaviou clays. Shallow Kannaviou clay flow deposit overrides slip mass. (Area 1m 1.3 km N of Phiti, GR 4578 38666)

Photos 8.21 to 8.22

8.23 Shallow translational debris slide in Melange slope 1km SW of Kritou Marottou (Area 1, GR 4594 38646)



8.24 Chasm at rear of deep-seated chalk/limestone translational block-slide, SE flank of 'Panayia Plateau' (Area 2, GR 4665 38622)



8.25 Chalk block-slide translating across Melange slope following initial rotational failure (Area 1, GR 4576 38657)

Photos 8.23 to 8.25

8.26 Recent debris (earth) flow in Kannaviou clay (Area 2, GR 4639 38636)

8.27 Large debris flow across Mamonia slopes below Ayios Photios landslide (Area 2, GR 4632 38601)

8.28 Debris flow involving Kannaviou clay and chalky Melange debris, extending across Kannaviou slopes N of Phiti (Area 1, GR 4576 38667)

Construction and engineering works may affect landslide potential locally by loading slopes (by buildings, roads or fill) and by the addition or redistribution of groundwater. Sources of additional water generally occur near villages and include waste water from soakaway pits and from damaged or leaking pipes carrying water from boreholes or collecting tanks sited at major springs. Redistribution of water results from the alteration of natural drainage and from the construction of large impermeable surfaces (e.g. roofs and paved or cobbled surfaces) that direct and concentrate rainfall run-off and locally accelerate erosion.

Slope movements associated with road construction or improvement works are of frequent occurrence in the Study Areas and in similar terrain in SW Cyprus, and have increased in recent years as demands for new permanent roads and the improvement of existing routes have grown with increasing vehicular traffic. The majority of movements appear to be triggered by over-steepened cutting slopes and the removal of support by excavation, particularly in previously landslipped ground and chalk talus deposits. In some instances (e.g. along the Kannaviou-Panayia road in Area 2, 400m W of Panayia village at G.R. 660 647), failures have been associated with culverts concentrating surface run-off from drains or ditches constructed on the upslope side of road pavements. Downslope of the roads, particularly where the slopes are steep and formed in Kannaviou/Melange clays or talus, increased erosion and saturation of the slope materials below the culvert mouths has triggered shallow slope movements, resulting in displacement, cracking and subsidence of the road surfaces.

9. CONCLUSIONS

The present study has concentrated on the engineering properties and behaviour of the cohesive soil formations which occur in close proximity to the Troodos ophiolite in SW Cyprus. Similar sediments have been reported from ophiolite terrains elsewhere in the world, particularly those associated with the younger ophiolites (less than c. 200 M yrs old) related to the present cycle of plate tectonics. These include, for example, those ophiolites emplaced along the western coast of the United States, Central America, the northern Mediterranean and the Middle East, and the Far East (e.g. in parts of Indonesia). The origin and mode of emplacement of these ophiolites and their associated, often 'tectonised', sediments have been discussed to varying degrees in the literature. With few exceptions, however, very little published information refers to their engineering properties and expected engineering behaviour.

Marine sediments associated with ophiolite terrains, i.e. deposited along active crustal plate boundaries in trenches, forearc basins or on continental slopes, are subject to complex stress-strain histories and do not conform to the one-dimensional no lateral strain "Ko"[1] loading-unloading cycle frequently adopted in soil mechanics modelling. They may have been compressed by complex tectonic forces either by scraping from the ocean floor against a continental margin during subduction (a process known as accretion) or by the emplacement of large scale, detached gravity slides (e.g. the Mamonia Complex of this study). The cohesive Kannaviou Formation sediments described in this report may be classified as over-consolidated, stiff, sheared (or 'tectonised'), highly to very highly plastic, montmorillonitic clays. In-situ moisture contents suggest the clays swell rapidly after excavation, with only limited delayed effects due to weathering and breakdown of cementation bonds. Strength determinations suggest that the in-situ mass shear strength is largely controlled by the undrained strength of the discontinuities which is substantially

[1]Ko = coefficient of earth pressure at rest, i.e. the effective horizontal pressure divided by the vertical effective pressure.

less than 'peak' laboratory values but above residual ($\phi r'$) values. Meaningful strength values using conventional soil mechanics analyses are difficult to determine in sheared clays, due to problems in modelling in-situ stress conditions and difficulties in obtaining suitably undisturbed laboratory samples. Further determinations of 'field' strength values by back analysis of first-time landslides coupled with seasonal monitoring of moisture content variations in these sediments is recommended.

Melanges and 'broken formations' have been reported in association with many ophiolite terrains. The sedimentary Melange (Kathikas Formation) described in this report may be classified as a medium to highly plastic, firm to stiff, fissured, montmorillonitic silty clay with embedded competent rock clasts of all sizes. Pervasive shear zones were noted in the Melange matrix in some pit sections, but these may be restricted to Melange that has undergone Recent landsliding. The engineering behaviour is dominantly controlled by the matrix which forms at least 70% by volume of the deposit. Despite local differences in clast content and lithology, the matrix shows a marked uniformity in geotechnical index properties which indicate more granular (less plastic) soil characteristics than the Kannaviou argillaceous sediments. Laboratory shear strengths, however, are difficult to ascertain owing to the difficulty of obtaining undisturbed, relatively clast-free test samples, even from carefully sampled trial pits. Mass field strengths will be influenced by local proportions of included clasts and shear discontinuities (particularly in landslipped ground). As with the Kannaviou sediments, back analysis of landslides on Melange slopes may yield an insight into shear strength values which may be expected in field situations, and further work along these lines is recommended in conjunction with monitoring of seasonal moisture contents.

The Superficial Melange, identified as a distinct deposit overlying the broken and disturbed Mamonia Complex during the geological mapping of Study Area 2, represents, at least in part, a colluvial slope deposit derived by subaerial weathering and breakdown of the underlying Mamonia rocks. Thicker accumulations may, however, be related to breakup of the Mamonia Complex rocks during emplacement as large scale gravity slides; with incomplete break-up and intermixing resulting in an 'immature Melange' which has not undergone resedimentation to the same extent as the Melange 'proper'. Unlike the latter, the Superficial Melange is highly variable in matrix:clast ratios, with local matrix and clast lithologies being closely related to underlying or adjacent Mamonia rock types. As such, regional geotechnical properties and engineering behaviour are unpredictable.

In areas of widespread slope movements, indications are that existing landslide deposits on the hillside slopes are probably at or close to limiting equilibrium, with shear strengths along pre-existing shear surfaces at or close to minimum residual, ϕ_r', values. In the present study, mean laboratory values of ϕ_r' ($c_r' = 0$) for the Kannaviou and Melange clays were found to be 20.7° and 18.5°, respectively.

The survey methods and techniques described in Chapter 5 highlight the value of aerial photographic analysis in undertaking regional geological and engineering geological assessments, both in defining geological boundaries and in the recognition and classification of unstable ground. The ultimate aim of the analysis is to present the interpreted ground information in the form of maps understandable to planners and engineers concerned with regional development. It is stressed, however, that in structurally and lithologically complex ophiolite terrains, good 'ground control' is essential, and re-assessment of air photo interpretations following reconaissance field surveys of characteristic terrain for 'ground truth' checking is advised prior to expanding air photo reconaissance techniques to other similar areas. Inspection of low-level, oblique, false colour infra-red photographs of selected landslide areas towards the latter stages of this survey, provided useful additional evidence of the presence of old, degraded landslide deposits and, more importantly, evidence of seepage lines and saturated zones within landslide debris and the hillside slopes. Based on these photographs, it is recommended that serious consideration be given to the commissioning of recent c. 1:10 000 scale, vertical, false colour infra-red aerial photographic coverage prior to undertaking regional engineering geological assessments of geologically complex landslide-prone terrain of the type described in this study. In areas such as SW Cyprus, where distinct colour differences are a characteristic feature of the main rock and cohesive soil formations, vertical colour photography would have assisted in the identification of geological outcrops. In view of the value of aerial photographic interpretations in regional surveys of this type, the extra cost of infra-red and colour air photography to supplement the more standard and widely available panchromatic black and white coverage would be justified.

Where weak, fissured and tectonically sheared, montmorillonitic mudstones and clays, such as the Kannaviou Formation, crop out on steep slopes in regions of high relief and seasonally high rainfalls (i.e. in terrains similar to Study Areas 1 and 2), widespread landsliding is to be expected. Slope instability is further enhanced by the presence of a thick permeable cap-rock on major slope crests (i.e. such as the 'chalks' encountered in this study), which not only maintain steep slopes in underlying less competent argillaceous strata, but act as major fissured aquifers capable of transmitting vast quantities of water to the clay slopes via stratum springs at their basal contact with the relatively impermeable clays. As shown on the 1:10 000 scale engineering geology maps, extensive coalescing complex landslides and debris flows are a characteristic feature of the middle and lower clay slopes in excess of c.8.5°-9°, with deep-seated, largeley rotational, failures associated with the steeper slopes around the peripheries of the capping plateaux. In this study, the majority of deep-seated failures appeared to be associated with the presence of faults.

In seismically active regions, major earthquake damage in terrains similar to those described in this study will result from the reactivation of existing slope failures. In such areas, the recognition and classification of these existing slope movements should be undertaken prior to local and regional development, in order that ground with the highest potential for further movement as a result of imposed engineering works and future earthquake shocks is identified. Specific investigations should be carried out to identify known or suspected faults. As the presence and extent of these features are often difficult to identify on the ground, particularly in geologically complex terrain comprising large areas of argillaceous strata, it is recommended that satellite imagery be used as a basis for more detailed ground checks (for example, data tapes of Cyprus acquired by the Landsat 5 Thematic Mapper satellite in June 1985, clearly show lineaments almost certainly indicative of major faults in Study Areas 1 and 2 which were virtually impossible to identify from the field surveys).

Intense erosion and active river downcutting is an important factor in the initiation and continued reactivation of slope movements in the highlands of SW Cyprus. This may be directly related to the continued uplift of the island as a result of obduction of Troodos onto the Afro-arabian continental margin and/or hydration and serpentinization of deep-seated ultramafic rocks. As in SW Cyprus, similar uplift in ophiolite terrains elsewhere has important long-term implications with regards to erosion and slope instability, and further work to elucidate its rate, extent, and whether it is continuous and gradual or episodic, would be enlightening. In SW Cyprus, the first stage of such research could, perhaps, concentrate on the identification and mapping of remnant stream and terrace levels on the valley slopes in an attempt to relate them to rates of river erosion and periods of widespread Recent landslide activity.

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APPENDICES

APPENDIX IA:

BOREHOLE LOGS

NOTES: 1. Borehole locations are shown on Fig. 5.1b
2. Logs are presented in order of drilling sequence as follows:

BH No. E610/84
E613/84
E618/84(DA1)
E619/84(A1)
E620/84(A2)
E621/84(A3)
E622/84(A4)
E624/84(A8)
E625/84(A7)
E626/84(A6)
E627/84(A10)
E628/84(D1) (continuation of BH DA1)
E629/84(D2)

GEOLOGICAL SURVEY DEPARTMENT
CYPRUS

RECORD OF BORING AND SELECTED LABORATORY TESTS

PROJECT: CYPRUS COHESIVE SOILS	LOCATION: Phiti village - Paphos	GRID REF: 45806 E, 386500 N	DATE: 12. 3. 84, 23. 3. 84	BOREHOLE No: EG 10/84
DRILLING METHOD: Percussion 0-48m, Rotary 48-178m, Core 125-127m; B/H DIA. Percussion - 250 mm, Rotary - 150 mm, Core - 75 mm	CORE DIA: 60 mm	GROUND LEVEL: 697.00 m	TOTAL DEPTH: 178.00 m	WATER LEVEL; SHEET 1 OF 2

Columns: DEPTH (m); CORE RECOVERY (%) 20 60 100; FORMATION; LOG; LITHOLOGICAL DESCRIPTION; SAMPLE TYPE & No; SAMPLE DEPTH (m); SPT (blows / ft) 10 20 30 40 50; M/C ⊙ PL ├──┤ LL (%) 10 20 30 40 50 60 70 80 90 100 110 120 130 140; GRAIN SIZE DISTRIBUTION Gr (%) Sa (%) Si (%) Cl (%); NCM; CaCO₃ CONT (%)

Formation: COLLUVIUM (0–3 m); MELANGE (below)

Lithological description:

- TOP SOIL of reworked melange - light reddish silt with sand with some clay and lithic fragments.
- Light reddish silty, clayey MELANGE acting as matrix with some fragments of both igneous and sedimentary rocks.
- As above with apparent occurrence of fragments.
- Overall a "homogeneous" succession of Melange consisting of a weak red (2.5 YR, 4/6) silty clay matrix in which fragments of variable size (from few mm.s to perhaps 10 m) are embedded. It is anticipated that there are bands with more or less marked occurence of fragments but their exact location can not be determined.
- Abundant fragments and blocks in a matrix of Melange.
- Matrix dominant with apparent reduction in fragments occurrence
- Large fragments in matrix
- Weak red silty clayey Melange matrix predominating over the occurence of dispersed fragments and blocks.

Sample type & No	Sample depth (m)	Gr (%)	Sa (%)	Si (%)	Cl (%)	NCM	CaCO₃ cont (%)
BH 1	1.00	0	35	37	28	13.75	58.75
BH 2	4.00	0	36	32	32	20.5	12.37
BH 3	10.5	0	26	36	38	12.0	16.26
BH 4	17.5	0	33	35	32	13.0	21.07
BH 5	26.5	0	34	30	36	16.0	16.25
BH 6	32.5	0	39	39	22	16.5	8.28
BH 7	37.5	0	22	37	41	18.5	13.1
BH 8	47.5	0	29	34	37	12.0	13.0
BH 9	57.5	0	37	31	32	16.8	13.75
BH 10	67.5	0	35	32	33	14.5	17.6
BH 11	74.5	0	21	37	42	15.6	13.12
BH 12	78.5	0	35	30	35	12.5	12.5
BH 14	87.5	5	39	28	28	19.3	12.0

Continues

NOTES: ¦ Disturbed sample

SHEET 1 OF 2	BOREHOLE No EG 10/84	FIG. No
PROJECT: CYPRUS COHESIVE SOILS		
LOCATION: Phiti village - Paphos		
LOGGED BY: G. Petrides	SCALE 1:200	

GEOLOGICAL SURVEY DEPARTMENT
CYPRUS
RECORD OF BORING AND SELECTED LABORATORY TESTS

PROJECT: CYPRUS COHESIVE SOILS	LOCATION Phiti village - Paphos	GRID REF 45806 E 385500 N	DATE 12.3.84 23.5.84	BOREHOLE No EG 10/84
DRILLING METHOD: Percussion 0.0-60 m, Rotary 60-178 m, Core 125-127 m. B/H DIA. Percussion - 260 mm, Rotary - 98 mm	CORE DIA 60 mm. GROUND LEVEL 69.80 m	TOTAL DEPTH 178.00 m	WATER LEVEL	SHEET 2 OF 2

Depth (m)	Formation	Lithological description
92–128	MELANGE	Weak red to brownish red (2.5 YR 4/2) Melange consisting of the typical silty clayey matrix in which fragments of variable size and origin are incorporated. Marked increase in presence of rock fragments at 110-113 and 123-125 m depth.
128–143.5	KANNAVIOU	Olive greenish grey (5Y, 5/4) overconsolidated hard mudstones and subordinate shales. Inclusions of melange near the contact represent probably pollutants from above
143.5–155.5	KANNAVIOU	Poorly cemented volcaniclastic siltstones and fine grained sandstones.
155.5–171.5	KANNAVIOU	Khaki to greenish grey mudstones.
171.5–175.5	KANNAVIOU	Volcaniclastic siltstones and sandstones, poorly cemented.
175.5–178	KANNAVIOU	Shales
178		178 m Bottom of Hole

Sample type & No	Sample depth (m)	Gr (%)	Sa (%)	Si (%)	Cl (%)	Moist. cont (%)	$CaCO_3$ cont (%)
BH 15	97.5	2	34	33	29	13.0	12.5
BH 16	107.5	5	50	25	20	16.6	21.80
BH 17	117.5	15	46	21	18	8.75	17.5
BH 18	125.5	0	0	39	61	47.5	1.87
BH 19	126.5	0	5	40	55	51.25	1.87
BH 20	129.5	0	47	26	25	22.5	18.5
BH 21	134.5	0	30	47.5	22.5	32.5	11.87
BH 22	139.5	0	36	36	28	27.5	11.25
BH 23	149.5	0	38	37	25	25.0	10.62
BH 24	154.5	0	47	43	10	18.75	11.25
BH 25	159.5	0	40	40	20	28.75	8.75
BH 26	169.5	0	47	36	17	22.5	11.87
BH 27	174.5	0	50	37	13	18.75	19.37
BH 28	177.5	0	26	50	24	27.5	15.0

NOTES

Disturbed sample

Core sample

PROJECT CYPRUS COHESIVE SOILS

LOCATION: Phiti village - Paphos

LOGGED BY G. Petrides

SCALE 1:200

SHEET 2 OF 2 BOREHOLE No. EG 10/84 FIG No.

GEOLOGICAL SURVEY DEPARTMENT
CYPRUS

RECORD OF BORING AND SELECTED LABORATORY TESTS

PROJECT: CYPRUS COHESIVE SOILS	LOCATION: Ayios Dhemetrianos	GRID REF: 49896 E, 386344 N	DATE: 28.3.84, 7.5.84	BOREHOLE No. EG 13/84
DRILLING METHOD Rotary, Core drilling at 30-33, 42-47, 61-63; Ø DIA Rotary – 100 mm, Core – 76 mm	CORE DIA 60mm; GROUND LEVEL 522.40m	TOTAL DEPTH 77.00m	WATER LEVEL	SHEET 1 OF 1

Columns: DEPTH (m) | CORE RECOVERY (20, 60, 100 %) | FORMATION | LOG | LITHOLOGICAL DESCRIPTION | SAMPLE TYPE & No | SAMPLE DEPTH (m) | SPT (blows / ft) 10 20 30 40 50 | M/c ⊙ PL ├──┤ LL (%) 10 20 30 40 50 60 70 80 90 100 110 120 130 140 | GRAIN SIZE DISTRIBUTION Gr (%) Sa (%) Si (%) Cl (%) | MOI. CONT (%) | $CaCO_3$ CONT (%)

Formation: MELANGE

Weak red (2.5YR, 4/2) melange, silty clayey matrix in which fragments of variable size and origin are embedded. Some zones include larger percentage of fragments than others but overall the matrix is dominant.

As above but with apparent increase in the content of fragments and blocks.

Predominance of pale red matrix of the melange with reduced content of fragments.

As above (53-57 m) with increased content of fragments.

Formation: KANNAVIOU

Greenish grey (5Y, 5/2) mudstones and subordinate thinly bedded shales.

77.00 m Bottom of Hole

Sample type & No	Sample depth (m)	Gr (%)	Sa (%)	Si (%)	Cl (%)	Moi. cont (%)	$CaCO_3$ cont (%)
BH 29	1.50	2	23	40	35	15.0	16.62
BH 30	3.50	3	28	39	30	13.75	15.00
BH 31	6.50	5	23	37	35	19.25	12.5
BH 32	10.50	7	23	37	33	14.0	14.37
BH 33	18.50	10	30	37	23	10.5	15.0
BH 34	28.50	12	28	39	26	8.75	21.25
BH 35	38.50	13	42	29	16	8.5	17.5
BH 36	42.50						
BH 37	48.50	20	43	21	16	8.75	15.0
BH 38	52.50	5	29	28	28	15.0	15.0
BH 39	59.50	7	47	29	17	12.0	10.12
BH 40	61.50	0	5	44	51	42.0	3.12
41	62.50	0	6	42	52	47.0	3.12
BH 42	65.50	9	30	37	24	20.25	13.75
BH 43	68.50	6	44	33	17	18.75	10.0
BH 44	77.50	8	32	39	21	17.5	11.87

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13?

SHEET 1 OF 1	BOREHOLE No EG 13/84	FIG. No	NOTES:	¦ Disturbed sample; ▮ Core sample; ● Ground water sample	PROJECT CYPRUS COHESIVE SOILS; LOCATION Ayios Dhemetrianos; LOGGED BY G. Petrides. SCALE 1:200

GEOLOGICAL SURVEY DEPARTMENT
CYPRUS
RECORD OF BORING AND SELECTED LABORATORY TESTS

PROJECT: CYPRUS COHESIVE SOILS	LOCATION Kritou Marottou, Paphos	GRID REF 45735 E 386441 N	DATE 18.6.84 20.6.84	BOREHOLE No DA1 (EG 18/84)
DRILLING METHOD: Auger — B/H DIA: 12"	CORE DIA: – — GROUND LEVEL 510.00m	TOTAL DEPTH: 18.00m	WATER LEVEL –	SHEET 1 OF 1

FORMATION: KANNAVIOU

LITHOLOGICAL DESCRIPTION

0–3 m: Sequence of moderately weathered, pale olive (5Y, 6/3) mudstones and shales with subordinate volcaniclastic siltstone bands. Discontinuities are oxide stained

3–14 m: Olive (5Y, 5/3) clayey, silty mudstones and laminated, thinnly bedded shales. Discontinuities are free of staining.

14–18 m: Olive grey (5Y, 5/2) poorly cemented volcaniclastic fine sandstones and siltstones.

18.00 m. Bottom of hole

Sample depth (m)	Gr (%)	Sa (%)	Si (%)	Cl (%)	Mon. cont (%)	Calc. cont (%)	
2.50	0	15	60	25	36.75	1.25	
	0	1	40	59			*
3.75	0	12	38	50	36.5	3.75	
5.50	1	3	56	40			*
	0	28	39	33	24.0	25.0	
6.75	0	12	48	40	39.25	3.75	
8.25	0	1	44	55	34.0	10.75	
9.75	0	0	50	50	32.5	22.5	
11.25	0	0	54	46			*
	0	1	43	56	34.5	21.87	
12.75	0	0	53	47	33.75	23.12	
13.50	0	0	46	54	29.75	3.75	
14.25	Sandstone						
15.75	0	25	60	15	18.75	19.37	
17.50	0	26	42	32	25.0	15.0	

NOTES:
* Asterisk indicates tests done by BGS

Disturbed sample
Undisturbed sample (U4)
Standard Penetration Test (SPT) - Raymond

PROJECT CYPRUS COHESIVE SOILS
LOCATION Kritou Marottou - Paphos
LOGGED BY E. Kyriakou — SCALE 1:50

SHEET 1 OF 1 — BOREHOLE No DA1 (EG 18/84) — FIG No

GSD (0S1 3/85 GSD(EGeol.) R 27/85

GEOLOGICAL SURVEY DEPARTMENT
CYPRUS

RECORD OF BORING AND SELECTED LABORATORY TESTS

PROJECT CYPRUS COHESIVE SOILS	LOCATION Ayios Dhemetrianos - Paphos	GRID MAP 45855 E 386332 N	DATE 21.6.84 22.6.84	BOREHOLE No A1 (BG 19/84)	
DRILLING METHOD Auger	B/H DIA 12"	CORE DIA –	GROUND LEVEL 511.00m	TOTAL DEPTH 8.05m	WATER LEVEL 3.00m	SHEET 1 OF 1

Lithological description

- 0.00–~0.5 m: TOP SOIL including derivaties of melange.
- FORMATION: KANNAVIOU
- KANNAVIOU SHALES. Alternating, thinly bedded greyish brown clayey silt - silty clay, poorly to moderately cemented.
- KANNAVIOU MUDSTONES. Bands of moderately hard silty clayey mudstones interbedded with layers of greenish grey shales. Volcaniclastic poorly cemented siltstones are encountered at the bottom of borehole.
- 8.05 m Bottom of hole

Samples and laboratory tests

Sample	Sample depth (m)	SPT (blows/ft)	Mc / PL–LL (%)	Gr (%)	Sa (%)	Si (%)	Cl (%)	Mont. cont. (%)	$CaCO_3$ cont. (%)	
B1 / ST	2.25			0	15	62	23	35.0	2.5	
B2 / S8	3.75	42		0	13	56	31	41.5	3.75	
B										
B3 / MA / MA2	5.25			0	43	32	25			*
				0	8	36	56			*
B4C				0	23	47	30	42.0	2.5	
B10	6.75	95		1	33	51	15	45.0	3.75	
61	7.50		Not Plastic	0	30	65	5	25.0	1.87	

NOTES:
- • Indicates tests done by BGS

Disturbed Sample
Undisturbed sample (Ua)
Standard Penetration Test (SPT) - Raymond

PROJECT CYPRUS COHESIVE SOILS	
LOCATION: Ayias Dhemetrianos - Paphos	
LOGGED BY E. Kyriakou	SCALE 1:50

SHEET 1 OF 1 — BOREHOLE No A1 (BG 19/84) — FIG No

GEOLOGICAL SURVEY DEPARTMENT
CYPRUS

RECORD OF BORING AND SELECTED LABORATORY TESTS

PROJECT	LOCATION	GRID REF	DATE	BOREHOLE No.
CYPRUS COHESIVE SOILS	Ayios Dhemetrianos, Paphos	45924 E 384368 N	25. 6. 84 26. 6. 84	42 (EG 20/84)

DRILLING METHOD	B/H DIA	CORE DIA	GROUND LEVEL	TOTAL DEPTH	WATER LEVEL	SHEET
Auger	12"		486.00 m	16.00 m.	7.00 m.	1 OF 1

FORMATION: MELANGE

LITHOLOGICAL DESCRIPTION
Weak red (2.5 YR, 4/2) MELANGE incorporating fragments of variable origin.
Fairly uniform reddish brown (2.5 YR, 5/4) sandy clayey MELANGE with small dispersed fragments.
Dark reddish brown (2.5 YR, 3/4) MELANGE matrix of very stiff silty clay incorporating fragments of 1-2 cms
As above but grey Kannaviou clays and siltstones are also incorporated.
Dark reddish brown (2.5 YR, 3/4) MELANGE matrix of silty clay with abundant fine fragments, some of which are of Kannaviou mudstones.
Fairly uniform dark reddish brown fine grained MELANGE.
16.00m. Bottom of Hole

SAMPLE TYPE & No	SAMPLE DEPTH (m)	SPT (blows/ft)	Gr (%)	Sa (%)	Si (%)	Cl (%)	MOIST. CONT. (%)	CaCO3 CONT. (%)	
BH 62	2.25		1	9	37	53	23.25 33.0	6.75 8.0	*
BH 63	3.75	10							
BH 64	4.50		0	21	44	35	15.75	49.37	
BH 65	5.25		2	16	29	53	19.0	33.0	*
BH 66	6.75	20					18.0	8.0	*
BH 67	7.50		0	25	40	35	16.25	13.75	
BH 68	8.50		0	20	35	45	16.25	11.07	
BH 69	9.75	20					16.85	10.0	
BH 70	10.50		0	10	35	55	32.75	5.0	
BH 71	12.75	26	4	21	40	35	25.0	10.0	
BH 72	15.50		0	19	37	44	21.25	11.25	

NOTES:
* Atterberg limits tests done by GGS.

Disturbed sample
Undisturbed sample U4
Standard Penetration Test (S.P.T.) - Raymond

PROJECT	LOCATION	LOGGED BY	SCALE
CYPRUS COHESIVE SOILS	Ayios Dhemetrianos, Paphos	E. Kyriakou	1:50

SHEET 1 OF 1 — BOREHOLE No. 42 (EG 20/84) — FIG. No

GEOLOGICAL SURVEY DEPARTMENT
CYPRUS

RECORD OF BORING AND SELECTED LABORATORY TESTS

PROJECT: CYPRUS COHESIVE SOILS	LOCATION: Kritou Marottou, Paphos	GRID REF: 45905 E, 386412 N	DATE: 27.6.84 – 27.6.84	BOREHOLE No: A3 (EG 21/84)
DRILLING METHOD: Auger	B/H DIA: 12"	CORE DIA: –	GROUND LEVEL: 512.00 m	TOTAL DEPTH: 8.00 m
WATER LEVEL: 1.50 m	SHEET 2 OF 2			

DEPTH (m)	FORMATION	LITHOLOGICAL DESCRIPTION	SAMPLE TYPE & No	SAMPLE DEPTH (m)	SPT (blows/ft)	Gr (%)	Sa (%)	Si (%)	Cl (%)	MONT. CONT. (%)	CaCO3 CONT. (%)
0–2.5	SLIPPED MELANGE	MELANGE Abundant fragments of variable sizes including also some Kannaviou deposits in a dark reddish brown matrix.	BH 73	1.50		0	25	32	43	29.85	13.75
2.5–8.0	SLIPPED MELANGE	MELANGE Fine fragments of rocks belonging to the Mamonia complex in a reddish brown clayey, silty clayey matrix. Fragments of Kannaviou clays and sandstones still present but considerably less.	BH 77	3.45	Refusal	0	22	33	37	12.75	14.87
			BH 75	4.50		0	20	30	24	21.85	37.5
			BH 76	5.85	128	0	17	45	30	15.0	9.87
			BH 77	7.50		0	20	36	36	24.5	12.5

8.00 m Bottom of hole

NOTES:

Disturbed sample
Undisturbed sample (U4)
Standard Penetration Test (SPT) - Raymond

PROJECT: CYPRUS COHESIVE SOILS	
LOCATION: Kritou Marottou, Paphos	
LOGGED BY: E. Kyriacou	SCALE 1:50

SHEET 2 OF 2 — BOREHOLE No A3 (EG 21/84) — FIG No

GEOLOGICAL SURVEY DEPARTMENT
CYPRUS

RECORD OF BORING AND SELECTED LABORATORY TESTS

PROJECT *PAPHOS COHESIVE SOILS*	LOCATION *Kritou Marottou, Paphos*	GRID REF *45993 E 386516 N*	DATE *29.6.84 3.7.84*	BOREHOLE No. *A4 (EG. 22/84)*
DRILLING METHOD *Auger* B/H DIA *12"*	CORE DIA *—* GROUND LEVEL *553.00m*	TOTAL DEPTH *18.00m*	WATER LEVEL	SHEET *1* OF *1*

Columns: DEPTH (m) · CORE RECOVERY 20 60 100 % · FORMATION · LOG · LITHOLOGICAL DESCRIPTION · SAMPLE TYPE & No · SAMPLE DEPTH (m) · SPT (blows/ft) 10 20 30 40 50 · M/C ⊙ PL ⊢—⊣ LL (%) 10 20 30 40 50 60 70 80 90 100 110 120 130 140 · GRAIN SIZE DISTRIBUTION Gr (%) Sa (%) Si (%) Cl (%) · MON. CONT (%) · CaCO₃ CONT (%)

Depth (m)	Formation	Lithological description
0–1.0		*Top soil consisting of reworked Kannaviou and chalks.*
1.0–6.9	SLIPPED KANNAVIOU	*Olive, (5Y, 5/3) clayey silt, silty, clay reworked with calcareous material, and fragments of relatively undisturbed Kannaviou mudstones.*
6.9–10.0	SLIPPED MELANGE	*Dark reddish brown (5YR, 3/3) reworked MELANGE incorporading also fragments of chalks.*
10.0–18.0	SLIPPED LEFKARA	*Whitish, moderately cemented chalky marl, marly chalk fractured and generally disturbed.* ?
18.00		*18.00m. Bottom of Hole.*

Sample type & No	Sample depth (m)	SPT (blows/ft)	Gr (%)	Sa (%)	Si (%)	Cl (%)	Mon. cont (%)	$CaCO_3$ cont (%)	
BH 78	2.25		0	9	55	36	33.75	6.25	
BH 79	3.75	30	0	15	41	44	31.25	11.25	
B									
BH 80	5.26		0	3	46	51			*
80B			0	15	31	54	36.25	1.25	
BH 81	6.75	32	0	12	36	52	25.0	16.25	
BH 82	7.50		0	22	32	46	20.0	51.62	
BH 83	8.25	46							
BH 84	9.75		1	24	42	33	18.25 / 26.0	33.75 / 46.0	*
B									
BH 85	11.25	50							
BH 86	12.65								
B									
BH 87	14.25	40							
BH 88	15.60								

NOTES:
* *Indicates tests done by B.G.S.*

Disturbed Sample
Undisturbed sample *(U4)*
Standard Penetration Test (S.P.T.) - Raymond

SHEET *1* OF *1*	BOREHOLE No *A4 (EG 22/84)*	FIG No
PROJECT *CYPRUS COHESIVE SOILS*	LOCATION *Kritou Marottou, Paphos*	
LOGGED BY *E. Kyriakou*	SCALE *1:50*	

GST (DS) 3/85 GSD (E.Geol.) R 22/86

GEOLOGICAL SURVEY DEPARTMENT
CYPRUS

RECORD OF BORING AND SELECTED LABORATORY TESTS

PROJECT: CYPRUS COHESIVE SOILS	LOCATION: Saramas, Paphos	GRID REF 45720 E 386608 N	DATE: 10.7.84 12.7.84	BOREHOLE No 48 (SO 24/84)
DRILLING METHOD Auger / B/H DIA 12"	CORE DIA: 2ppl.00m / GROUND LEVEL	TOTAL DEPTH 18.00m	WATER LEVEL: —	SHEET 1 OF 1

Lithological description:

TOP SOIL

SLIPPED MELANGE — Dark reddish brown (5YR, 3/3) Melange, consisting basically of clayey silt and silty clay matrix in which there is an abundance of fragments ranging in size from 1mm to 10 cm. Fragments consist of Mamonia rocks Kannaviou and chalks.

KANNAVIOU — Alternating horizons of olive (5Y, 3/3) thinnly laminated shales and mudstones.

18.00m Bottom of Hole

Formation	Sample No	Sample depth (m)	Gr (%)	Sa (%)	Si (%)	Cl (%)	Moist. cont. (%)	$CaCO_3$ cont. (%)
SLIPPED MELANGE	87	1.50	0	21	32	47	24.25	13.75
	[illegible]	2.25	0	25	35	40	24.25	15.0
	91	3.75	2	21	40	37	24.0	10.0
	92	4.50	0	17	36	47	22.75	11.25
	93	5.25						
	[illegible]	6.75	1	19	37	43	19.25 / 18.0	17.5 / 19.0 *
	[illegible]	7.50	0	18	35	47	20.75	17.5
	96	8.25	2	26	32	40	22.5	8.75
	97	9.75	2	23	30	37	23.0	12.6
	98	10.50	0	21	35	44	22.0	7.5
KANNAVIOU	99	11.25	0	8	42	50	36.75	5.62
	100	12.75						
	101	13.50	0	8	33	59	36.25	8.75
	102	14.25	0	0	50	39	40.5	3.75
	103	17.50	0	0	49	48	33.75	2.5

NOTES:
* Asterisk indicates tests done by B.G.S.

Disturbed sample
Undisturbed sample (U4)
Standard Penetration Test (S.P.T) - Raymond

PROJECT: CYPRUS COHESIVE SOILS
LOCATION: Saramas, Paphos
LOGGED BY: E. Kyriakou
SCALE: 1:50

SHEET 1 OF 1 — BOREHOLE No 48 (SO 24/84) — FIG. No

GEOLOGICAL SURVEY DEPARTMENT
CYPRUS

RECORD OF BORING AND SELECTED LABORATORY TESTS

PROJECT: *CYPRUS COHESIVE SOILS*	LOCATION: *Saramas, Paphos*	GRID REF: *45573 E 386774 N*	DATE: *13.7.84 17.7.84*	BOREHOLE No: *A7 (EG 25/84)*
DRILLING METHOD: *Auger*	B/H DIA: *12"*	CORE DIAM: –	GROUND LEVEL: *240.00m*	TOTAL DEPTH: *18.00 m*
WATER LEVEL: –	SHEET 1 OF 1			

DEPTH (m) | CORE RECOVERY | FORMATION | LOG | LITHOLOGICAL DESCRIPTION | SAMPLE TYPE & No | SAMPLE DEPTH (m) | SPT (blows / ft) | MC ⊙ PL ⊢——⊣ LL (%) | GRAIN SIZE DISTRIBUTION | CONE | CaCO₃ CONT.

TOP SOIL

SLIPPED MELANGE

SLIPPED MELANGE Dark reddish brown (5YR, 3/3) silty clayey matrix incorporating inclusions of pale olive (5Y, 6/3) Kannaviou clay and siltstones, up to 10 cm in size, and also fragments of Mamonia rocks up to 8 cms.

KANNAVIOU

KANNAVIOU Alternating, thinnly laminated olive (5Y, 5/3) shales and silty, clayey mudstones.

18.00m Bottom of Hole

Sample	Depth (m)	Gr (%)	Sa (%)	Si (%)	Cl (%)	Cone (%)	$CaCO_3$ Cont. (%)
BH 104	1.50	0	6	21	73	50.0	3.12
BH 105	2.25	1	19	38	42	18.75 / 25.0	8.75 / 5.0 *
BH 106	5.50	0	20	37	43	22.5	8.75
BH 107	6.75						
BH 108	7.50	0	18	38	44	23.75	8.25
BH 109	8.10	3	11	34	52	26.0	8.0 *
BH 110	9.75	6	16	30	48	28.25	10.0
BH 111	11.10	0	17	36	47	27.5	11.25
112	12.50	0	11	39	50	32.5	11.25
113 B	13.25	0	18	44	38	28.25	7.5
114	14.75						
115	16.25	0	9	35	56	40.75	7.5
116	17.50	0	12	41	47	39.0	6.25

NOTES
* Indicates tests done by B.G.S.

Disturbed sample
Undisturbed sample (U_4)
Standard Penetration Test (S.P.T.) Raymond

PROJECT *CYPRUS COHESIVE SOILS*
LOCATION *Saramas, Paphos*
LOGGED BY *E. Kyriakou* SCALE *1:50*

SHEET 1 OF 1 | BOREHOLE No *A7 (EG 25/84)* | FIG No

GSO (OS) 1/85 G.S.D.(E.Geol.) R24/86

GEOLOGICAL SURVEY DEPARTMENT

CYPRUS

RECORD OF BORING AND SELECTED LABORATORY TESTS

PROJECT CYPRUS COHESIVE SOILS	LOCATION Saramas, Paphos	GRID REF 45712 E 386681 N	DATE 18.7.84 23.7.84	BOREHOLE No A6 (EG 26/84)
DRILLING METHOD Auger	B/H DIA 12"	CORE DIA –	GROUND LEVEL 366.00 m	TOTAL DEPTH 18.00 m
WATER LEVEL –	SHEET 4 OF 4			

Depth (m)	Formation	Lithological description
0.00–3.00	SLIPPED KANNAVIOU	Reworked olive (5Y, 4/3) clayey silt with calcareous rock fragments.
3.00–5.00	KANNAVIOU	Olive, (5Y, 5/3) clayey, silty mudstones.
5.00–7.00	KANNAVIOU	Olive (5Y, 5/3) thinnly bedded laminated shales.
7.00–18.00	KANNAVIOU	Olive (5Y, 5/3) silty clayey mudstones and subordinate thinnly bedded, laminated shales.
18.00		18.00 m. Bottom of Hole

Sample	Sample depth (m)	SPT (blows/ft)	Gr (%)	Sa (%)	Si (%)	Cl (%)	Mon. cont (%)	$CaCO_3$ cont (%)
	1.00							
BH 119	1.50		0	12	40	48	32.5	10.62
BH [illegible]	2.25							
BH [illegible]	3.75	23	0	6	44	50	38.75	9.37
BH 120	4.50		0	17	35	48	27.5	26.25
BH [illegible]	5.25		3	19	51	27		*
BH [illegible]	6.75	26	0	3	61	36	37.5	2.5
BH 123	7.50		0	8	40	52	35.0	20.12
BH [illegible]	8.25							
BH [illegible]	9.75	80	0	8	73	19	53.5	4.37
BH 126	10.30		0	9	55	36	54.0	6.87
BH [illegible]	11.15	Refusal	0	9	77	14	31.25	3.12
BH 128	13.50		0	8	70	22	34.75	2.5
BH [illegible]	14.25	89	0	0	55	45	61.25	3.12
BH 131	15.50							
BH 132	17.50		0	31	51	18	40.0	2.5

NOTES:
* Indicates tests done by BGS

Disturbed sample

Undisturbed sample (U_4)

Standard Penetration Test (S.P.T.) - Raymond

PROJECT CYPRUS COHESIVE SOILS	
LOCATION Saraman, Paphos	
LOGGED BY E. Kyriakou	SCALE 1:50

SHEET 1 OF 1 BOREHOLE No A6 (EG 26/84) FIG No

GEOLOGICAL SURVEY DEPARTMENT
CYPRUS

RECORD OF BORING AND SELECTED LABORATORY TESTS

PROJECT: CYPRUS COHESIVE SOILS	LOCATION: Simou, Paphos	GRID REF: 45648 E, 386684 N	DATE: 24.7.84, 26.7.84	BOREHOLE No: A10 (EO 27/84)
DRILLING METHOD: Auger	B/H DIA: 12"	CORE DIA: –	GROUND LEVEL: 341.00 m	TOTAL DEPTH: 16.00 m
WATER LEVEL: –	SHEET 1 OF 1			

Formation: KANNAVIOU

Lithological description

0.00–5.00 m: Olive (5Y, 5/3) silty clayey mudstones with blackish staining on the discontinuities.

5.00–16.00 m: Olive (5Y, 5/3) poorly cemented volcaniclastic Sandstones and siltstones with thin interbeds of silty mudstones.

16.00 m Bottom of Hole

Sample type & No	Sample depth (m)	SPT (blows/ft)	Gr (%)	Sa (%)	Si (%)	Cl (%)	Mon. cont. (%)	$CaCO_3$ cont. (%)
BH 133	1.50							
BH 134	2.25	115	0	0	52	48	38.75	21.87
BH 135	3.75	119	0	0	58	42	33.75	23.50
BH 136	4.50		0	0	61	39	26.25	19.75
BH 137	5.15	Refusal	0	0	70	22	21.25	18.75
BH 138	6.75	Refusal	0	10	68	22	20.0	13.68
BH 139	9.00	Refusal	0	38	51	11	15.0	18.75
BH 140	10.50		0	43	42	15		
BH 141	11.25	Refusal	0	41	41	18	15.0	18.75
BH 142	12.60	Refusal						
BH 143	14.15	Refusal	0	44	34	22	17.5	10.75
BH 144	15.50			17	49	34		

W/c ⊙ PL├──┤LL (%)

SHEET 1 OF 1 BOREHOLE No A10 (EO 27/84) FIG No

NOTES:

Disturbed Sample
Undisturbed sample (U4)
Standard Penetration Test (S.P.T.) - Raymond

PROJECT: CYPRUS COHESIVE SOILS
LOCATION: Simou, Paphos
LOGGED BY: E. Kyriakou
SCALE: 1:50

G.S.D. (O.S.) 3/85 G.S.D. (E.Geol.) R 26/86

GEOLOGICAL SURVEY DEPARTMENT
CYPRUS

RECORD OF BORING AND SELECTED LABORATORY TESTS

PROJECT: CYPRUS COHESIVE SOILS	LOCATION: Kritou Marottou, Paphos	GRID REF: 45935 E, 386991 N	DATE: 10.8.84 – 23.8.84	BOREHOLE No: D1 (EG 28/84)
DRILLING METHOD: Roller 0 - 13.5 m; Core 13.5 - 62.7 m	B/H DIA: 75 mm	CORE DIA.: 60 mm	GROUND LEVEL: 510.00 m	TOTAL DEPTH: 62.70 m
WATER LEVEL: –	SHEET 1 OF 1			

Column headings: DEPTH (m) · CORE RECOVERY (20 40 60 80 100 %) · FORMATION · LOG · LITHOLOGICAL DESCRIPTION · SAMPLE TYPE & No · SAMPLE DEPTH (m) · SPT (blows / ft) (10 20 30 40 50) · Mc ⊙ PL ├──┤ LL (%) (10 20 30 40 50 60 70 80 90 100 110 120 130 140) · GRAIN SIZE DISTRIBUTION: Gr (%), Sa (%), Si (%), Cl (%) · MON. CONT. (%) · $CaCO_3$ CONT. (%)

Formation: KANNAVIOU

Lithological description	Sample type & No	Sample depth (m)	Mon. cont. (%)	$CaCO_3$ cont. (%)	
No core recovered					
Moderately sheared shales and mudstones.					
Poorly cemented siltstones and sandstones.	84/145	16.50	17.5 / 21.0	20.6 / 14.0	*
	84/146	18.75	[illegible]	[illegible]	*
	84/147	19.50	[illegible]	[illegible]	*
Dark greenish in places highly sheared shales and poorly cemented siltstones.	84/148	20.05	[illegible]	[illegible]	*
Greyish, hard, in places especially below 20.0 m. depth, highly sheared mudstones.	84/149	27.50	20.0 / 32.0	8.1 / 7.0	*
Shale	84/150	38.00	43.7 / 42.0	15.0 / 16.0	*
Greyish, fresh hard mudstones.	84/151	43.00	37.0 / 41.0	15.0 / 19.0	*
Greyish, poorly to moderately cemented siltstones and sandstones. Gradual increase in cementation and grain size with depth apparent.	84/152	50.15	24.0	5.0	*
	84/153	56.20	7.0 / 18.0	33.1 / 22.0	*
	84/154	57.80	61.0	3.0	*
Moderately to highly sheared mudstone.	84/155	58.75	33.0	22.0	*
62.70 m Bottom of Hole					

BOREHOLE No: D1 (D4) (EG 28/84) · SHEET 1 OF 1 · FIG. No

NOTES

* Asterisk indicates chemical tests done by A.G.S.

N.D. Not Done

▌ Core Sample

PROJECT: CYPRUS COHESIVE SOILS	
LOCATION: Kritou Marottou, Paphos	
LOGGED BY: M. Charalambous	SCALE 1:200

GEOLOGICAL SURVEY DEPARTMENT
CYPRUS

RECORD OF BORING AND SELECTED LABORATORY TESTS

PROJECT: CYPRUS COHESIVE SOILS	LOCATION: Phili, Paphos	GRID REF: 45782 E, 386604 N	DATE: 3.9.84 – 12.9.84
DRILLING METHOD: Roller 0-30m, Core 30-64m	B/H DIA: 75 mm	CORE DIA: 60 mm	GROUND LEVEL: 536.00m
TOTAL DEPTH: 64.10m	WATER LEVEL: –	BOREHOLE No: D2 (EG 29/84)	SHEET 1 OF 1

Column heads: DEPTH (m) · CORE RECOVERY (20, 60, 100 %) · FORMATION · LOG · LITHOLOGICAL DESCRIPTION · SAMPLE TYPE & No · SAMPLE DEPTH (m) · SPT (blows/ft) 10 20 30 40 50 · M/c ⊙ PL ├──┤ LL (%) 10–140 · GRAIN SIZE DISTRIBUTION Gr (%) Sa (%) Si (%) Cl (%) · MON. CONT (%) · $CaCO_3$ CONT (%)

Formation: KANNAVIOU

Lithological description	Sample type & No	Sample depth (m)	Mon. cont (%)	$CaCO_3$ cont (%)	
No core recovered					
Greyish to olive mudstone with oxide stained joints.					
Greenish grey, highly to moderately sheared shales.	BH 156	9.35	48.0 / 46.0	8.7 / 6.0	*
Moderately cemented sandstone	BH 157	13.25	31.0 / 38.0	6.2 / 1.0	*
Alternating shales mudstones and sandstones. Shales are generally sheared.	BH 158 / 159	17.00 / 17.50	41.2 / 29.0 / 39.2 / 48.0	6.8 / 6.3 / 4.2 / 9.0	* *
Moderately to highly cemented sandstone	BH 160	20.25	36.7 / 31.0	6.8 / N.D.	*
Alternating shales and mudstones. Strong shearing at 23.0-24.0 m					
Moderately cemented siltstones and sandstones					
Bands of moderately sheared mudstones interbedded with laminated shales. Mudstones get hard and massive with depth. Strong shearing at 35-36m and around 42.0 m depth.	BH 161	38.25	29.5 / 30.0	22.5 / 23.0	*
Grey siltstones (which gradually they get coarse grained with depth) and sandstones. They are moderately to highly cemented.	BH 162	46.85	22.5 / 20.0	22.0 / 6.0	*
Alternating sequence of shales, thin sandstones and subordinate mudstones. Very strong shearing below 61.0 m depth.	BH 163	52.40	20.0 / 93.0	16.3 / ND	*
	BH 164	56.90	23.7 / 31.0	1.2 / ND	*
64.10 m Bottom of Hole					

NOTES:
* Asterisk indicates chemical tests done by A.G.S.
N.D- Not done

█ Core sample

SHEET 1 OF 1	BOREHOLE No D2 (EG 29/84)
FIG No	
PROJECT	CYPRUS COHESIVE SOILS
LOCATION	Phili, Paphos
LOGGED BY	M. Charalambous
SCALE	1:200

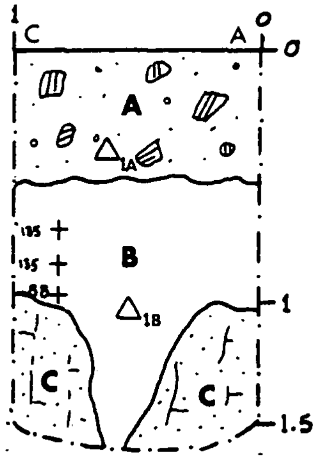
APPENDIX IB:

PIT SECTIONS

NOTES: 1. Pit locations are shown on Fig. 5.1b
2. Survey Area 1: Pit Nos. 1-7,10A,10B,11A,11B,
(Phiti) 12-24,7(85).

Survey Area 2: Pit Nos. 1(85)-6(85).
(Statos)

BRITISH GEOLOGICAL SURVEY		SITE: Ayios Dhimitrianos	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 5935.6452	PIT No.: 1



ZONE	DESCRIPTION
A	Dry, structureless Melange (slopewash ?) comprising Mamonia clasts of c.gravel to cobble grade in reddish brown (5Y5/3) sandy SILT/CLAY matrix charged with Mamonia clasts of c.sand - f.gravel grade.
B	Highly fissured, weathered, soft to firm, olive (5Y5/4), slightly sandy, silty Kannaviou CLAY. Manganiferous staining on fissure surfaces.
C	Moderately hard, light olive grey (5Y6/2), argillaceous Kannaviou SILTSTONE grading to hard SANDSTONE with depth. Moderately jointed with manganiferous staining on fracture surfaces. Open joint shown in pit section infilled with soft clay and fine clayey sand.

KEY:

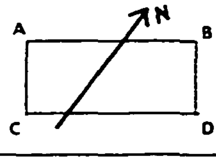
- Δ BAG SAMPLE
- □ BLOCK
- U 100 SAMPLE
- U 35
- + HAND VANE TEST (S_u kN/m^2)
- PENETROMETER
- SEEPAGE
- STANDING WATER LEVEL
- PHOTOGRAPH

LOGGED BY: PRNH

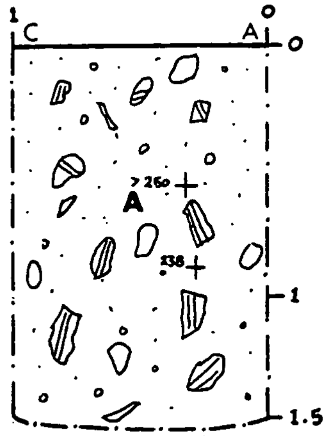
DATE: 6/84

SCALE: 1:30

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Kritou Marottou	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 5940.6468	PIT No.: 2



ZONE	DESCRIPTION
A	Structureless Melange comprising angular to sub-rounded Mamonia clasts of c.gravel to cobble grade in dark reddish grey (5YR4/2) sandy silty CLAY matrix. Slickensiding occurs on many cobble grade clasts. Probable landslip deposit.

KEY:

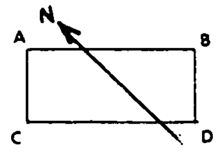
- △ BAG SAMPLE
- □ BLOCK "
- U 100 SAMPLE
- U 35 "
- \+ HAND VANE TEST (S_u kN/m²)
- PENETROMETER " "
- SEEPAGE
- STANDING WATER LEVEL

LOGGED BY: PRNH

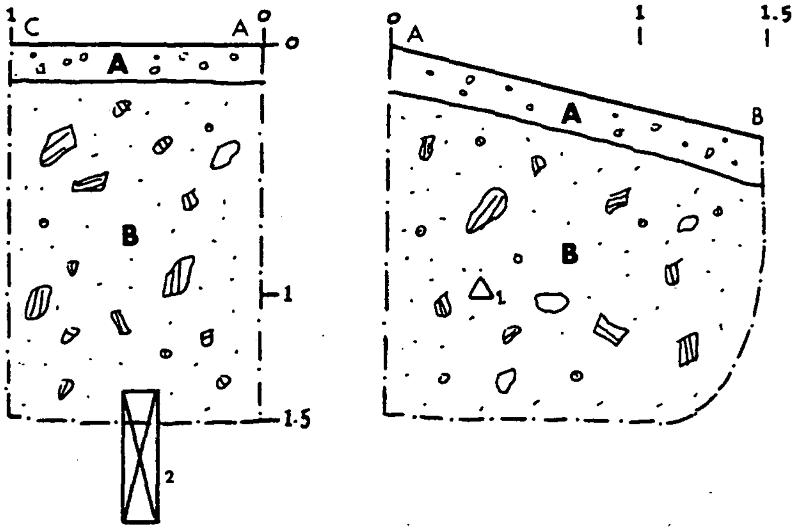
DATE: 6/84

SCALE: 1:30

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Kritou Marottou	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 5982.6553	PIT No.: 3



ZONE	DESCRIPTION
A	Chalk TALUS slope deposit comprising gravel grade, weathered chalk clasts in m-c sand grade chalk 'matrix'.
B	Melange, comprising Mamonia clasts of c.gravel and occasional cobble grade in hard, fissured, strongly sheared and slickensided, dark reddish grey (5YR4/2) silty CLAY matrix. Shears and slickensiding appear unrelated to present surface slope.

KEY:

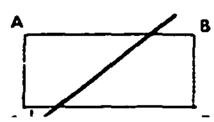
- Δ BAG SAMPLE
- □ BLOCK
- U100 SAMPLE
- + HAND VANE TEST (S_u kN/m²)
- PENETROMETER
- SEEPAGE
- STANDING WATER LEVEL

LOGGED BY: PRNH

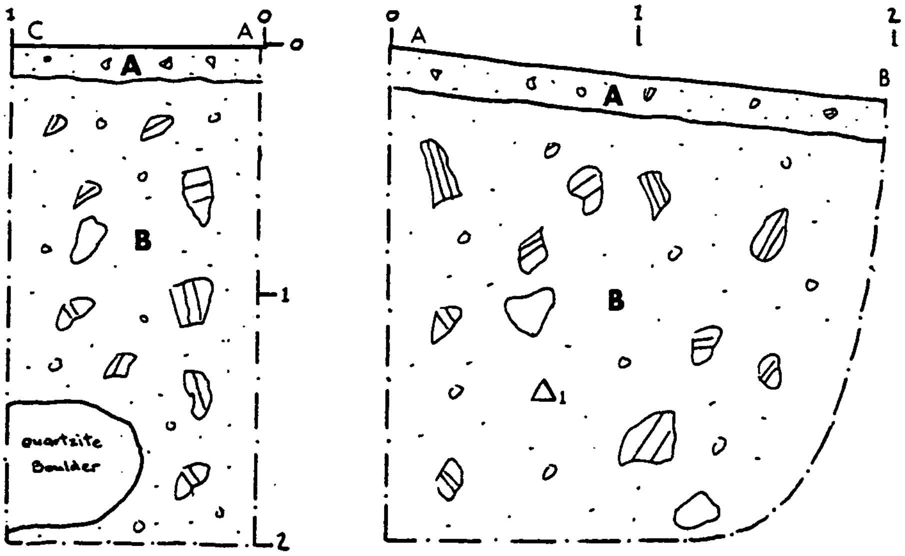
DATE: 6/84

SCALE: 1:30

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Phiti	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 5872.6475	PIT No.: 4



ZONE	DESCRIPTION
A	Dry reworked Melange topsoil.
B	Melange, structureless, comprising cobble grade and occasional boulder grade Mamonia clasts in firm to stiff dark reddish brown (5YR3/3) silty CLAY matrix charged with c.sand - m.gravel grade Mamonia clasts.

KEY:

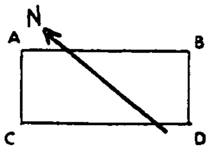
- △ BAG SAMPLE
- ▢ BLOCK "
- U 100 SAMPLE
- U 35 "
- + HAND VANE TEST (S_u kN/m²)
- ● PENETROMETER " "
- SEEPAGE
- STANDING WATER LEVEL
- PHOTOGRAPH

LOGGED BY: PRNH

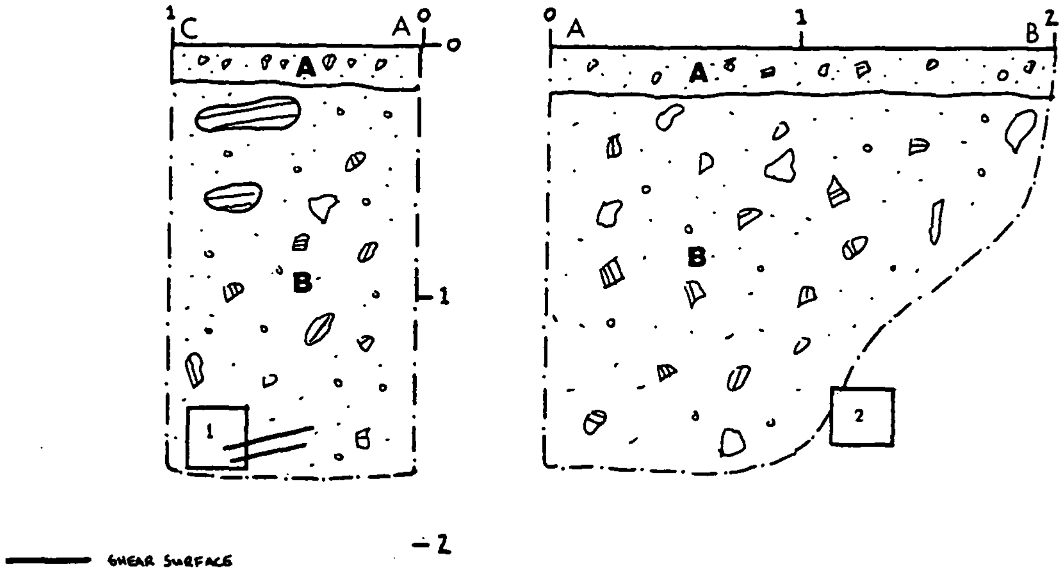
DATE: 6/84

SCALE: 1:30

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Milia	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 5798.6370	PIT No.: 5



ZONE	DESCRIPTION
A	Dry, reworked Melange topsoil.
B	Melange, structureless, comprising sub-angular to sub-rounded Mamonia clasts of c.gravel to cobble grade in slightly fissured, firm to stiff, dark reddish grey (5YR4/2) sandy silty CLAY matrix. Several slickensided discontinuous shear planes occur near base of pit (1.7m) showing average 20° dip to S.

KEY:

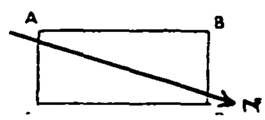
△ BAG SAMPLE
□ BLOCK
U 100 SAMPLE
U 35
+ HAND VANE TEST (S_u kN/m²)
● PENETROMETER
SEEPAGE
STANDING WATER LEVEL

LOGGED BY: PRNH

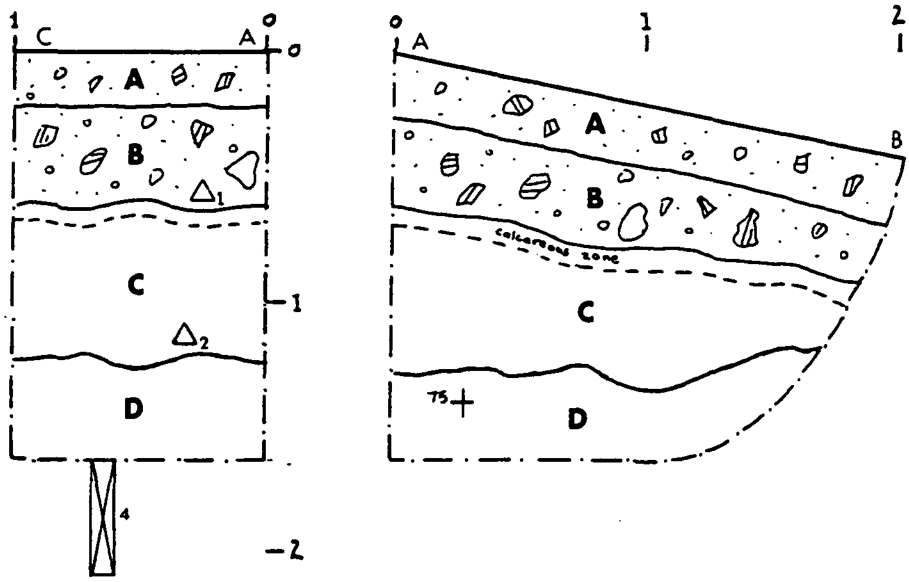
DATE: 6/84

SCALE: 1:20

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Ayios Dhimitrianos	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 5840.63501	PIT No.: 6



ZONE	DESCRIPTION
A	Dry, reworked Melange. Slopewash/topsoil.
B	Melange, structureless, comprising c.gravel grade to occasional cobble grade Mamonia clasts in soft to firm, reddish brown (5YR4/3) mottled olive (5Y4/3) CLAY matrix charged with c.sand - f.gravel grade Mamonia clasts. Probable landslip deposit.
C	Moderately loose, rubbly, weathered, clast-dominant, light olive grey (5Y7/2) CLAYSTONE. Whitish calcareous-rich zone of approx. 10 cm thickness at top of sequence
D	Highly fissured, weathered, soft to firm Kannaviou CLAY.

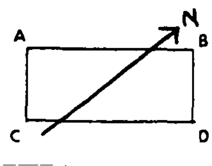
KEY:
- △ BAG SAMPLE
- □ BLOCK "
- U100 SAMPLE
- U35 "
- + HAND VANE TEST (S_u kN/m^2)
- ● PENETROMETER " "
- SEEPAGE
- STANDING WATER LEVEL

LOGGED BY: PRNH

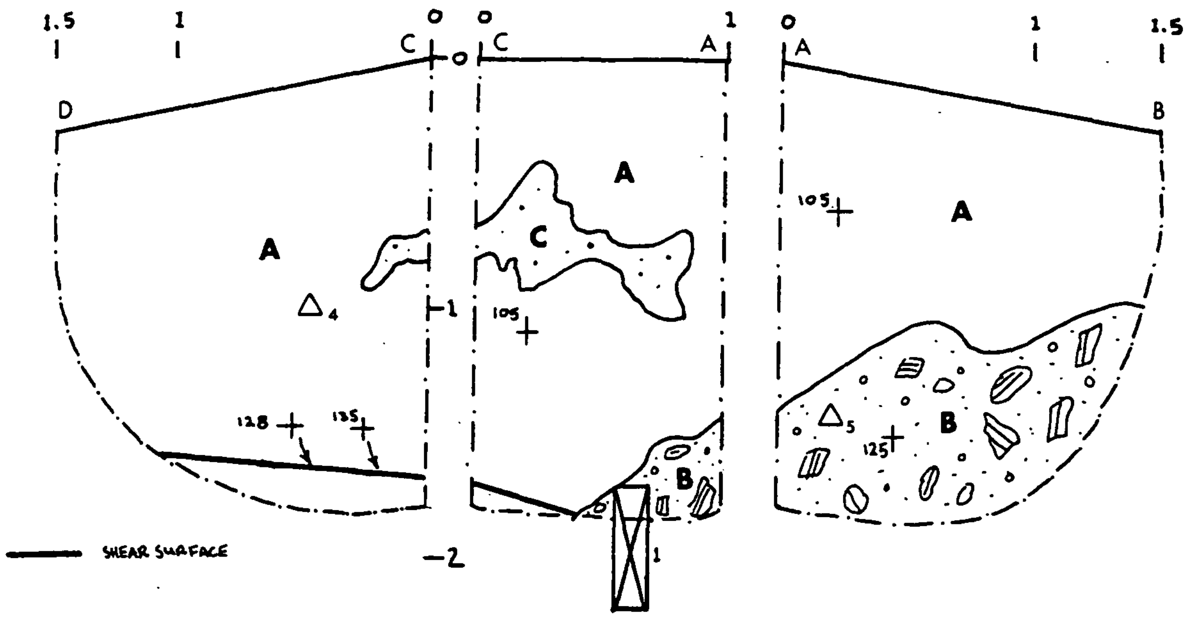
DATE: 6/84

SCALE: 1:30

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Ayios Dhimitrianos	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 5918.6442	PIT No.: 7



ZONE	DESCRIPTION
A	Weathered, soft, plastic, olive (5Y5/3) Kannaviou CLAY with numerous weathered 'soft' mudstone/shaly claystone clasts of gravel grade. Shear plane near base of pit (1.8m) marked by thin reddish brown (5YR4/4) CLAY streak, 22° dip to ENE.
B	Soft, plastic, reddish brown (2.5YR4/2) Melange CLAY matrix, with angular to rounded Mamonia clasts of gravel to cobble grade.
C	Disturbed, soft, slickensided, reddish brown (5YR4/4) CLAY. Pit is very moist throughout.

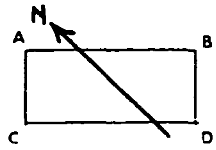
KEY:
- △ BAG SAMPLE
- □ BLOCK
- ⊠ U100 SAMPLE
- ⊓ U35
- + HAND VANE TEST (S_u kN/m²)
- ● PENETROMETER
- SEEPAGE
- STANDING WATER LEVEL

LOGGED BY: PRWH

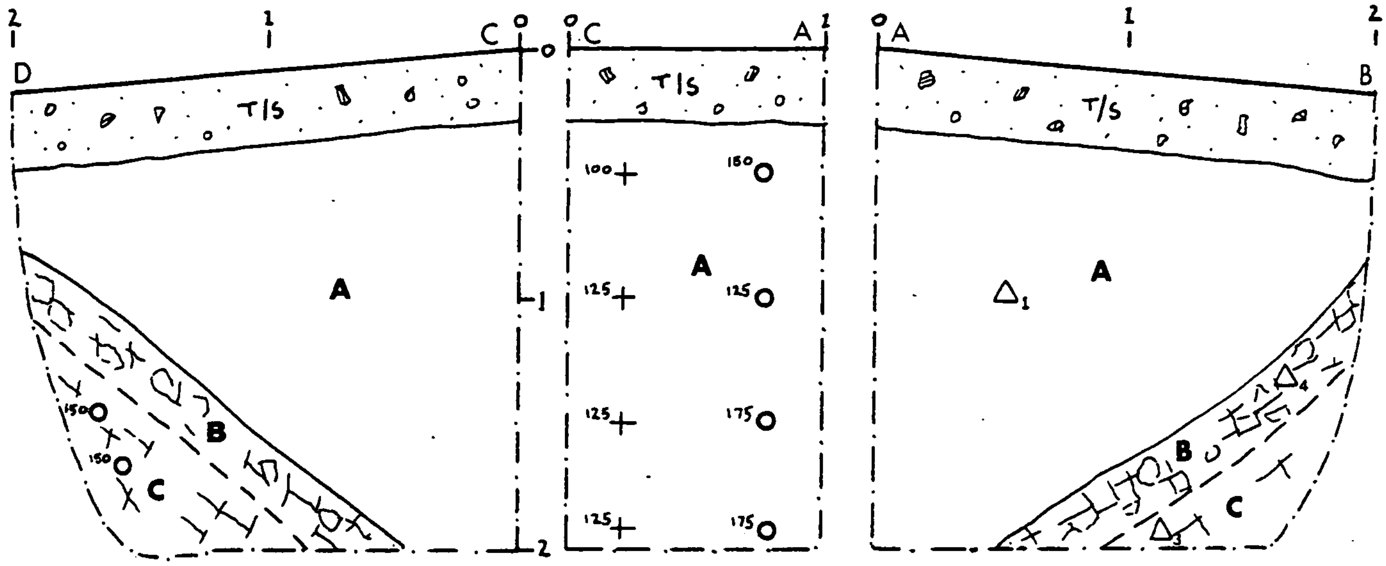
DATE: 6/84

SCALE: 1:30

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Ayios Dhimitrianos	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 5893.6366	PIT No.: 10 A



ZONE	DESCRIPTION
T/S	Reworked Melange topsoil/slopewash with Mamonia clasts to gravel grade in brownish red (2.5YR4/2) sandy, silty CLAY matrix.
A	Firm, slightly friable, weathered, olive (5Y5/3) Kannaviou CLAY with numerous weathered, olive mudstone clasts of gravel grade.
B	Highly fissured, with manganiferous staining on slickensided fissure surfaces, v.hard, olive (5Y5/3) Kannaviou v.silty MUDSTONE.
C	Fissured, moderately hard, olive (5Y5/3) Kannaviou silty MUDSTONE, weathering to soft silty clay around fissure surfaces. No staining on fissures.

KEY:

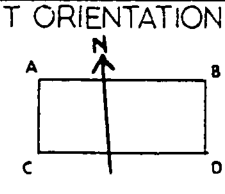
- △ BAG SAMPLE
- □ BLOCK "
- U 100 SAMPLE
- U 35 "
- + HAND VANE TEST (S_u kN/m²)
- ● PENETROMETER " "
- SEEPAGE
- STANDING WATER LEVEL
- PHOTOGRAPH

LOGGED BY: PRNH

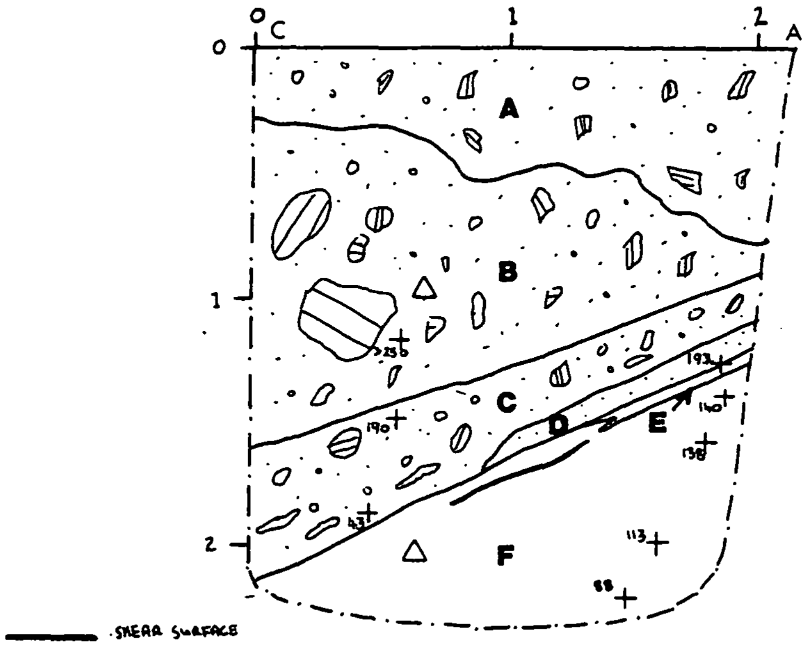
DATE: 6/84

SCALE: 1:30

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Ayios Dhimitrianos	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 5893. 6364	PIT No.: 10B



ZONE	DESCRIPTION
A	Dry, reworked Melange topsoil/slopewash.
B	Melange. Firm, dark reddish brown (7.5YR4/2) CLAY matrix, with random Mamonia clasts of c.gravel to cobble grade and occasional boulder grade.
C	Firm, reddish brown (5YR4/3) mottled olive grey (5Y5/2) CLAY with sub-rounded to sub-angular Mamonia clasts of c.gravel to occasional cobble grade. Melange with incorporated Kannaviou clay.
D	Friable brownish orange, sandy CLAY.
E	Thin discontinuous band of grey slightly olive (5Y6/1) CLAY.
F	Firm, fissured, olive (5Y4/3) Kannaviou CLAY. Slickensided shear surface near contact with overlying Zones C and D.

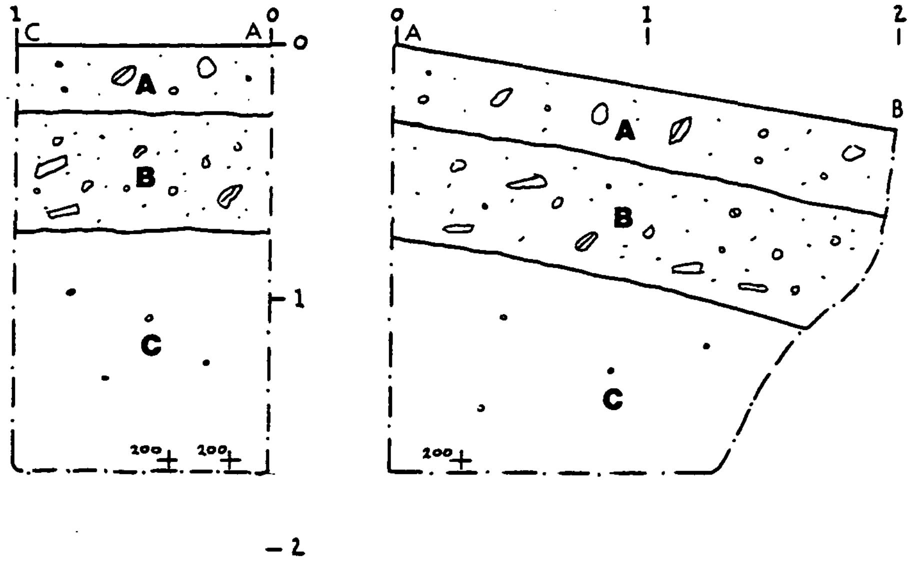
KEY:
- △ BAG SAMPLE
- ☐ BLOCK
- U 100 SAMPLE
- U 35
- + HAND VANE TEST (S_u kN/m^2)
- ● PENETROMETER
- SEEPAGE
- STANDING WATER LEVEL
- PHOTOGRAPH

LOGGED BY: PRWH
DATE: 6/84
SCALE: 1:30

PIT ORIENTATION:

N
A B
C D

BRITISH GEOLOGICAL SURVEY		SITE: Kritou Marottou	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 6072.6490	PIT No.: 11A



ZONE	DESCRIPTION
A	Dry, friable sandy, brownish grey, CLAY/SILT with gravel to cobble grade Mamonia and chalk clasts. Topsoil/slopewash.
B	Stiff to hard, slightly friable, becoming more plastic with depth, dark brown (7.5YR4/4) sandy SILT/CLAY with Mamonia clasts of dominantly c.gravel grade, chalk clasts of c.sand - f.gravel grade, and occasional Kannaviou mudstone clasts of gravel grade. Superficial deposit.
C	Stiff to hard, friable, light yellowish brown (2.5Y6/4) CLAY with f-m gravel grade Kannaviou mudstone and chalk clasts. Random calcareous 'veining' in sequence decreasing with depth. Superficial deposit.

KEY:

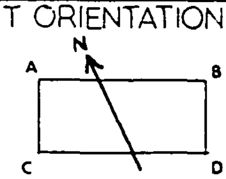
- △ BAG SAMPLE
- □ BLOCK "
- U100 SAMPLE
- U35 "
- + HAND VANE TEST (S_u kN/m²)
- PENETROMETER " "
- SEEPAGE
- STANDING WATER LEVEL
- PHOTOGRAPH

LOGGED BY: PRWH

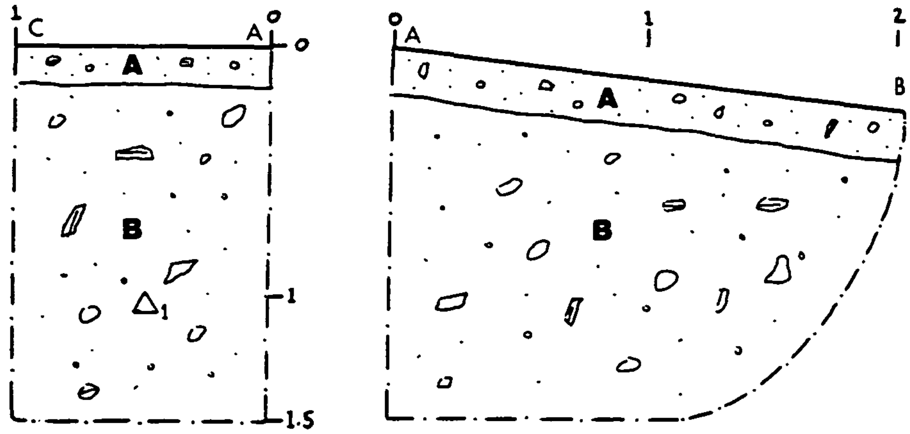
DATE: 6/84

SCALE: 1:30

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Kritou Marottou	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 6095.6470	PIT No.: 11 B



ZONE	DESCRIPTION
A	Dry, friable, reworked chalky Melange topsoil/slopewash.
B	Dry, structureless, clast-dominant sequence comprising Mamonia and pale grey Kannaviou SANDSTONE, SILTSTONE and MUDSTONE clasts of f.gravel to cobble grade with subordinate pale olive grey, friable silty sandy matrix becoming more clayey with depth. Occasional fissures with calcareous deposits on fissure surfaces. Superficial deposit.

KEY:

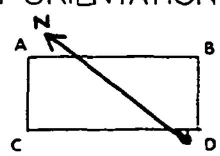
- △ BAG SAMPLE
- □ BLOCK
- U100 SAMPLE
- U35
- + HAND VANE TEST (S_u kN/m^2)
- PENETROMETER
- SEEPAGE
- STANDING WATER LEVEL
- PHOTOGRAPH

LOGGED BY: PRNH

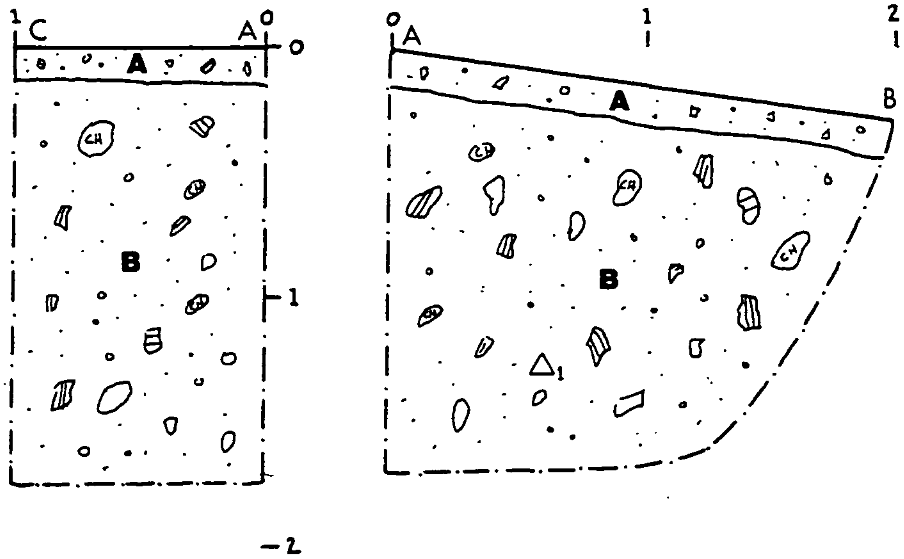
DATE: 6/84

SCALE: 1:30

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Kritou Marottou	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 6061.6494	PIT No.: 12



ZONE	DESCRIPTION
A	Dry, friable, pale greyish brown silty CLAY topsoil/slopewash with Mamonia and Chalk clasts of m-c.gravel grade.
B	Melange, structureless, comprising Mamonia clasts of m-c gravel grade and occasional cobble grade in stiff to hard, dark reddish grey (5YR4/2) silty CLAY matrix. Chalk clasts of gravel-cobble grade occur throughout but more prominent in upper 1 metre. Matrix shows occasional 'streaks' of powdery chalk.

KEY:

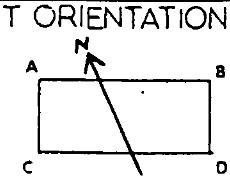
- △ BAG SAMPLE
- □ BLOCK "
- U100 SAMPLE
- U35 "
- + HAND VANE TEST (S_u kN/m²)
- ● PENETROMETER " "
- SEEPAGE
- STANDING WATER LEVEL

LOGGED BY: PRNH

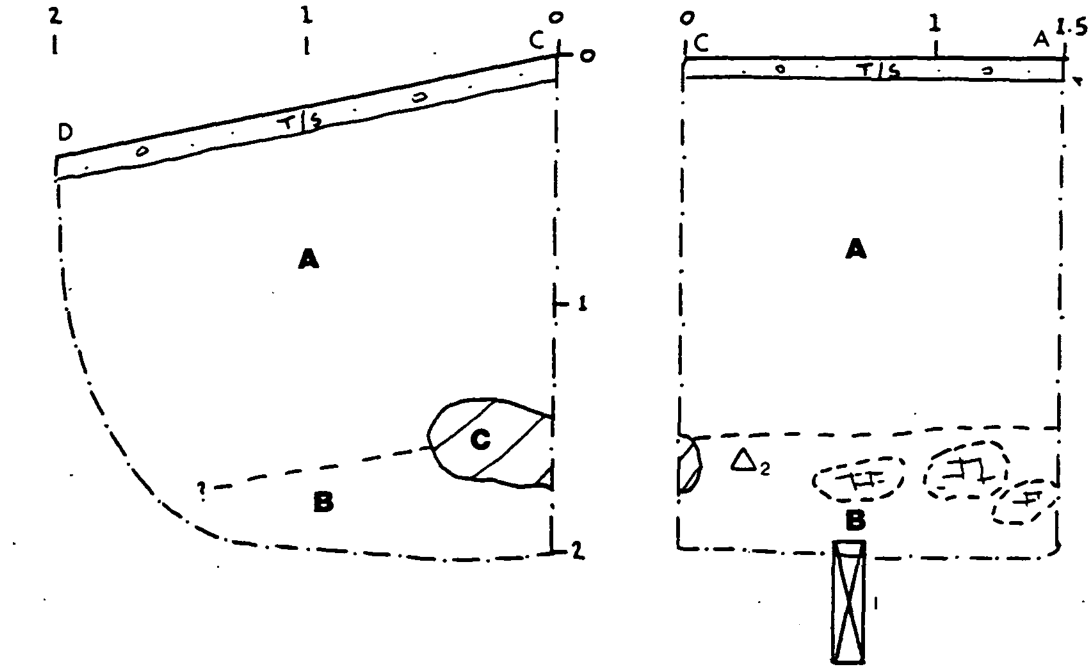
DATE: 6/84

SCALE: 1:30

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Kritou Marottou	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 6007.6550	PIT №.: 13



ZONE	DESCRIPTION
T/S	Thin, loose topsoil.
A	Weathered, fissured, olive (5Y5/3) slightly sandy, silty Kannaviou CLAY with gravel grade clasts and indistinct 'bands' of soft weathered mudstone. Grades to:
B	Highly fissured, firm, olive (5Y5/3) Kannaviou silty CLAY, with manganiferous staining on fissure surfaces, with indistinct soft clasts of fissured mudstone. More plastic than overlying Zone A.
C	Mamonia boulder (derived from Melange) with reddish brown (5YR5/4) CLAY on surface, within weathered Kannaviou sequence.

KEY:

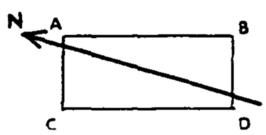
- △ BAG SAMPLE
- □ BLOCK
- ⊠ U100 SAMPLE
- ⊓ U35
- + HAND VANE TEST (S_u kN/m²)
- ● PENETROMETER
- SEEPAGE
- STANDING WATER LEVEL

LOGGED BY: PRWH

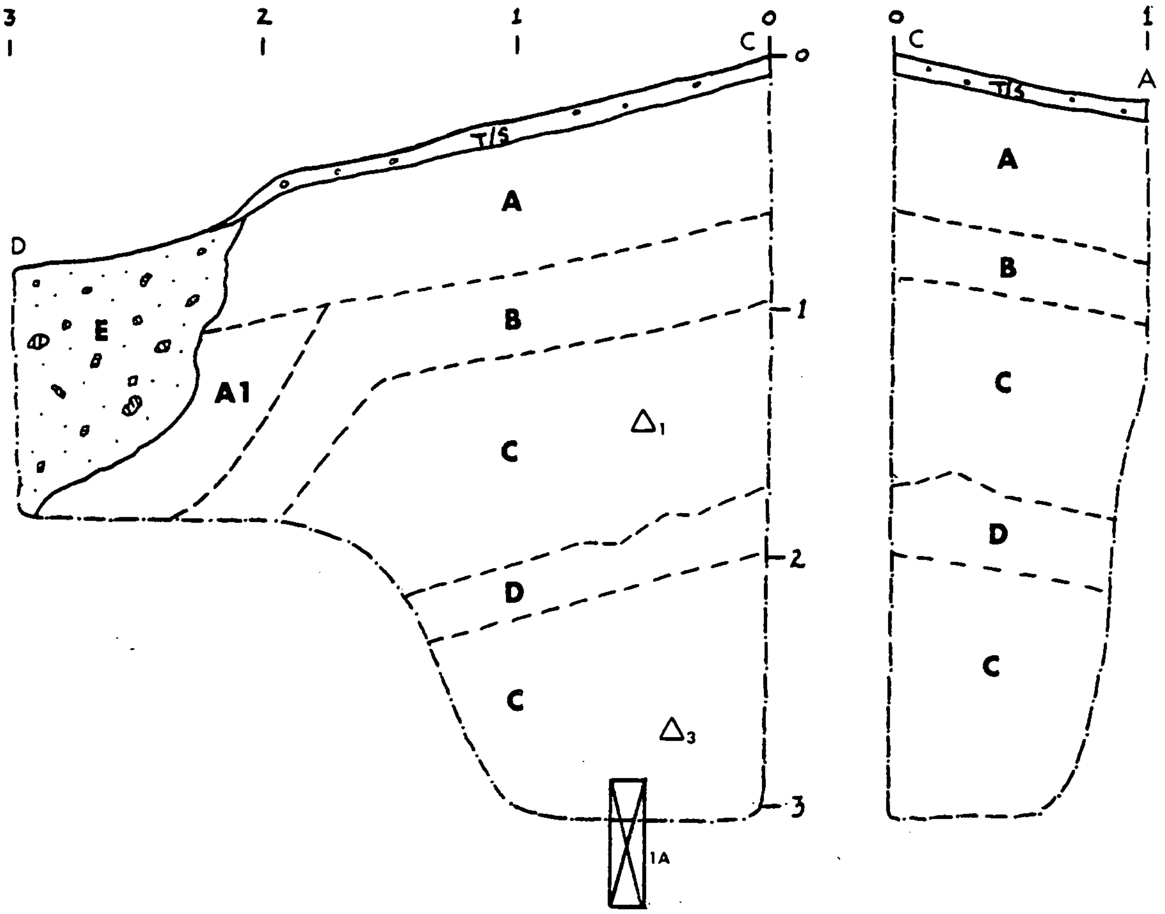
DATE: 6/84

SCALE: 1:30

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Phiti	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 5790.6588	PIT No.: 14



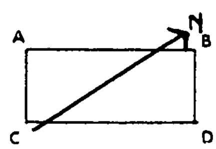
ZONE	DESCRIPTION
T/S	Topsoil of remoulded Kannaviou CLAY with many f-m gravel grade Mamonia clasts.
A	Firm to stiff, fissured, weathered olive grey (5Y5/4) Kannaviou CLAY.
A1	Firm to stiff, fissured, weathered olive grey (5Y5/4) Kannaviou CLAY with occasional remnants of harder fissured clay/highly weathered olive grey mudstone clasts of f-c gravel grade.
B	Stiff to hard, highly fissured, weathered olive grey (5Y5/4) Kannaviou CLAY. Many fissures appear orientated parallel to surface slope.
C	Stiff to hard, highly fissured, dark greyish olive (5Y4/3) Kannaviou CLAY. Dark brownish black manganiferous staining on fissure surfaces which are randomly orientated and slickensided with 'soapy' feel.
D	As Zone C but more weathered firm to stiff, moderate olive grey (5Y5/3) Kannaviou CLAY with occasional small 'pockets' of Fe-stained zones charged with small gypsum crystals as secondary weathering products.
E	Structureless Melange, comprising firm to stiff, reddish brown sandy silty CLAY matrix with sub-rounded to angular Mamonia clasts to c.gravel grade. Matrix dominant.

KEY:

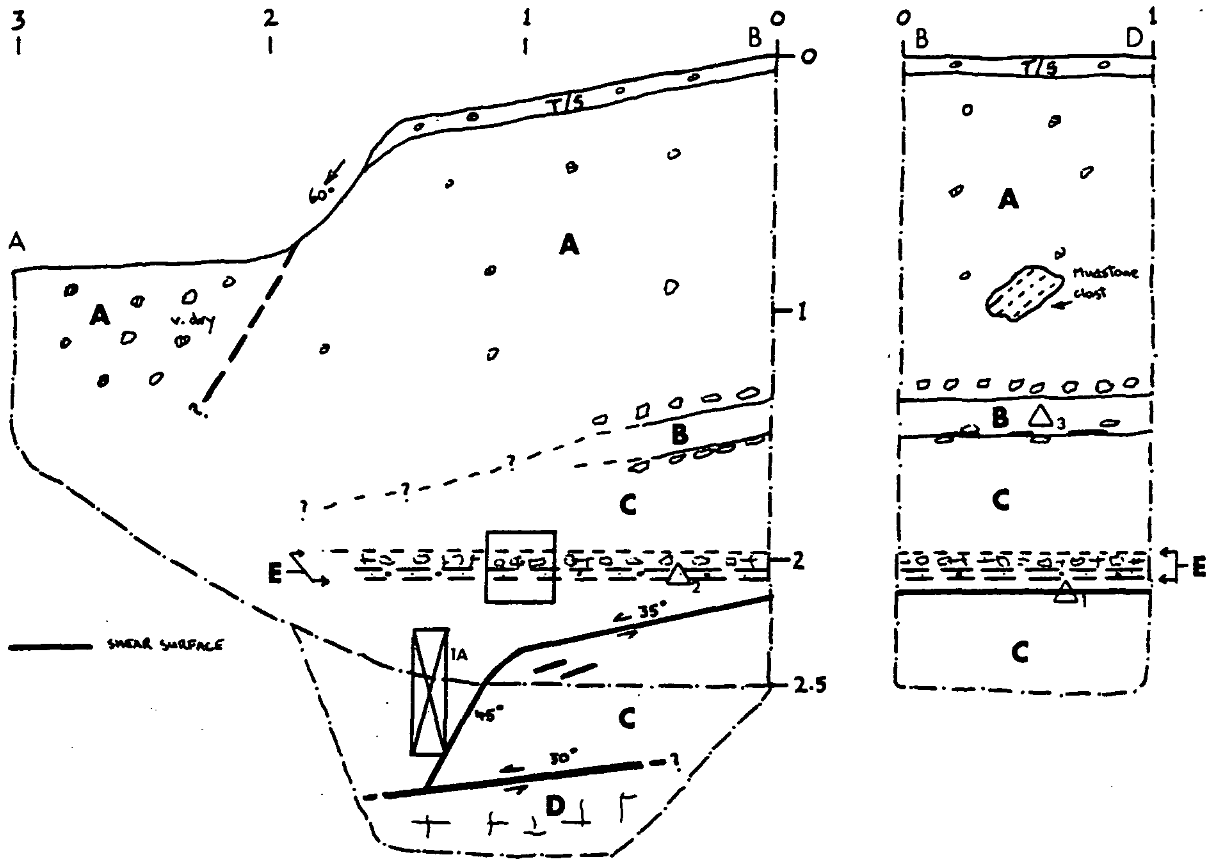
- △ BAG SAMPLE
- □ BLOCK
- ⊠ U 100 SAMPLE
- ∏ U 35
- + HAND VANE TEST (S_u kN/m^2)
- ● PENETROMETER
- SEEPAGE
- STANDING WATER LEVEL

LOGGED BY: KJN
DATE: 6/84
SCALE: 1:30

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Lasa	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 5713 . 6680	PIT No.: 15



ZONE	DESCRIPTION
T/S	Topsoil of reworked Kannaviou CLAY with chalk and Mamonia clasts of f-c gravel grade.
A	Firm, slightly friable, weathered olive grey (5Y5/3) Kannaviou silty CLAY with numerous weathered olive grey mudstone clasts, small calcareous 'spots' and concretions and occasional chalk and Mamonia clasts of f-c gravel grade. At 1.5m - discontinuous layer of broken, weathered, hard olive grey silty mudstone fragments.
B	As Zone A but more plastic, moist, soft to firm, olive grey (5Y5/2) Kannaviou CLAY with reddish brown (5YR4/3) mottling and many calcareous concretions of 1-2cm dia. Occasional c.gravel grade mudstone clasts with slickensided surfaces at base of zone (1.6m).
C	Firm, fissured, weathered olive grey (5Y5/2) Kannaviou CLAY, drier than Zone B and with no colour mottling or calcareous concretions. Distinct shear zones occur below 2.1m comprising 1 cm thickness of hard pale olive (5Y6/4) CLAY on hard slickensided shear surface(s).
D	Hard, fissured, olive grey (5Y4/2) Kannaviou silty MUDSTONE weathering to CLAY with Fe-staining on fissure surfaces.
E	2.0 - 2.1m. Soft, fissured, weathered olive grey Kannaviou MUDSTONE with manganiferous staining on fissure surfaces overlying thin (1-2cm) discontinuous layer of soft to firm dark reddish grey (5YR4/2) CLAY with f.gravel grade Mamonia clasts.

KEY:

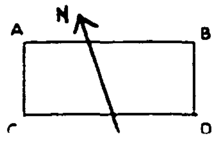
△ BAG SAMPLE
□ BLOCK
⊠ U100 SAMPLE
⊓ U35
+ HAND VANE TEST (S_u kN/m²)
● PENETROMETER
SEEPAGE
STANDING WATER LEVEL

LOGGED BY: KJN

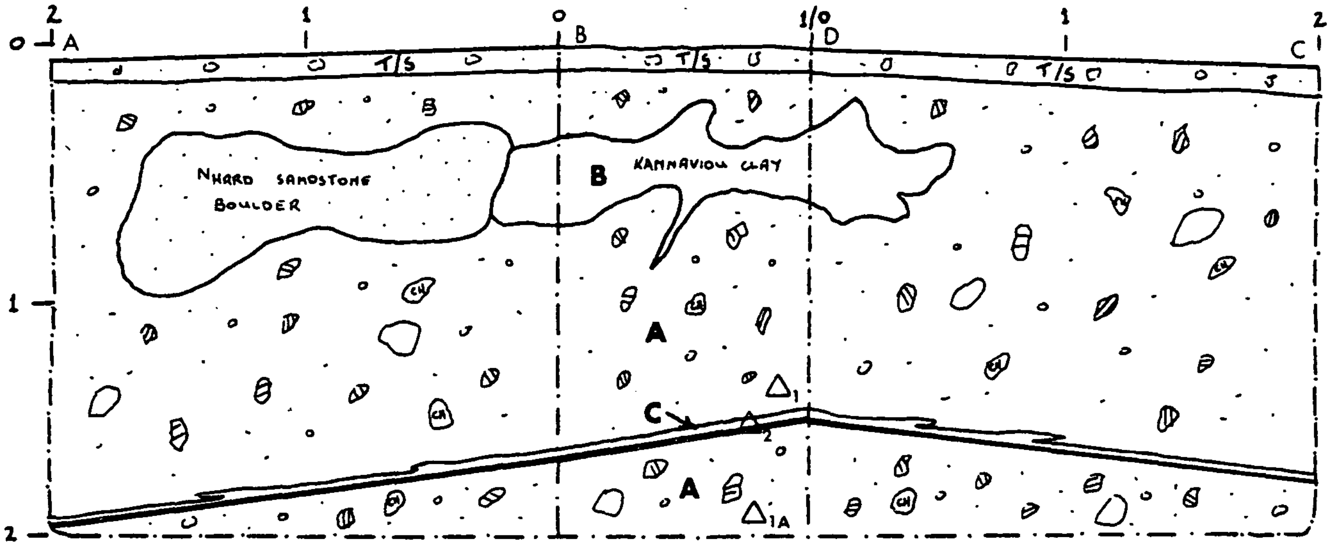
DATE: 6/84

SCALE: 1:30

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Phiti	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 5781 · 6678	PIT No.: 16



ZONE	DESCRIPTION
T/S	Topsoil, reworked Melange.
A	V.stiff to hard, dark reddish grey (5YR4/2) sandy, silty CLAY with sub-rounded to angular Mamonia clasts of dominantly f-c gravel grade and many sub angular Chalk clasts of cobble grade, Matrix dominant.
B	Firm, slightly friable, weathered, fissured, olive grey (5Y5/2) silty Kannaviou CLAY 'raft' with irregular 'flame-structures' extending into surrounding Melange.
C	Shear zone: comprising 1-2cm thick, stiff, slightly friable, structureless, olive (5Y5/3) CLAY on stiff to hard slickensided Melange shear surface, dipping 20° to SW (approx. downslope).

KEY:

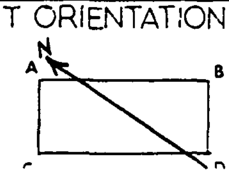
- BAG SAMPLE
- BLOCK "
- U 100 SAMPLE
- U 35 "
- HAND VANE TEST (S_u kN/m²)
- PENETROMETER "
- SEEPAGE
- STANDING WATER LEVEL

LOGGED BY: KJN

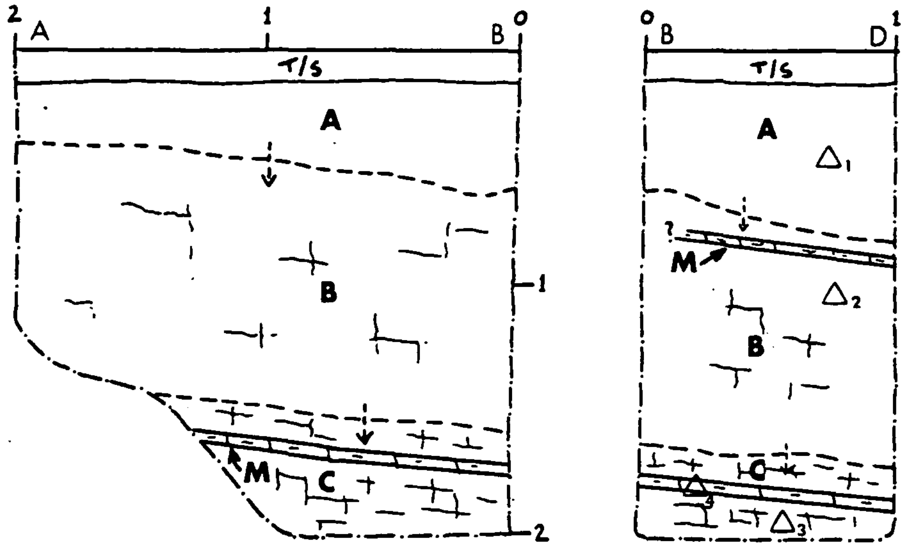
DATE: 6/84

SCALE: 1:30

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Sarama	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 5732.6745	PIT No.: 17



ZONE	DESCRIPTION
T/S	Topsoil. Dry reworked Kannaviou CLAY.
A	Firm to stiff, weathered, fissured, light olive grey (5Y6/2) silty Kannaviou CLAY with numerous soft weathered olive grey (5Y5/2) mudstone clasts increasing with depth, and occasional calcareous 'spots'. Grades to:
B	Highly fissured, olive grey (5Y5/2) Kannaviou MUDSTONE weathering to friable silty CLAY along fissures with manganiferous staining and occasional calcareous 'spots'. Remnant bedding structure visible. Grades to:
C	Highly fissured, slightly to moderately weathered, thinly-bedded Kannaviou silty MUDSTONE with manganiferous staining on fissure surfaces. Conchoidal fractures common, minor Fe-staining on bedding surfaces which show average 10^{o} dip to NE.
M	V. hard , 1-3cms thick, purple/black manganiferous MUDSTONE layer.

KEY:

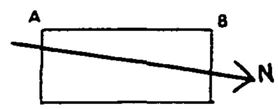
- △ BAG SAMPLE
- □ BLOCK
- U100 SAMPLE
- + HAND VANE TEST (S_u kN/m²)
- ● PENETROMETER
- SEEPAGE
- STANDING WATER LEVEL

LOGGED BY: KJN

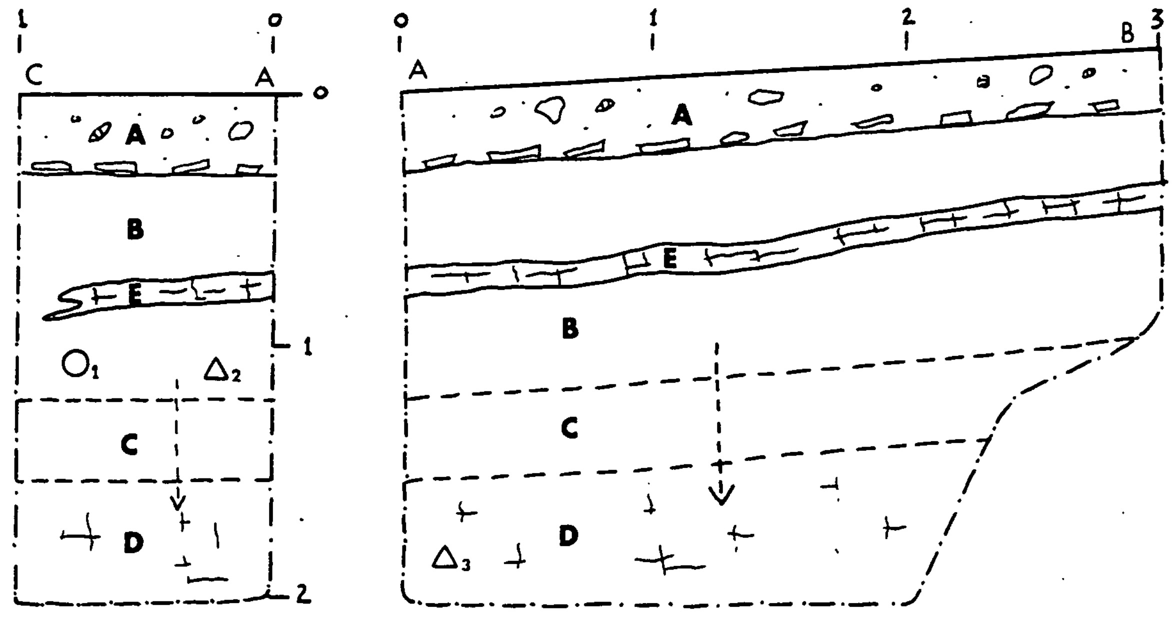
DATE: 6/84

SCALE:

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Sarama	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 5764.6819	PIT No.: 18



ZONE	DESCRIPTION
A	Dry, stony topsoil/slopewash of Kannaviou silty CLAY with numerous weathered, olive grey mudstone clasts and occasional Mamonia clasts of f-c gravel grade and cobble-grade chert clasts. Sequence is matrix dominant with distinct horizon of tabular disturbed, weathered, olive mudstone clasts orientated sub-parallel to surface slope at base of zone. Grades to:
B	Firm, weathered, slightly fissured olive (5Y5/4) Kannaviou CLAY with numerous soft weathered olive mudstone fragments of c. sand - f. gravel grade, and calcareous 'spots' becoming less common with depth.
C	As Zone B but more moist and plastic, fissured, olive CLAY with numerous c. sand to f. gravel grade weathered olive silty mudstone clasts becoming more dominant with depth. No calcareous 'spots'. Grades to:
D	Weathered, highly fissured, olive (5Y5/4) Kannaviou silty MUDSTONE, with manganiferous staining on fissure surfaces. Remnant bedding not discernible.
E	Band of moderately hard, fissured, weathered olive grey (5Y5/2) Kannaviou silty MUDSTONE, with manganiferous staining on fissure surfaces, and occasional Fe-staining along faint remnant bedding surfaces dipping approx. parallel to 9° surface slope.

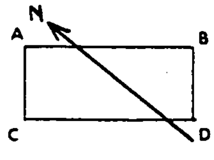
KEY:
- ○ DENSITY RING SAMPLE
- △ BAG SAMPLE
- □ BLOCK
- U 100 SAMPLE
- U 35
- + HAND VANE TEST (S_u kN/m^2)
- PENETROMETER
- SEEPAGE
- STANDING WATER LEVEL
- PHOTOGRAPH

LOGGED BY: KJN

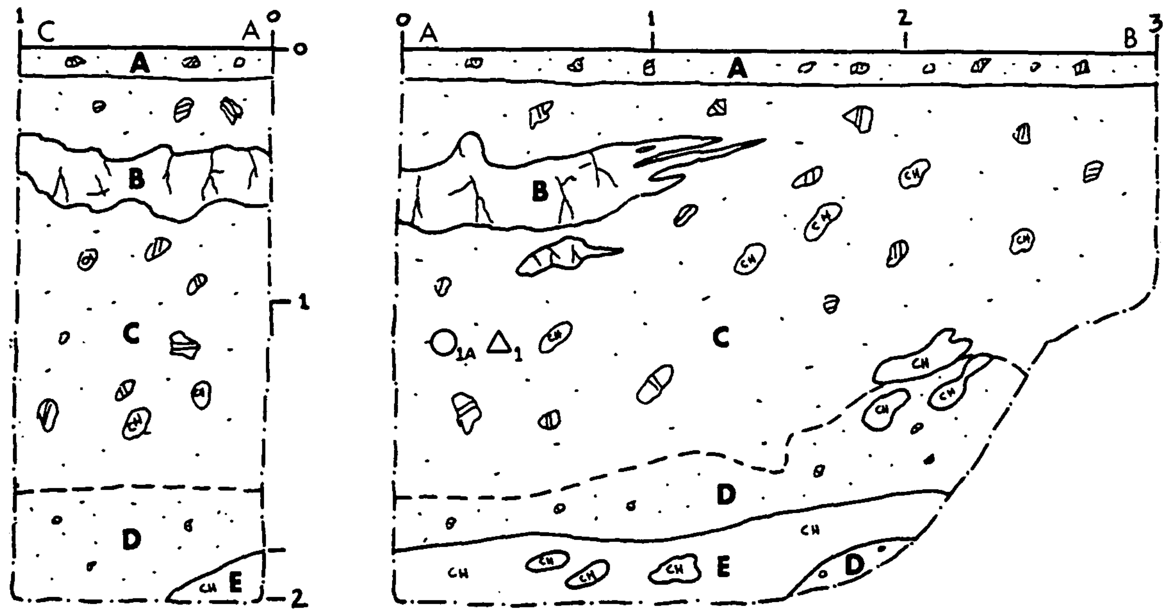
DATE: 6/84

SCALE: 1:30

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Sarama	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 5553.6781	PIT No.: 19



ZONE	DESCRIPTION
A	Dry topsoil of reworked Melange. Matrix dominant.
B	Highly weathered, fissured olive grey (5Y5/2) Kannaviou silty CLAY 'raft' with reddish grey (5YR5/2) staining on random, irregular fissure surfaces. Irregular 'flame-structures' extend into surrounding Melange sequence.
C	Structureless Melange, comprising stiff to very stiff, fissured, dark reddish brown (5YR4/3) sandy silty CLAY with many Mamonia clasts to c. gravel grade, occasional sub-rounded to sub angular Chalk clasts to cobble grade and small calcareous 'spots'. Grades to:
D	Firm to stiff, pinkish brown (7.5YR6/4) CLAY with streaks and irregular patches of dark reddish brown (5YR4/3), occasional Mamonia clasts of c. sand to f. gravel grade.
E	Highly to completely weathered, structureless powdery CHALK with occasional more coherent chalk 'lumps'. Sequence is damp to moist and slightly cohesive.

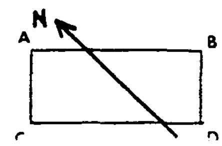
KEY: ○ DENSITY RING SAMPLE
△ BAG SAMPLE
□ BLOCK
U 100 SAMPLE
U 35
+ HAND VANE TEST (S_u kN/m²)
● PENETROMETER
SEEPAGE
STANDING WATER LEVEL

LOGGED BY: KJN

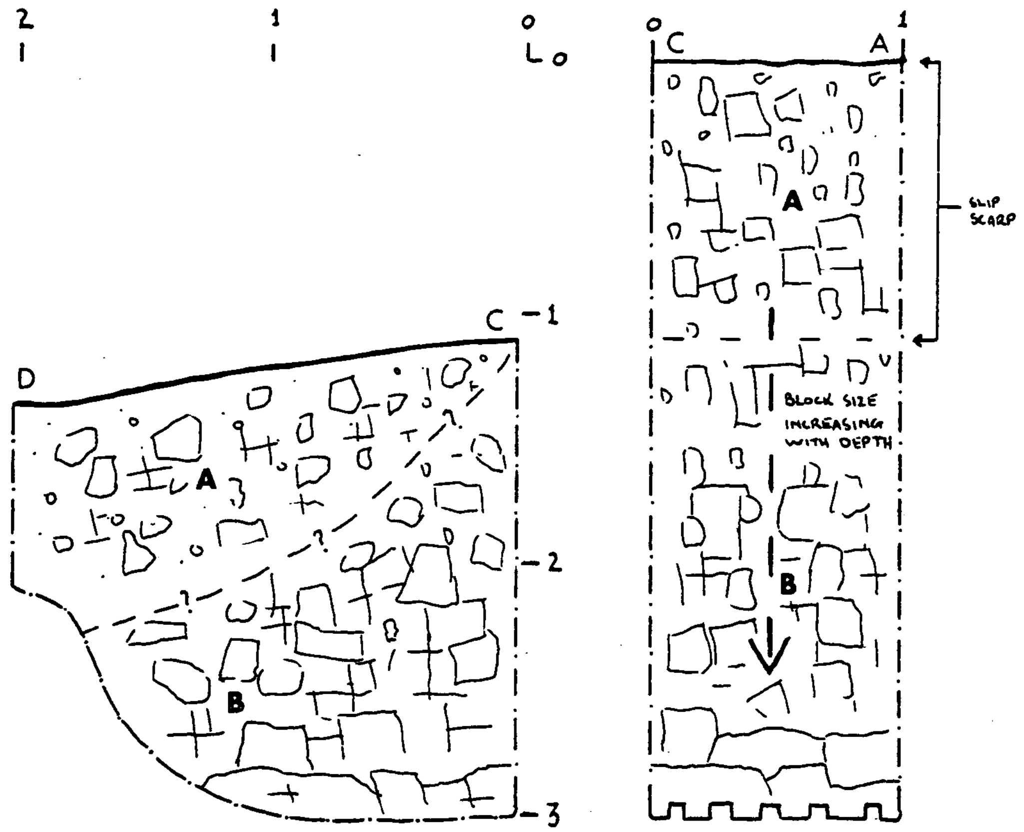
DATE: 6/84

SCALE: 1:30

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Simou	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 5505. 6732	PIT Nº.: 20



ZONE	DESCRIPTION
A	Structureless sequence of broken, rubbly CHALK debris, clast-dominant with blocks of c. gravel to cobble/small boulder grade. Grades to:
B	Very blocky, structureless CHALK debris with blocks ranging from cobble to boulder grade, size increasing with depth, and occasional irregular chert cobble. Huge block of marly chalk halted excavator bucket at 3m. depth.
	Tenuous boundary between 'finer' and more 'blocky' debris. May represent shallow slip zone coinciding with surface scarp. Whole sequence represents slipped chalk debris resting on Kannaviou sandstone.

KEY:

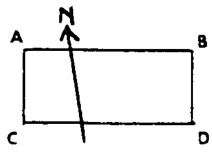
- △ BAG SAMPLE
- □ BLOCK "
- U 100 SAMPLE
- U 35 "
- + HAND VANE TEST (S_u kN/m²)
- ● PENETROMETER " "
- SEEPAGE
- STANDING WATER LEVEL

LOGGED BY: KJN

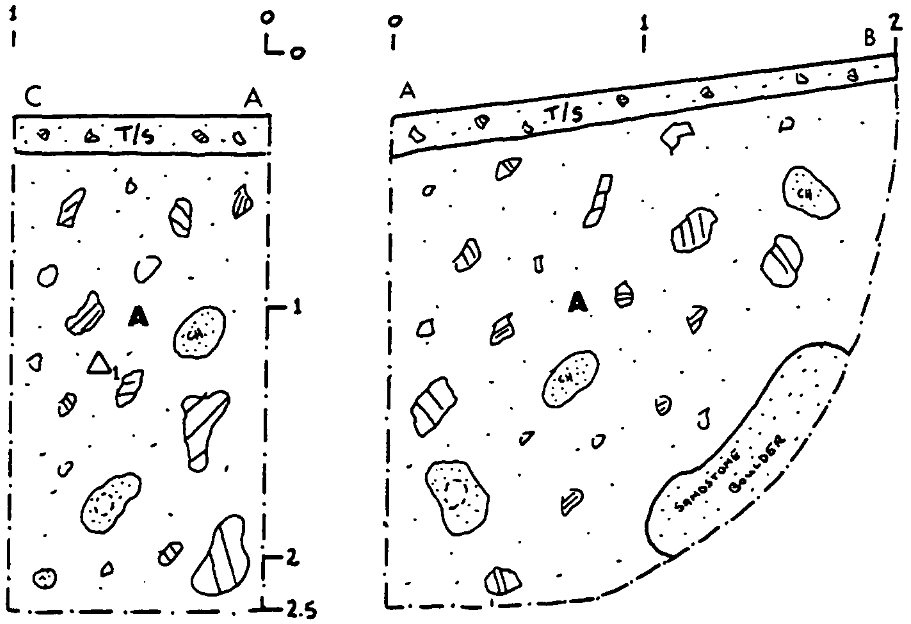
DATE: 6/84

SCALE: 1:30

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Simou	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 5417.6750	PIT No.: 21



ZONE	DESCRIPTION
T/S	Dry topsoil of reworked Melange.
A	Structureless Melange comprising randomly distributed sub-angular to sub-rounded Mamonia clasts of cobble to boulder grade in a firm to stiff, fissured, greyish red (2.5YR4/2) sandy silty CLAY matrix charged with Mamonia clasts of f-m. gravel grade. Numerous cobble grade chert clasts and rounded gravel-cobble size 'pockets' of highly-completely weathered slightly cohesive powdery chalk present, occasionally chert occurs within centre of powdery chalk 'pocket'. Occasional slickensiding seen on matrix fissures and clast surfaces show average direction and dip to S.

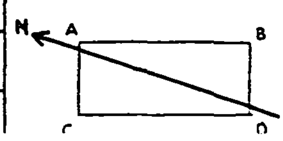
KEY:
- △ BAG SAMPLE
- □ BLOCK
- U100 SAMPLE
- U35
- + HAND VANE TEST (S_u kN/m²)
- ● PENETROMETER
- SEEPAGE
- STANDING WATER LEVEL

LOGGED BY: KJN

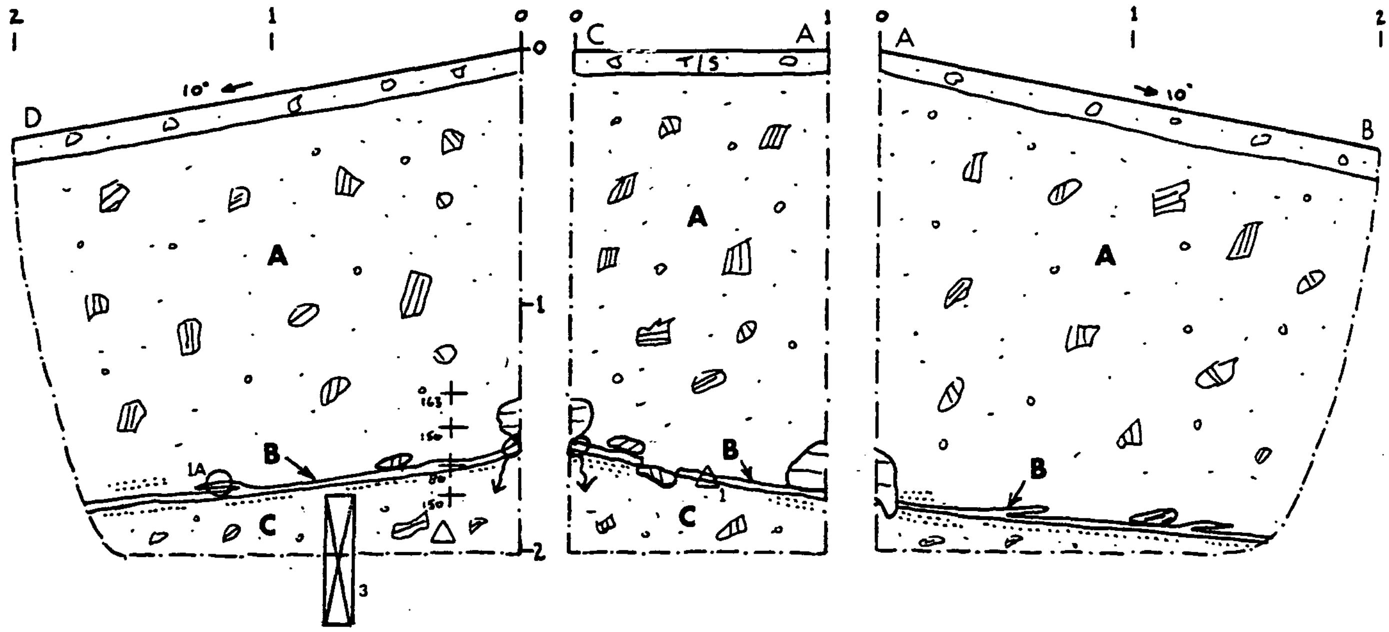
DATE: 6/84

SCALE: 1:30

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Simou	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 5423.6750	PIT No.: 22



ZONE	DESCRIPTION
T/S	Reworked Melange topsoil.
A	Structureless Melange comprising sub-rounded to angular Mamonia clasts of cobble grade in firm to stiff dark reddish grey (5YR4/2) to reddish brown (5YR4/3) sandy silty CLAY matrix with f-m gravel grade Mamonia clasts. Rounded c. gravel size pockets of completely weathered powdery chalk and calcareous 'spots' occur throughout.
B	Shear zone. Continuous but irregular (av. 2cm thick) layer of soft, plastic, greyish blue green (5BG5/2) CLAY. Fe-staining associated with small gypsum crystals present above and below clay layer, and apparent concentration of gravel-cobble grade clasts occur immediately above clay zone. Continuous water seepage occurs in pit corner at clay horizon and Melange matrix is wetter and more plastic 3-10 cms either side of clay zone.
C	As Zone A but Melange shows more c.sand - f.gravel grade Mamonia clasts in sandy silty CLAY matrix.

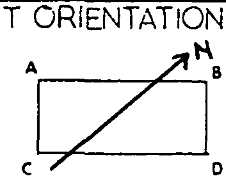
KEY:
- ○ DENSITY RING SAMPLE
- △ BAG SAMPLE
- □ BLOCK SAMPLE
- ⊠ U100 SAMPLE
- U35 SAMPLE
- + HAND VANE TEST (S_u kN/m^2)
- ● PENETROMETER TEST
- SEEPAGE
- STANDING WATER LEVEL
- PHOTOGRAPH

LOGGED BY: KJN

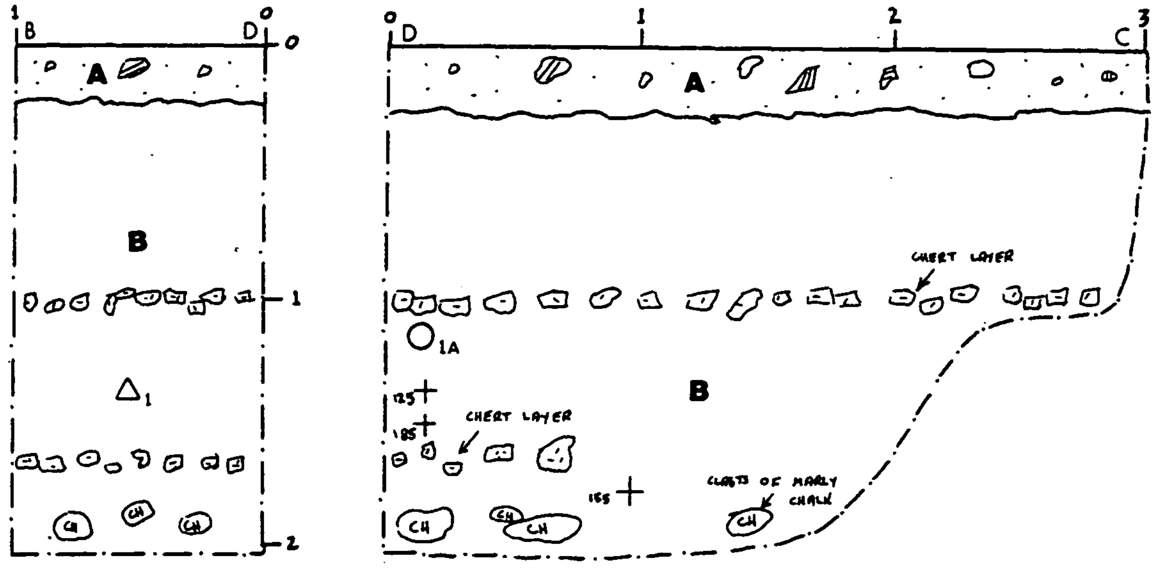
DATE: 6/84

SCALE: 1:30

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Simou	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 5602.6676	PIT No.: 23



ZONE	DESCRIPTION
A	Reworked Melange comprising occasional sub-rounded to sub-angular Mamonia, chalk, marly chalk and chert clasts of c.gravel to cobble grade in dry, friable, reddish brown (5YR5/3) sandy CLAY/SILT matrix. Sharp colour change at base of zone with small 'toungues' of reddish brown clay extending into underlying Zone B material.
B	Friable, whitish brown, chalky silty CLAY with numerous gravel grade clasts of marly chalk and cobble grade chert clasts. Sequence becomes more moist and cohesive with depth. Bands of chert clasts to cobble grade at 1.0m and 1.7m depth mark upper and lower boundaries of light grey (2.5Y7/2) mottled greyish yellow (5Y7/2) zone of chalky clay. Below 1.7m sequence is less mottled becoming light greyish white (5Y7/1) with increase in occurrence of hard marly chalk clasts of c.gravel to cobble grade. Sequence probably represents highly weathered marly chalk with cherts. Matrix dominated throughout.

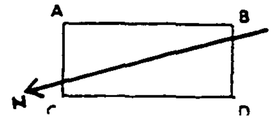
KEY:
- O DENSITY RING SAMPLE
- Δ BAG SAMPLE
- □ BLOCK
- U100 SAMPLE
- U35
- + HAND VANE TEST (S_u kN/m²)
- PENETROMETER
- SEEPAGE
- STANDING WATER LEVEL

LOGGED BY: KJN

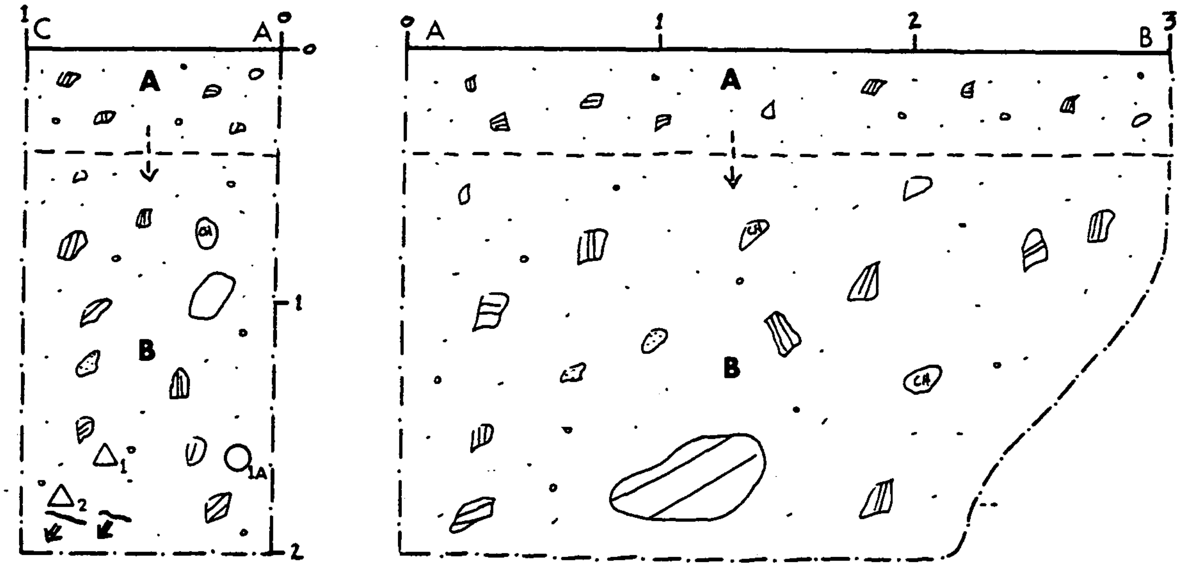
DATE: 6/84

SCALE: 1:30

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Simou / Lasa	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 5594.6606	PIT No.: 24



ZONE	DESCRIPTION
A	Dry, loose, topsoil of reworked Melange comprising Mamonia, chert and hard chalk clasts of f-m-c gravel grade in reddish brown (5YR5/3) sandy CLAY/SILT matrix. Grades to:
B	Structureless Melange comprising stiff to v.stiff, becoming firm to stiff and more moist and plastic with depth, fissured, reddish brown (5Y4/4) sandy silty CLAY matrix charged with c.sand - f.gravel grade Mamonia clasts, and numerous Mamonia clasts of cobble and occasional boulder grade. Occasional hard chalk clasts and 'pockets' of highly weathered 'powdery' slightly cohesive chalk to cobble grade occur above 1.8m depth. Occasional slickensided, generally sub-horizontal, fissures are present near base of pit c.2.0m.

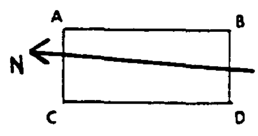
KEY:
- ○ DENSITY RING SAMPLE
- △ BAG SAMPLE
- □ BLOCK
- U 100 SAMPLE
- U 35
- + HAND VANE TEST (S_u kN/m^2)
- ● PENETROMETER
- SEEPAGE
- STANDING WATER LEVEL

LOGGED BY: KJN

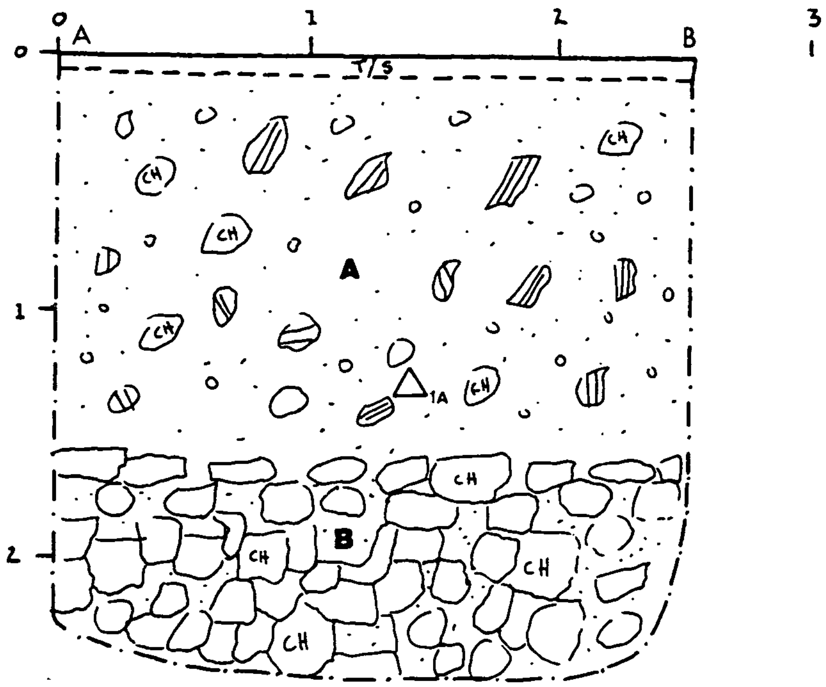
DATE: 6/84

SCALE: 1:30

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Galataria	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 6535.5865	PIT No.: 1(85)



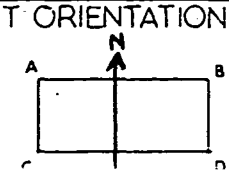
ZONE	DESCRIPTION
T/S	Thin topsoil.
A	Moist, slightly friable, dark reddish grey-brown (5YR4/2), slightly sandy, SILT/CLAY with f-c. gravel grade Mamonia clasts and sub-rounded to sub-angular gravel to cobble grade chalk and chert clasts. Sequence marginally matrix dominant with Mamonia clasts dominated by hard silicified sandstone/orthoquartzites.
B	Clast-dominant sequence of sub-angular to sub-rounded CHALK and CHERT clasts to cobble grade. Occasional 'flaggy' clasts orientated sub-parallel to ground surface.

KEY:

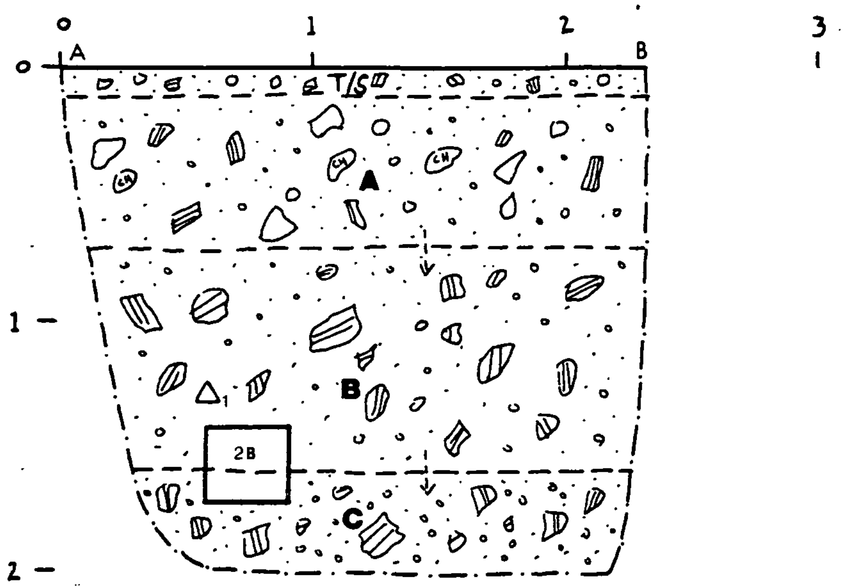
- △ BAG SAMPLE
- □ BLOCK
- U100 SAMPLE
- U35
- + HAND VANE TEST (S_u kN/m²)
- ● PENETROMETER
- SEEPAGE
- STANDING WATER LEVEL

LOGGED BY: KSW/PH
DATE: 5/85
SCALE: 1:30

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Galataria	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 6540.5915	PIT No.: 2(85)



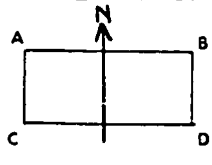
ZONE	DESCRIPTION
T/S	Reworked Melange topsoil.
A	Mottled reddish grey (5YR5/2) and brown (7.5YR4/2), slightly fissured, dry, weathered, stiff to firm, silty CLAY matrix with numerous Mamonia and chalk clasts of f.gravel grade, and chert clasts and hard silicified Mamonia sandstone clasts of c.gravel to cobble grade. Structureless, Melange.
B	Dark reddish greyish brown (7.5YR4/2) to dark greyish brown (10YR4/2), firm to stiff, slightly silty CLAY matrix with numerous c.sand to c.gravel grade and occasional cobble grade sub-rounded to angular Mamonia clasts. Structureless, with random orientation of clasts. Small gypsum crystals are present throughout sequence. No calcareous clasts or spots. Melange.
C	As overlying Zone B, but more greyish (10YR4/2) and with greater proportion of grey (10YR4/1) Mamonia clasts of c-f.gravel grade in matrix.

KEY:

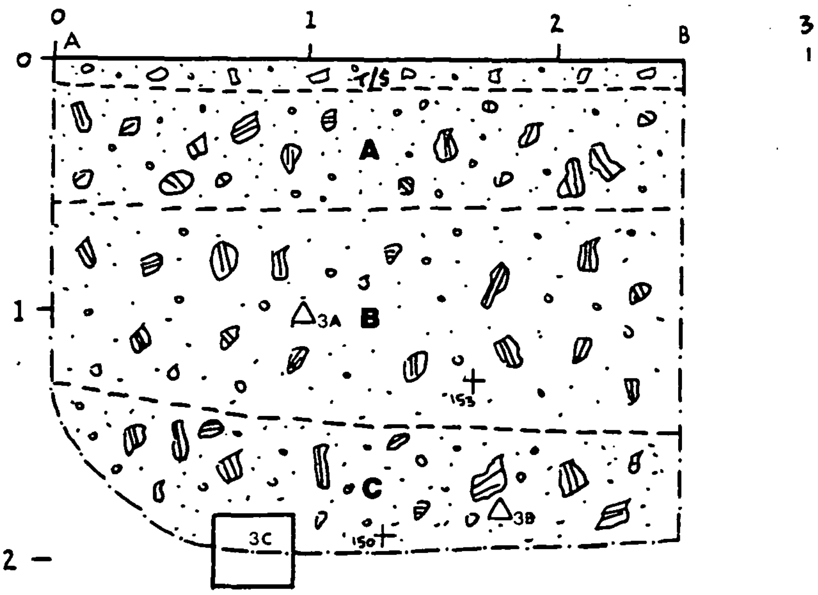
- △ BAG SAMPLE
- □ BLOCK
- U 100 SAMPLE
- U 35
- + HAND VANE TEST (S_u kN/m^2)
- PENETROMETER
- SEEPAGE
- STANDING WATER LEVEL
- PHOTOGRAPH

LOGGED BY:	KJW/PH
DATE:	5/85
SCALE:	1:30

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Vrecha	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 6850.6000	PIT No.: 3(85)



ZONE	DESCRIPTION
T/S	Reworked Melange topsoil.
A	Structureless, weathered, firm to stiff, reddish grey (5YR5/2) silty CLAY matrix with small calcareous 'pockets' and clasts to gravel grade, and m-c.gravel grade and occasional cobble grade Mamonia clasts. Small gypsum crystals present throughout. Melange.
B	Similar to overlying Zone A, but no calcareous pockets or clasts, comprising slightly fissured, firm to stiff, reddish brown (7.5YR5/2), sandy silty CLAY matrix with c.sand to f.gravel grade Mamonia clasts, and occasional sub-angular to sub-rounded Mamonia clasts of cobble grade. Gypsum crystals throughout. Melange.
C	Similar to overlying Zone B, but more granular and less plastic matrix comprising dark grey (5YR4/1) mottled slightly purple grey, fissured, slickensided, stiff CLAY with numerous c.sand to f.gravel grade Mamonia clasts, and occasional cobble grade clasts. Melange.

KEY:

- △ BAG SAMPLE
- □ BLOCK
- U 100 SAMPLE
- + HAND VANE TEST (S_u kN/m^2)
- ● PENETROMETER
- SEEPAGE
- STANDING WATER LEVEL

LOGGED BY: KJN/PH

DATE: 5/85

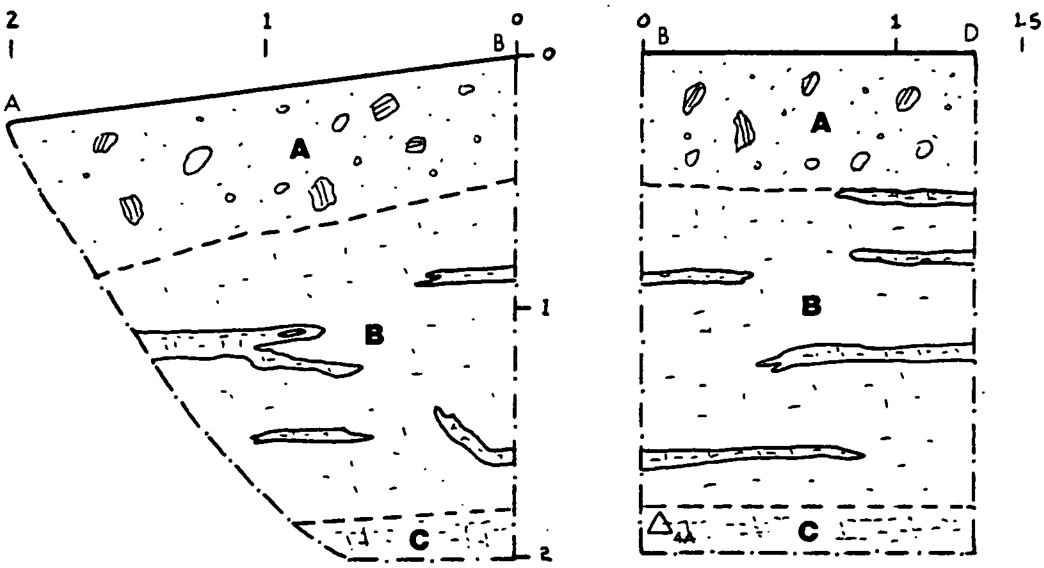
SCALE:

PIT ORIENTATION:

A B

N

BRITISH GEOLOGICAL SURVEY		SITE: Vrecha	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 6835.6075	PIT No.: 4 (85)



ZONE	DESCRIPTION
A	Slightly friable, moderately cohesive, f.dry, reddish brown (5YR5/3) silty CLAY with occasional sub-rounded chert clasts of cobble grade. Melange slopewash.
B	Highly weathered, dusky red (10R4/4) shaly silty MUDSTONE clasts weathering to reddish, moderately cohesive, fissured silty CLAY with irregular bands and lenses of olive yellow (5Y6/6) to pale olive (5Y6/4) hard shaly silty MUDSTONE clasts weathering to subordinate pale olive CLAY. Remnant bedding features very obscure to absent. Weathered Mamonia rock.
C	Highly fissured, highly weathered to moderately weathered, dusky red, hard silty MUDSTONE/SHALE with irregular pale olive hard, silty MUDSTONE/SHALE bands, weathering to subordinate moist silty clay. Remnant bedding structure visible. Weathered Mamonia rock.

KEY:

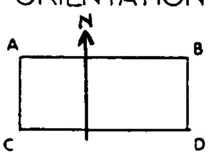
- △ BAG SAMPLE
- □ BLOCK
- U 100 SAMPLE
- U 35
- + HAND VANE TEST (S_u kN/m^2)
- PENETROMETER
- SEEPAGE
- STANDING WATER LEVEL

LOGGED BY: KJN/PH

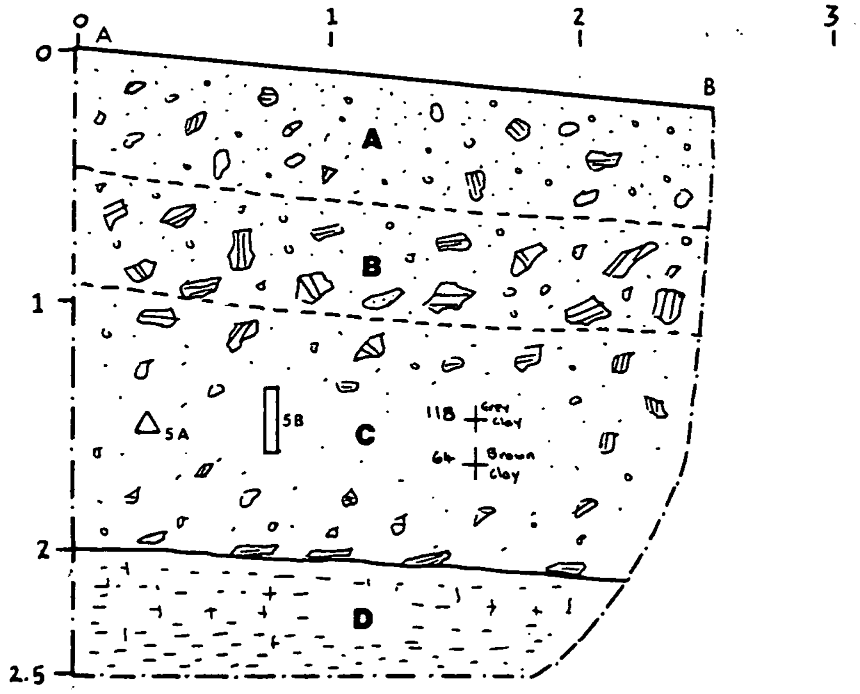
DATE: 5/85

SCALE: 1:30

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Ayios Photios	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 6430.5915	PIT No.: 5(85)



ZONE	DESCRIPTION
A	Dry, reddish grey (5YR5/2), friable SILT/CLAY with sub-angular Mamonia clasts of m-c gravel grade. Reworked Melange topsoil/slopewash.
B	Dry, stiff, reddish grey (5YR5/2) sandy silty CLAY matrix with calcareous inclusions and numerous sub-angular to angular Mamonia clasts of c.gravel to cobble grade. Cobble grade clasts are dominantly hard m-f grained sandstone and hard silicified grey sandstone. Melange, structureless.
C	Structureless, soft to firm, moderately plastic, reddish brown (5YR5/3) silty CLAY matrix with numerous c.sand to f-m.gravel grade Mamonia clasts, and occasional Mamonia clasts of cobble grade. Becoming softer, more moist and mottled dark grey (5YR4/1) with depth, with Mamonia clasts showing occasional sub-horizontal orientation and slickensided surfaces at base of sequence. Melange.
D	Highly weathered, becoming moderately weathered with depth, moderately hard, dusky red (10R4/4), silty MUDSTONE/SHALE. Relic bedding visible becoming more defined with depth. No distinct shear surface between overlying Zone C but contact is wetter with occasional orientated, slickensided Mamonia clasts.

KEY:

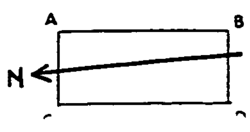
- △ BAG SAMPLE
- □ BLOCK
- U100 SAMPLE
- U35
- + HAND VANE TEST (S_u kN/m²)
- ● PENETROMETER
- SEEPAGE
- STANDING WATER LEVEL

LOGGED BY: KJN/PH

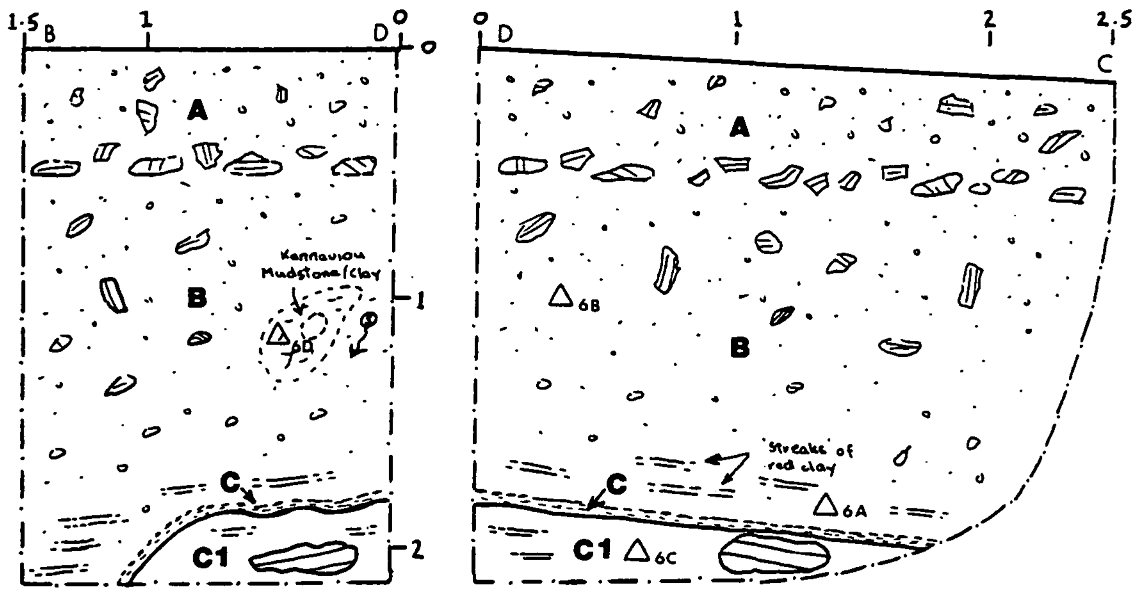
DATE: 5/85

SCALE: 1:20

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Ayios Photios	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 6410. 5980	PIT No.: 6 (85)



ZONE | **DESCRIPTION**

A — Dry, weathered, stiff, reddish brown (5YR5/4) silty CLAY matrix, with sub-rounded to angular chert, quartzite and hard sandstone Mamonia clasts of f-c gravel to cobble grade. Calcareous 'spots' common throughout, cobbles apparently more concentrated at base of zone. Melange, reworked.

B — Soft to firm, becoming soft to v.soft with depth, moderately plastic, slightly fissured, reddish brown (5YR5/4) silty CLAY matrix with occasional c.sand to fine gravel grade red shaly Mamonia clasts, and occasional hard Mamonia siltstone clasts of cobble grade, and single hard olive silty mudstone clast of cobble grade weathering to olive grey clay on surface. Very few calcareous 'spots' decreasing with depth. Clasts of c.sand to f.gravel grade in matrix decrease with depth particularly below, small water seep at approx. 1m. Clay matrix develops discontinuous but sub-parallel 'streaks' of soft dark red (10R3/6) CLAY near base of zone. Dominantly Melange.

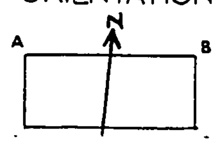
C — Thin layer (approx. 2cm) of weathered, f.soft silty SHALE clasts weathering to reddish clay. Clast dominant. Weathered Mamonia shale.

C1 — Dark greenish grey brown (2.5Y4/1) silty CLAY with discontinuous but sub-parallel 'streaks' of dark red (10R3/6) shaly clay and frequent greenish brown weathered silty mudstone/shale clasts. Soft to firm throughout becoming very soft and plastic immediately below contact with overlying Zone C. Highly weathered Mamonia shale.

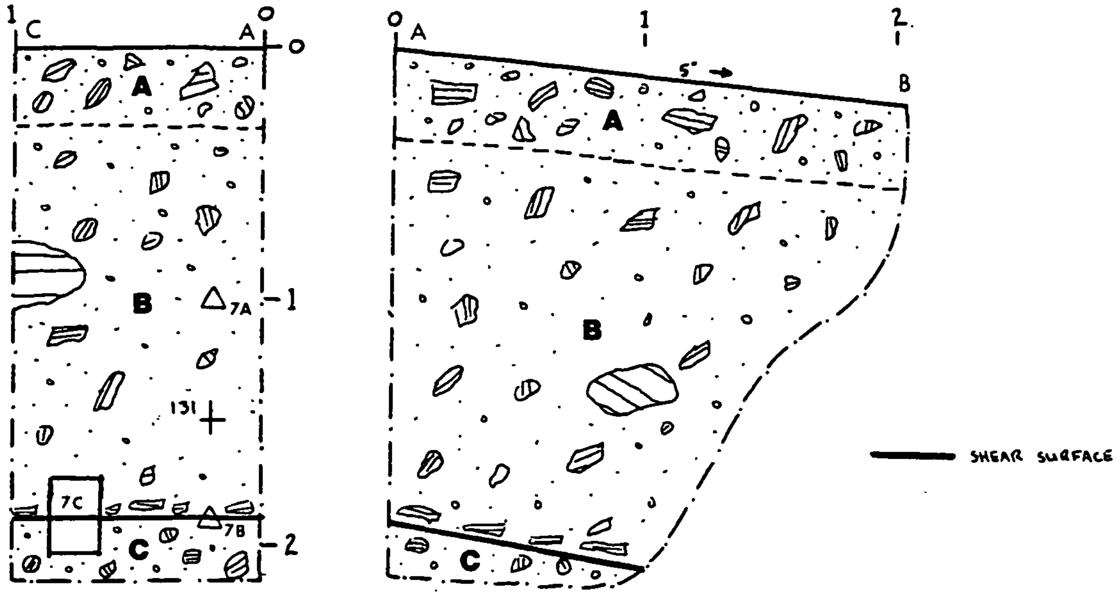
KEY:
- △ BAG SAMPLE
- □ BLOCK
- ☒ U100 SAMPLE
- + HAND VANE TEST (S_u kN/m^2)
- ● PENETROMETER
- SEEPAGE
- STANDING WATER LEVEL

LOGGED BY: KJN/PH
DATE: 5/85
SCALE:

PIT ORIENTATION:



BRITISH GEOLOGICAL SURVEY		SITE: Melamiou	
ENGINEERING GEOL. RESEARCH GROUP	TRIAL PIT LOG	GRID REF.: 6025.6235	PIT No.: 7(85)



ZONE	DESCRIPTION
A	Dry, structureless, grey (5YR5/1) silty CLAY with numerous light grey siliceous Mamonia sandstone clasts of f.gravel to cobble grade. Reworked Melange.
B	Greyish brown (10YR5/2) mottled dark reddish grey (5YR4/2), fissured, firm to stiff, silty CLAY with Mamonia clasts of c.sand to f.gravel grade, and numerous sub-angular Mamonia clasts of cobble to occasional small boulder grade of dominantly hard silicified sandstone and siltstone. Base of zone marked by distinct hard, slightly undulating, slickensided shear surface dipping approx. 20° to SSE (downslope), overlain by 2mm thickness of clast-free, firm brownish grey (10YR5/1) silty CLAY. Apparent concentration of tabular cobble-grade clasts immediately above and orientated sub-parallel to shear surface.
C	Similar to overlying Zone B, but stiff brownish grey (10YR5/1) to greyish brown (10YR5/2), sandy silty CLAY matrix with numerous angular to sub-angular, flaggy to tabular, hard siliceous grey (10YR5/1) Mamonia clasts of cobble to small boulder grade. Listric surfaces present on many Mamonia clasts throughout Zone B and C.

KEY:

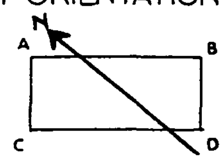
- BAG SAMPLE
- BLOCK "
- U 100 SAMPLE
- U 35 "
- HAND VANE TEST (S_u kN/m²)
- PENETROMETER "
- SEEPAGE
- STANDING WATER LEVEL
- PHOTOGRAPH

LOGGED BY: KJN | PH

DATE: 5/85

SCALE: 1:30

PIT ORIENTATION:



APPENDIX II:

SAMPLE LISTING AND SUMMARY OF
GEOTECHNICAL AND MINERALOGICAL
TEST RESULTS

CYPRUS TEST DATA

SAMPLE LISTING and INDEX TEST RESULTS

PIT/BH NO.	SAMPLE NO.	DEPTH m	LITHOLOGY	GRID REFERENCE	TYPE	MC %	BD Mg/m3	DD Mg/m3	LL %	PL %	PI %	LI	LS %	SG	Gr %	Sa %	Si %	Cl %	A
AREA 1 SAMPLES 1984																			
	84/1	S	KAN cl+clst clasts	45745/386560	D														
	84/2	S	KAN cl+clst clasts	"	D														
	84/3A	S	MEL cl matrix	45785/386598	D				169	45	124		25		-	2	15	83	1.49
	84/3B	S	KAN mst clasts	"	D														
	84/3C	S	KAN slty cl	"	D														
	84/3D	S	KAN mst clasts	"	D														
	84/3E	S	KAN slty cl	"	D				206	51	155				-	-	34	66	2.41
	84/3F	S	KAN cl,sheared,fissd	"	D														
	84/3G	S	KAN cl,hard,fissd	"	D				190	49	141				-	3	34	63	2.24
	84/4A	S	KAN slty sst,f.g.	45745/386780	D														
	84/4B	S	KAN cly sltst	"	D														
	84/5	S	KAN cly sltst,sheared	45815/386852	D														
	84/6	S	KAN cly sltst	45780/386760	D														
	84/7	S	KAN sst	45770/386652	D														
	84/8	S	KAN sst	45855/386730	D														
	84/9	S	KAN sst	45760/386600	D														
	84/10	S	KAN mst sheared	45985/386545	D														
	84/11	S	KAN sst	45990/386535	D														
	84/12	S	KAN slty cl	45612/386480	D				107	32	75				-	10	28	62	1.21
	84/13	S	KAN sst	45970/386685	D														
	84/14	S	KAN sst	45990/386675	D														
	84/15	S	KAN sst	45994/386670	D														
	84/16A	S	KAN sst	45880/386375	D														
	84/16B	S	KAN sst	"	D														
	84/17	S	KAN cl slip debris	45850/386280	D				97	28	69				-	5	29	66	1.04
	84/18	S	KAN cl slip debris	45865/386280	D				95	39	56				-	14	34	52	1.07
	84/19	S	MEL cl,slip debris	46020/386227	D				55	21	34				-	18	45	37	0.93
	84/20	S	MEL cl,slip debris	45990/386170	D				46	16	30				-	23	46	31	0.97
	84/21	S	MEL cl,silp debris	45935/386200	D				79	26	53				-	20	37	43	1.24
	84/22	S	MEL cl,slip debris	45990/386240	D														
	84/23	S	KAN sst	46050/386325	D														
	84/24	S	KAN sst	46040/386325	D														
	84/25	S	KAN sst	46050/386330	D														
	84/26	S	KAN sst	46120/386400	D														
	84/27	S	KAN sltst,slickensided	45985/386339	D														
	84/28	S	KAN cl	46000/386325	D				191	48	143				-	2	27	71	2.01
	84/29	S	KAN sst	46130/386470	D														
	84/30	S	KAN sst,f.g.	46035/386390	D														
	84/31	S	CH	45950/386575	D														
	84/32	S	KAN+MEL cl,slip debris	45875/386420	D				199	41	158				-	2	27	71	2.23
	84/33	S	KAN sltst	45865/386315	D														
AREA 1 PITS 1984																			
PIT 1	Tv/1	0.60	KAN slty cl	45935/386452	Tv														
	P1/A	0.40	MEL cl,slipped	"	D														
	P1/B	1.00	KAN cly snd-slt	"	D				85	45	40				2	43	48	7	5.71
PIT 2	Tv/2	0.70	MEL cl slipped	45940/386468	Tv														

SAMPLE LISTING and INDEX TEST RESULTS (cont'd).

PIT/BH NO.	SAMPLE NO.	DEPTH m	LITHOLOGY	GRID REFERENCE	TYPE	MC %	BD Mg/m3	DD Mg/m3	LL %	PL %	PI %	LI	LS %	SG	Gr %	Sa %	Si %	Cl %	A
PIT 3	P3/1	1.00	MEL matrix dom,slipped	45982/386553	D														
	P3/2	1.80	MEL matrix dom,slipped	"	U	17	2.13	1.82											
PIT 4	P4/1	1.50	MEL	45872/386475	D				79	24	55				1	23	40	36	1.53
PIT 5	P5/1	1.70	MEL tectonic shears	45798/386370	D				79	22	57				-	18	46	36	1.58
PIT 6	P6/1	0.50	MEL with KAN	45840/386350	D				102	36	66			2.77	-	7	29	64	1.03
	P6/2	1.20	KAN slty mudst distbd.	"	D				66	35	31				-	3	58	39	0.79
	P6/4	2.20	KAN cl fissd. distbd.	"	U	47	1.59	1.08											
PIT 7	P7/1	2.20	MEL + KAN slip mass	45918/386442	U														
	P7/2	1.10	KAN cl slipped	"	Tv														
	P7/3	1.50	MEL slipped	"	Tv														
	P7/4	1.00	KAN cl slipped	"	D														
	P7/5	1.70	MEL cl	"	D														
PIT 10A	P10A/1	1.00	KAN cl	45893/386366	D				198	55	143				-	3	34	63	2.27
	P10A/3	1.90	KAN slty mudst	"	D				183	52	131				-	3	42	55	2.38
	P10A/4	1.00	KAN mudst disturbd	"	D														
	P10A/T	1.25	KAN cl	"	Tv														
	P10A/P	1.25	KAN mudst cl	"	Pen														
PIT 10B	P10B/T	2.05	KAN cl	45893/386364	Tv														
	P10B/1	2.00	KAN cl	"	D														
	P10B/T	1.50	MEL cl matrix	"	Tv														
	P10B/2	1.00	MEL cl matrix	"	D				122	39	83				-	8	34	58	1.43
PIT 11A	P11A/T	1.80	MEL+KAN supfl debris	46072/386490	Tv														
PIT 11B	P11B/1	1.00	MEL+KAN supfl debris	46095/386470	D										2	77	19	2	-
PIT 12	P12/1	1.50	MEL+KAN supfl debris	46061/386494	D				73	23	50				1	26	33	40	1.25
PIT 13	P13/1	2.20	KAN cl,fissd.	46007/386550	U	51	1.86	1.23	116	40	76	+0.14			-	3	52	45	1.69
	P13/2	1.60	KAN cl,fissd.	"	D				116	40	76				-	3	52	45	1.69
PIT 14	P14/1A	3.40	KAN cl,highly fissd.	45790/386588	U														
	P14/1	1.50	KAN cl,highly fissd.	"	D										-	-	34	66	
	P14/3	2.80	KAN cl,highly fissd.	"	D				207	54	153				-	2	28	70	2.19
PIT 15	P15/1A	2.60	KAN cl,slipped	45713/386680	U														
	P15/1	2.10	KAN shear-plane cl	"	D														
	P15/2A	2.10	KAN shear-plane cl	"	D				103	42	61				-	7	46	47	1.30
	P15/3	1.55	KAN cl,soft,mottled red	"	D				118	42	76				-	5	37	58	1.31
PIT 16	P16/1A	2.00	MEL cl,stiff-hard	45781/38667	U	18	2.07	1.76											
	P16/1	1.40	MEL cl,stiff-hard	"	D														
	P16/2	1.50	MEL slip-plane cl,green	"	D										-	4	24	72	
PIT 17	P17/1	0.50	KAN cl+mdst frags,fissd	45732/386745	D				106	48	58				-	3	46	51	1.14
	P17/2	1.00	KAN mdst,fissd,weathd.	"	D														
	P17/3	2.00	KAN mdst,fissd,weathd.	"	D				94	47	47				-	4	62	34	1.38
	P17/4	1.80	KAN mdst,black stained	"	D														
PIT 18	P18/1	1.10	KAN cl+mdst frags,firm	45764/386819	R	28	1.62	1.26											
	P18/2	1.10	KAN cl+mdst frags,firm	"	D	28			110	42	68	-0.20			-	3	46	51	1.33
	P18/3	1.80	KAN mdst,soft,fissd.	"	D				100	47	53				-	4	57	39	1.36
PIT 19	P19/1A	1.10	MEL cl,stiff	45553/386781	R	19	1.81	1.52											
	P19/1	1.10	MEL cl,stiff	"	D	19			84	28	56	-0.16			-	17	31	52	1.08
PIT 21	P21/1	1.20	MEL cl,stiff	45417/386750	D				69	25	44				3	36	41	20	2.20
PIT 22	P22/1A	1.50	MEL cl,firm-stiff	45423/386750	R	13	2.03	1.80											
	P22/1	1.60	MEL shear-zone cl,soft	"	D										11	38	9	42	
	P22/2	2.00	MEL cl matrix	"	D	19			60	21	39	-0.05			2	26	39	33	1.18

SAMPLE LISTING and INDEX TEST RESULTS (cont'd)

PIT/BH NO.	SAMPLE NO.	DEPTH m	LITHOLOGY	GRID REFERENCE	TYPE	MC %	BD Mg/m3	DD Mg/m3	LL %	PL %	PI %	LI	LS %	SG	Gr %	Sa %	Si %	Cl %	A
	P22/3	2.40	MEL cl matrix	"	U	19	2.10	1.77											
	P22/4	1.70	MEL cl matrix	"	Tv														
PIT 23	P23/1A	1.20	CH,weathd. chalky cl	45602/386676	R	19	1.80	1.51											
	P23/1	1.50	CH,weathd. chalky cl	"	D	19			69	28	41	-0.22			-	14	45	41	1.00
	P23/1B	1.60	CH,weathd. chalky cl	"	Tv														
PIT 24	P24/1A	1.80	MEL cl,stiff,fissd.	45594/386606	R	19	2.03	1.72	58	21	37	-0.05			9	18	43	30	1.23
	P24/1	1.80	MEL cl,stiff,fissd.	"	D	19			71	24	47	-0.11			-	21	41	38	1.23
	P24/2	1.90	MEL cl,stiff,fissd.	"	D										-	-	61	39	
AREA 1																			
BH'S																			
1984																			

E610/84	BH 1	1.00	MEL topsoil	45806/386500	D				37	15	22				-	35	37	28	0.79
Phiti	BH 2	4.00	MEL topsoil	"	D				60	20	40				-	36	32	32	1.25
	BH 3	10.50	MEL cl matrix	"	D				53	17	36				-	26	36	38	0.95
	BH 4	17.50	MEL cl matrix	"	D				41	14	27				-	33	35	32	0.84
	BH 5	26.50	MEL cl matrix	"	D				53	23	30				-	34	30	36	0.83
	BH 6	32.50	MEL cl matrix	"	D				53	17	36				-	34	34	32	1.13
	BH 7	37.50	MEL cl matrix	"	D				74	15	59				-	22	37	41	1.16
	BH 8	47.50	MEL cl matrix	"	D				73	20	53				-	29	34	37	1.43
	BH 9	57.50	MEL cl matrix	"	D				58	17	41				-	37	31	32	1.28
	BH 10	67.50	MEL cl matrix	"	D				47	15	32				-	35	32	33	0.97
	BH 11	74.50	MEL cl matrix	"	D				55	17	38				-	21	37	42	0.90
	BH 12	78.50	MEL cl matrix	"	D				74	17	57				-	35	30	35	1.63
	BH 14	87.50	MEL cl matrix	"	D				52	16	36				5	39	28	28	1.29
	BH 15	97.50	MEL cl matrix	"	D				50	20	30				2	36	33	29	1.03
	BH 16	107.5	MEL cl matrix	"	D				45	15	30				5	50	25	20	1.50
	BH 17	117.5	MEL cl matrix	"	D				36	14	22				15	46	21	18	1.23
	BH 18	125.5	KAN clay	"	C				154	43	111				6	49	24	21	1.57
	BH 19	126.5	KAN clay	"	C				152	47	105				-	5	40	55	1.90
	BH 20	129.5	KAN cl with MEL	"	D				75	25	50				-	49	26	25	2.00
	BH 21	134.5	KAN sndy slty mudst	"	D				90	29	61				-	30	47	23	2.65
	BH 22	139.5	KAN slt/mudst	"	D				94	31	63				-	36	36	28	2.25
	BH 23	149.5	KAN slt/mudst	"	D				93	35	58				-	38	37	25	2.32
	BH 24	154.5	KAN fine sst/sltst	"	D				69	28	41				-	47	43	10	4.10
	BH 25	159.5	KAN fine sst/sltst	"	D				85	37	48				-	40	40	20	2.40
	BH 26	169.5	KAN fine sst/sltst	"	D				75	31	44				-	49	34	17	2.58
	BH 27	174.5	KAN fine sst/sltst	"	D				70	29	41				-	50	37	13	3.15
	BH 28	177.5	KAN slty mudst	"	D				91	5	86				-	26	50	24	3.58
E613/84																			
Ayios	BH 29	1.50	MEL matrix	45896/386344	D				49	18	31				2	23	40	35	0.88
Dhim'os	BH 30	3.50	MEL matrix	"	D				50	17	33				3	28	39	30	1.10
	BH 31	6.50	MEL matrix	"	D				43	14	29				5	23	37	35	0.83
	BH 32	10.50	MEL matrix	"	D				45	15	30				7	23	36	34	0.88
	BH 33	18.50	MEL matrix	"	D				38	16	22				10	30	36	24	0.92
	BH 34	28.50	MEL matrix	"	D				34	15	19				12	28	34	26	0.73
	BH 35	38.50	MEL matrix	"	D				37	15	22				13	42	29	16	1.37
	BH 36A	46.50	MEL matrix	"	C														

SAMPLE LISTING and INDEX TEST RESULTS (cont'd)

PIT/BH NO.	SAMPLE NO.	DEPTH m	LITHOLOGY	GRID REFERENCE	TYPE	MC %	BD Mg/m3	DD Mg/m3	LL %	PL %	PI %	LI	LS %	SG	Gr %	Sa %	Si %	Cl %	A
E613/84																			
Ayios	BH 36B	43.50	MEL grey gravels	45896/386344	C														
Dhim'os	BH 36C	43.50	MEL grey rock	"	C														
	BH 36D	43.50	MEL lmst in matrix	"	C														
	BH 37	48.50	MEL matrix	"	D				34	16	18				20	43	21	16	1.12
	BH 38	52.50	MEL matrix	"	D				46	16	30				5	30	36	29	1.03
	BH 39	58.50	MEL matrix	"	D				43	15	28				7	47	29	17	1.65
	BH 40	61.50	KAN + MEL	"	C				182	47	135				-	5	45	50	2.70
	BH 41	62.50	KAN + MEL	"	C				173	46	127				-	6	42	52	2.44
	BH 42	65.50	KAN + MEL	"	D				67	25	42				9	30	37	24	1.75
	BH 43	68.50	KAN snd/sltst	"	D				68	24	44				5	45	33	17	2.60
	BH 44	77.50	KAN snd/sltst	"	D				66	53	13				8	32	39	21	0.62
E618/84																			
(DA1)	BH 45A	2.50	KAN slty cl	45935/386441	U	34			113	49	64				-	15	60	25	2.56
Kritou	BH 45B	2.50	KAN slty cl	"	U	34			144	47	97	-0.13			-	1	40	59	1.63
Marr.	BH 46	3.75	KAN slty mudst	"	SPT	42	1.68	1.18	131	47	84	-0.06			-	12	38	50	1.68
	BH 47	5.50	KAN slty mudst	"	U	39	1.69	1.22	102	27	75	+0.16	17		1	3	56	40	1.87
	BH 48	6.75	KAN cl in mudst	"	SPT	42			139	48	91	-0.07			-	12	48	40	2.28
	BH 49	8.25	KAN cl in mudst	"	U	33			130	43	87	-0.11			-	1	44	55	1.58
	BH 50	9.75	KAN cl mudst	"	SPT	33	2.02	1.53	158	40	118	-0.06			-	-	50	50	2.36
	BH 51	11.25	KAN cl mudst	"	U	30			134	37	97	-0.07			-	-	44	56	1.73
	BH 52	12.75	KAN cl mudst	"	SPT	24	1.89	1.52	138	41	97	-0.13			-	-	53	47	2.06
	BH 53	13.50	KAN cl mudst	"	D				99	43	56				-	-	45	55	1.02
	BH 54	14.25	KAN sndy slt	"	U	22													
	BH 55	15.75	KAN sndy slt	"	SPT	24	2.18	1.75	89	21	67	+0.04			-	25	60	15	4.46
	BH 56	17.50	KAN sndy slt	"	D				89	25	64				-	26	42	32	2.00
E619/84																			
(A1)																			
Ayios	BH 57	2.25	KAN cl slt	45855/386352	U	38	1.58	1.15	106	44	62	-0.09			-	15	62	23	2.69
Dhim'os	BH 58	3.75	KAN cl slt	"	SPT	39	1.72	1.33	107	45	62	-0.10			-	13	56	31	2.00
	BH 59A	5.25	KAN slty cly snd	"	U	30	1.72	1.32							-	43	32	25	
	BH 59B	5.25	KAN slty cl	"	U	30	1.78	1.37	109	45	64	-0.23			-	8	36	56	
	BH 60	6.75	KAN slty cl mudst	"	SPT	62			99	45	54				1	33	51	15	3.60
	BH 61	7.50	KAN fine sandy silt	"	D				NP	NP	NP				-	30	65	5	-
E620/84																			
(A2)																			
Ayios	BH 62	2.25	MEL matrix	45924/386368	U	25	1.92	1.54	82	27	55	-0.04			1	9	37	53	1.04
Dhim'os	BH 63	3.75	MEL sndy cly flow	"	SPT	34	1.91	1.47											
	BH 64	4.50	MEL sndy cly flow	"	D				53	21	32				-	20	45	35	0.91
	BH 65	5.25	MEL sndy cly flow	"	U	29	2.03	1.57	60	27	33	+0.06		2.69	2	16	29	53	0.62
	BH 66	6.75	MEL sndy cl flow	"	SPT	20	2.06	1.72											
	BH 67	7.50	MEL sndy cl flow	"	D				51	17	34				-	25	40	35	0.97
	BH 68	8.50	MEL slty cl matrix	"	D				60	17	43				-	20	35	45	0.95
	BH 69	9.75	MEL slty cl matrix	"	SPT	39			55	20	35	+0.05							
	BH 70	10.50	MEL + KAN	"	D				129	30	99				-	10	35	55	1.80
	BH 71	12.75	MEL slt/cl KAN clasts	"	SPT	18			97	25	72	-0.09			4	21	40	35	2.05
	BH 72	15.50	MEL matrix flow	"	D				70	23	47				-	19	38	43	1.09

SAMPLE LISTING and INDEX TEST RESULTS (cont'd)

PIT/BH NO.	SAMPLE NO.	DEPTH m	LITHOLOGY	GRID REFERENCE	TYPE	MC %	BD Mg/m3	DD Mg/m3	LL %	PL %	PI %	LI	LS %	SG	Gr %	Sa %	Si %	Cl %	A
EG21/84 (A3)																			
Kritou	BH 73	1.50	MEL matrix + KAN frags	45905/386412	D				67	22	45				2	23	32	43	1.04
Marr.	BH 74	3.65	MEL matrix + KAN frags	"	SPT	17			54	23	31	-0.19			8	22	33	37	0.83
	BH 75	4.50	MEL matrix + KAN frags	"	D				66	24	42				2	26	38	34	1.23
	BH 76	5.25	MEL matrix + KAN frags	"	SPT	16			56	18	38	0.05			8	17	45	30	1.27
	BH 77	7.40	MEL matrix + KAN frags	"	D				91	25	66				2	26	36	36	1.83
EG22/84 (A4)																			
Kritou	BH 78	2.25	KAN slty cl+cly mudst	45993/386516	U	39	1.56	1.12	112	41	71	+0.01			-	10	55	35	2.14
Marr.	BH 79	3.75	KAN slty cl+cly mudst	"	SPT	36	1.93	1.42	110	35	75	+0.01			-	15	41	44	1.02
	BH 80A	5.25	KAN slty cl+cly mudst	"	U	39	1.95	1.40	120	45	75	-0.08			-	3	46	51	1.47
	BH 80B	5.25	KAN slty cl+cly mudst	"	U	38			117	43	74	-0.07			-	15	31	54	1.37
	BH 81	6.75	KAN slty cl+cly mudst	"	SPT	38	1.72	1.25	86	31	55	+0.12			-	12	36	52	1.06
	BH 82	7.50	MEL matrix slip	"	D				61	24	37				-	22	32	46	0.80
	BH 83	8.25	MEL matrix slip	"	SPT	14													
	BH 84	9.75	MEL matrix slip	"	U	26	2.00	1.67	69	22	47	+0.09			1	24	42	33	1.42
	BH 85	11.25	CHALK marl	"	SPT	15	1.91	1.65											
	BH 86	12.75	CHALK marl	"	U	17													
	BH 87	14.25	CHALK marl	"	SPT	21	2.17	1.70											
	BH 88	15.70	CHALK marl	"	U	22													
EG24/84 (A8)																			
S of	BH 89	1.50	MEL matrix	45720/386805	D				73	27	46				1	19	33	47	0.98
Sarama	BH 90	2.25	MEL matrix	"	SPT	21	2.21	1.82	90	25	65	-0.06			-	25	35	40	1.60
	BH 91	3.75	MEL matrix	"	SPT	27	2.10	1.66	73	23	50	0.08			2	21	40	37	1.35
	BH 92	4.50	MEL matrix	"	D				85	24	61				1	16	36	47	1.29
	BH 93	5.25	MEL matrix	"	SPT	27													
	BH 94	6.75	MEL matrix	"	SPT	22	2.13	1.75	78	24	54	-0.04			1	19	37	43	1.26
	BH 95	7.50	MEL matrix	"	D				81	21	60				1	17	35	47	1.27
	BH 96	8.25	MEL matrix	"	SPT	20			76	23	53	-0.05			2	26	32	40	1.32
	BH 97	9.75	MEL matrix	"	SPT				77	20	57				2	23	38	37	1.54
	BH 98	10.50	MEL matrix	"	D				74	23	51				1	20	35	44	1.16
	BH 99	11.25	KAN bands slty cl mudst	"	SPT	39			110	38	72	0.01			-	8	42	50	1.44
	BH 100	12.75	KAN bands slty cl mudst	"	U	40								2.59					
	BH 101	13.50	KAN bands slty cl mudst	"	D				117	42	75				1	7	33	59	1.27
	BH 102	14.25	KAN bands slty cl mudst	"	SPT	29	1.80	1.40	113	48	65	-0.20			-	8	58	34	1.91
	BH 103	17.50	KAN bands slty cl mudst	"	D				95	40	55				-	8	44	48	1.14
EG25/84 (A7)																			
SW of	BH 104	1.50	MEL soil	45573/386774	D				200	44	156				-	6	22	72	2.16
Sarama	BH 105	2.25	MEL matrix + KAN	"	U	25	1.88	1.51	73	26	47	-0.02			1	19	38	42	1.12
	BH 106	5.50	MEL matrix + KAN	"	D				70	18	52				-	20	37	43	1.21
	BH 107	6.75	MEL matrix + KAN	"	SPT	22	1.94	1.59											
	BH 108	7.50	MEL matrix + KAN	"	D				82	26	56				-	18	38	44	1.27
	BH 109	8.25	MEL matrix + KAN	"	U	31	1.99	1.56	141	46	95	-0.33	18	2.66	3	11	34	52	1.83
	BH 110	9.75	MEL matrix + KAN	"	SPT	21	2.00	1.66	113	29	82	-0.09			6	16	30	48	1.70
	BH 111	11.75	MEL matrix + KAN	"	U	37			73	27	46	+0.21			-	17	36	47	0.98
	BH 112	12.50	MEL matrix + KAN	"	D				106	30	76				-	11	39	50	1.52
	BH 113	13.25	KAN slty mudst+cl	"	SPT	31			88	32	56	-0.02			-	18	44	38	1.47

SAMPLE LISTING and INDEX TEST RESULTS (cont'd)

PIT/BH NO.	SAMPLE NO.	DEPTH m	LITHOLOGY	GRID REFERENCE	TYPE	MC %	BD Mg/m3	DD Mg/m3	LL %	PL %	PI %	LI	LS %	SG	Gr %	Sa %	Si %	Cl %	A
E625/84																			
(A7)																			
SW of	BH 114	14.75	KAN slty cly mud/clst	45573/386774	U	47													
Sarama	BH 115	16.25	KAN slty cly mud/clst	"	SPT	34	1.73	1.30	132	36	96	-0.02			-	9	35	56	1.71
	BH 116	17.50	KAN slty cly mud/clst	"	D				119	38	81				-	12	40	48	1.68
E626/84																			
(A6)																			
S of	BH 117	1.50	KAN slty cl slipped	45712/386681	D				85	32	53				-	11	41	48	1.10
Sarama	BH 118	2.25	KAN slty cl slipped	"	U	29	1.53	1.05											
	BH 119	3.75	KAN slty cly mudst	"	SPT	35	1.67	1.23	101	40	61	+0.08			-	6	44	50	1.22
	BH 120	4.50	KAN slty cly mudst	"	D				68	30	38				-	17	36	47	0.81
	BH 121	5.25	KAN slty cly mudst	"	U	50	1.81	1.21	77	44	33	+0.18			3	19	51	27	1.22
	BH 122	6.75	KAN slty cly mudst	"	SPT	47	1.72	1.16	109	42	66	+0.08				3	61	36	1.80
	BH 123	7.50	KAN slty cl/cly slt	"	D				104	35	69				-	7	41	52	1.32
	BH 124	8.25	KAN slty cl/cly slt	"	U	42													
	BH 125	9.75	KAN slty cl/cly slt	"	SPT	30	2.06	1.76	123	44	79	-0.32			-	8	73	19	4.15
	BH 126	10.50	KAN slty cl/cly slt	"	D				112	41	71				-	8	56	36	1.97
	BH 127	11.15	KAN slty cl/cly slt	"	SPT	29			86	39	47	-0.20			-	9	77	14	3.35
	BH 128	13.50	KAN slty cl/cly slt	"	D				79	39	40				-	8	70	22	1.82
	BH 129	14.25	KAN slty cl/cly slt	"	SPT	42	1.79	1.31	141	47	94	-0.05			-	-	55	45	2.10
	BH 131	15.75	KAN slty cl/cly slt	"	U	28													
	BH 132	17.50	KAN slty cl/cly slt	"	D				93	42	51				-	31	51	18	2.83
E627/84																			
(A10)																			
Simou	BH 133	1.50	KAN slty cly slt/mudst	45648/386684	D														
	BH 134	2.25	KAN slty cly slt/mudst	"	SPT	20			116	37	79	-0.20			-	-	52	48	1.65
	BH 135	3.75	KAN slty cly slt/mudst	"	SPT	20			129	33	96	-0.13			-	-	58	42	2.30
	BH 136	4.50	KAN slty cly slt/mudst	"	D				85	33	52				-	-	60	40	1.30
	BH 137	5.15	KAN slty snd/sndy slt	"	SPT	18			74	31	43	-0.30			-	8	70	22	1.95
	BH 138	6.75	KAN slty snd/sndy slt	"	SPT	20			74	30	44	-0.22			-	10	68	22	2.00
	BH 139	9.70	KAN slty snd/sndy slt	"	SPT	18	1.93	1.66	58	25	33	-0.20			-	38	51	11	3.00
	BH 140	10.50	KAN slty snd/sndy slt	"	D				56	20	36				-	42	43	15	2.40
	BH 141	11.25	KAN slty snd/sndy slt	"	SPT	17			58	18	40	-0.03			-	41	41	18	2.20
	BH 142	12.75	KAN slty snd/sndy slt	"	SPT	18													
	BH 143	14.15	KAN slty snd/sndy slt	"	SPT	23			56	16	40	+0.18			-	44	34	22	1.80
	BH 144	15.50	KAN slty snd/sndy slt	"	D				75	26	49				-	20	48	32	1.53
E628/84																			
D1(DA1)																			
Kritou	BH 145	16.50	KAN sst/sltst	45935/386441	C				78	34	44		12						
Marr.	BH 146	18.75	KAN sst/sltst	"	C														
	BH 147	19.50	KAN slty shly mudst	"	C				168	54	114		24						
	BH 148	20.05	KAN mudst	"	C														
	BH 149	29.50	KAN mudst shl sheared	"	C				112	51	61		19		-	-	35	65	0.93
	BH 150	38.00	KAN mdst sheared	"	C														
	BH 151	43.00	KAN mudst	"	C				125	53	72		20		-	-	62	38	1.90
	BH 152	50.15	KAN slty sst	"	C														
	BH 153	56.20	KAN sst	"	C														
	BH 154	57.80	KAN sst coarse	"	C														
	BH 155	58.75	KAN mdst sheared	"	C				90	39	51		14						

SAMPLE LISTING andINDEX TEST RESULTS (cont'd)

PIT/BH NO.	SAMPLE NO.	DEPTH m	LITHOLOGY	GRID REFERENCE	TYPE	MC %	BD Mg/m3	DD Mg/m3	LL %	PL %	PI %	LI	LS %	SG	Gr %	Sa %	Si %	Cl %	A
E629/84 (D2)																			
Phiti	BH 156	9.35	KAN mdst/shl sheared	45782/386604	C														
	BH 157	13.25	KAN sltst	"	C														
	BH 158	17.00	KAN mdst	"	C														
	BH 159	17.50	KAN mdst	"	C														
	BH 160	20.25	KAN sst	"	C										-	37	48	15	
	BH 161	38.25	KAN mdst	"	C														
	BH 162	46.85	KAN sst	"	C														
	BH 163	51.40	KAN shly mdst sheared	"	C														
	BH 164	56.40	KAN shly mdst sheared	"	C														
AREA 2 SURFACE SAMPLES 1985																			
-------	85/1	S	KAN cl,slip zone in CH	46150/386280	D				170	69	101			2.59	-	14	40	46	2.20
	85/2	S	MEL cl,slip zone in CH	"	D				75	27	48				26	14	32	28	1.71
	85/3	S	CHALK + exotics	"	D														
	85/5	S	Weath'd LAVA soil	46300/386490	D														
	85/6	S	MEL matrix	46390/386370	D				48	17	31				1	16	51	32	0.97
	85/7	S	KAN cl slump flow	"	D				79	29	50				1	11	43	45	1.11
	85/8	S	CHALK talus	46610/386370	D				31	15	16				2	50	31	17	0.94
	85/9	S	KAN cl red stained	46280/386445	D				71	26	45				-	6	56	38	1.18
	85/10	S	MEL matrix grey	46445/386395	D				48	18	30				-	30	43	27	1.11
	85/11	S	KAN cl recent slip	46620/386385	D														
	85/12	S	MEL matrix grey	46170/386205	D				61	27	34				-	5	48	47	0.72
	85/13	S	MEL/STRAT MAM	46645/385765	D				59	18	41				-	4	46	50	0.82
	85/14	S	STRAT MAM	"	D														
	85/15	S	ST.MAM. sl cly silt	46735/385785	D				32	22	10		7		-	1	93	6	1.66
	85/16	S	ST.MAM. supfl cly silt	46790/385690	D				35	20	15		9		11	6	62	21	0.71
	85/17	S	STRAT MAM reworked	"	D				34	17	17				-	42	39	19	0.89
	85/18	S	STRAT MAM sltv mudst	46591/385872	D														
	85/19	S	MEL slipped	46620/385840	D				56	19	37				-	19	38	43	0.86
	85/20	S	STRAT MAM slope debris	46325/385980	D				32	15	17				-	33	43	24	0.71
	85/21	S	STRAT MAM slty mudst	46140/386075	D														
	85/22A	S	MEL matrix	"	D				47	20	27								
	85/23	S	ST.MAM. grey slty cl	46175/386120	D														
	85/24	S	MEL matrix grey	46025/386235	D														
	85/25	S	ST.MAM. spfl grey clay	46460/386400	D				50	18	32				-	18	47	35	0.91
	85/26A	S	KAN cl fisd	46585/386465	D				64	19	45				-	50	35	15	3.00
	85/26B	S	KAN slty mudst	"	D				149	47	102				-	-	42	58	1.76
	85/27	S	KAN cl	"	D				110	57	53				-	1	48	51	1.04
	85/28	S	KAN cl in CHALKY MEL sl	46510/386265	D														
	85/29	S	STRAT MAM slope debris	46200/385930	D				45	19	26			2.70	35	17	28	20	1.30
	85/30	S	STRAT MAM slope debris	"	D				34	16	18				-	28	45	27	0.67
	85/31	S	STRAT MAM grey fisd cl	46405/385975	D				57	23	34				1	1	62	36	0.94
	85/32	S	KAN cl/mudst	46230/386430	D				120	41	79				-	-	42	58	1.36
	85/33	S	KAN cl fisd	46195/386520	D				69	32	37				-	-	74	26	1.42

SAMPLE LISTING and INDEX TEST RESULTS (cont d)

PIT/BH NO.	SAMPLE NO.	DEPTH m	LITHOLOGY	GRID REFERENCE	TYPE	MC %	BD Mg/m3	DD Mg/m3	LL %	PL %	PI %	LI	LS %	SG	Gr %	Sa %	Si %	Cl %	A
	85/34	S	KAN cl	46560/386485	D														
	85/35	S	LAVA	46620/386500	D														
	85/36	S	KAN cl with CH+MEL	46235/386465	D														
	85/37	S	KAN cl/mudst	46215/386475	D														
	85/38	S	KAN slty mudst/cl	46875/385950	D				96	40	56				-	18	49	33	1.70
	85/39	S	MEL matrix	45940/386475	D				51	17	34				-	19	43	38	0.89
AREA 2 PITS 1985																			
PIT 1	P85/1A	1.20	MEL chalky cl	46535/385865	D														
PIT 2	P85/2A	1.40	MEL matrix	46540/385915	D														
	P85/2B	1.65	MEL matrix	"	B														
PIT 3	P85/3A	1.00	MEL matrix slipped	46850/386000	D				63	27	36								
	P85/3B	1.80	MEL matrix slipped	"	D														
	P85/3C	2.00	MEL matrix slipped	"	B														
	P85/3D	1.80	MEL matrix slipped	"	Tv														
PIT 4	P85/4A	1.80	STRAT MAM silt shl	46835/386075	D														
PIT 5	P85/5A	1.60	MEL matrix slipped	46430/385915	D				55				13						
	P85/5B	1.60	MEL matrix slipped	"	U														
	P85/5C	1.60	MEL matrix slipped	"	Tv														
PIT 6	P85/6A	1.80	MEL matrix slipped	46410/385980	D				63	23	40				1	2	18	79	
	P85/6B	1.00	MEL matrix slipped	"	D														
	P85/6C	2.00	STRAT MAM cl grey	"	D														
	P85/6D	1.00	KAN cl	"	D														
PIT 7	P85/7A	1.00	MEL matrix grey	46025/386235	D				91						5	5	50	40	
	P85/7B	1.90	MEL grey	"	D														
	P85/7C	1.90	MEL grey	"	B														
	P85/7D	1.60	MEL grey	"	Tv														

CYPRUS TEST DATA

LABORATORY STRENGTH TEST RESULTS

(CIU Triaxial Tests and Ring Shear Tests)

PIT/BH NO.	SAMPLE NO.	DEPTH m	LITHOLOGY	Cu kPa	Øu Deg	C' kPa	Ø' Deg	Ør' Deg (σn'=76kPa)	Ør' Deg (σn'=150kPa)	Ør' Deg (σn'=248kPa)	Ør' Deg (σn'=497kPa)	Best Linear Envelope Cr' kPa	Best Linear Envelope Ør' Deg
	84/3A	S	MEL cl matrix					20.9	16.5	14.5	12.4	15.1	10.8
	84/3F	S	KAN cl,sheared,fissd					13.0	10.3	9.8	8.3	8.2	7.5
PIT 4	P4/1	1.50	MEL cl matrix					18.0	15.1	13.7	12.5	10.2	11.3
PIT 13	P13/2	1.60	KAN cl,fissd					19.2	16.5	14.7	12.1	12.7	10.8
PIT 14	P14/1	1.50	KAN cl,highly fissd					14.3	11.8	10.4	10.1	6.5	9.1
PIT 16	P16/2	1.50	MEL slip-plane cl,green					23.5	19.8	18.6	15.7	16.0	14.0
PIT 22	P22/1	1.60	MEL shear-zone cl,soft					13.4	12.5	12.4	11.5	3.9	11.1
PIT 24	P24/2	1.90	MEL cl,stiff,fissd					19.6	18.2	16.6	15.0	10.7	14.0
E610/84	BH18	126.00	MEL cl matrix					23.2	20.1	16.4	13.6	19.0	11.9
E613/84	BH36/1	43.50	MEL matrix					23.8	23.3	23.1	22.4	3.3	22.3
"	BH/40	61.50	KAN cl with MEL					19.5	15.2	14.8	13.5	8.6	12.4
E618/84	BH45	2.50	KAN slty cl					22.3	19.5	15.4	14.1	7.2	12.4
"	BH47	5.50	KAN slty mudst	15.0	13.5	9.0	18.3						
"	BH51	11.25	KAN cl mudst					15.3	12.6	11.2	9.7	10.4	8.5
E619/84	BH57	2.25	KAN v.slty cl	10.0	14.0	18.0	19.0						
"	BH59AB	5.25	KAN cly slt snd/slty cl	5.0	25.6	0.0	29.7						
E620/84	BH62	2.25	MEL matrix					21.4	17.3	16.1	13.6	15.1	11.9
"	BH65	5.25	MEL sndy cl	35.0	11.3	30.0	13.0	24.4	23.2	22.9	22.3	3.9	22.1
E622/84	BH78	2.25	KAN slty cl+mudst clsts	40.0	16.0	50.0	21.0						
"	BH80	5.25	KAN slty cl+mudst frags	18.0	16.2	13.0	23.0	19.5	17.5	15.6	14.1	11.0	13.0
E625/84	BH105	2.25	MEL matrix+KAN cl/sltst					21.2	18.0	16.0	13.6	15.9	12.0
"	BH109	8.25	KAN cl+MEL matrix	10.0	20.8	4.0	31.7	12.2	10.7	8.6	7.8	8.4	6.9
E626/84	BH121	5.25	KAN slty cly mudst	30.0	14.3	18.4	25.0						
E628/84	BH145	16.5	KAN sltst,weakly cem'td					31.6	31.2	29.7	28.4	10.2	29.0
"	BH147	19.5	KAN slty shaley mudst					17.7	14.6	13.7	12.7	8.3	11.8
"	BH149	29.5	KAN mudst/shale,sheared					11.2	7.7	7.7	6.5	6.3	5.7
"	BH151	43.00	KAN mudst					20.7	17.7	17.5	15.4	7.1	14.4
"	BH155	58.75	KAN mudst,sheared					26.4	25.5	24.0	22.6	10.2	21.8
E629/84	BH158	17.00	KAN shaley mudst					25.4	21.3	20.6	20.3	7.1	19.4
"	BH160	20.25	KAN sst,mod. cemented					35.9	32.4	32.4	31.6	7.7	30.9
"	BH164	56.40	KAN shale/mudst,sheared					29.2	25.0	23.0	22.3	12.2	20.8
	85/1	S	KAN slip zone in chalk					21.7	19.2	16.8	15.3	12.8	13.9
	85/15	S	ST.MAM. grey cl in sst					18.1	17.5	16.6	15.6	6.0	15.0
	85/16	S	ST.MAM. sup'fl sndy cl					26.2	23.9	23.9	20.8	18.0	18.2
	85/27	S	KAN cl,fissd					18.2	15.5	12.7	11.3	13.2	9.9
PIT 5	P85/5B	1.60	MEL cl ,slipped	35.0	11.3	9.0	13.0						
PIT 6	P85/6A	1.85	MEL cl,soft,slipped					18.0	15.0	14.6	13.0	9.3	12.2
PIT 7	P85/7A	1.00	MEL cl matrix,grey					21.4	18.2	16.0	12.7	19.3	10.8

CYPRUS TEST DATA - MINERALOGICAL RESULTS

Melange

PIT/BH NO.	SAMPLE NO.	DEPTH m	LITHOLOGY	(GSD) CaCO3 %	(Meth. Blue) MONT. %	(Thmo. grav.) CaCO3 %	(EGME-sam.) MONT. %	(XRD) QTZ. %	Mineralogical Comp'sn. (XRD)
	84/19	S	MEL cl,slip.	8.7	14.0				
	84/20	S	MEL cl,slip.	16.2	11.7				
	84/21	S	MEL cl,slip.	13.1	22.0				
PIT 4	P4/1	1.50	MEL cl matrix	9.5	28.0				Mont/qtz/calc/felsp/mica
PIT 16	P16/1	1.40	MEL cl matrix			15	21	10	Calc/qtz/felsp/mont/chl
"	P16/2	1.50	MEL grn cl,sh			ND	56	3	Qtz/felsp/mont
PIT 19	P19/1	1.10	MEL cl matrix	16.0	36.9				Mont/qtz/calc/mica
PIT 22	P22/2	2.00	MEL cl matrix	11.2	17.5				
EG10/84	BH1	1.00	MEL topsoil	58.7	13.7				
"	BH2	4.00	MEL topsoil	19.4	20.5				
"	BH3	10.5	MEL cl matrix	16.2	18.0				
"	BH4	17.5	MEL cl matrix	21.9	13.0				
"	BH5	26.5	MEL cl matrix	16.2	16.0				
"	BH6	32.5	MEL cl matrix	11.2	16.5				
"	BH7	37.5	MEL cl matrix	13.1	18.5				
"	BH8	47.5	MEL cl matrix	15.0	17.8				
"	BH9	57.5	MEL cl matrix	13.7	15.5				
"	BH10	67.5	MEL cl matrix	17.5	14.5				
"	BH11	74.5	MEL cl matrix	13.1	15.5				
"	BH12	78.5	MEL cl matrix	12.5	17.5				
"	BH14	87.5	MEL cl matrix	15.0	14.3				
"	BH15	97.5	MEL cl matrix	17.5	13.8				
"	BH16	107.5	MEL cl matrix	21.2	11.5				
"	BH17	117.5	MEL cl matrix	17.5	8.7				
"	BH18	125.5	MEL cl matrix	13.7	11.2				Mont/mica/qtz/felsp/kaol
EG13/84	BH29	1.50	MEL cl matrix	10.6	15.0				
"	BH30	3.50	MEL cl matrix	15.0	13.7				
"	BH31	6.50	MEL cl matrix	12.5	14.2				
"	BH32	10.50	MEL cl matrix	14.4	14.0				
"	BH33	18.50	MEL cl matrix	15.0	10.5				
"	BH34	28.50	MEL cl matrix	21.2	9.7				
"	BH35	38.50	MEL cl matrix	17.5	9.5				
"	BH36A	42.00	MEL cl matrix						Qtz/felsp/kaol/chl/calc/m
"	BH37	48.50	MEL cl matrix	15.0	8.7				
"	BH38	52.50	MEL cl matrix	15.0	15.0				
"	BH39	59.50	MEL cl matrix	18.1	12.0				
EG20/84	BH62	2.25	MEL cl,slip	8.7	23.2	8	33	10	Qtz/calc/mont/chl/mica
"	BH64	4.50	MEL cl,slip	44.4	15.7				
"	BH65	5.25	MEL cl,slip			33	14	12	Calc/qtz/mont/chl/mica
"	BH66	6.75	MEL cl,slip			8	18	12	Calc/qtz/mont/chl/mica
"	BH67	7.50	MEL cl,slip	13.7	16.2				
"	BH68	8.50	MEL cl,slip	11.9	16.2				
"	BH69	9.75	MEL cl,slip	10.0	16.2				
"	BH70	10.50	MEL+Kan frags	5.0	38.7				
"	BH71	12.75	MEL cl,slip	10.0	25.0				
"	BH72	15.50	MEL cl	11.2	21.2				
EG22/84	BH82	7.50	MEL cl,slip	51.6	20.0				
(A4)	BH84	9.75	MEL cl,slip	33.7	18.2	46	26	4	Calc/qtz/mont/chl/mica
EG24/84	BH89	1.50	MEL cl matrix	13.7	24.2				
(A8)	BH90	2.25	MEL cl matrix	15.0	24.2				
"	BH91	3.75	MEL cl matrix	10.0	24.0				

MINERALOGICAL TEST RESULTS

Melange cont'd.

PIT/BH NO.	SAMPLE NO.	DEPTH m	LITHOLOGY	(GSD) CaCO3 %	(Meth. Blue) MONT. %	(Thmo. grav.) CaCO3 %	(EGME-sam.) MONT. %	(XRD) QTZ. %	Mineralogical Comp'sn. (XRD)
"	BH92	4.50	MEL cl matrix	11.2	28.7				
"	BH94	6.75	MEL cl matrix	17.5	19.2	19	18	9	Calc/qz/mont/chl/mica
"	BH95	7.50	MEL cl matrix	17.5	20.7				
"	BH96	8.25	MEL cl matrix	8.7	22.5				
"	BH97	9.75	MEL cl matrix	12.5	23.0				
"	BH98	10.5	MEL cl matrix	7.5	28.0				
PIT 2	P85/2A	1.40	MEL cl matrix			10	18	24	Qtz/calc/mont/chl/mica/gy
"	P85/2B	1.65	MEL cl matrix			11	22	26	Qtz/calc/mont/chl/mica
PIT 3	P85/3B	1.80	MEL cl matrix			9	20	26	Qtz/calc/mont/chl/mca/fsp
PIT 5	P85/5A	1.60	MEL on St.Mam			11	15	27	Qtz/calc/mont/chl/mica/gy
PIT 6	P85/6A	1.80	MEL on St.Mam			7	25	25	Qtz/calc/mont/chl/mica/gy
"	P85/6B	1.00	MEL on St.Mam			11	23	26	Calc/qtz/mont/chl/mica
	85/2	S	MEL,shear pl.			10	14	25	Qtz/calc/mont/chl/mica
	85/19	S	MEL cl,slip	13.7	15.0				
	85/39	S	MEL cl matrix	8.7	15.0				
PIT 7	P85/7A	1.00	MEL,grey cl			7	19	22	Qtz/calc/mont/chl/mica
"	P85/7B	1.90	MEL,grey cl			16	20	18	Qtz/calc/mont/chl/mca/dol
	85/10	S	MEL,grey cl	13.1	15.0	9	17	7	Calc/qtz/mont/chl/mica
	85/12	S	MEL,grey cl	5.0	12.5	Tr	33	23	Qtz/calc/mont/mica/chl
EG21/84	BH73	1.50	MEL+Kan frags	13.7	24.2				
(A3)	BH74	3.65	MEL+Kan frags	14.3	18.7				
"	BH75	4.50	MEL+Kan frags	27.5	21.2				
"	BH76	5.25	MEL+Kan frags	9.3	15.0				
"	BH77	7.50	MEL+Kan frags	12.5	24.5				
EG25/84	BH104	1.50	MEL+Kan	3.1	50.0				
(A7)	BH105	2.25	MEL+Kan	8.7	18.7	5	25	9	Qtz/calc/mont/chl
"	BH106	5.50	MEL+Kan	8.7	22.5				
"	BH108	7.50	MEL+Kan	8.2	23.7				
"	BH109	9.25	MEL+Kan			8	36	13	Qtz/calc/mont/chl
"	BH110	9.75	MEL+Kan	10.0	29.2				
"	BH111	11.10	MEL+Kan	11.2	27.5				
"	BH112	12.50	MEL+Kan	11.2	32.5				

Stratified Mamonia and Superficial Melange(weathered St.Mam.)

	85/13	S	ST.M.spfl gr cl	3.1	15.0				
	85/15	S	ST.M. grey cl			4	ND	30	Qtz/calc/chl/mica/felsp
	85/16	S	ST.M.spfl gr cl			22	ND	27	Calc/qtz/felsp/mica
	85/23	S	ST.M. grey cl			7	ND	25	Qtz/calc/chl/mica/felsp
	85/25	S	ST.M.spfl gr cl	11.9	12.0				
	85/31	S	ST.M. grey cl			5	14	28	Qtz/calc/mont/chl/mca/fsp
PIT 6	P85/6C	2.00	ST.M. grey cl			18	13	26	Calc/qtz/mont/chl/mica/gy
	85/17	S	ST.M.red supfl	3.1	9.5				
	85/21	S	ST.M,red shlycl			ND	23	28	Qtz/mont/chl/mica/gy
	85/29	S	ST.M,red supfl			9	ND	31	Qtz/calc/chl/mica
	85/30	S	ST.M,red supfl	6.9	10.5				
PIT 4	P85/4A	1.80	ST.M,red shale			ND	27	30	Qtz/mont/chl/mica

MINERALOGICAL TEST RESULTS

Kannaviou

PIT/BH NO.	SAMPLE NO.	DEPTH m	LITHOLOGY	(GSD) CaCO3 %	(Meth. Blue) MONT. %	(Thmo. grav.) CaCO3 %	(EGME-sam.) MONT. %	(XRD) QTZ. %	Mineralogical Comp'sn. (XRD)
	84/3E	S	KAN silty clay	- 3.1	51.2				
	84/3G	S	KAN clay,fissd.	2.5	52.2				
	84/4A	S	KAN f.g. sst	Tr					Mont/calc/felsp
	84/4B	S	KAN silty mudst	26.1					Mont/calc/qtz/dol/chrys/k
	84/5	S	KAN silty mudst		31.0				Mont/chrys/calc/qtz
	84/9	S	KAN m.g. sst		26.4				Mont/qtz/felsp/calc
	84/12	S	KAN silty clay	3.7	38.7				
	84/17	S	KAN clay,slip	3.1	26.0				
	84/18	S	KAN clay,slip	15.6	32.5				
	84/28	S	KAN clay	5.0	47.5				
PIT 10A	P10A/3	1.90	KAN silty mudst	3.7	43.7				
PIT 13	P13/2	1.60	KAN clay,fissd	28.7	33.5				Mont/calc/dol/qtz/kaol
PIT 14	P14/1	1.50	KAN clay,fissd		64.3				Mont/qtz/felsp/cristob
"	P14/3	2.80	KAN clay,fissd	3.7	52.5				
PIT 15	P15/2A	2.10	KAN clay,sh-pl	5.0	42.0				
"	P15/3	1.55	KAN clay,slip	12.5	51.2				
PIT 17	P17/1	0.50	KAN clay,fissd	5.6	45.0				
"	P17/3	2.00	KAN mudst,fissd	5.0	32.5				
PIT 18	P18/2	1.10	KAN clay	10.0	42.5				
"	P18/3	1.80	KAN clay	10.0	37.5				
EG10/84	BH20	129.5	KAN cl,some Mel	12.5	22.5				
(Phyti)	BH21	134.5	KAN silty mudst	11.8	32.5				
"	BH22	139.5	KAN silty mudst	11.2	27.5				
"	BH23	149.5	KAN silty mudst	10.6	25.0				
"	BH24	154.5	KAN f.sst/sltst	11.2	18.7				
"	BH25	159.5	KAN f.sst/sltst	8.7	28.7				
"	BH26	169.5	KAN f.sst/sltst	11.8	22.5				
"	BH27	174.5	KAN f.sst/sltst	19.3	18.7				
"	BH28	177.5	KAN silty mudst	15.0	27.5				
EG13/84	BH43	68.50	KAN silty mudst	10.0	18.7				
	BH44	77.50	KAN silty mudst	11.9	17.5				
EG18/84	BH45	2.50	KAN silty clay	1.2	30.7				Mont/qtz/crst/zeo/mca/fsp
(DA1)	BH46	3.75	KAN silty mudst	3.7	36.5				
"	BH47	5.50	KAN silty mudst	25.0	24.0				Mont/calc/felsp
"	BH48	6.75	KAN clay/mudst	3.7	39.2				
"	BH49	8.25	KAN clay/mudst	18.7	34.0				
"	BH50	9.75	KAN clay/mudst	22.5	37.5				
"	BH51	11.25	KAN clay/mudst	21.9	34.5				Mont/mca/kal/ch/qz/ca/fsp
"	BH52	12.75	KAN clay/mudst	23.1	33.7				
"	BH53	13.50	KAN clay/mudst	3.7	29.7				
"	BH55	15.75	KAN cly siltst	19.4	18.7				
"	BH56	17.5	KAN sndy silt	15.0	25.0				
EG28/84	BH145	16.50	KAN sltst/f.ss	20.6	17.5	14	21	8	Fsp/qz/ca/mont/chl/mca/cl
(D1)	BH146	18.75	KAN sltst/f.ss	10.0	16.2	5	25	5	Fsp/qz/calc/mont/clin
	BH147	19.50	KAN shly mudst	13.7	37.5	13	41	4	Calc/qtz/felsp/mont/mica
	BH148	20.05	KAN mudst	18.7	38.2	ND	45	Tr	Mont/qtz
	BH149	29.50	KAN shly mudst	8.1	40.0	7	47	Tr	Calc/mont/chl/mca/qtz/dol
	BH150	38.00	KAN shly mudst	15.0	43.7	16	47	Tr	Calc/fsp/mont/chl/mca/qtz
	BH151	43.00	KAN mudst	15.0	37.0	14	41	Tr	Ca/fsp/mont/chl/mca/qz/cl
	BH152	50.15	KAN slty f.sst			5	24	3	Fsp/ca/amph/qz/mont/chl/m
	BH153	56.20	KAN sst,cmntd	33.1	7.0	22	12	1	Ca/amph/fsp/qz/mont/chl/a
	BH154	57.80	KAN cg.sst			3	21	4	Fsp/qz/ca/amph/mont/chl/m
	BH155	58.75	KAN mudst,shd			22	33	Tr	Calc/qz/mont/chl/mica

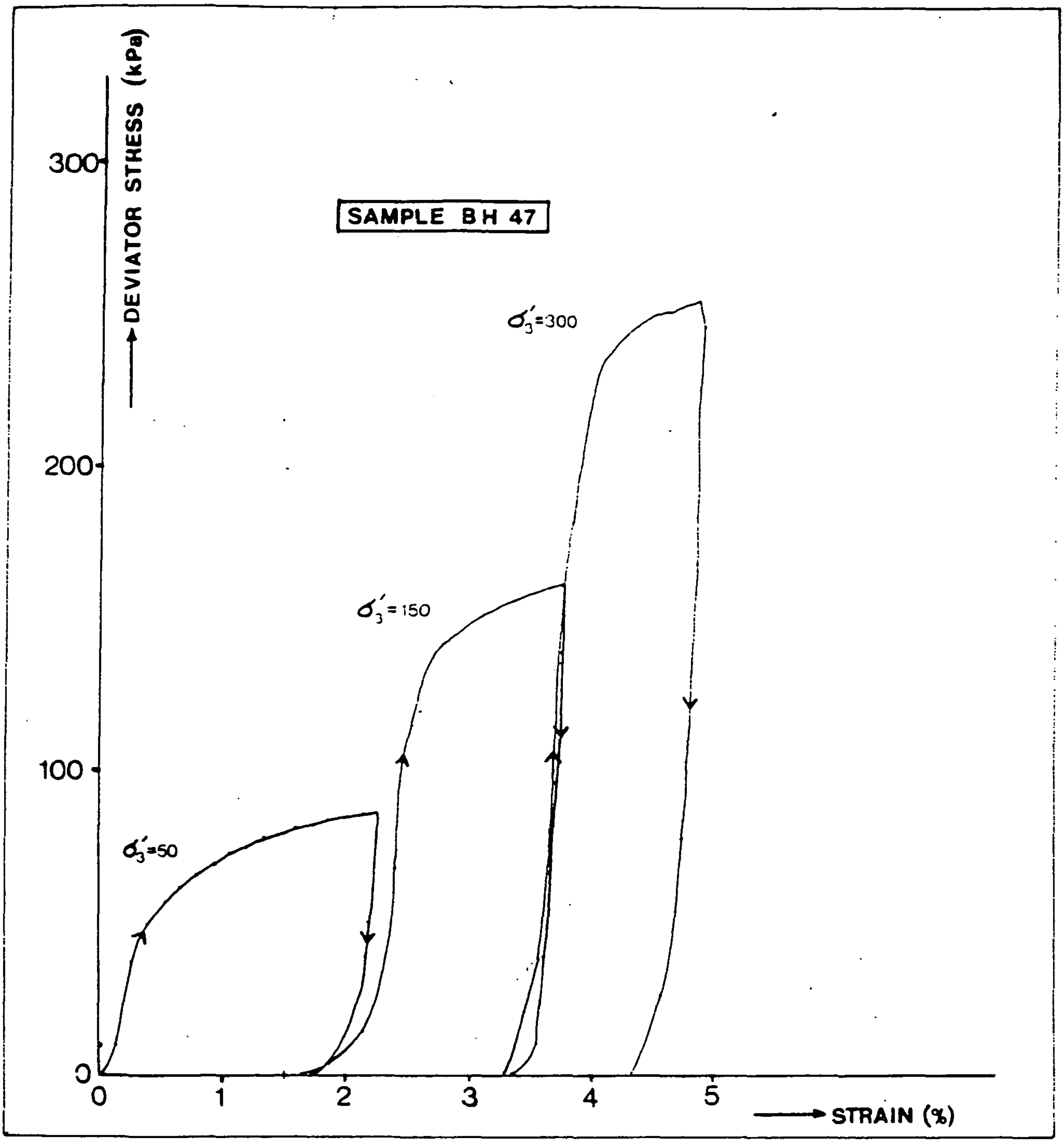
MINERALOGICAL TEST RESULTS

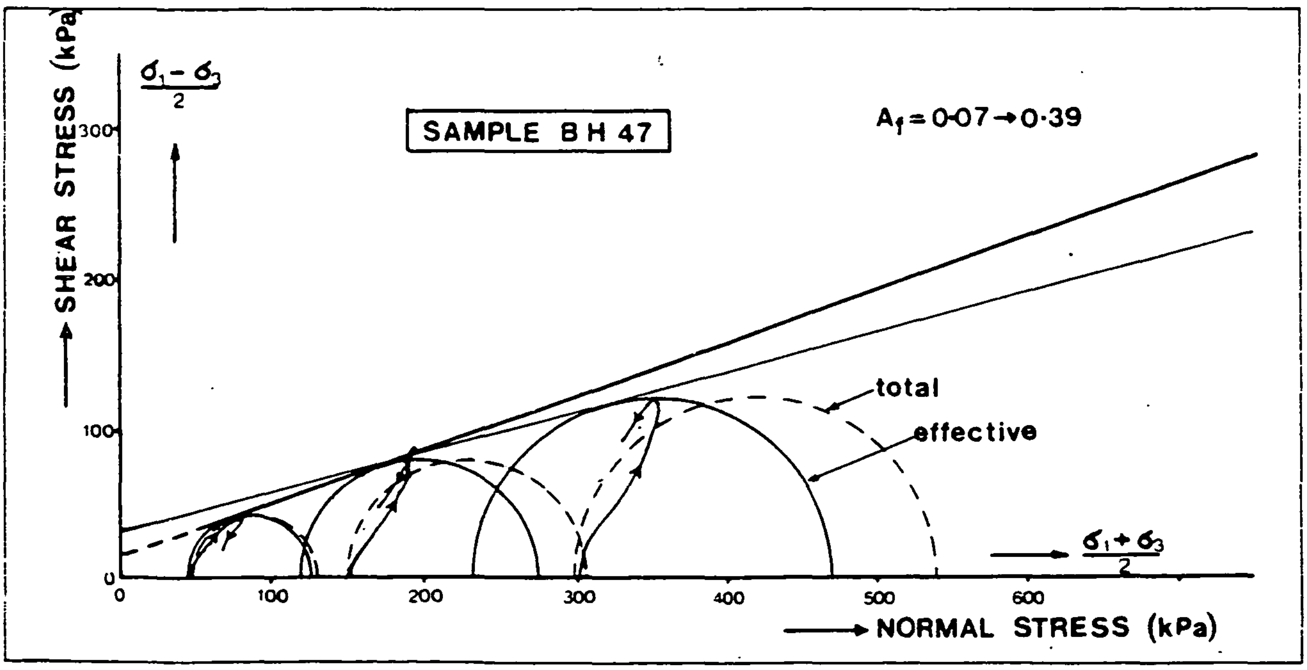
Kannaviou cont'd.

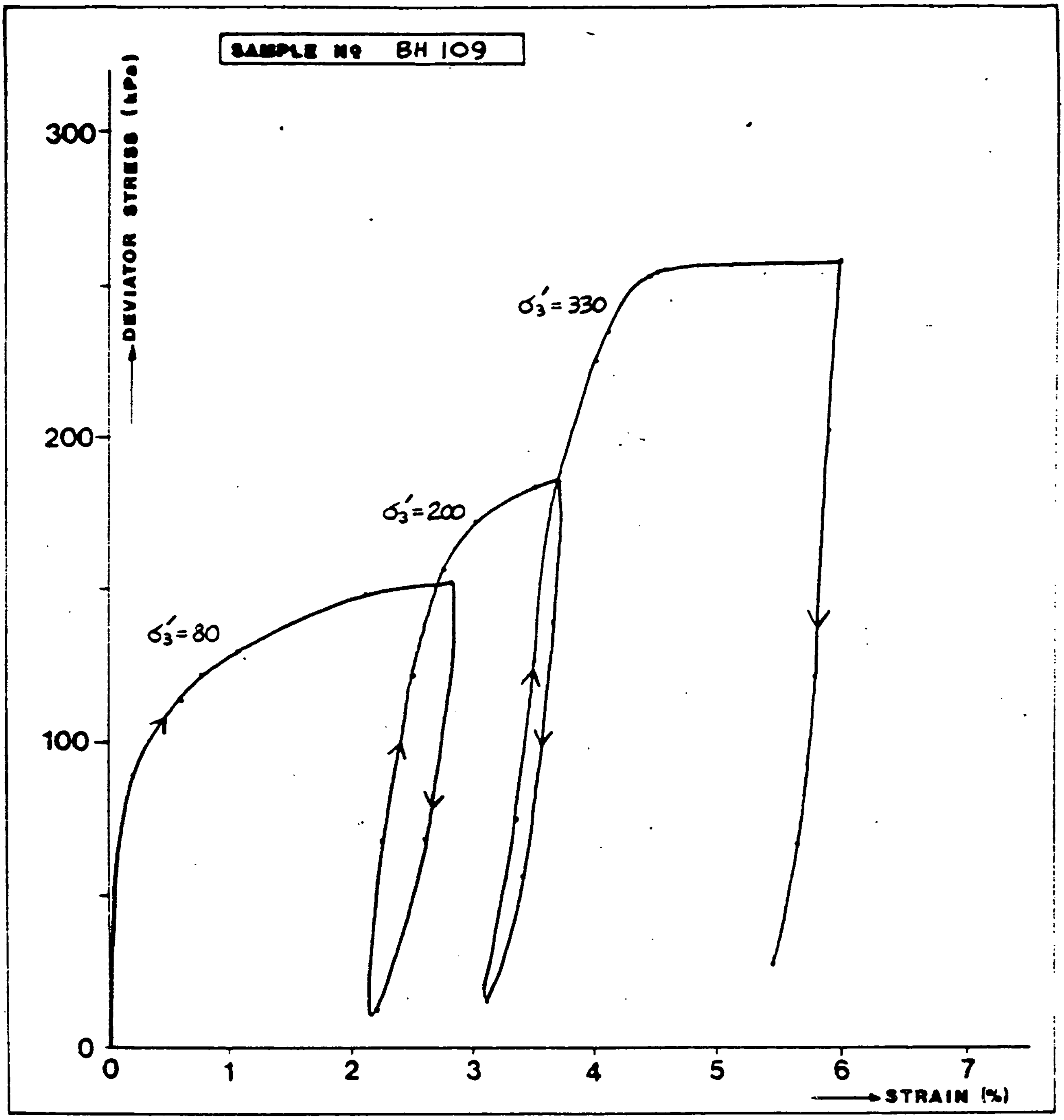
PIT/BH NO.	SAMPLE NO.	DEPTH m	LITHOLOGY	(GSD) CaCO3 %	(Meth. Blue) MONT. %	(Thmo. grav.) CaCO3 %	(EGME-sam.) MONT. %	(XRD) QTZ. %	Mineralogical Comp'sn. (XRD)
E619/84	BH57	2.25	KAN v.slty clay	2.5	35.0				
(A1)	BH58	3.75	KAN v.slty clay	3.7	41.5				
"	BH59B	5.25	KAN slty clay	2.5	42.0				
"	BH60	6.75	KAN v.slty muds	3.7	45.0				
"	BH61	7.50	KAN slty mudst	1.9	25.0				
E622/84	BH78	2.25	KAN slty cl/mds	8.2	33.7				
(A4)	BH79	3.75	KAN slty cl/mds	11.2	31.2				
"	BH80	5.25	KAN slty cl/mds	1.2	36.2				
"	BH81	6.75	KAN slty cl/mds	16.2	25.0				
E624/84	BH99	11.25	KAN slty cl/mds	5.6	36.2				
(A8)	BH101	13.50	KAN slty cl/mds	8.7	36.7				
"	BH102	14.25	KAN slty cl/mds	3.7	40.5				
"	BH103	17.50	KAN slty cl/mds	2.5	33.7				
E625/84	BH113	13.25	KAN slty cl/mds	7.5	28.2				
(A7)	BH115	16.25	KAN clay/mudst	7.5	40.7				
"	BH116	17.5	KAN clay/mudst	6.2	39.0				
E626/84	BH117	1.50	KAN slty cl	10.6	32.5				
(A6)	BH119	3.75	KAN clay/mudst	9.4	38.7				
"	BH120	4.50	KAN slty cl/mds	26.2	27.5				
"	BH122	6.75	KAN slty cl/mds	2.5	37.5				
"	BH123	7.50	KAN slty clay	24.1	35.0				
"	BH125	9.75	KAN slty cl/mds	4.4	52.5				
"	BH126	10.50	KAN slty clay	6.9	54.0				
"	BH127	11.15	KAN slty cl/mds	3.1	31.2				
"	BH128	13.50	KAN slty clay	2.5	34.7				
"	BH129	14.25	KAN slty cl/mds	3.1	61.2				
"	BH132	17.50	KAN slty clay	2.5	40.0				
E627/84	BH134	2.25	KAN slty cl/mds	21.9	30.7				
(A10)	BH135	3.75	KAN slty cl/mds	22.5	33.7				
"	BH136	4.50	KAN slty cl/mds	19.7	26.2				
"	BH137	5.15	KAN snd/slts/md	18.8	21.2				
"	BH138	6.75	KAN slty clay	15.6	20.0				
"	BH139	9.70	KAN snd/slts/md	19.7	15.0				
"	BH141	11.25	KAN snd/slts/md	18.7	15.0				
"	BH143	14.15	KAN snd/slts/md	18.7	17.5				
E629/84	BH156	9.35	KAN shaly mdst	8.7	48.0	6	46	Tr	Fsp/calc/mont/qtz
(D2)	BH157	13.25	KAN sltst	6.2	31.0	1	38	Tr	Qtz/calc/mont/mca/clino
"	BH158	17.00	KAN shaly mdst	6.2	41.2	ND	49	Tr	Mont/qtz
"	BH159	17.50	KAN mdst	6.2	34.2	4	48	Tr	Calc/mont/qtz/clino
"	BH160	20.25	KAN sst	6.2	36.7	Tr	31	Tr	Felsp/mont/qtz
"	BH161	38.25	KAN mdst,hard	22.5	29.5	23	38	2	Calc/qtz/mont/chl/mca/dol
"	BH162	46.85	KAN sst	25.0	12.5	6	20	41	Fsp/qz/ca/amph/mont/chl/m
"	BH163	51.40	KAN shaly mdst	16.2	20.0	ND	43	Tr	Mont/qtz
"	BH164	56.40	KAN shaly mdst	1.2	23.7	ND	51	Tr	Mont/qtz
	85/7	S	KAN clay,slip	9.4	27.0				
	85/9	S	KAN cl,reddish	2.5	27.7	ND	38	24	Qtz/mont/chl/mica
	85/11	S	KAN clay,slip	2.5	45.2				
	85/32	S	KAN cl/mudst	15.0	28.7				
	85/33	S	KAN clay,fiss'd	20.0	25.0				
	85/38	S	KAN slty mds/cl	3.1	26.2				
	84/32	S	KAN+Mel,slip						
E613/84	BH40	61.50	KAN+Mel	3.1	45.0				Mont/qz/mca/kaol/fsp/crst
(Ayios	BH41	62.50	KAN+Mel	3.1	47.0				
Dhim.)	BH42	65.50	KAN+Mel	13.7	20.2				

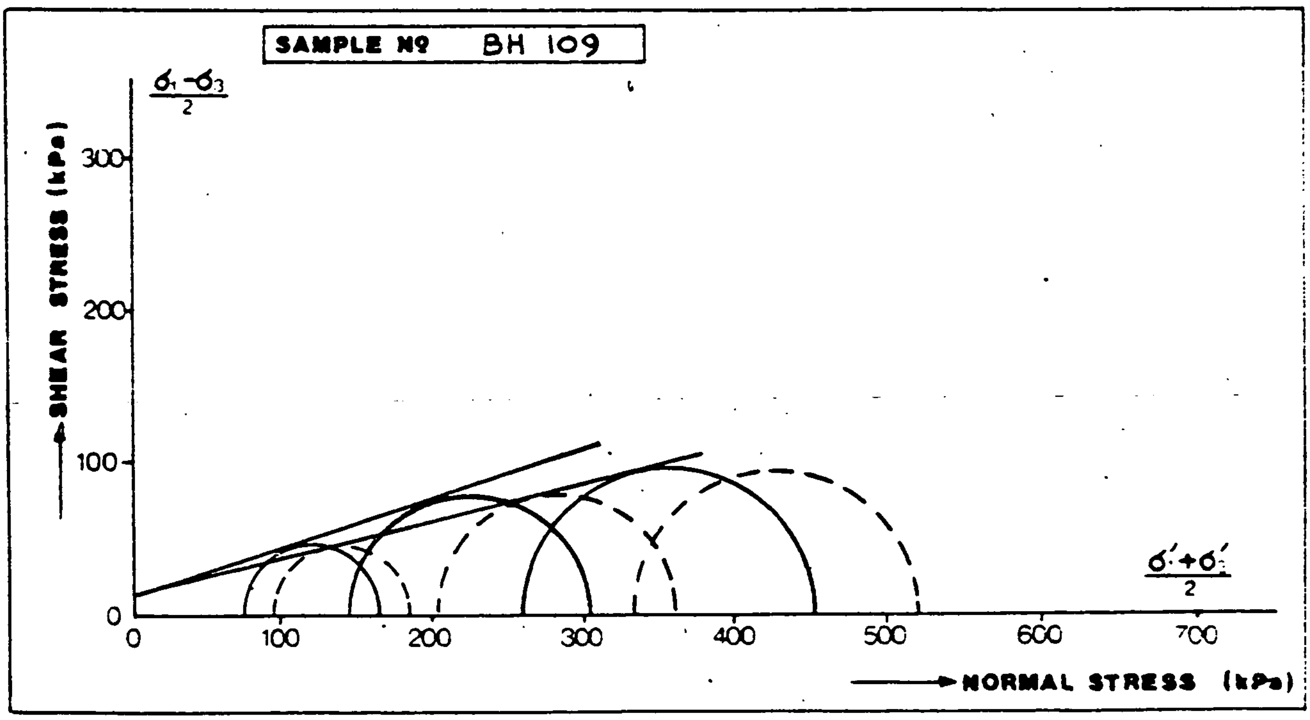
APPENDIX IIIA:

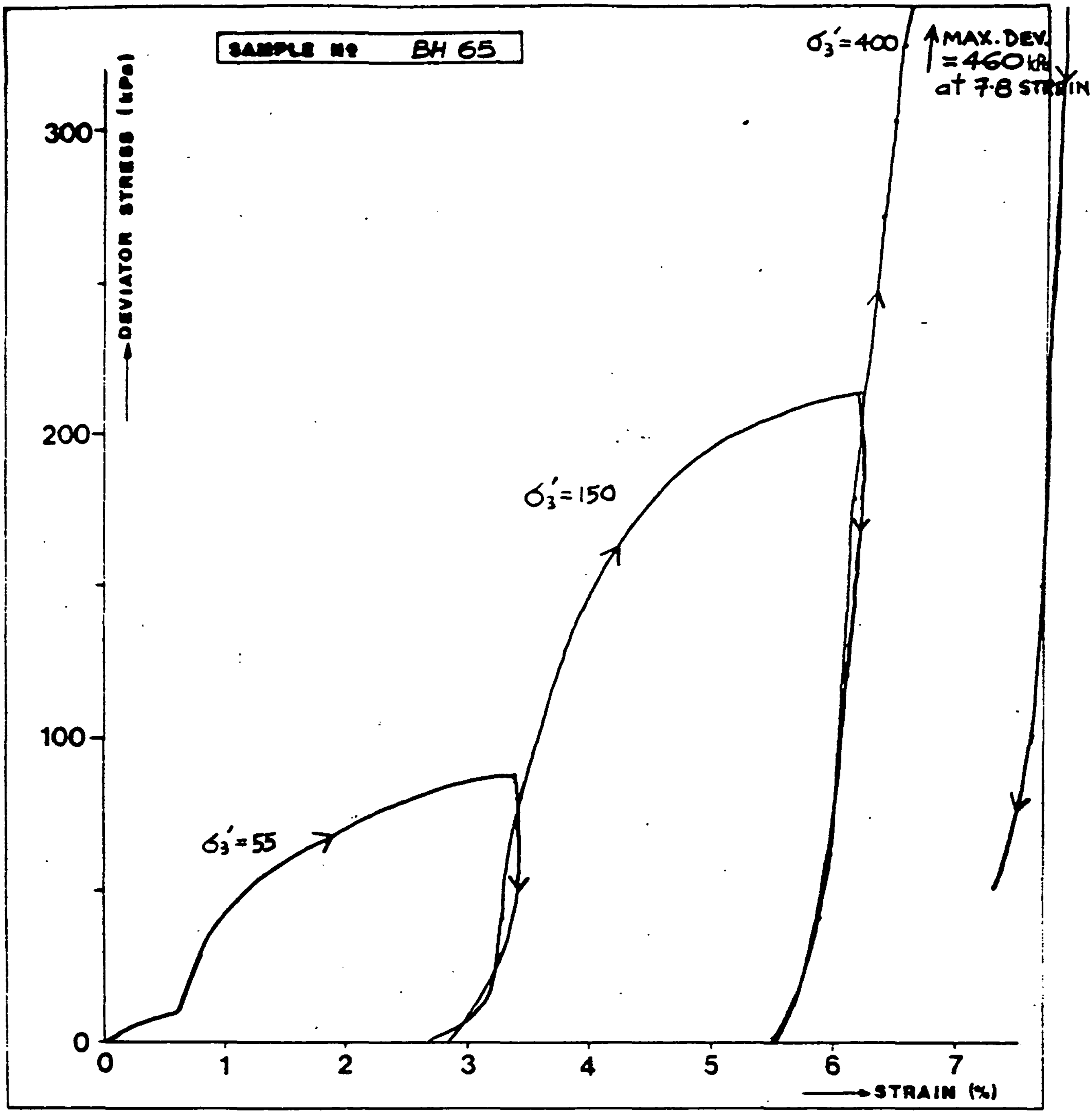
TRIAXIAL TEST: STRESS-STRAIN
AND MOHR CIRCLE PLOTS

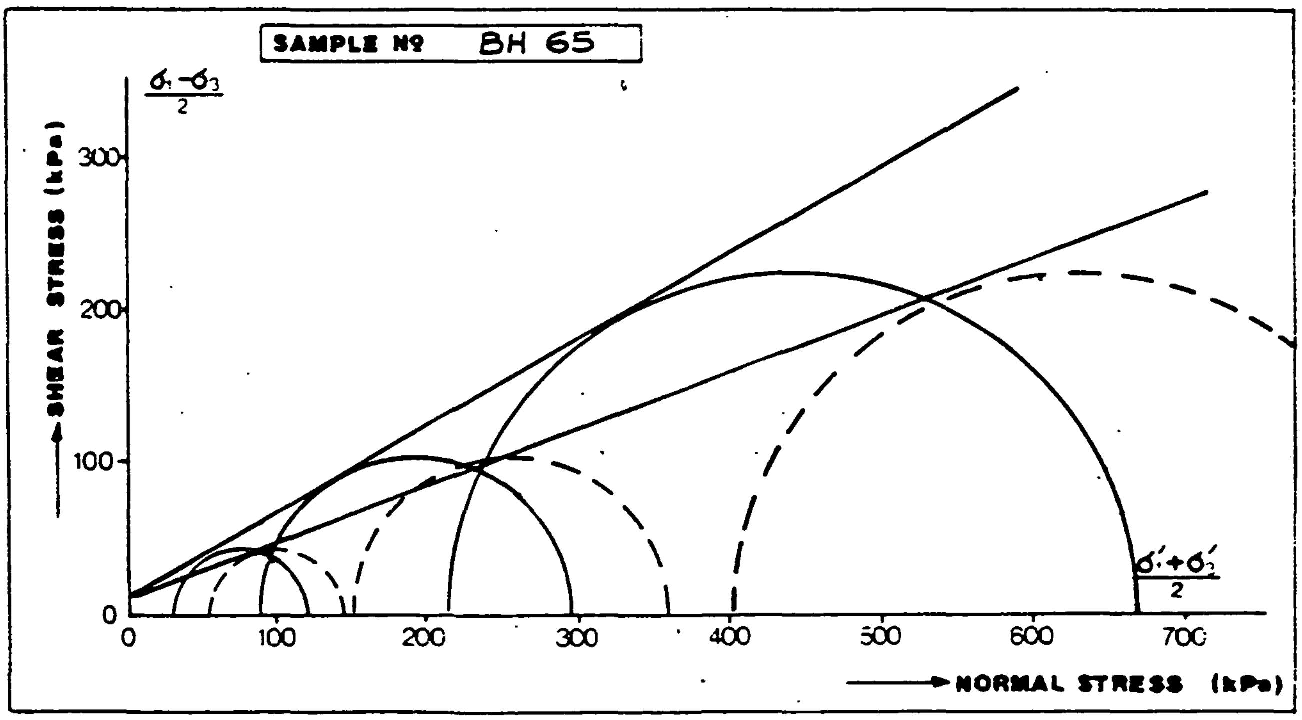

SAMPLE BH 47
DEVIATOR STRESS (kPa)
STRAIN (%)
$\sigma_3'=300$
$\sigma_3'=150$
$\sigma_3'=50$
300
200
100
0
0
1
2
3
4
5

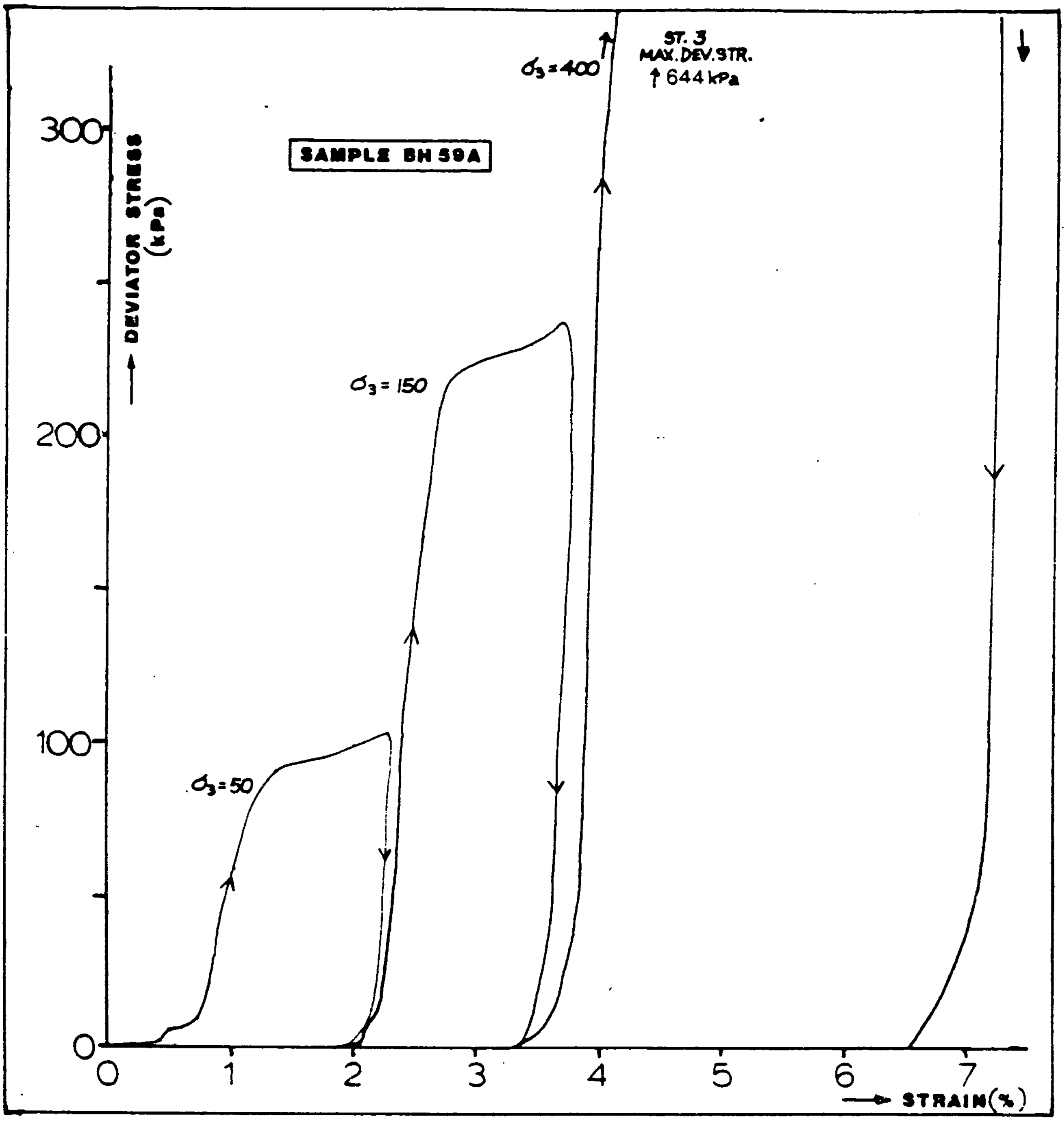

SAMPLE BH 47
SHEAR STRESS (kPa)
$\frac{\sigma_1-\sigma_3}{2}$
$A_f = 0{\cdot}07 \rightarrow 0{\cdot}39$
total
effective
$\frac{\sigma_1+\sigma_3}{2}$
NORMAL STRESS (kPa)
300
200
100
0
0
100
200
300
400
500
600


SAMPLE Nº BH 109
DEVIATOR STRESS (kPa)
300
200
100
0
$\sigma_3' = 330$
$\sigma_3' = 200$
$\sigma_3' = 80$
0
1
2
3
4
5
6
7
STRAIN (%)

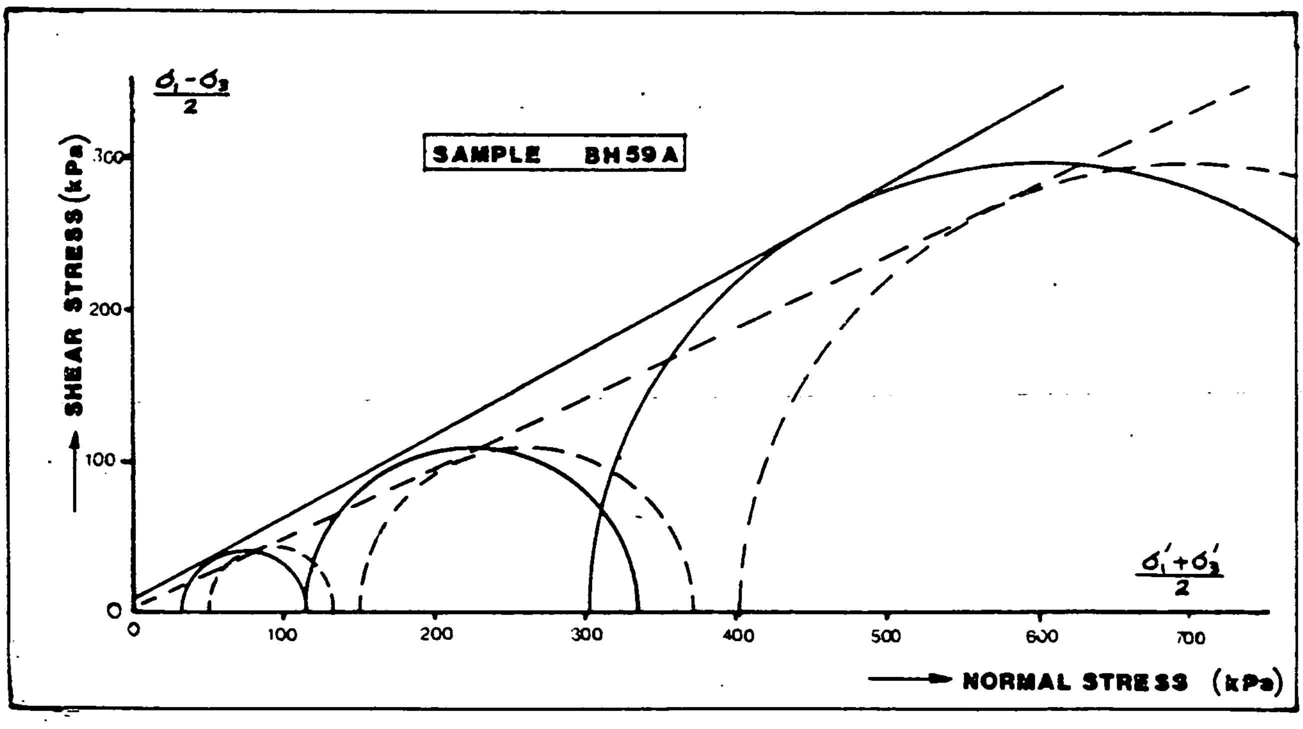

SAMPLE Nº BH 109
$\frac{\sigma_1 - \sigma_3}{2}$
SHEAR STRESS (kPa)
300
200
100
0
$\frac{\sigma_1' + \sigma_3'}{2}$
0
100
200
300
400
500
600
700
NORMAL STRESS (kPa)


SAMPLE Nº BH 65
DEVIATOR STRESS (kPa)
STRAIN (%)
0
1
2
3
4
5
6
7
100
200
300
σ₃'=55
σ₃'=150
σ₃'=400
MAX. DEV. =460 kPa at 7·8 STRAIN

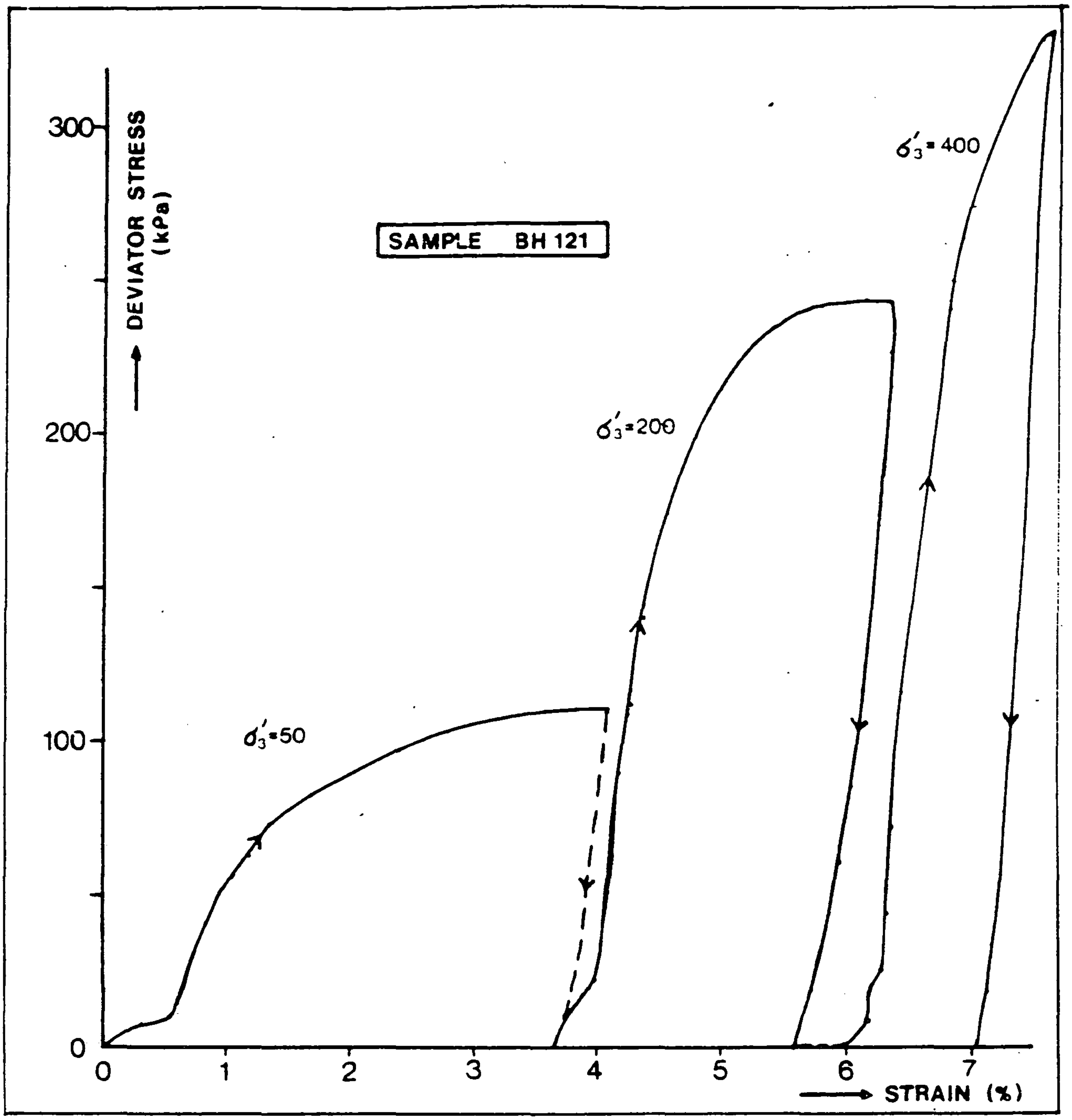

SAMPLE Nº BH 65
SHEAR STRESS (kPa)
σ₁-σ₃ / 2
σ₁'+σ₃' / 2
NORMAL STRESS (kPa)
0
100
200
300
400
500
600
700



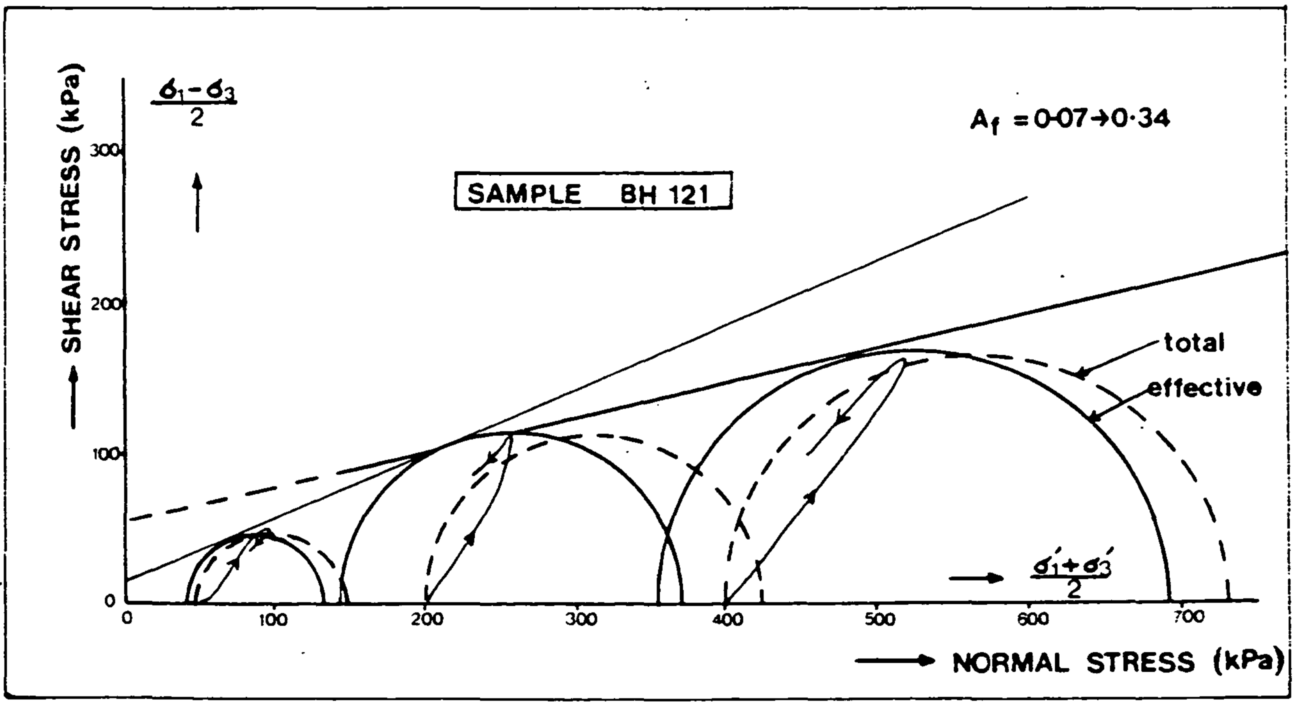
SAMPLE BH 59A
DEVIATOR STRESS (kPa)
STRAIN (%)
σ_3=50
σ_3=150
σ_3=400
ST. 3
MAX. DEV. STR.
644 kPa
0
100
200
300
0
1
2
3
4
5
6
7



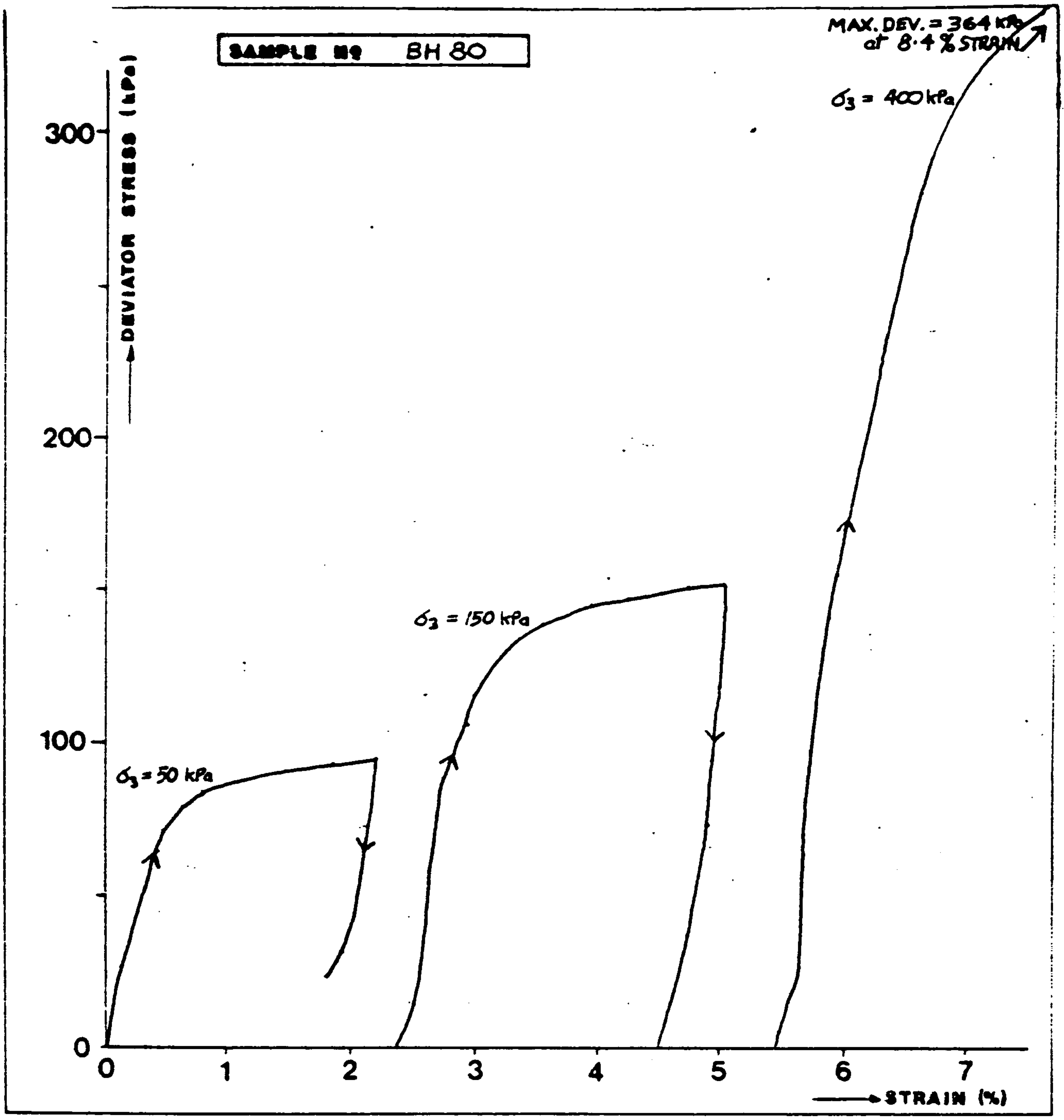
SAMPLE BH 59A
$\frac{\sigma_1-\sigma_3}{2}$
SHEAR STRESS (kPa)
$\frac{\sigma_1'+\sigma_3'}{2}$
NORMAL STRESS (kPa)
0
100
200
300
400
500
600
700



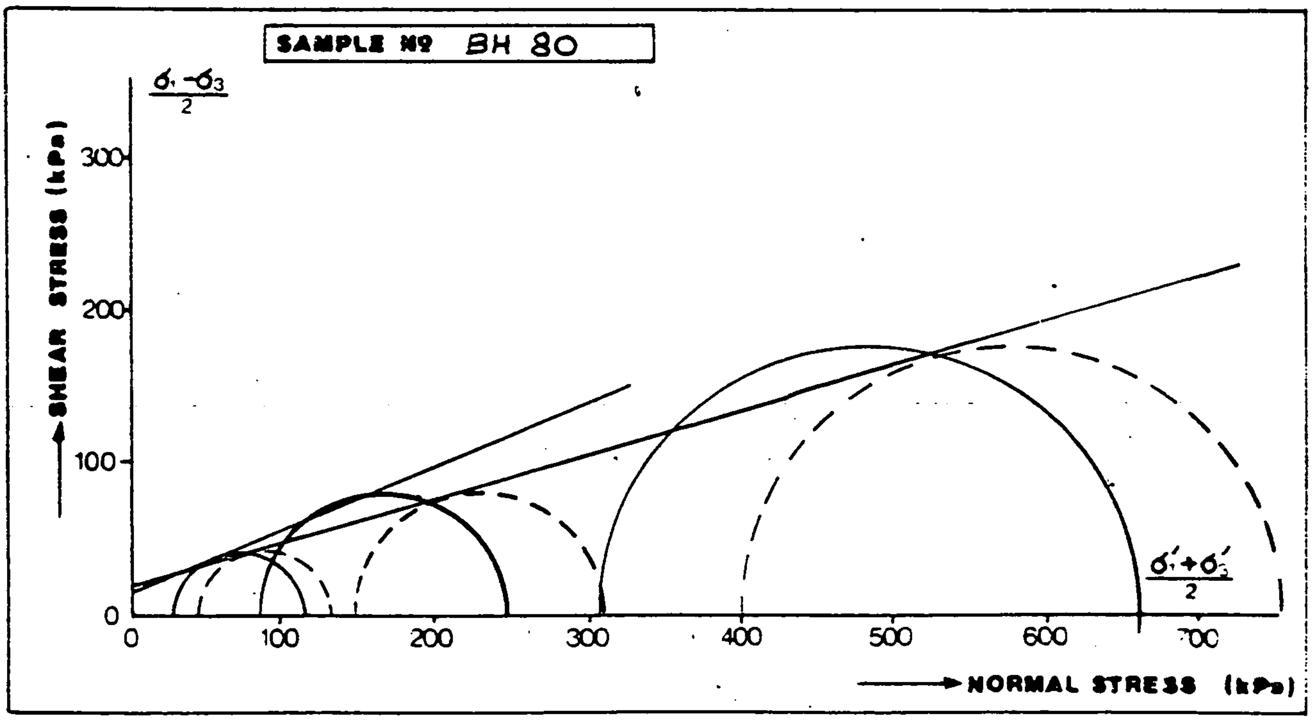
SAMPLE BH 121
DEVIATOR STRESS (kPa)
STRAIN (%)
$\sigma_3' = 50$
$\sigma_3' = 200$
$\sigma_3' = 400$
0
100
200
300
0
1
2
3
4
5
6
7



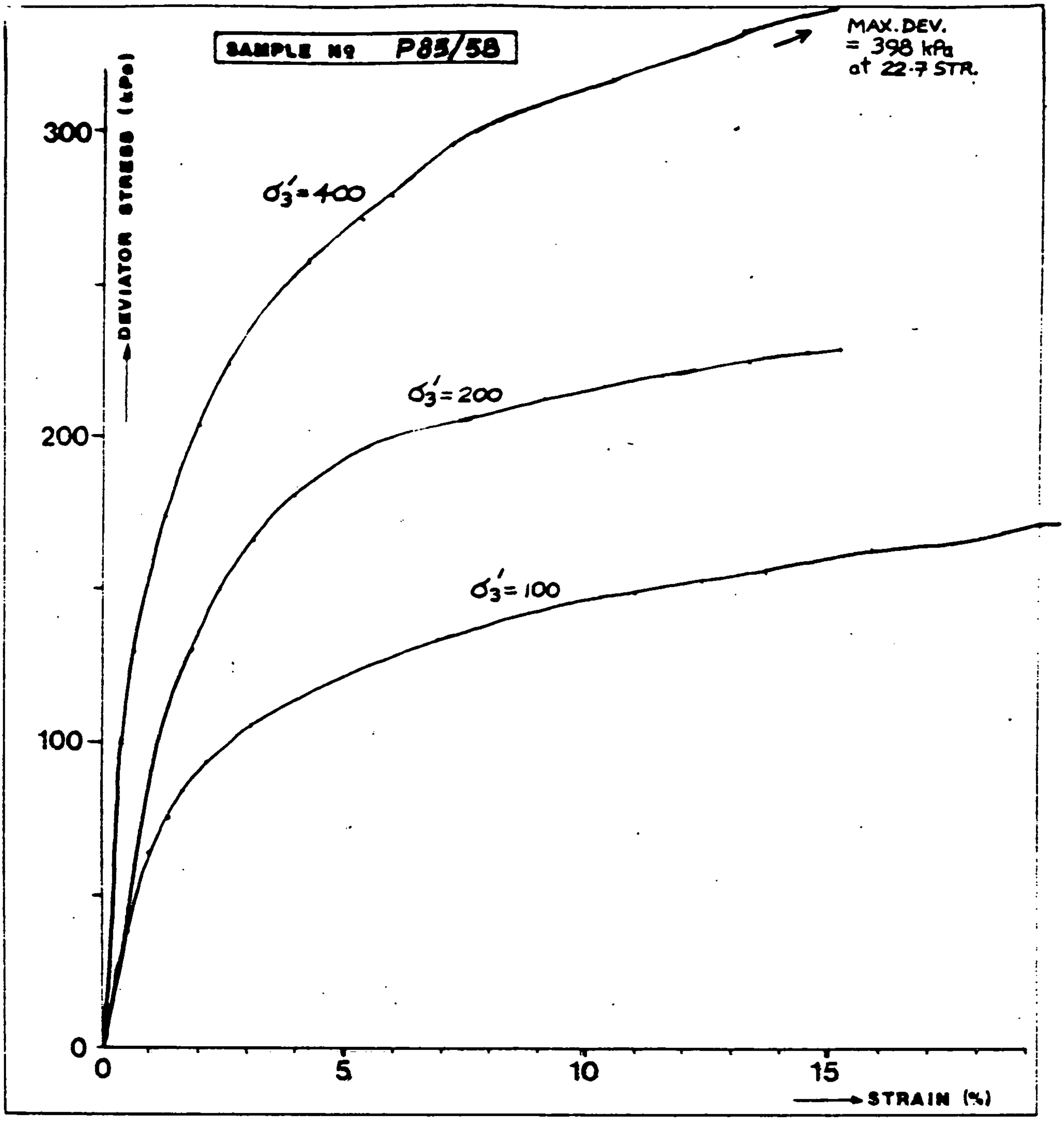
SAMPLE BH 121
$A_f = 0{\cdot}07 \rightarrow 0{\cdot}34$
SHEAR STRESS (kPa)
$\frac{\sigma_1 - \sigma_3}{2}$
$\frac{\sigma_1' + \sigma_3'}{2}$
total
effective
NORMAL STRESS (kPa)
0
100
200
300
400
500
600
700

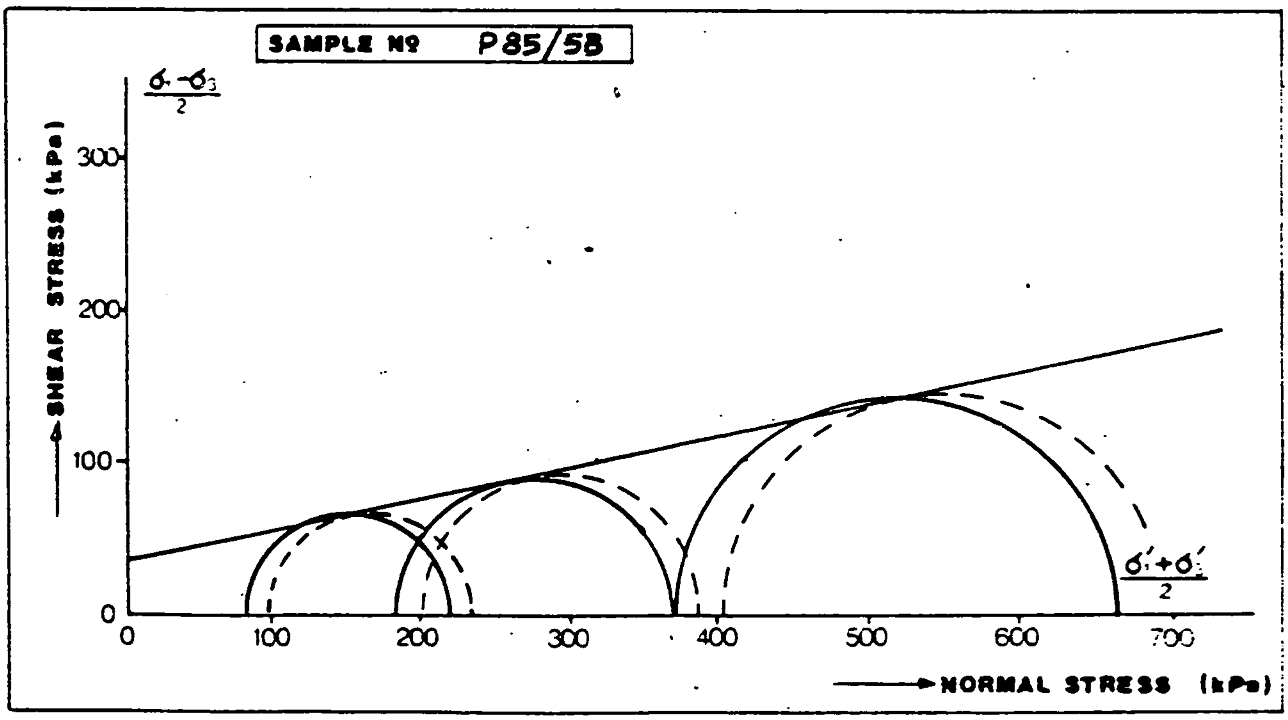


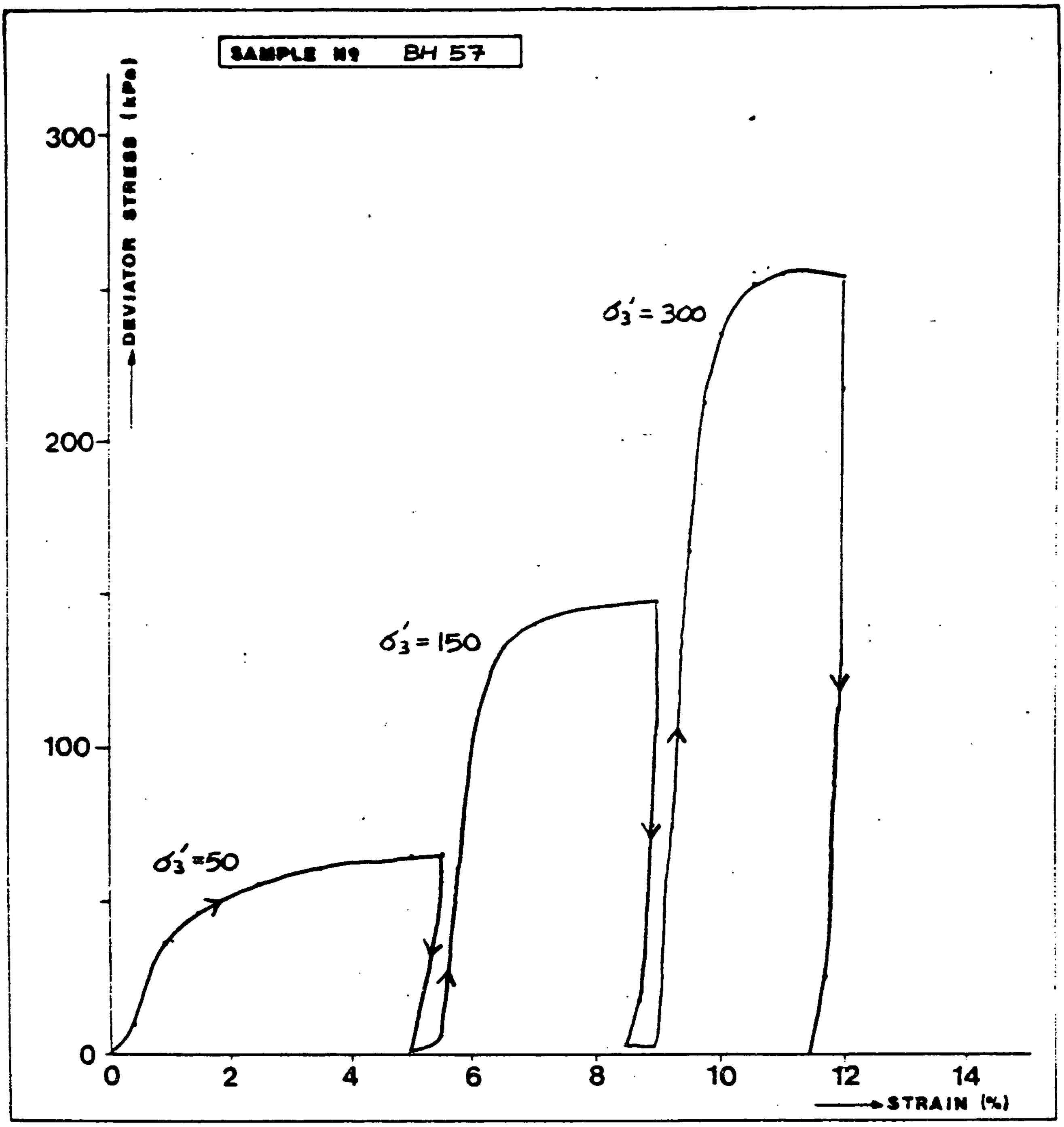
SAMPLE Nº BH 80
MAX. DEV. = 364 kPa at 8·4 % STRAIN
σ_3 = 400 kPa
σ_3 = 150 kPa
σ_3 = 50 kPa
DEVIATOR STRESS (kPa)
STRAIN (%)
0
100
200
300
1
2
3
4
5
6
7

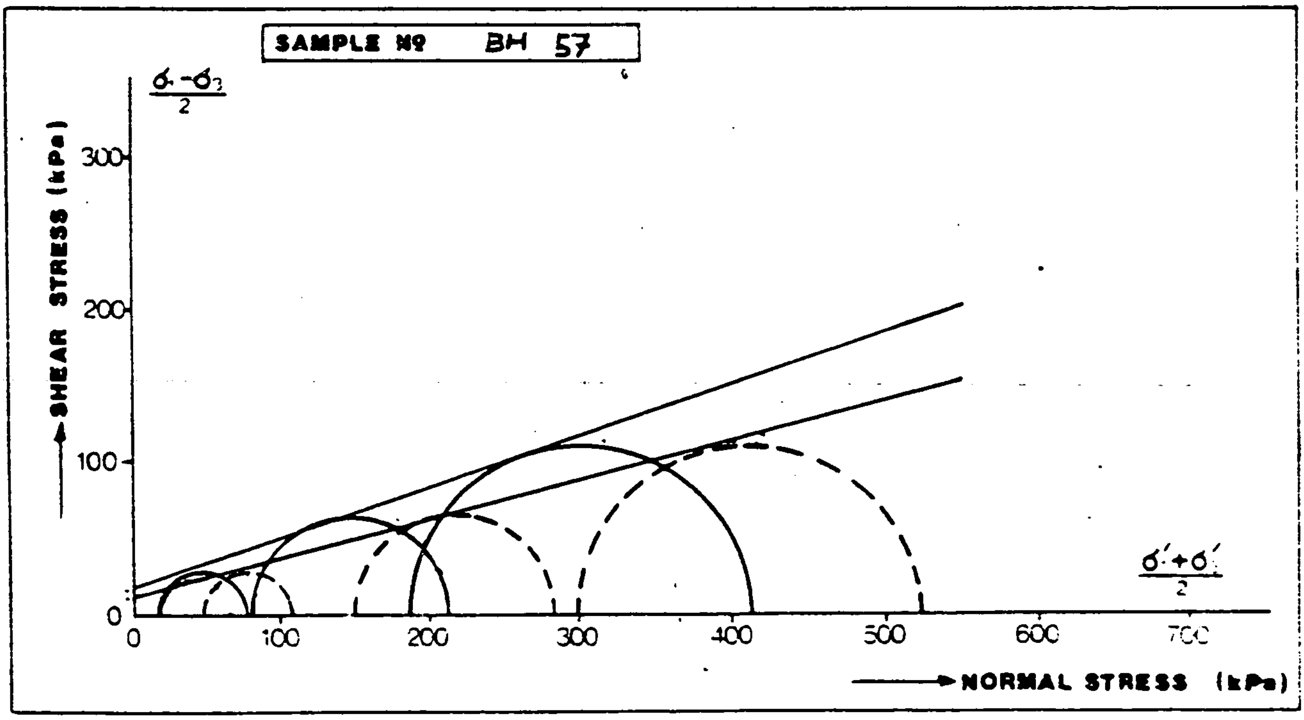


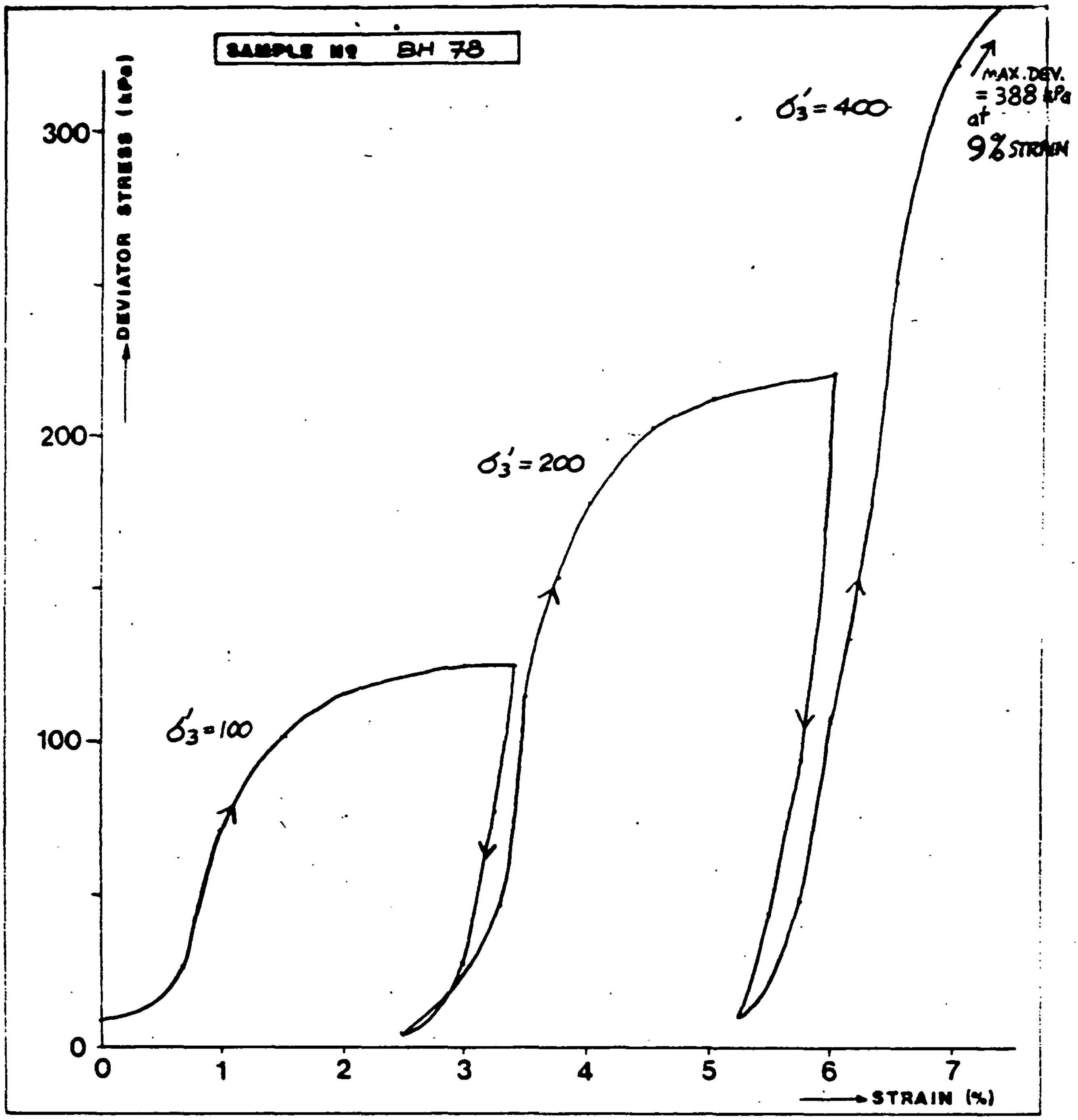
SAMPLE Nº BH 80
$\frac{\sigma_1 - \sigma_3}{2}$
$\frac{\sigma_1' + \sigma_3'}{2}$
SHEAR STRESS (kPa)
NORMAL STRESS (kPa)
0
100
200
300
400
500
600
700

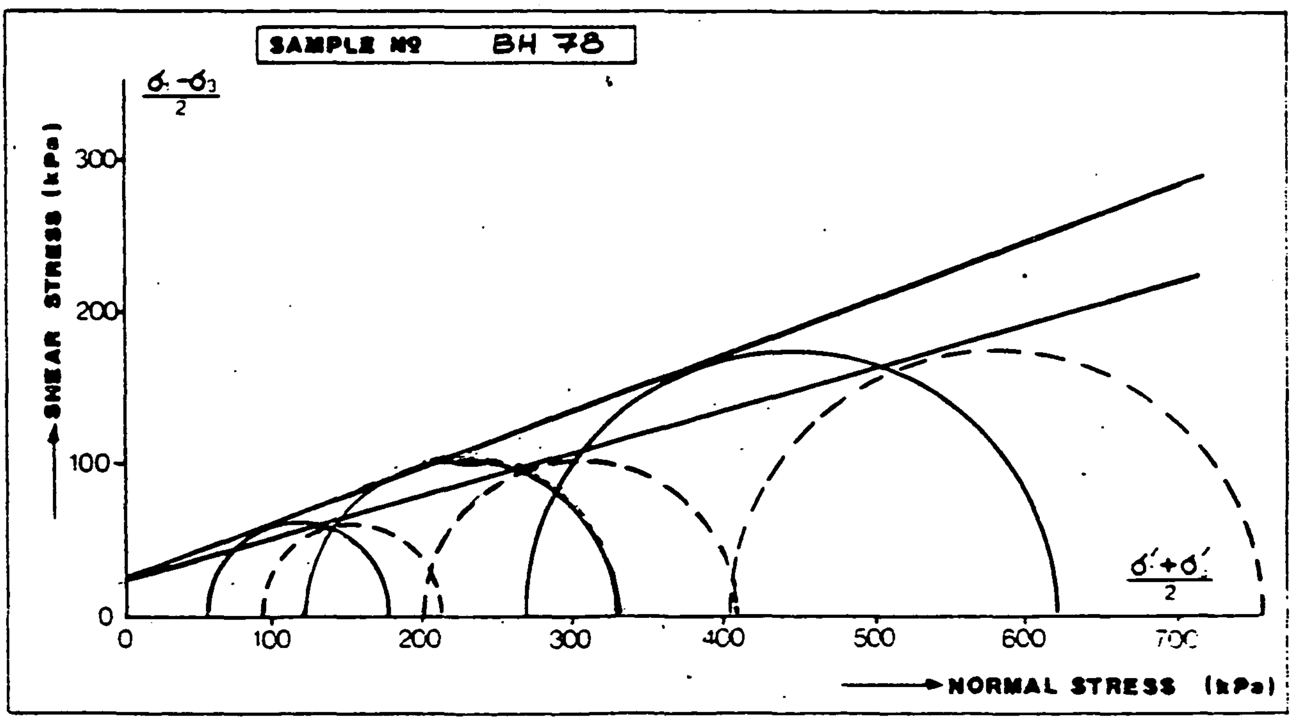

SAMPLE Nº P85/58
MAX. DEV.
= 398 kPa
at 22·7 STR.
DEVIATOR STRESS (kPa)
σ3' = 400
σ3' = 200
σ3' = 100
300
200
100
0
5
10
15
STRAIN (%)


SAMPLE Nº P85/58
σ1 - σ3 / 2
SHEAR STRESS (kPa)
300
200
100
0
100
200
300
400
500
600
700
σ1' + σ3' / 2
NORMAL STRESS (kPa)


SAMPLE Nº BH 57
DEVIATOR STRESS (kPa)
STRAIN (%)
$\sigma_3' = 50$
$\sigma_3' = 150$
$\sigma_3' = 300$
0
100
200
300
0
2
4
6
8
10
12
14

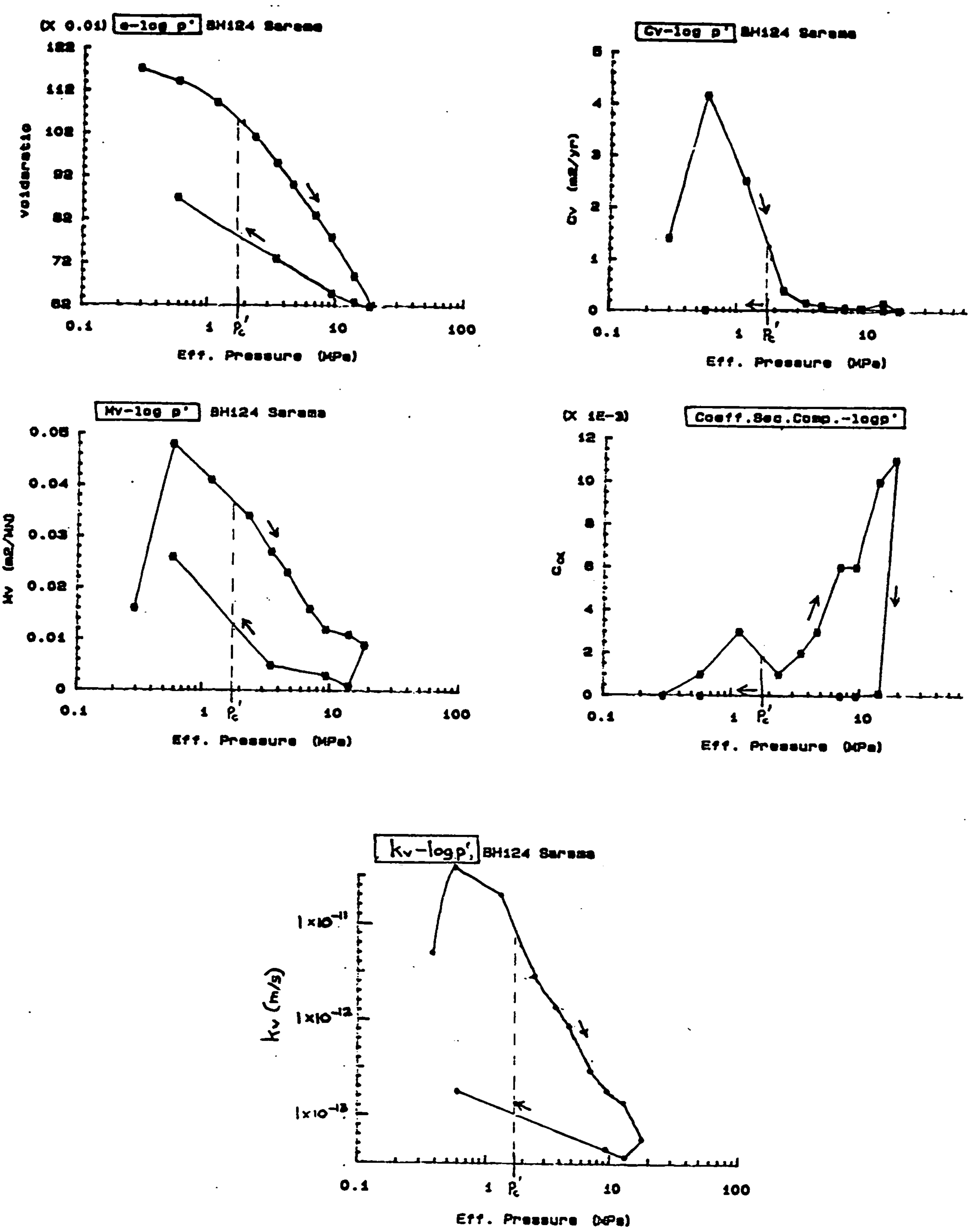

SAMPLE Nº BH 57
SHEAR STRESS (kPa)
NORMAL STRESS (kPa)
$\frac{\sigma_1 - \sigma_3}{2}$
$\frac{\sigma_1' + \sigma_3'}{2}$
0
100
200
300
0
100
200
300
400
500
600
700


SAMPLE Nº BH 78
DEVIATOR STRESS (kPa)
300
200
100
0
0
1
2
3
4
5
6
7
STRAIN (%)
$\sigma_3' = 100$
$\sigma_3' = 200$
$\sigma_3' = 400$
MAX. DEV. = 388 kPa at 9% STRAIN


SAMPLE Nº BH 78
$\frac{\sigma_1 - \sigma_3}{2}$
SHEAR STRESS (kPa)
300
200
100
0
0
100
200
300
400
500
600
700
$\frac{\sigma_1' + \sigma_3'}{2}$
NORMAL STRESS (kPa)

APPENDIX IIIB:

HIGH PRESSURE CONSOLIDATION
TEST PLOTS



Appendix IIIb Results of high-pressure consolidation test: Effective applied pressure plotted against voids ratio, Coeff. of volume compressibility (m_v), Coeff. of Consolidation (c_v), Coeff. of secondary compression (c_α), and vertical permeability (k_v, derived from m_v and c_v).

APPENDIX IIIC:

SWELLING PRESSURE TEST RESULTS

Sample No.	Depth (m)	m/c (%)	lith.	max. swelling pressure (kPa)
P3/2	1.8	17	Melange	640
P6/4	2.2	47	Kannaviou	149
P13/1	2.2	51	Kannaviou	108
P16/1A	2.0	18	Melange	442
P22/3	2.4	19	Melange	56
BH57	2.25	38	Kannaviou	68
BH62	2.25	25	Melange	129
BH65	5.25	29	Melange	153
BH78	2.25	39	Kannaviou	180
BH84	9.75	20	Melange	151
BH105	2.25	-	Mel. + Kan	81
BH109	8.25	24	Kannaviou	114
"	"	24	Melange	88
BH118	2.25	29	Kannaviou	45

Appendix IIIc Results of swelling pressure tests.